Xcel Energy – LBNL ‘Beyond Widgets’ Project

Workstation Specific Lighting with Daylight Dimming Controls

System Program Manual

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Disclaimer

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Executive Summary

This program manual was developed through a U.S. Department of Energy project to develop streamlined utility program approaches to the deployment of integrated systems in commercial offices. Integrated systems present deep opportunities for energy savings, however by nature these systems have additional levels of complexity and effort required for their design and energy savings assessment, which create barriers for utility incentive programs to develop streamlined cost effective incentive programs to capture these savings. This project worked with Xcel Energy in Colorado and Minnesota to select an integrated system and develop a streamlined approach to its deployment for small and large commercial offices.

Xcel Energy worked with LBNL to select a workstation specific lighting system with daylight dimming controls, applied as a retrofit in commercial office spaces. Previous studies indicated a potential lighting annual energy savings of 28-63%[1], with an average of 47% for this system type[2], due to reduced fixture LPD and controls only, not including a full fixture replacement from a condition such as T8 to LED. Xcel also had a desire to incorporate this fixture replacement in their integrated system package, and as a result annual energy lighting savings are expected to be higher. FLEXLAB testing of the system for 500 lux minimum output conditions translated into a 97% annual energy savings for this system.

Market analysis was developed for large and medium commercial office buildings in Xcel's Minnesota and Colorado markets showing a potential for 48-295 and 120-672 GWh of energy savings potential for Colorado and Minnesota respectively. Total Resource Costs (TRC) vary by location and technology package used (enterprise versus non-enterprise lighting controls system), and vary from 0.29 to 1.27 and 0.06 and 0.44 for a Retrofit case, and 0.20 to 1.63 and 0.07 to 0.57 for a Replace on Burnout strategy for Colorado and Minnesota respectively. These results indicate good potential for demonstrating a strong technical and economic case for deployment of this system type in Xcel's Colorado territory, while deployment in the Minnesota market may be advisable as well as part of a portfolio of programs, or as an effort to help shift the market into integrated systems deployment in general. It should be noted that the cost of avoided energy in both markets is significantly low ($0.07/kWh for Minnesota, $0.08/kWh for Colorado), and these TRC values would not be representative of deployment potential in other markets with higher utility rates. In addition, installation costs used for these systems may decrease with time, further enhancing their return on investment.

This program manual documents candidate site criteria for selection to implement this system through a utility incentive program. The system was also configured and tested in LBNL's FLEXLAB™ (flexlab.lbl.gov) under conditions representing a range of implementations of the system including different tuned light output levels at the occupant's workstation (300 and 500 lux) and different light fixture types (LED pendant and troffer). The FLEXLAB testing demonstrated strong energy savings against the baseline case of a T-8 zonal lighting configuration typical for Xcel's office market, with ~97% annual lighting energy savings. These

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[1] Wei, J., A. Enscoe, F. Rubinstein. 2012. Responsive Lighting Solutions. GSA Green Proving Ground.

[2] Robinson, A., C. Regnier. 2015. Zone Level Occupant-Responsive Building Energy Systems at the GSA. LBNL-182574.

results validated the energy savings potential illustrated by earlier work, and also provided empirical data to develop a streamlined customer savings assessment methodology. This methodology assesses the annual energy savings potential from reduced installed LPD. S study was conducted to assess whether variances in workplane illuminance values, and LPD would change significantly for a range of occupant densities not tested in the FLEXLAB tests. The tested case was the 2015 International Building Code maximum occupant density of 100 gross sf/person. Simulation studies of a 150 gross sf/person condition did not result in a significant difference in LPD, while the illuminance minimums were still met in the space.

The FLEXLAB™ test data also validated that minimum light levels were achieved in the workplane and egress areas. Visual comfort performance was evaluated for the workstation specific lighting system tested in FLEXLAB through the use of High Dynamic Range imaging to evaluate Discomfort Glare Performance. The workstations specific lighting systems demonstrated good visual comfort performance consistent with that experienced with other lighting system types, over the seasonal variations studied, including summer, fall and low sun angle conditions in winter. Some periods of higher levels of DGP were documented, also consistent with other lighting systems deployment that did not employ shading to block direct sunlight into the work space. To ensure satisfactory DGP is experienced throughout the course of all times of day and seasons, the use of an adjustable shading system is required to block out direct solar radiation. A venetian blind system would be recommended in order to allow for direct sun angle to be controlled while still permitting daylighting in to benefit the space.

Implementation guidance is presented in this program manual to assist utility program managers in their design of incentive programs and educate customers on key aspects of the system to focus on in commissioning and operations to ensure that lighting savings are realized. These include aspects such as a requirement for a commissioned lighting system that tunes light output levels to desired lux levels at the workplane, and verification that daylight dimming controls features are enabled and perform as desired.

Overall, workstation specific lighting systems with daylight dimming controls present a very strong potential for cost effective lighting energy savings, as demonstrated by the FLEXLAB test results and previous case studies. Further energy savings may be realized from the use of fixture-specific occupancy sensors as well, although this approach was not considered in this study.

1 Introduction

This program manual contains detailed technical information for developing an incentive program for enterprise-level, workstation specific intelligent networked lighting controls, combined with enhanced daylighting controls. Lawrence Berkeley National Laboratory developed this manual in collaboration with Xcel Energy as a partner in the ‘Beyond Widgets’ program funded by the U.S. Department of Energy Building Technologies Office. The primary audience for this manual is the Xcel Energy incentive program staff. It may also be used by other utilities to develop a similar incentive program, or be designers or other practitioners in the specification and assessment of this system in commercial office settings. Also, it is anticipated that Xcel Energy staff may utilize this manual’s content for developing related documents such as their Technical Resource Manual and other filings.

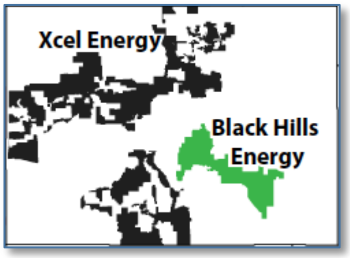
This manual covers a range of information needed by various stakeholders involved in developing a utility incentive program. It is not necessarily intended for any one stakeholder to read cover-to-cover, but rather read each pertinent section or appendix.

- **Section 2** describes the system features, it’s energy savings potential and its specifications of system components.
- **Section 3** describes minimum and recommended criteria for candidate customer sites for this system.
- **Section 4** presents the system’s verified energy impacts through testing at LBNL’s FLEXLAB integrated systems testbed. Savings include test period and annual lighting energy savings. An assessment of potential whole building energy savings based on the validated test results is also included, as applied to the DOE Reference Commercial Building Models.
- **Section 5** describes the methodology for assessing potential savings at candidate sites.
- **Section 6** addresses measurement and verification (M&V) including various options for project M&V at the customer site.
- **Section 7** provides guidelines for implementation and operations practices to maximize savings persistence, based on industry experience as well as findings from FLEXLAB testing.
- **Section 8** provides some guidance for training for program implementers.

1.1 Summary of Systems Selection and Markets, Xcel Energy – CO/MN

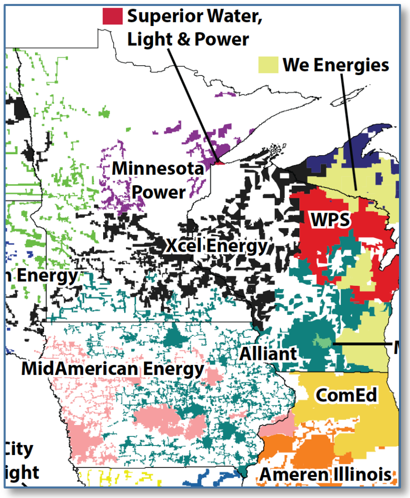
Utility Area

Xcel Energy is a major U.S. electric and natural gas company based in Minneapolis, MN, with regulated operations in eight Midwestern and Western states, and they provide a comprehensive energy-related products and services portfolio to approximately 3.5 million electricity customers and 2 million natural gas customers through four operating companies.



Public Service Company of Colorado:

- Electricity: 1,375,574
- Natural gas: 1,314,895



Xcel Energy Company Statistics

Electricity operations

- 2014 Electricity revenues: $9.5 billion
- Customers: 3.5 million
- Transmission lines: 93,100 miles
- Distribution lines: 196,889 miles

Natural gas operations

- 2014 Natural gas revenues: $2.1 billion
- Customers: 2 million
- Transmission pipeline: 2,405 miles
- Distribution pipeline: 34,091 miles

States served:

- Colorado
- Michigan
- Minnesota
- New Mexico
- North Dakota
- South Dakota
- Texas
- Wisconsin

Employees:

- 12,469

2014 Total revenues: $11.7 billion

2014 Earnings: $1.0 billion

Northern States Power Company-Minnesota (NSPM):

- Electricity: 1,403,544
- Natural gas: 484,720

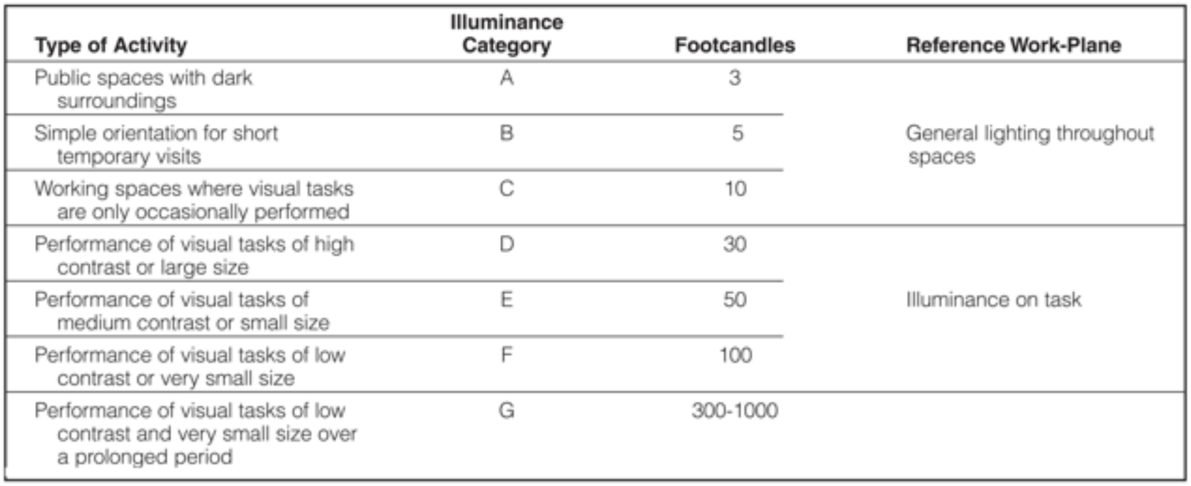
1.2 System Selection Description and Potential Energy Savings

Xcel Energy considered several system choices and finally selected:

- Daylight dimming lighting controls system implemented with ***workstation-specific fixtures*** and fixture-mounted sensors coupled with a T-8 light fixture replacement to LED

Workstation specific lighting systems provide opportunities for deeper levels of energy savings by designing the lighting system with one overhead light fixture positioned over each workstation. Design efforts in this system focus on providing a minimum lighting level provided at the workstation's workplane – in our case the selected system was evaluated both at a 300 lux and 500 lux condition at the workplane. The light levels are then allowed at lower levels in surrounding corridors and egress pathways, but at levels no lower than minimum acceptable levels per the Illuminating Engineering Society (IES) 2011 Handbook[3] (see Figure 1-1).

Figure 1-1: Minimum required light levels per IES 2011 Handbook[4]



Type of Activity	Illuminance Category	Footcandles	Reference Work-Plane
Public spaces with dark surroundings	A	3	General lighting throughout spaces
Simple orientation for short temporary visits	B	5	
Working spaces where visual tasks are only occasionally performed	C	10	
Performance of visual tasks of high contrast or large size	D	30	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	50	
Performance of visual tasks of low contrast or very small size	F	100	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	300-1000	

Overall, this design focuses on a delivery of light levels where needed at workplanes and egress pathways, and avoids providing excess lighting levels beyond this. By following this approach, an overall lower Lighting Power Density (LPD) (W/sf) can be installed than a more traditional zonal lighting system approach which emphasizes a more even light fixture distribution throughout all portions of the space, set to higher light output levels. This workstation specific approach has the additional advantage of enabling occupant-level daylight dimming and occupancy controls. In more traditional zonal lighting system approaches daylight dimming and occupancy are controlled through single sensor points to ensure lighting is available throughout the entire zone if only one occupant is present, and that dims for daylighting only in prescribed multi-fixture zones.

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 studies[5,6] have shown that for offices, daylighting alone yielded an average lighting energy savings of 41% (N=78 projects), institutional tuning yielded 38% average savings (n=17), personal tuning, 34 % average savings (n=18), and occupancy provided 30% average savings (n=66) (Figure 1-2).

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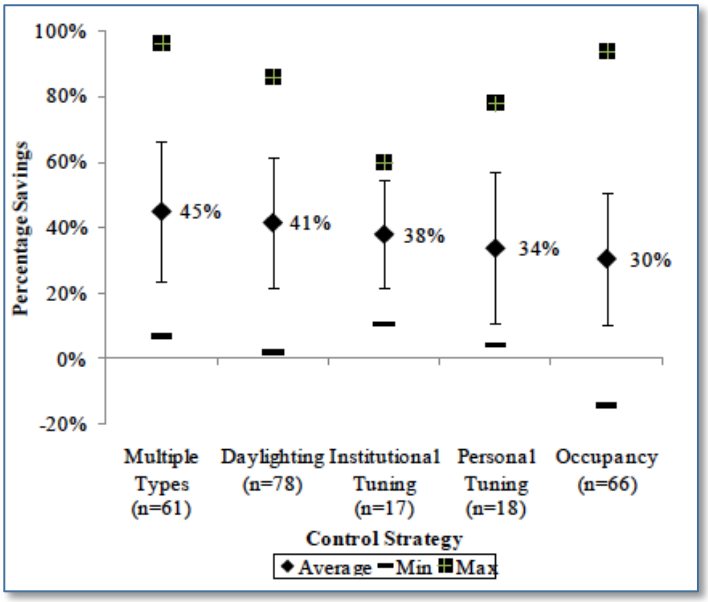
[3] Illuminating Engineering Society (IES), 2011, The Lighting Handbook, 10th Edition.

[4] Illuminating Engineering Society (IES), 2011, The Lighting Handbook, 10th Edition.

[5] Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, Lawrence Berkeley National Laboratory. Page, E, Erik Page & Associates, Inc. May 2012. Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings. LBNL-5895E.

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

Figure 1-2: Average energy savings (%) by control strategy (Williams, et al. 2012)[7]



Additional data from the U.S. Department of Energy and LBNL's Commercial Buildings Partnership (CBP) project[8,9] analyzed a wide subset of GSA-operated buildings in California and Nevada that were retrofitted with responsive lighting control strategies. This study's analysis is presented below showing results of targeted deployment of responsive lighting controls throughout the GSA building portfolio.

Unique to this particular study, in a number of the sites the retrofits resulted in similar or increased installed lighting power densities (LPDs), yet the installations still lowered energy consumption significantly through the use of advanced lighting controls (Figure 1-3). The retrofits achieved an average energy savings of around 1.5 kWh/ft^2/yr, resulting in calculated annual lighting savings ranging from 26% to 66%.

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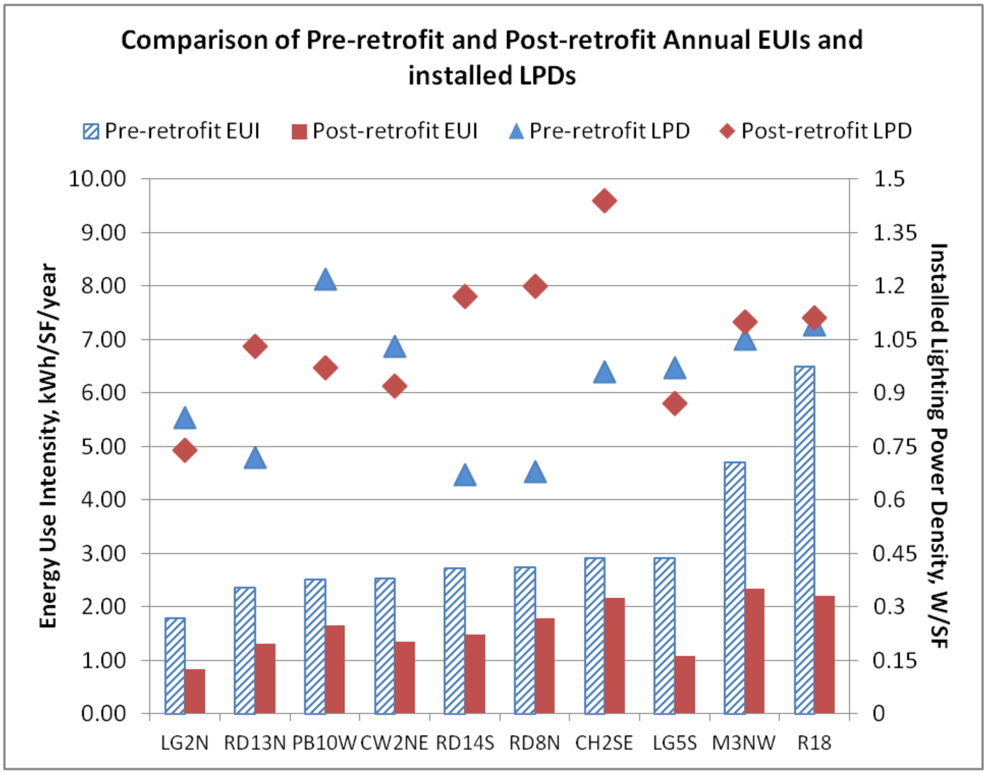
[7] Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, Lawrence Berkeley National Laboratory. Page, E, Erik Page & Associates, Inc. May 2012. Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings. LBNL-5895E.

[8] Robinson, A., C. Regnier. 2015. Zone Level Occupant-Responsive Building Energy Systems at the GSA. LBNL-182574.

[9] Rubinstein, F., M. Wei, A. Enscoe. 2012. Saving Energy with Advanced Lighting Controls: A Study of Lighting Retrofits in 10 Federal Building Offices

Figure 1-3: Comparison of pre-retrofit and post-retrofit energy use intensities (EUIs) and installed lighting power densities (LPDs). Calculated annual EUIs are depicted as columns, pre-retrofit in blue, post-retrofit in red. Installed LPDs are depicted in points, hollow blue triangles for pre-retrofit LPDs and solid red diamonds for post-retrofit LPDs. Sites are sorted left to right by increasing pre-retrofit LPDs.[10]



Another study involving the use of improved daylighting practices concerned a post-occupancy LBNL study of the New York Times headquarters building[11] showed 38% lighting energy savings compared to code, with a simple payback of 4.1 years (Figure 1-4). Improved daylighting practices employing automated shades, in this case, 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 hard-wired systems) serve as an added incentive to increase adoption.

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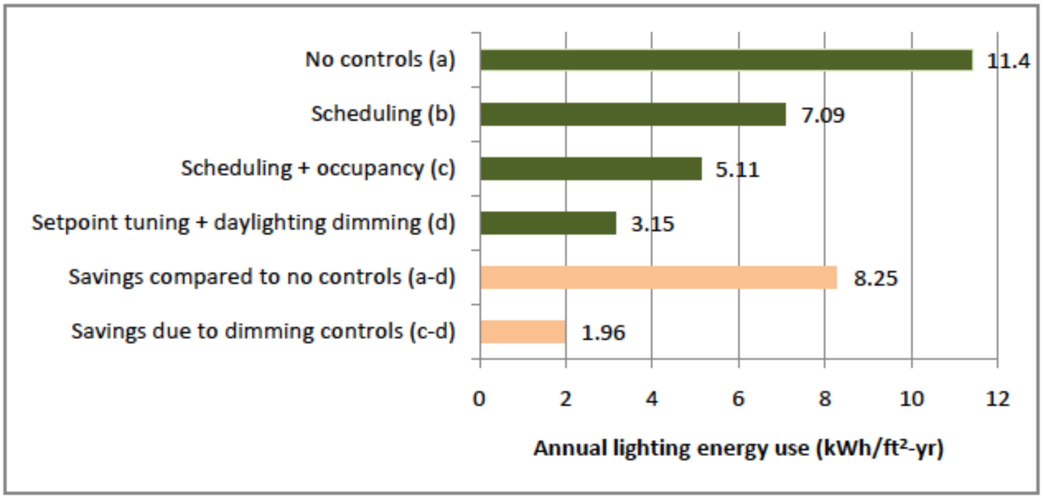
[10] Wei, J., A. Enscoe, F. Rubinstein. 2012. Responsive Lighting Solutions. General Services Administration.

[11] 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. LBNL-6023E

Figure 1-4: Lighting energy use savings in the New York Times headquarters building (Lee, et al. 2013)[12]



Xcel Energy chose this lighting system to partner with their customer opportunities to retrofit their current lighting configurations. This system overall addresses the realities of many of their customer’s conditions: typical retrofit projects which currently employ zonal lighting approaches, and current lighting replacement opportunities which are frequently associated with total system replacements associated with gut rehabs, tenant improvements or new construction projects.

The key technology features of this integrated system are:

Occupant/Workstation Specific Lighting — One individual light fixture per occupant workstation. Lighting is designed to provide a reasonable light output at the occupant’s workplane (i.e. 300 or 500 lux).

Daylight Dimming Lighting Controls— Enterprise-level or local, intelligent granular workstation specific control through local photosensors tied to the lighting control system. Lighting control will respond to available daylight illuminance levels. Illuminance-driven control will dim lights continuously based on daylight availability, down to a zero lux light output at full dimming.

Fixture-integrated sensors are becoming more prevalent as the cost of sensors has been driven lower. While it may be that fixtures with embedded occupancy sensors may become the norm, for the purposes of the system energy savings testing, evaluation and assessment method development it was assumed that the system did not have wokstation specific occupancy controls enabled. Should the system be deployed with this feature it is expected that additional energy savings would be incurred. A typical occupancy-driven control would switch lights on/off or dim to minimum background levels.

No integration of lighting controls with HVAC controls was specified or tested as part of this system selection. The working assumption in this study however was that the customer’s

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[12] 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. LBNL-6023E

HVAC control will be enabled to maintain their thermostatic setpoints. Interactive HVAC load effects due to reduced lighting loads were not quantified in this study. The benefits of HVAC load reduction on HVAC energy use will vary depending on the customer's HVAC system type, fuel mix, and it's efficiency/load profile and were not developed into an energy saving assessment methodology as part of this work. In addition, the effects will vary based on climate and heating and cooling load profiles for each customer site. However it may be useful for utility programs to be aware of this potential added energy impact.

Section 2 describes performance-based systems specifications that allow a range of different system technology options.

1.3 Market Analysis

Xcel Energy identified the commercial office target market segment for this system package focusing on small and large size buildings. The systems-based approach targets both retrofit and new construction projects with appropriate system types and glazing systems. DNV GL was commissioned to conduct a market assessment for economic and technical potential for cost and energy savings in these markets for each of Colorado and Minnesota. The results of this study are presented in Appendix H. The market impact analysis was conducted prior to FLEXLAB testing.

It should be clarified at this point that the market segmentation study was originally conducted for a slightly modified version of the integrated system where a window film retrofit was also included to allow for deeper daylight penetration and impacts on dimming systems and consequently further energy savings. The daylight redirecting window film was consequently removed from the system definition while under FLEXLAB testing as described in Section 4. While the report in Appendix H has not been updated, the analysis has been updated to capture the revised system energy savings and system costs to only include those associated with the workstation specific lighting system and its controls. These results are documented in Appendix J. The energy savings estimates for the system were also adjusted to account for the workstation specific lighting system only as well. Note that the original market analysis included in Appendix H has been included to outline the process used for the analysis.

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 building-level savings estimates were based on literature review and simulation analysis. However, the results of FLEXLAB testing are largely consistent with the range used in the market analysis.

The technical potential of the integrated system refers to the energy savings of that system if applied with complete penetration in all market segments that are deemed technically feasible from an engineering perspective. Overall, Xcel's Colorado markets demonstrated a technical potential of 120 to 672 GWh energy savings, while Minnesota's medium and large commercial markets demonstrated a range of 48 to 295 GWh of energy savings. Using TRC criteria, this system is cost-effective only for specific sub-segments and only when evaluated using incremental system costs (Retrofit and Replace on Burnout scenarios). This is primarily due to the low avoided cost rates in Minnesota, which are about $0.07/kWh ($0.08 per kWh for Xcel Colorado).

The economic potential of the integrated system is the portion of the technical potential that the utility considers cost-effective when compared to supply-side alternatives. Technologies are generally considered cost effective from the utility's perspective if the Total Resource Cost (TRC) is greater than or equal to 1.0. Differences in cost effectiveness for a system in one utility area versus another relate to the levels of each utility's avoided costs, which is tied to the cost of energy supplied in that utility area. The avoided cost stream average for Xcel Colorado was used at $0.07/kWh and at $0.03/kWh for Minnesota. This large variation in supply side avoided costs creates markedly different value propositions for utility incentive programs in each market area. Xcel Colorado's TRC was estimated to range from 0.20-1.27, and for Xcel Minnesota at 0.06-0.44 if in both cases the customers were targeted as a retrofit mid-stream during their existing technology's lifespan. If the incentive program is design for a replace on burnout of their existing technology the TRC values improve to 0.20 to 1.63 for Colorado, and 0.07 to 0.57 for Minnesota. As stated earlier, it is expected that these values would be higher with the removal of the cost of the daylight redirecting film. It is also important to note that utility incentive programs often take a portfolio approach to determining which incentive programs are selected to move forward, balancing out other factors such as need for market demand to lower costs of the technology through improved market penetration.

Further discussion on potential for market adoption, barriers and opportunities for deployment are illustrated in Appendices H and J.

2 System Technology Description

2.1 System Features

Xcel Energy considered a list of several systems and selected integrated, networked advanced lighting controls systems with sensors. The key features of this system are:

- Workstation-specific LED lighting fixtures, sensors and daylight dimming controls

The proposed systems energy-efficiency program package features create a technology options suite, which were pursued for testing, validation and program implementation guidance development.

Key aspects for systems selection are their level of functionality (intelligent granular control) and their inclusion of additional sensor types tied to the lighting control system (daylight dimming and photosensors).

2.2 Functional performance requirements

2.2.1 Automated lighting controls for daylighting and occupancy sensing

The lighting control system, of which daylight dimming is a part, shall comprise of the following equipment:

1. Digitally addressable ballasts or LED drivers

2. Panel and remote mounted load control relays and dimmers
3. Power supplies
4. Routers, controllers, processors and servers
5. Analog and digital input and output modules
6. Daylight responsive sensors and controllers

In addition the following optional equipment may be present:

1. Occupant/vacancy sensors and controllers
2. Group/scene and manual zone controls
3. Integral time clock control
4. Emergency lighting control
5. Utility "demand response" control.

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. Photosensors and controls shall be programmed to ensure minimal lamp cycling (and associated reduced lamp-life and occupant distraction) due to varying daylight levels and should be capable of easy recalibration to accommodate changes in environment/preferences. They should be calibrated (tuned) to ensure that IES guidelines or code standards are maintained. This fixture tuning is required to achieve the energy savings as presented in this study. Occupant sensors may control lighting at the zone or individual workstation level. Lighting output should be adjusted to user requirements (lamp output tuning relative to maximum rated output).

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

- Occupancy
- Workplane illuminance (measured directly or calculated from measured reflectance)

Example operational modes:

1. Scheduled
2. Occupied/vacant
3. Daylight dimming

Operation of automated lighting controls shall take also into account energy optimized performance of daylighting dimming controls to ensure minimal glare issues arise than necessary.

Occupancy control shall be at the individual cubicle or private office level in order that control signals may appropriately control the local lighting levels.

3 Candidate Site Requirements

3.1 Site Requirements

Utility customer site requirements to apply for the incentive program are likely to include the following. The minimum site requirements for the system are:

- 10 ft. floor-to-ceiling heights with dropped ceiling/plenum
- Perimeter spaces with window greater than 30% of the wall area.
- Minimum of 8 hours daily average occupied hours from Monday to Friday
- 25ft Perimeter constitutes significant proportion of total floor area (~>25%)
- Open office partitions 4 ft. or less.
- 2nd or 3rd generation linear fluorescent lamps and ballasts with zonal control or scheduling.
- Multi-workstation spaces

Additional requirements for preferred sites:

- Moderate to large windows (window-wall ratio > 40%).
- Clear or low tint glazing.
- Better to have more open office on perimeter than closed office.

4 Energy Impacts

4.1 Customer Energy Impacts

4.1.1 Baseline Case

For Colorado, the minimum compliant code for a building without energy modeling is ASHRAE 90.1-2010 as modified, or local code when more stringent. The EDA Modeling Protocol is based on a utility modified version of the ANSI/ASHRAE/IESNA Standard 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings utilizing Appendix G.

For Minnesota, code is based on the 2012 International Energy Conservation Code® and ANSI/ASHRAE/IES Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings. All prescriptive measures utilize the energy savings calculations listed in the State of Minnesota Technical Reference Manual For Energy Conservation Improvement Programs, Version 1.2, Effective: January 1, 2015 – December 31, 2015, which specifies the following baselines:

- New construction: building code or federal standards.
- Retrofit: existing equipment or the existing condition of the building or equipment

Baseline Building Description:
The building selected for this study is based on an office building with a typical 2'x4' acoustical grid ceiling along with the following characteristics. These conditions were used to help define the parameters for the FLEXLAB base case (reference) cell test conditions, and were also used to define the envelope and interior conditions for the test cell case.

Ceiling Height: 9'-0"
Windows:

- Sill Height: 2'-6"
- Top of Window: 8'-0"
- Glazing/Façade Area Ratio: 40%
- Glazing Type: Double Low-e Tvis = 0.65
- 40% window-to-wall ratio
- Manually operated interior shading

4.2 FLEXLAB Test Methodology and Plan

4.2.1 Test Methodology

FLEXLAB testing provides savings data based on controlled side-by-side testing compared to the utility baseline over a range of seasonal and test conditions. FLEXLAB testing covered various configurations of lighting system types (LED pendant and troffer), light level output (300lux and 500lux) and shading configurations (no shades, and shades mounted and positioned at various angles). The test period also included periods where a daylight redirecting film was employed periodically as it was evaluated in an earlier version of the system being studied – however it should be noted that those test periods did not demonstrate any difference in workplane illuminance or additional effects on lighting system dimming and energy performance. Test results, an assessment and discussion of this result are detailed in Appendix D.

LBNL's FLEXLAB test facility allows energy-efficient 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 major objectives of the FLEXLAB testing for this system were to:

- Analyze the energy savings impact of the workstation specific lighting system with daylight dimming controls as compared to the base case condition.
- Evaluate the visual comfort and illuminance provided in the workplane and surrounding areas of the workstation specific lighting system with daylight dimming controls as compared to the base case condition.

Side-by-side "controlled" testing: The test case (i.e., workstations specific LED lighting fixtures, sensors and daylight dimming controls, and manually operated venetian blinds) and the base case (i.e., T8 lighting with manually operated venetian blinds, recessed fluorescent troffers and no daylight-based dimming) were tested at the same time under identical conditions using the two FLEXLAB testbed cells. Figures 4-1 and 4-2 show the floor plan and external view respectively of the testbed. Each test cell is approximately 20' wide and 30' deep.

Figure 4-1: FLEXLAB Test Cells: Proposed (Cell A) & Basecase (Cell B).

Test Cells
X1B (Basecase)
X1A (Proposed)

Figure 4-2: FLEXLAB Test Cell Floor Plan: Proposed (Cell A) & Basecase (Cell B).

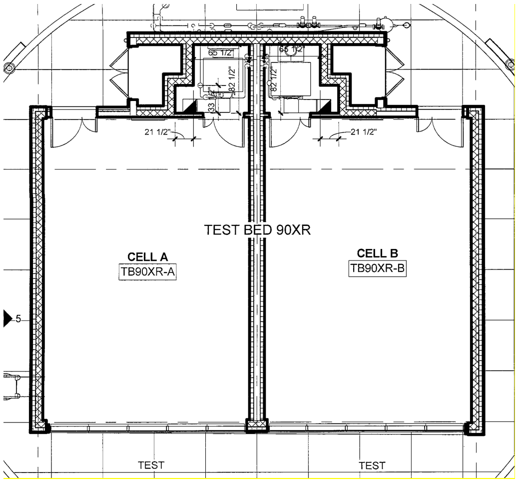


Table 4-1 lists the key envelope and other conditions that were fixed parameters in each of the base case and test cells. These conditions were picked to represent a typical 'worst case' representative of the conditions in the existing building stock in the MN and CO markets.

Table 4-1: Fixed FLEXLAB test parameters

Feature	Description
Glazing	Single pane, clear glazing as representative of some existing buildings. Visible transmittance = 89%; U-value = 1.03 Btu/hr-ft2-F (winter), 0.93 Btu/hr-ft2-F (summer); Solar heat gain coefficient = 0.84. Window to wall ratio of 48%.
Wall construction	R-11 batt insulation, between metal studs on window wall. Other walls near adiabatic (zero heat flow) due to increased insulation.
Roof insulation	Near adiabatic due to increased insulation.
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. At 0.75W/sf peak, controlled to approximate schedule in ASHRAE 90.1 user guide.
Occupancy schedule	Occupied hours 7am-7pm.

In addition to the fixed test parameters, the following conditions were tested to enable the base case to test case comparisons.

Table 4-2: FLEXLAB test parameters

Feature	**Base Case Description**	**Test Case Description**
Lighting Fixtures	(6) 2'x4', 3-lamp T8 fluorescent, recessed, parabolic troffers	(6) 4' pendant-mounted, LED direct-indirect luminaires with integral occupancy/photosensors
Light Fixture Layout	8' x 8' spacing between fixture center lines (see Figure below)	(6) 4' workstation-specific fixtures centered above the workstation task areas.
Light Output Level	[Fixed output fixtures, not tunable]	Light levels were tuned to meet: A) ~ 300 lux min. (~30 fc) B) ~ 500 lux min. (~50 fc) Workplane illuminance set points.
Lighting Controls	Scheduled on/off control	Scheduled on/off control; as well as dimming all lights throughout day based on available daylight measured by on-board photosensors.
Lighting Schedule	The lights were turned off during unoccupied hours (7pm to 7am).	The lights were turned off during unoccupied hours (7pm to 7am).
Shading	Venetian blinds were in the deployed horizontal position for all test configurations. Blade angle was adjusted seasonally to a direct-sun blocking angle.	Venetian blinds were in the deployed horizontal position for all test configurations. Blade angle was adjusted seasonally to a direct-sun blocking angle.

Figure 4-3: Typical recessed 2'x4' fluorescent luminaire layout showing 8' on center layout

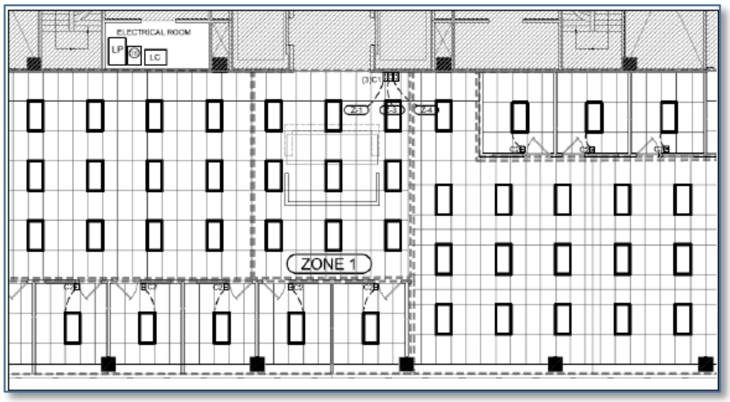
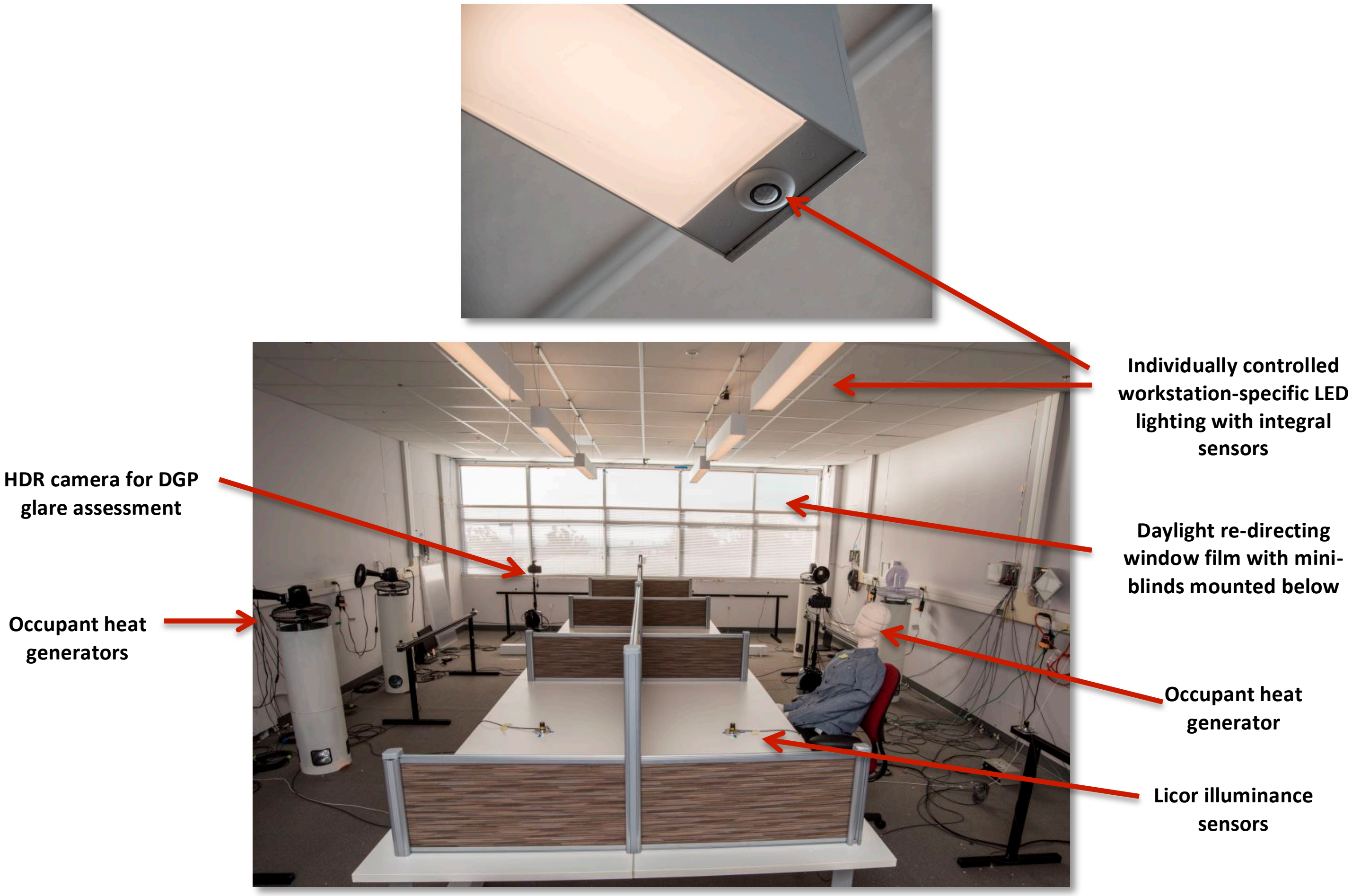


Figure 4-4 illustrates the interior of the test cell for one of the test configurations. Other test configurations were similar in setup, with variances occurring for the tuned maximum light output of the fixtures, presence or absence of light redirecting film, and venetian blind mounting height and blade angle position.

Figure 4-4: FLEXLAB Internal Test Cell View with Key Features
(Film 2 plus Workstation-Specific Lighting)



4.2.2 Test and measurement plan

The FLEXLAB test plan was developed to enable parametric testing of each system parameter of interest as described in section 4.2.1. These parametric variations were applied as described in Table 4-3. In general, the intent was to have each major configuration tested for at least 3 days each month. The intent was to conduct solstice-to-solstice testing in order to capture the full range of solar positions. Testing was commenced in July 2016, and ran until January 2017. Some data from this date range was not used in the energy savings or visual comfort analysis as it was for periods when the test conditions were not applicable, such as days when the system was being reconfigured from one condition to the next. Some conditions also related to non-workstation specific lighting test conditions in earlier periods of the test period, as captured before the daylight redirecting film was determined to be not of significant contribution to the system performance.

Test Permutations

Permutations of each set of test conditions were conducted over the course of a 6 month period, with test lengths and timing of tests varied to make sure that each permutation had adequate data collection coverage across a range of weather conditions (e.g. cloudy, sunny), while also testing across a full range of seasonal conditions to capture a the range of sun angles from summer, fall and winter. The parameters varied were as follows:

- Lighting system
  - Suspended direct/indirect LEDs w/ daylight harvesting; General Lighting Configuration
  - Suspended direct/indirect LEDs w/ daylight harvesting; Workstation Specific Lighting Configuration
  - Lights OFF

- Film
  - Film 1
    - Blinds suspended across full window
  - Film 2
    - Blinds suspended below film
  - No film

Table 4-3 documents each test configuration.

Table 4-3: FLEXLAB Test configurations

Experimental Configuration
Workstation-Specific - 300 lux
▪ Film 2**
▪ Film 1*
Workstation-Specific - 500 lux
▪ Film 2**
▪ Film 1*
▪ Film 2 - blinds in Film 1 position

Notes:
* Blinds in Film 1 position indicates that the mini-blinds were full height mounted at the window head.
** Blinds in Film 2 position indicates that the mini-blinds were partial height mounted below the Film 2 window film panels (see Figure 6 above).

A detailed accounting of the test dates and configurations tested is documented in Appendix C.

Data collection

FLEXLAB offers extensive and highly granular data collection capabilities. Table 4-4 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 4-4: Primary data categories collected for test

Metric
Shade position
Global and diffuse horizontal illuminance; HDR imaging
Workplane illuminance
Daylight glare probability
Power Metering including: **Lighting power per fixture** (All internal loads independently, overhead lighting, task lighting, fan powered terminal units, computers, and simulated people, and control and DAQ power if within the cell. Current transducers on each luminaire. Power measurements on individual components of heating and cooling systems.)
1. Air supply airflow measurement **2. Room pressure measurement** **3. Chilled water flow meters** **4. Chilled water supply and return temperature sensors** **5. Hot water flow meters** **6. Hot water supply and return temperature sensors** **7. Room pressure measurement**
Set point temperature - Interior dry bulb temps

Table 4-5: Processed (Calculated) Data Using FLEXLAB Measured Data

Metric
Daylight Glare Probability (DGP)
1. Chilled water thermal load **2. Hot water thermal load**

A record of the accuracy of the FLEXLAB sensors and measurements conducted is also documented in Appendix C.

Data cleansing

The data were plotted 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 FLEXLAB Testing Results

The Figures which follow present the lighting energy savings for each configuration calculated for each hour, day and over the multi-day test period 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.

4.3.1 Testing Summary

The major findings are as follows:

- The lighting energy savings for workstation specific lighting are substantial, varying depending upon available daylight and seasonally, with energy savings FLEXLAB test results ranging from 82 to 94% daily over the fall and winter periods. Summer periods were projected at higher savings, in the range of 98-99%. Overall, equivalent annual lighting energy savings for the FLEXLAB test are 97%.
- Annualized whole building energy savings were estimated using these FLEXLAB test results as follows, being applied to the DOE Reference models[13] for large and medium commercial office buildings. In each case the system was assumed applied to all South zones, SE and SW corner zones, and core areas (LPD savings only applied, no daylighting) in the DOE reference models.
    - Large
- As expected, the LED light fixtures show significant static energy savings, in part due to their increased efficiency, but also due to the decreased lighting power density (LPD) for the workstation specific lighting system compared to a traditional zonal level lighting design and layout.

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[13] https://energy.gov/eere/buildings/commercial-reference-buildings

- The test system easily maintained illuminance at or above 300 lux in the workplace, as well as minimum light levels of 100 lux in egress pathways.
- The test system maintained daylight glare probability (DGP) within acceptable levels throughout some of the testing period. There was no appreciable difference in DGP measured between the basecase and test system conditions. Periods of increased DGP included times with high exterior illuminance, and seasonally low sun angles. Manual or operable shade would be required to ensure visual comfort throughout the year.
- Daylight re-directing window film was not optimally applied for demonstrating potential energy savings, and as installed produced very small savings during high sun angles and the overall savings were ‘dwarfed’ by the LED fixture savings and normal daylight controls. The film did demonstrate an ability to improve light distribution in the space, particularly with a lit ceiling plane, however the system setup and tuning were not coordinated to capture this benefit and translate it into energy savings. As such the daylight film results were deemed useful for use in conditions where the workstation specific lighting system was studied, as the difference in energy use with and without the film was negligible.

Table 4-6 summarizes the overall range of lighting savings in the daylit zones. These savings are attributable to LED lighting system efficiencies, the reduced overall Lighting Power Density (LPD) of the workstation specific lighting system, and the control strategies employing daylight dimming. The baseline had manual shades and no dimming. Note that the lighting % savings at the whole building level will be lower because it includes portions of the building that are not daylit.

Table 4-6: Summary lighting energy savings attributable to workstation specific lighting system operation, lower LPD and daylight dimming during occupied hours (7am – 7pm) for selected FLEXLAB testing configurations, adjusted to allow for complete dimming

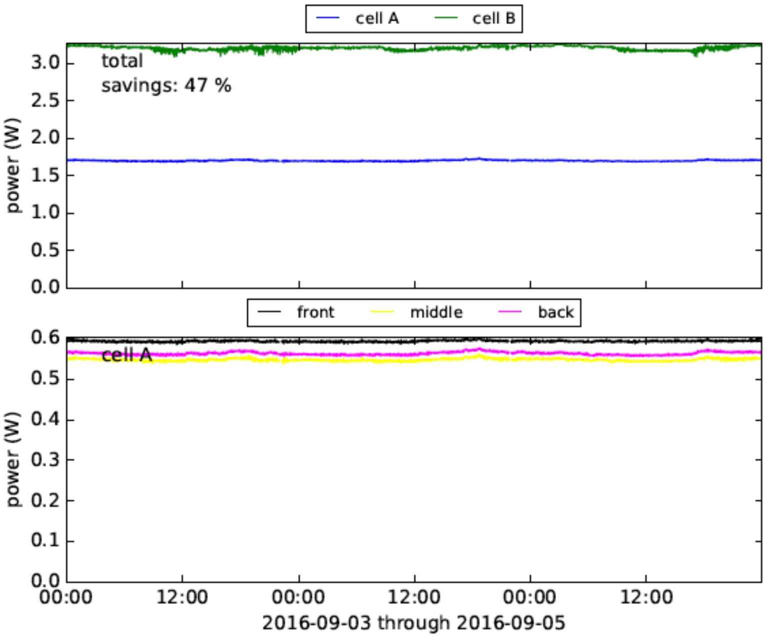
Lighting Setpoint	FLEXLAB Test Configuration	Summer (% Savings)	Fall (% Savings)	Winter (% Savings)
300 lux	Film 1 – Workstation-Specific Lighting	NA	98-99%	NA
300 lux	Film 2 – Workstation-Specific Lighting	NA	98-99%	NA
500 lux	Film 1 – Workstation-Specific Lighting	NA	NA	83-94%
500 lux	Film 2 – Workstation-Specific Lighting	NA	95-96%	82-94%
500 lux	No Film – Workstation Specific Lighting	NA	NA	86-94%

4.3.2 FLEXLAB Test Lighting Savings

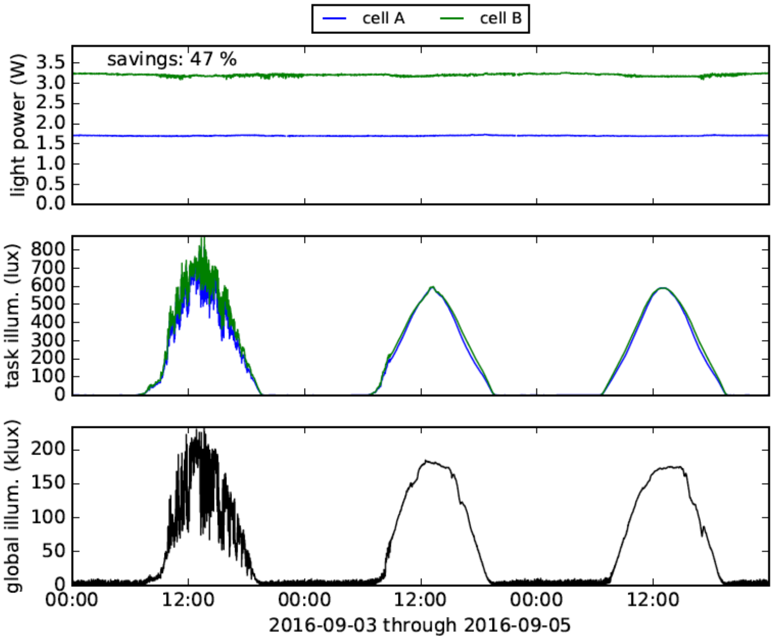
Table 4-6 summarizes the overall range of lighting savings in the daylit zones. These savings are attributable to LED lighting system efficiencies, the lower LPD of the workstation specific lighting system, and the control strategies employing daylight dimming. The baseline had manual shades and no dimming. Note that the lighting % savings at the whole building level will be lower because it includes portions of the building that are not daylit, and energy savings will vary with other orientations besides South.

Figure 4-5 below shows the parasitic system electric load savings for LED lighting versus the Basecase fluorescent system. The LED fixture configuration shows that when the lights are off, there is approximately a 47% electric savings versus the fluorescent base case system, however the parasitic loads due to the lighting controls system being on are very low, ranging from ~1.5 to 3 Watts. This test is presented to provide a further level of information on how the energy savings can be compared between the two operating systems.

Figure 4-5: Film 1 Test Results with Electric Lighting off indicating parasitic loads; a) Average & Individual Power Levels for Fixture Rows; b) Average Power & Task & Global illuminance Levels; Blinds Full Height (09/03/16 – 09/05/16)



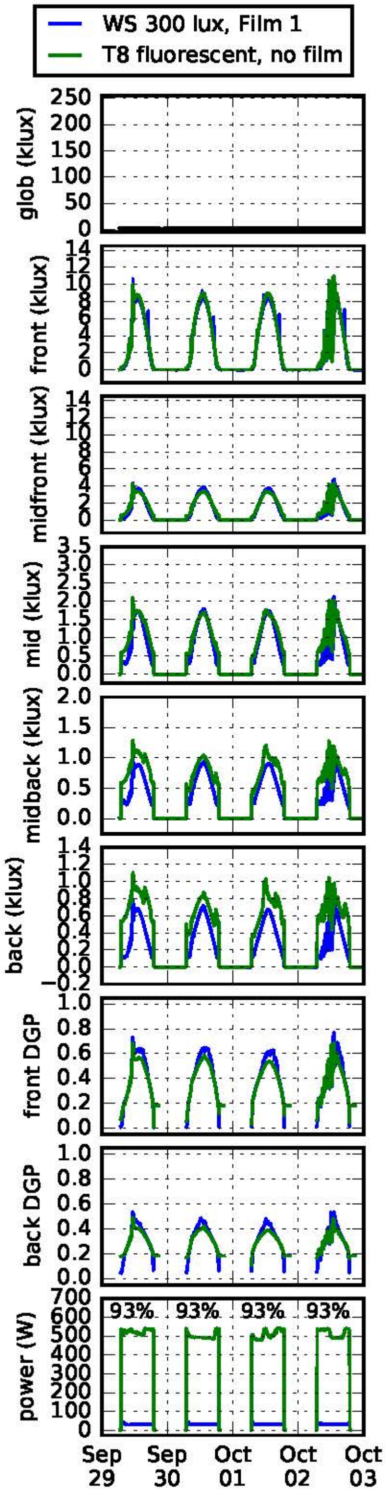
a)



b)

Figure 4-6 below shows a representative sample of performance of the Workstation Specific (WS) system as compared to the baseline system. Energy savings of ~93% are shown during periods of sunny weather.

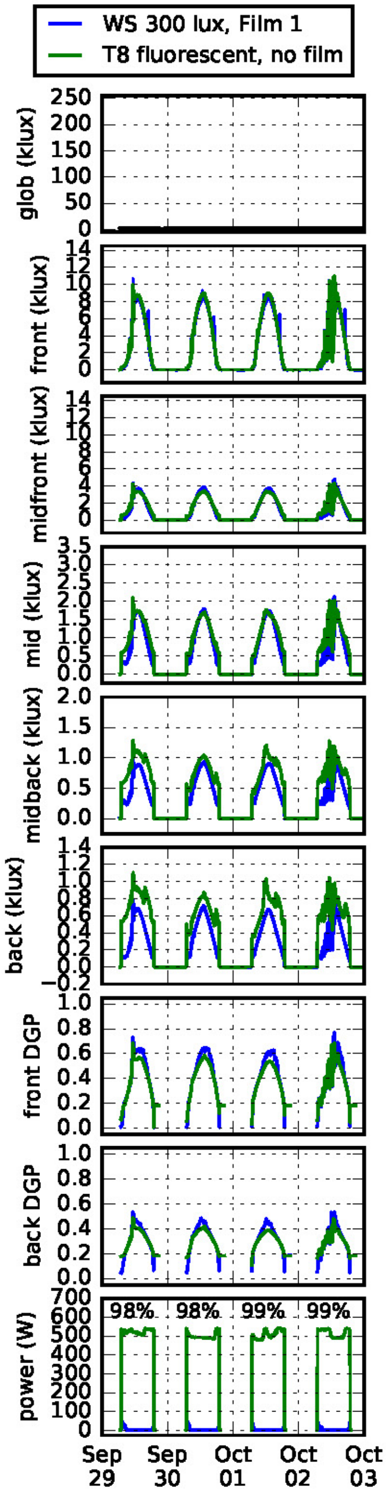
Figure 4-6: Film 1 plus Workstation-Specific Lighting set at 300 lux; Blinds Full Height (09/29/16 – 10/03/16)



This result shows 93% lighting energy savings for the period studied, and represents the lighting energy savings for all 3 rows of light fixtures dimming in the space. A complete set of test results for 3 rows dimming, as well as a study for just the first 2 south rows dimming are presented in Appendix E. In general, there was not an appreciable additional energy savings benefit to having the third row dim, and so deployment of workstation specific lighting systems might want to target applications within the first 20 ft of the window as a more economic approach to system deployment.

Figure 4-6 also indicates that at full dimming, the installed system did not dim down to zero (or near zero) light output or energy draw. During these tests, the lighting controls system was used in an ‘out of the box’ condition. In Figure 4-6 the workstation specific lighting system power dimmed to a lower level of approximately 30 watts while in full dimming mode. This indicates that the dimming controls were not tuned to allow for full energy reduction while at 100% dimming. This is a condition that has been experienced in other LBNL lighting tests, and indicates a need to tune these systems in the field, and verify performance across the range of settings, in order to achieve the energy reduction expected. An assessment of the impact of not tuning the system to this minimum light output condition was conducted post-processing the test data to dim to a level similar to the draw experienced during the unoccupied periods, as shown in Figure 4-7.

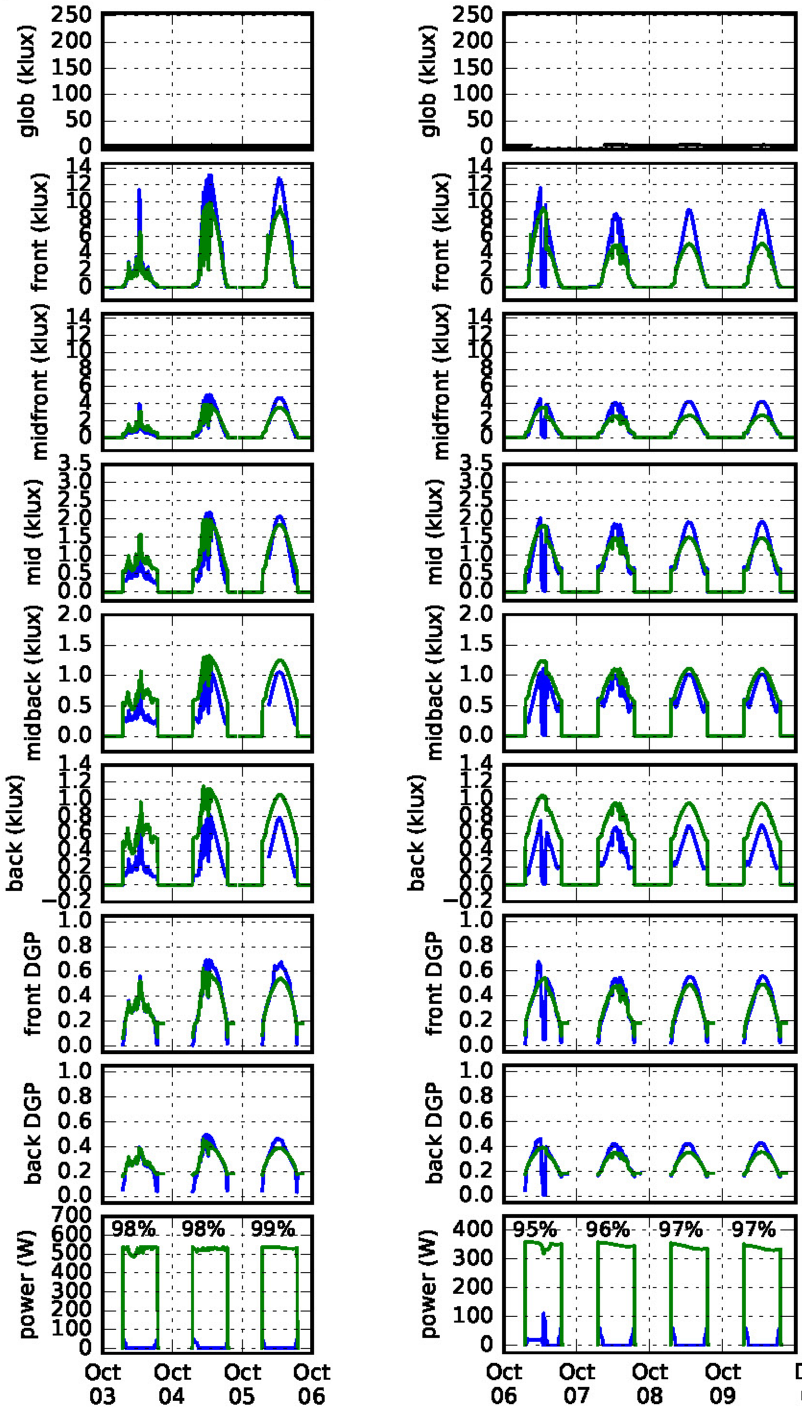
Figure 4-7: WS 300 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (09/29/16 – 10/03/16)



A significant increase in energy savings is shown in Figure 4-7, with energy savings increasing from 93% to 98%.

Figure 4-8 shows a comparison of Workstation Specific lighting system savings for a 300lux condition at the workplane (98-99% savings), versus a 500 lux condition (95-97% energy savings), with both sets of data adjusted for full dimming. It can be seen that the energy savings impact of the higher lux level is small between these two cases.

Figure 4-8: Film 2 plus Workstation-Specific Lighting set at 300 lux [Left] & 500 lux [Right]; Blinds Partial Height (10/03/16 – 10/06/16; 10/06/16 – 10/10/16)



Daily profiles were also analyzed to identify how savings varied with different sky conditions. As illustrated in the example above for the Film 2 and Film 1 films for adjacent days indicate how the savings vary from due to variable sky conditions, all other parameters being identical.

The major findings are as follows:

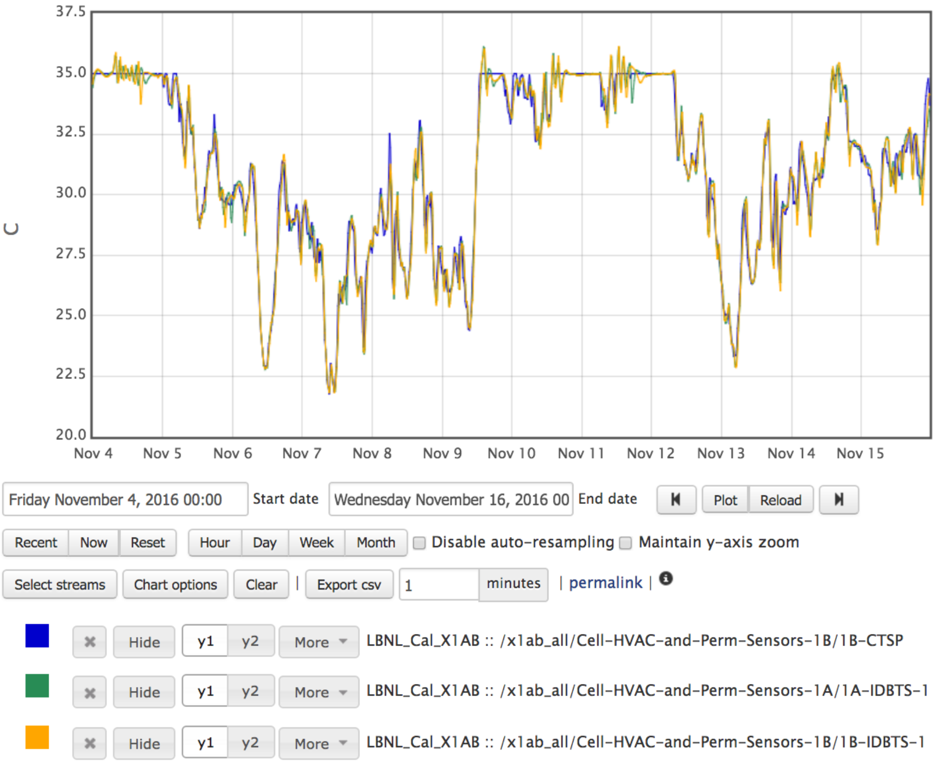
- The lighting savings are substantial, varying depending upon available daylight.
- As expected, the LED light fixtures show greater savings from static energy savings.

4.3.3 FLEXLAB Test HVAC Savings

HVAC Interactive Load Effects for Minnesota and Colorado climate: Xcel Energy was interested in savings estimates for their service territory located in Minnesota and Colorado. As part of the FLEXLAB testing, an approach was used to determine whether the net thermal effect of the reduced lighting energy load had a positive or negative effect on HVAC load and consequently energy use, in heating and cooling. As FLEXLAB is located in Berkeley, California, in order to obtain a HVAC loads assessment for these two climates, the internal temperature setpoints in FLEXLAB were adjusted in real time to match the indoor-outdoor temperature difference in as it would occur in that time period in Denver, using the Typical Meteorological Year (TMY) temperature data for Denver. In effect, at any given moment the internal to exterior temperature difference in FLEXLAB (delta T) was the same as if that test cell had been located in the Denver climate. Section 4.2.3.3 documents and describes findings from this approach.

During the FLEXLAB tests, the interior setpoint of each cell was set to track and emulate the same indoor-outdoor temperature difference as would occur for Denver using its TMY climate data. Both test cells were able to maintain very good tracking over a wide range of indoor setpoints, from 10C (50F) to 33C (91F). A sample of the temperature tracking performance is illustrated in Figure 4-11.

Figure 4-9: Test cells A and B Temperature Tracking Performance
(CTSP = Cell Temperature Tracking Setpoint; 1A-IDBTS-1 = Interior Dry Bulb Temperature Cell A; 1B-IDBTS-1 = Interior Dry Bulb Temperature Cell B)



Friday November 4, 2016 00:00 Start date
Wednesday November 16, 2016 00 End date

☐ Disable auto-resampling ☐ Maintain y-axis zoom

1 minutes

🟦 LBNL_Cal_X1AB :: /x1ab_all/Cell-HVAC-and-Perm-Sensors-1B/1B-CTSP

🟩 LBNL_Cal_X1AB :: /x1ab_all/Cell-HVAC-and-Perm-Sensors-1A/1A-IDBTS-1

🟧 LBNL_Cal_X1AB :: /x1ab_all/Cell-HVAC-and-Perm-Sensors-1B/1B-IDBTS-1

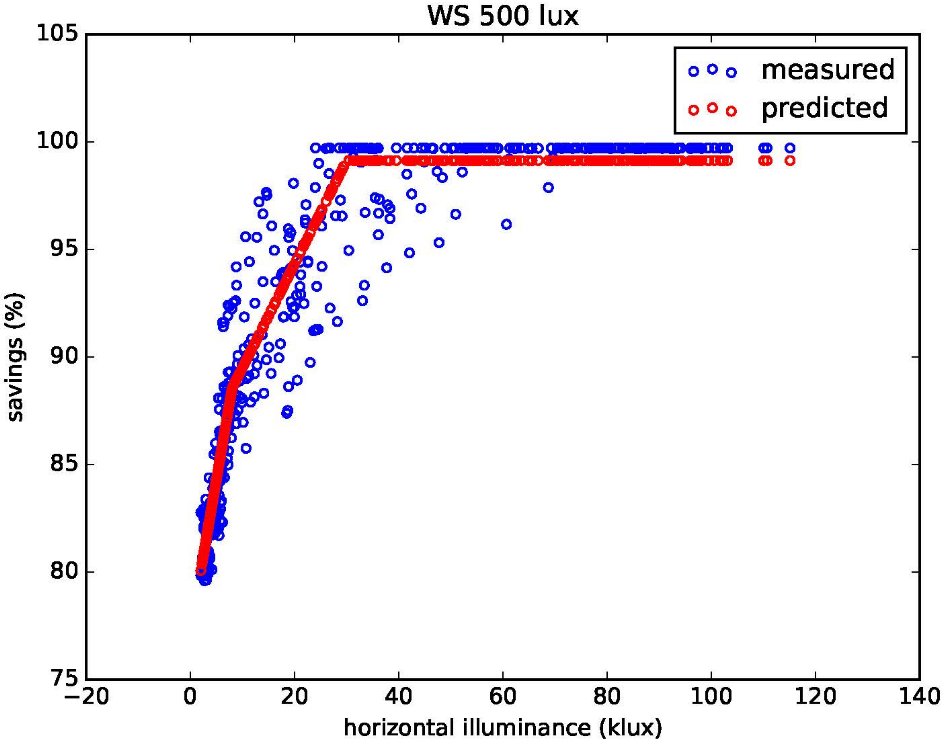
While the temperature tracking would enable the same thermal loading as would have been experienced by the test cell in the other climate, overall insufficient data was collected for the workstation specific lighting system across a range of climate conditions to warrant a comprehensive analysis of interactive effects on the HVAC system. This resulted from the evolution of the project starting out testing the daylight redirecting film, coupled with either general (zonal) lighting control or the workstation specific lighting system. Initial tests were conducted over the summer, cooling, period mainly focusing on the two different film types, as well as permutations of the two lighting systems. However with the main focus initially on the performance of the film, complete permutations of the workstation specific lighting system were not conducted across all climate conditions. A complete listing of the test configurations conducted appears in Appendix C. Once it was determined that the daylight redirecting film was not a significant contributor to the system savings, the test configurations were reoriented towards the workstation specific lighting system. The data collected for this system was mainly occurring in the fall and winter periods. As it turns out, the system performs very well, even in the periods of lower sun angles and periods of cloud cover. Effectively the workstation specific lighting system’s lighting energy performance was shown to dim fully at sufficiently lower exterior illuminance levels such that performance could be well predicted for summer months with the range of conditions experienced in the fall and winter months. However, there were not sufficient climatic variation (e.g. peak cooling condition was not achieved) in the test period to warrant a comprehensive assessment of HVAC interactive effects.

Overall, it is expected that with sufficient retrofit of the workstation specific lighting system throughout a customer site that there would be effects on heating and cooling of the building. Specific adjustments to HVAC energy consumption would need to take into account the relative efficiency of the customer's existing HVAC system both in heating and cooling mode, across a range of loads, to understand the overall impact potential.

4.3.4 FLEXLAB Testing Annual Lighting Savings

FLEXLAB test data for the Workstation Specific lighting system over a range of seasonal conditions. A regression model was developed for collected data to correlate lighting system energy savings over the baseline condition for the 500 lux workstation specific lighting system. Figure 4-11 documents the regression model for lighting energy savings for the 500 lux system against the dataset measured from the FLEXLAB tests, documenting the case where all 3 rows of lights dimmed.

Figure 4-10: 500 Lux Workstation Specific Lighting System – Annual Lighting Energy Savings Regression Model fit Against Measured Test Results, 3 Rows Dimming



The above regression model fits the measured test data with an R^2 of 0.94. The coefficients describing the regression model planes are as follows:

- Offset = 77.2
- 1st slope for illuminance = 1.41
- 2nd slope for illuminance = 0.482

This model assumes no lighting usage outside of the hours of 7pm to 7am. If night time lighting usage is expected this should be added into the lighting energy use projection. This regression model results in an annual savings estimate for the different locations are as follows (at a 95% confidence level), using TMY data for each location:

- Oakland: 97% +/- 1%
- Denver: 97% +/ 1%
- Minneapolis: 97% +/- 1%

This regression model indicates a very strong correlation for prediction of energy savings based on the exterior illuminance level. These regression models serve two purposes – they can be used to extend the test data to predict annual energy savings from the FLEXLAB test cases. Further, they can be adapted for use as an assessment tool for a customer's site. This will be further address in Section 5.

Using this regression model for the 3 rows dimming case, the annual energy savings from the FLEXLAB testing are as shown in Table 4-7.

Table 4-7: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System tested in FLEXLAB, 3 Rows Dimming

Month	WS 500
Jan	93%
Feb	97%
Mar	97%
Apr	99%
May	98%
Jun	99%
Jul	99%
Aug	98%
Sep	97%
Oct	95%
Nov	95%
Dec	94%
Annual	**97%**

- Savings from 7am-7pm as % of baseline
- **Dark grey** cells: include savings measured from FLEXLAB data
- **White** cells: estimated using regression model

- Note: These system results only include impact of reduced number of fixtures for workstation condition, along with daylight dimming. Additional savings possible through inclusion of occupancy controls, although the remaining energy use is very small, and might not likely warrant the extra cost of these sensors.

Using this regression model generated from the FLEXLAB test, and applying it to the Denver and Minneapolis TMY data provides the following projections of energy use reduction, for a south facing zone, similar to the FLEXLAB test condition.

Table 4-8: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System – Denver Location, 3 Rows Dimming

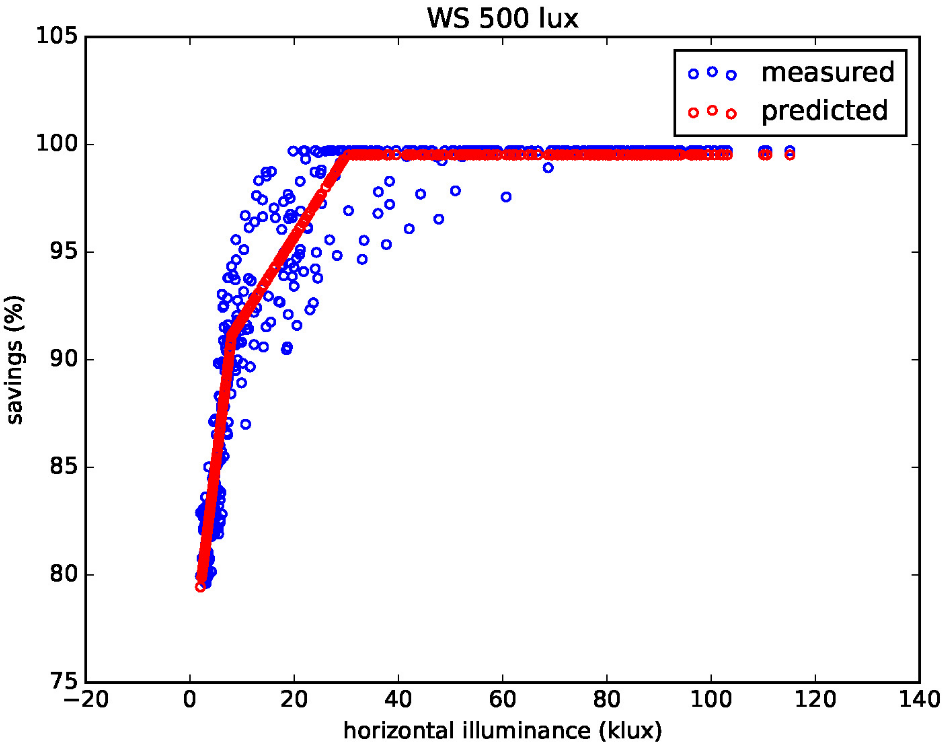
Month	WS 500
Jan	95%
Feb	96%
Mar	97%
Apr	98%
May	99%
Jun	99%
Jul	99%
Aug	99%
Sep	97%
Oct	96%
Nov	94%
Dec	94%
Annual	**97%**

Table 4-9: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System – Minneapolis Location, 3 Rows Dimming

Month	WS 500
Jan	93%
Feb	96%
Mar	98%
Apr	99%
May	99%
Jun	99%
Jul	99%
Aug	99%
Sep	98%
Oct	96%
Nov	93%
Dec	92%
Annual	**97%**

A second regression model study was conducted to understand the impact of only dimming the first two rows of lighting. The results of this model are shown in Figure 4-12 for the 500 lux test data.

Figure 4-11: 500 Lux Workstation Specific Lighting System – Annual Lighting Energy Savings Regression Model fit Against Measured Test Results, 2 Rows Dimming



The above regression model fits the measured test data with an R^2 of 0.94. The coefficients describing the regression model planes are as follows:

- Offset = 75.5
- 1st slope for illuminance = 1.95
- 2nd slope for illuminance = 0.381

This model assumes no lighting usage outside of the hours of 7pm to 7am. If night time lighting usage is expected this should be added into the lighting energy use projection. This regression model results in an annual savings estimate for the different locations are as follows (at a 95% confidence level), using TMY data for each location:

- Oakland: 97% +/- 1%
- Denver: 97% +/ 1%
- Minneapolis: 97% +/- 1%

Table 4-10: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System tested in FLEXLAB, 2 Rows Dimming

Month	WS 500
Jan	93%
Feb	97%
Mar	98%
Apr	99%
May	98%
Jun	100%
Jul	99%
Aug	98%
Sep	97%
Oct	96%
Nov	95%
Dec	94%
Annual	**97%**

- Savings from 7am-7pm as % of baseline
- **Dark grey** cells: include savings measured from FLEXLAB data
- **White** cells: estimated using regression model
- Note: These system results only include impact of reduced number of fixtures for workstation condition, along with daylight dimming. Additional savings possible through inclusion of occupancy controls, although the remaining energy use is very small, and might not likely warrant the extra cost of these sensors.

Using this regression model generated from the FLEXLAB test, and applying it to the Denver and Minneapolis TMY data provides the following projections of energy use reduction, for a south facing zone, similar to the FLEXLAB test condition.

Table 4-11: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System – Denver Location, 2 Rows Dimming

Month	WS 500
Jan	95%
Feb	96%
Mar	97%
Apr	98%
May	99%
Jun	100%
Jul	100%
Aug	99%
Sep	97%
Oct	96%
Nov	94%
Dec	95%
Annual	**97%**

Table 4-12: Monthly and Annual Lighting energy savings vs basecase for 500 lux Workstation Specific Lighting System – Minneapolis Location, 2 Rows Dimming

Month	WS 500
Jan	93%
Feb	96%
Mar	98%
Apr	99%
May	100%
Jun	100%
Jul	100%
Aug	100%
Sep	98%
Oct	96%
Nov	93%
Dec	92%
Annual	**97%**

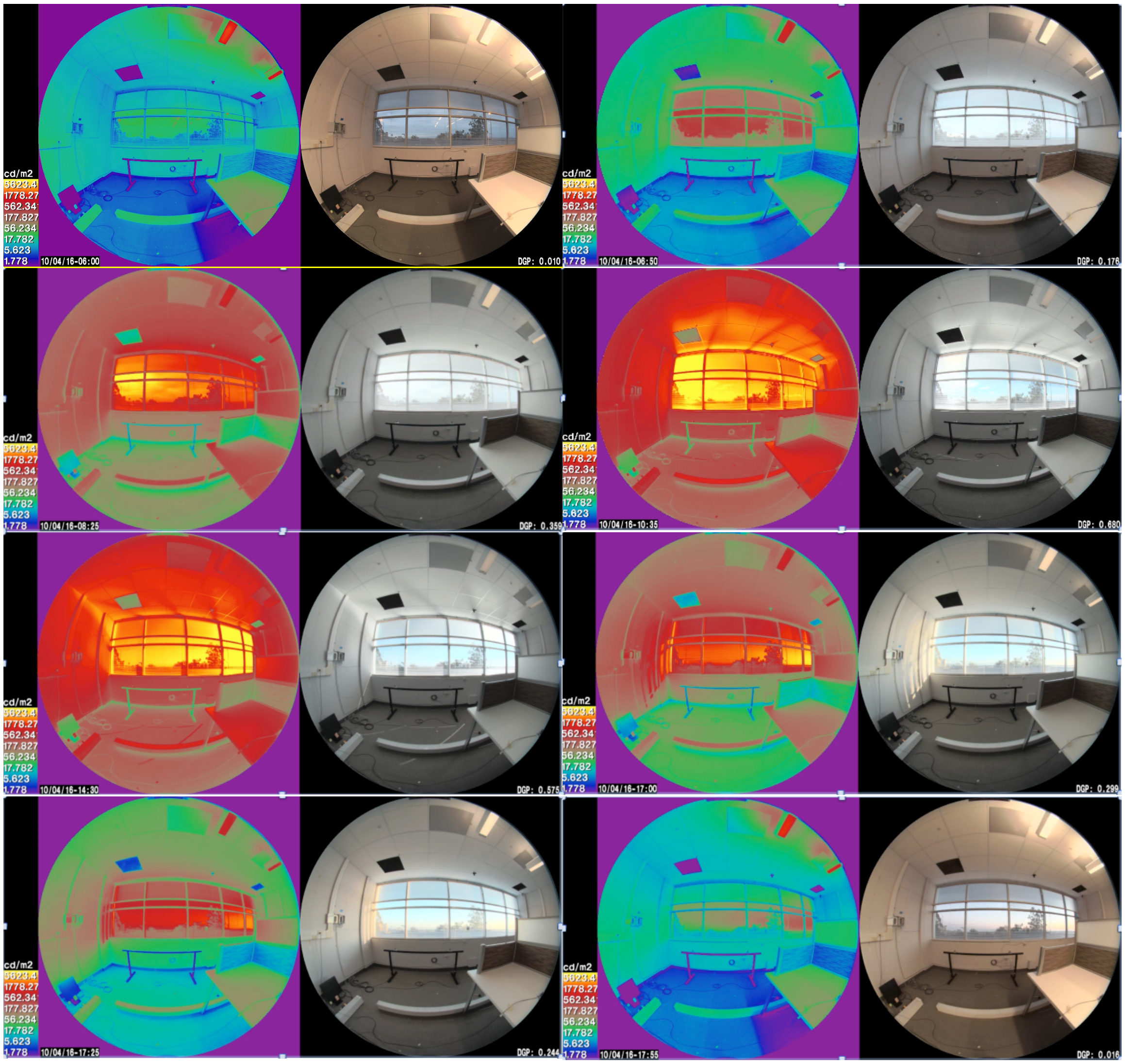
As can be seen, there is virtually no difference in lighting energy use reduction using the first 2 rows of lighting, versus the 3 rows of lighting. As such, it is recommended that incentive programs primarily focus on the first 20ft from the south window for designing and implementing such programs.

4.3.5 FLEXLAB Testing Visual Comfort Results

Visual comfort was measured in these tests through the use of a grid of Licor photosensors located throughout the test cells, and through the use of two High Dynamic Range (HDR) cameras set up in each cell. Photosensor data was captured to document light levels at the worksurfaces and in egress pathways, and HDR cameras provided the imagery of key perspectives in the space to capture data for analysis related to Discomfort Glare Probability (DGP). A complete description of the test setup, analysis methods and results for light distribution and for DGP is detailed in Appendix F.

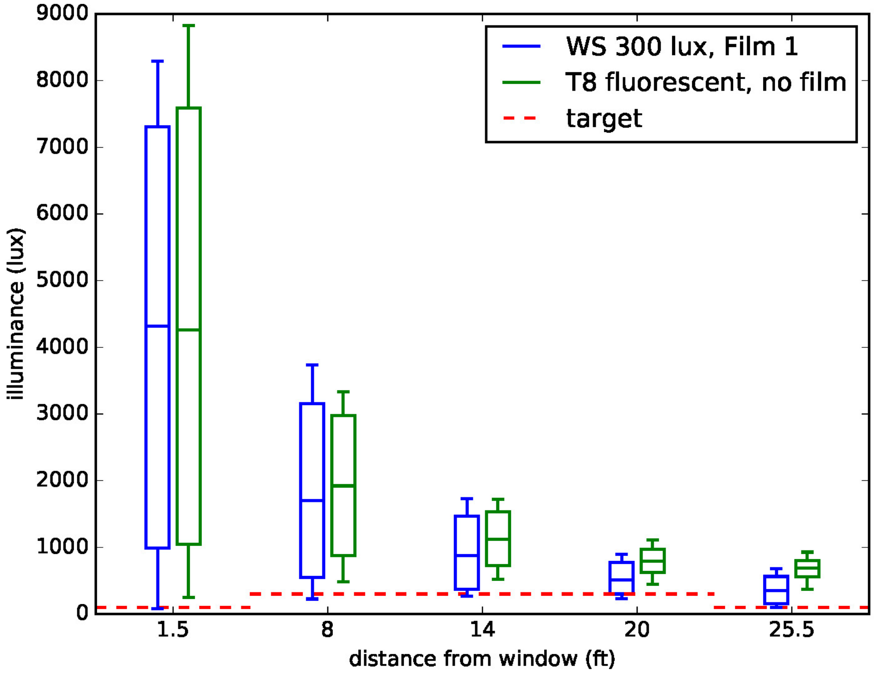
Figure 4-13 provides representative, detailed images and measurements from the HDR cameras of the Discomfort Glare Probability (DGP) for the reference Basecase test cell (X1B) and proposed test cell (X1A) for workstation-specific lighting combined with the Film 2 with the mini-blinds at partial height.

Figure 4-12: Representative HDR Camera Images for Film 2 plus Workstation-Specific Lighting Showing Discomfort Glare Probability throughout the Day; Blinds Partial Height (10/04/16)



In summary, in all cases, it was seen that the illuminance levels throughout each test case met or exceeded the minimum illuminance levels as set by IES for egress purposes (i.e. 100 lux), or for the minimum levels desired at the workplane (i.e. 300 or 500 lux). As expected, increased light levels occur closer to the window, and at significant levels that may cause glare issues at times. Figure 4-14 provides a representative result of the illuminance distribution for a given test configuration. The data shown are for photosensor readings taken from set distances from the window.

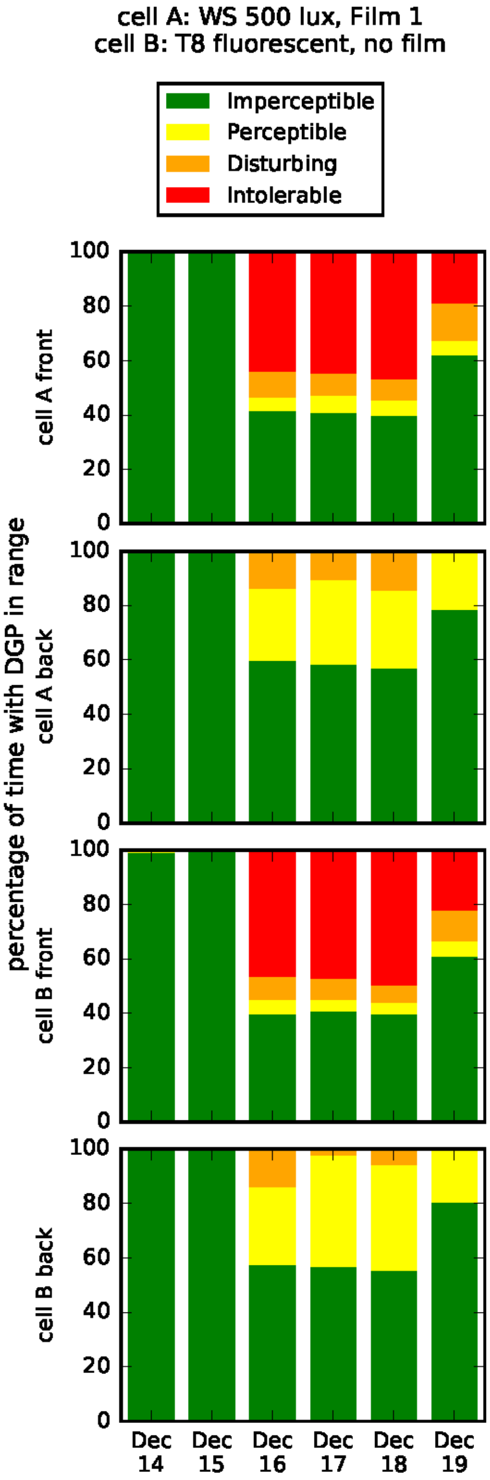
Figure 4-13: Workstation Specific Lighting System, Illuminance Distribution, 300lux minimum workplane case with Film 1.



A complete set of photosensor distribution results can be found in Appendix F.

In general, the distribution of higher illuminance values closer to the window is sufficient for glare issues to be present. However, the occurrence of these values is similar in both the reference (base case) cell and the test cell, indicating that additional measures would be needed in both cells to mitigate glare issues. This finding is supported by the HDR camera data and the DGP analysis. Figure 4-15 provides a representative result for HDR analysis for a specific test period.

Figure 4-14: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 500lux Maximum Output. Film 1 test condition.



From this result, it can be seen that there are some days when DGP levels are low enough to be considered to have imperceptible levels of glare. However, there are other days when light levels are high enough to contribute to periods of perceptible, disturbing and intolerable levels of glare. These results indicate that additional use of a manual or automated shade would be required in both the base case and test system conditions in order to ensure that visual comfort was achieved throughout the various seasonal and light level conditions.

4.4 Equivalent Annual Whole Building Energy Savings for DOE Reference Buildings

FLEXLAB test results provide the basis for an annual assessment of energy savings for a relatively small south facing perimeter zone. In order to provide context for how these savings could translate into whole building savings an assessment was conducted using the U.S. Department of Energy's reference building models[14], for medium and large commercial offices. The DOE reference models provide a standard whole building configuration to represent a portion of the U.S. building stock.

Using the annual lighting energy % savings validated through FLEXLAB testing, an equivalent whole building energy savings was determined for the DOE reference models for each of the Colorado and Minnesota markets. In each case the FLEXLAB annualized test energy savings were applied to the south facing zones in each floor of the building, along with all southeast and southwest corners, In the following results, the energy savings were applied to the lighting system in the south zone on each floor, as well as southeast and southwest corner offices. Additional savings may be realized by deploying the system in east and west facing zones with the reduced LPD and daylighting controls. Further savings in core zones may also be possible due to the reduced LPD due to the workstation specific lighting layout.

Table 4-13: Colorado whole building annual energy savings for workstation specific lighting system, applied to DOE Reference models, 500 lux, 3 rows dimming

Building	Annual Whole Bldg % Energy Savings Over Baseline
	WS set to 500 lux
Large Commercial Office	6-15%*
Medium Commercial Office	13%

*Note: 6% figure applies to a large commercial office building that has a data center

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[14] https://energy.gov/eere/buildings/commercial-reference-buildings

Table 4-14: Minneapolis whole building annual energy savings for workstation specific lighting system, applied to DOE Reference models, 500 lux, 3 rows dimming

Building	Annual Whole Bldg % Energy Savings Over Baseline
	WS set to 500 lux
Large Commercial Office	6-13%*
Medium Commercial Office	11%

*Note: 6% figure applies to a large commercial office building that has a data center

5 Technology Assessment for Customers

5.1 Methodology for Assessment

FLEXLAB test results provide the basis for a validated assessment methodology to determine energy savings for a customer site. Appendix A describes the development and accuracy of a regression model, derived using FLEXLAB test data. In addition, an Excel file is appended along with this program manual for use in customer site assessments for given conditions. While the test data was developed with the Denver location in mind, other sites of similar latitudes may make use of the regression model based methodology, inputting that location's exterior horizontal illuminance data from available TMY3 climate data for that site. The regression model correlates exterior horizontal illuminance to the energy savings of the workstation specific lighting system, which is derived from the TMY3 data[15].

Appendix A provides further details on the accuracy of the model, and describes key considerations for its use.

6 Measurement and Verification (M&V)

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 workstation specific lighting systems with daylight dimming is strongly dependent on correct programming and operation of controls in response to changing internal and external illuminance and solar parameters, as well as on verified minimum and maximum

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[15] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

light output level set for the system. Given that, we strongly recommend that operational verification utilize a combination of sample spot measurements, and data trending and control logic review. In particular, we recommend the following at a minimum:

Light fixture maximum and minimum output:

- 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 and in egress paths meets the minimum criteria desired, whether IES standards, 300lux or 500lux as studied for this program design. This test should be conducted at night, with a minimum of other artificial light sources impacting the area being verified.

Daylight dimming system

- 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.

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. A sample Installation Verification Checklist has been included in Appendix B for use for this purpose.

6.2 M&V Approaches and Metrics

6.2.1 Project M&V

Table 6-1 presents several IPMVP[16] options for measurement and verification (M&V) that are viable for this program. Some M&V options comprise an inherently greater level of uncertainty in the energy savings than other approaches.

Using this information, a utility DSM program may decide to adjust the incentive amount to the customer to account for the uncertainty of energy performance associated with each of the M&V options described below. The aim of offering the menu of options is to present different M&V approaches, including traditional ones and new options that could streamline measurement and verification activities at customer sites, potentially reducing the cost of implementing these M&V strategies.

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[16] http://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

Table 6-1: Overview of IPMVP Options [Source: International Performance Measurement & Verification Protocol Concepts and Options for Determining Energy and Water Savings Volume I, January 2012, p.17-18

IPMVP Option	How Savings Are Calculated	Typical Applications
A. Retrofit Isolation: Key Parameter Measurement *Savings* are determined by field measurement of the key performance parameter(s), which define the *energy* use of the *ECM*'s affected system(s) and/or the success of the project. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the *reporting period*. Parameters not selected for field measurement are *estimated.* *Estimates* can based on historical data, manufacturer's specifications, or engineering judgment. Documentation of the source or justification of the *estimated* parameter is required. The plausible *savings* error arising from *estimation* rather than measurement is evaluated.	Engineering calculation of *baseline* and *reporting period energy* from: • Short-term or continuous measurements of key operating parameter(s); and • *Estimated* values. *Routine* and *non- routine adjustments* as required.	A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimate operating hours of the lights based on *facility* schedules and occupant behavior.
B. Retrofit Isolation: All Parameter Measurement *Savings* are determined by field measurement of the *energy* use of the *ECM*-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the *savings* and the length of the *reporting period*.	Short-term or continuous measurements of *baseline* and *reporting- period energy*, and/or engineering computations using measurements of proxies of *energy* use. Routine and non- routine adjustments as required.	Application of a variable- speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power every minute. In the *baseline period* this meter is in place for a week to verify *constant* loading. The meter is in place throughout the *reporting period* to track variations in power use.
C. Whole Facility Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.	Analysis of whole facility baseline and reporting period (utility) meter data. Routine adjustments as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments as required.	Multifaceted energy management program affecting many systems in a facility. Measure energy use with the gas and electric utility meters for a twelve-month baseline period and throughout the reporting period.
D. Calibrated Simulation Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)	Multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period. Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation. Baseline energy use, determined using the calibrated simulation, is compared to a simulation of reporting period energy use.

6.2.2 Program EM&V

The integrated system described for this program does not inhibit any traditional approaches to program EM&V. Should the customer buildings involved include whole building smart meters or EMIS systems other EM&V approaches may be applicable.

7 Savings Persistence Guidelines

A study out of LBNL 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"[17]. 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)[18].

However, a 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 and GUI, 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

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[17] May 2015 Energy Savings Lifetimes and Persistence: Practices, Issues and Data Ian M. Hoffman, Steven R. Schiller, Annika Todd, Megan A. Billingsley, Charles A. Goldman, Lisa C. Schwartz, Lawrence Berkeley National Laboratory.

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

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 overlighting or underlighting 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.

Recommendations:

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.

Periodic (annual, 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 B for a sample verification checklist process that can be periodically applied to ensure that light levels and controls operation are set to desired levels.

8 Training for Program Implementers

The following stakeholders should be considered for outreach efforts in the development and deployment of the workstation specific lighting system incentive program:

- **Program Design & Planning**: Responsible for developing and proposing programs including specification levels, evaluating cost-effectiveness, establishing incentive levels and deciding which activities the program will encompass (e.g., stakeholder education).
- **Program Management**: Oversees program delivery and provides insights for process regarding what has or hasn't worked in the past.
- **Marketing & Outreach**: Promotes programs to the public and trade allies and makes decisions regarding promotional materials, advertising placements and conducting on-line promotions.
- **Evaluation or Market Research**: Plans and oversees: market research for program planning or baseline setting, tracking and assessment of program impacts, progress towards program goals, and/or process evaluation. May also collect and analyze data in support of these efforts.
- **Regulatory Affairs**: Responsible for working with regulators on rate cases.
- **Technology & Engineering**: Qualified to evaluate the technical potential, performance, or safety of equipment under consideration for inclusion in programs.
- **Portfolio Management**: Responsible for assessing efficiency program objectives, timelines, and resources (for a sector or the total portfolio), planning a set of sector programs needed to meet requirements beyond the current program year, and maintaining a balance of sector program activities across the portfolio in order to achieve multi-year goals, among other responsibilities.
- **Government**: Has government perspective of working toward energy efficiency goals.

9 References

In addition to the footnotes appended throughout this program manual, the following references are recommended in particular related to the workstation specific lighting system.

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. LBNL-6023E

Robinson, A., C. Regnier. 2015. Zone Level Occupant-Responsive Building Energy Systems at the GSA. LBNL-182574.

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, Lawrence Berkeley National Laboratory. Page, E, Erik Page & Associates, Inc. May 2012. Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings. LBNL-5895E

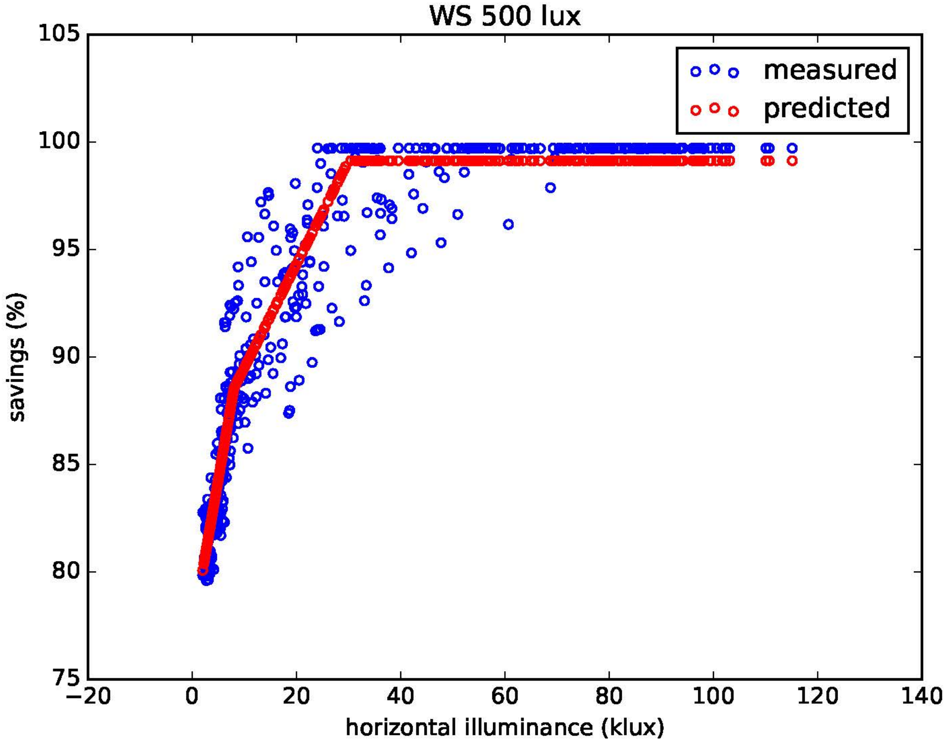
Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein. 2011. A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings. Technical report. LBNL-5095E.

Wireless Lighting Control, A Life Cycle Cost Evaluation of Multiple Lighting Control Strategies, Prepared For: Daintree Networks; Clanton & Associates, Inc., Dane Sanders, PE, LEED™ AP, Darcie Chinnis, EI, LEED™ AP,

Appendix A: Assessment Methodology

FLEXLAB testing has provided the basis for a validated assessment strategy for workstation specific lighting systems, with daylight dimming, for south facing zones at 300 or 500 lux. The data collected from these tests was analyzed to create a regression model, that correlates lighting system energy savings to exterior horizontal illuminance, as shown in Figure A-1.

Figure A-1: 500 Lux Workstation Specific Lighting System – Annual Lighting Energy Savings Regression Model fit Against Measured Test Results, 3 Rows Dimming



The above regression model fits the measured test data with an R^2 of 0.94. The coefficients describing the regression model planes are as follows:

- Offset = 77.2
- 1st slope for illuminance = 1.41
- 2nd slope for illuminance = 0.482

This model assumes no lighting usage outside of the hours of 7pm to 7am. If night time lighting usage is expected this should be added into the lighting energy use projection. This regression model results in an annual savings estimate for the different locations are as follows (at a 95% confidence level), using TMY data for each location:

- Oakland: 97% +/- 1%
- Denver: 97% +/ 1%
- Minneapolis: 97% +/- 1%

This regression model can be used for other locations of similar latitude to assess their potential workstation specific lighting savings, using that location's TMY data to create lighting use profiles for the horizontal illuminance expected for the other location. A draft methodology is provided as a separate Excel file illustrating this concept.

System testing was not conducted for other, non-South orientations as of this writing. Consequently regression models for other orientations are not provided. A methodology to assess energy use reduction solely from the reduced LPD from the workstation specific lighting design, over a traditional zonal lighting design has been provided in the Excel file, which can be used to assess energy savings for core areas.

Assessment Method Accuracy

There are three sources of uncertainty that should be accounted for in the use of the regression model derived approach for assessing customer site potential energy savings:

- Regression model uncertainty
- FLEXLAB measured test data accuracy
- Variance in customer site conditions or behavior from FLEXLAB test conditions

The regression model as developed quantifies the uncertainty of the model in representing the given data set. As presented earlier these models were providing very accurate prediction, with an uncertainty of +/- 1%. In addition, these models were derived from measured data in FLEXLAB. FLEXLAB's power measurement system has an accuracy of: +/- 2% of reading, for readings greater than 25W (see Appendix C for a more thorough description through the range of readings). Combined, these two sources of inaccuracy result in an approximately +/-3% uncertainty for the presented energy savings results.

The last source of error is unfortunately much harder to quantify and mitigate. Measures to reduce the potential for unrealized energy savings have been provided in this program manual, such as the Installation Verification Checklist (Appendix B) and the Savings Persistence Guidelines. It may be beneficial to pilot this system in the Denver and Minneapolis markets in occupied buildings to gain a better sense of the range of potential savings, and identify other barriers to realized energy savings and strategies to mitigate them.

Appendix B: 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 (eg. 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.

Appendix C: FLEXLAB Test Plan – Detailed

Table C-1: Primary data collected for test

Metric	Measurement
Shade position	Manual setting
Global and diffuse horizontal illuminance; **HDR imaging**	Pyranometer w/shadow band and automated tracker. Delta-T Devices Sunshine Pyranometer SPN1. Accuracy - PAR = +- 12%, Energy = +-12%, Illuminance (+-12%); Eye On the Sky (EOS). Mounted on automated solar tracker with other solar instrumentation
Workplane illuminance	Licor sensors on workplane and throughout test cell at 4' intervals from window wall; LICOR 210 - accuracy = +- 5%
Daylight glare probability	HDR cameras oriented parallel and perpendicular to window; Canon EOS 5D Digital Camera with SIGMA lens - accuracy = +-10%
Power Metering including: **Lighting power per fixture** (All internal loads independently, overhead lighting, task lighting, fan powered terminal units, computers, and simulated people, and control and DAQ power if within the cell. Current transducers on each luminaire. Power measurements on individual components of heating and cooling systems.)	1. True RMS real power with accuracy: a. at zero real power, +/- 0.1W, b. between 0 and 25W real power +/- 0.5W, c. above 25W +/- 2% of reading. All accuracies are all in, including CT, A/D conversion and calculation. In addition, the meter reading shall increase monotonically with an increase in real power. The meter shall be capable of accurately accounting for harmonics up to the 50th. 2. Logging of the average power should be done at a 1-second interval, with the interval adjustable to gather less frequently, up to 15 minutes. Accuracy vs. actual value plots shall be submitted for unity power factor and for 50% power factor with 1.0 displacement power factor (i.e. power factor degradation all due to harmonics). 3. True RMS voltage and current, average values, shall also be logged at a one-second (adjustable up to 15 minute) interval. 4. Power quality parameters (voltage and current waveforms, statistics including minimum and maximum voltage and current and voltage and current harmonics) do not need to be recorded except when automatic trigger values (typically high or low voltages) are hit or when manually triggered. Any trigger will result in 60 cycles being recorded immediately after the trigger, and 10 cycles immediately before the trigger.
8. Air supply airflow measurement **9. Room pressure measurement** **10. Chilled water flow meters** **11. Chilled water supply and return temperature sensors** **12. Hot water flow meters** **13. Hot water supply and return temperature sensors** **14. Room pressure measurement**	1. Variable metering to allow for very low and very high flow measurements to same level of accuracy. Accuracy +/-2% of reading. 2. Pressure: Room, supply plenum absolute and deltaP. Accuracy +/- 1% full scale. Indicative specification DG700 pressure sensors from The Energy Conservancy with auto-zero ability. 3. Variable metering to allow for very low and very high flow measurements to same level of accuracy. Overall Btu meter accuracy = +- 0.2% of FS accuracy. Platinum turbine flow meters piped in full size bypass for calibration. 4. Selected to ensure Btu meter accuracy listed, but no lower accuracy than 0.15°F matching differential between two sensors. High stability thermistors, accuracy = +-0.05°F. Sealed temperature wells that accept stainless PRT probes for accuracy, stability and ease of recalibration. 5. Variable metering to allow for very low and very high flow measurements to same level of accuracy. Overall Btu meter accuracy = +- 0.2% of FS accuracy. Platinum turbine flow meters piped in full size bypass for calibration. 6. Selected to ensure Btu meter accuracy listed, but no lower accuracy than 0.15°F matching differential between two sensors. Accuracy = +-0.05°F. Sealed temperature wells that accept stainless PRT probes for accuracy, stability and ease of recalibration. 7. Pressure: Room, supply plenum absolute and deltaP. Accuracy +/- 1% full scale. Indicative specification DG700 pressure sensors from The Energy Conservancy with auto-zero ability.
Set point temperature - Interior dry bulb temps	Thermistors. Calibrated accuracy =+- 0.1 °C. Consider network data bus devices rather than multiple channels to centralized multipliers.

Table C-2: Configurations Tested. These Settings Compared the Test Case X1A to the Baseline Case X1B

ID	Lighting System Operation	Daylight Redirecting Window Film	Miniblinds Configuration	Lighting System Type	Light Level Setpoint (Task Plane)
1	Lights On	Film 1	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
2	Lights Off	Film 1	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
3	Lights On	Film 1	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
4	Lights Off	Film 1	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
5	Lights Off	No Film	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
6	Lights Off	No Film	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
7	Lights On	Film 1	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
8	Lights Off	Film 1	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
9	Lights On	Film 1	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
10	Lights Off	Film 1	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
11	Lights Off	No Film	Blinds mounted full window height	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
12	Lights Off	No Film	Blinds mounted full window height	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
13	Lights On	Film 2	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
14	Lights Off	Film 2	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
15	Lights On	Film 2	Blinds mounted below DRWF	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
16	Lights Off	Film 2	Blinds mounted below DRWF	(6) 4’ Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
17	Lights Off	No Film	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	300 lux
18	Lights Off	No Film	Blinds mounted	(6) 4’ Pendant Mounted Workstation-	300 lux

ID	Lighting System Operation	Daylight Redirecting Window Film	Miniblinds Configuration	Lighting System Type	Light Level Setpoint (Task Plane)
			below DRWF	Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	
19	Lights On	Film 2	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
20	Lights Off	Film 2	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
21	Lights On	Film 2	Blinds mounted below DRWF	(6) 4' Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
22	Lights Off	Film 2	Blinds mounted below DRWF	(6) 4' Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
23	Lights Off	No Film	Blinds mounted below DRWF	(3) 12' Pendant Mounted LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
24	Lights Off	No Film	Blinds mounted below DRWF	(6) 4' Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux
25	Lights On	No Film	Blinds mounted full window height	(6) 4' Pendant Mounted Workstation-Specific LED; w/ (6) - 3 fluorescent T-8 lamp troffers in ref. Cell B	500 lux

Appendix D: FLEXLAB Test Results – Daylight Redirecting Film Impacts and Recommendations

Results With and Without Daylight Redirecting Film

LBNL ran a series of tests that omitted the daylight redirecting window film as part of the investigation to see if the film impacts were negligible in determining the performance of the Workstation Specific lighting system. The data captured addressed the different mini-blind configurations for both Film 1 – full height, and Film 2 – partial height, different light level setpoints (300 lux and 500 lux), and were tested both with and without electric lighting in operation. Testing periods and configurations are listed below:

1. July 26, 2016 (300 lux, zonal lighting (lights off), blinds retracted).
2. September 9 – 18, 2016 (300 lux, zonal lighting (lights on), blinds partial height).
3. October 20 – 23, 2016 (500 lux, zonal lighting (lights on), blinds partial height).
4. November 18, 2016 (500 lux, zonal lighting (lights off), blinds partial height).
5. November 21 – 30, 2016 (500 lux, zonal lighting (lights on), blinds full height).
6. November 30, 2016 (500 lux, zonal lighting (lights off), blinds full height).
7. December 20, 2016 – January 2, 2017 (500 lux, workstation-specific lighting (lights on), blinds full height).

Evaluations were made for each of these conditions to compare and contrast light distribution and light levels to determine whether there were significant impacts from having the light redirecting film installed. The follow results are indicative of the analysis, and are presented for a test on November 18.

Figure D-1: Film 2 Installed in Upper Right Window Panes

Figure D-2: November 18th, 12:00 pm, HDR Imaging for No Film, Full Blinds, No Lights Condition

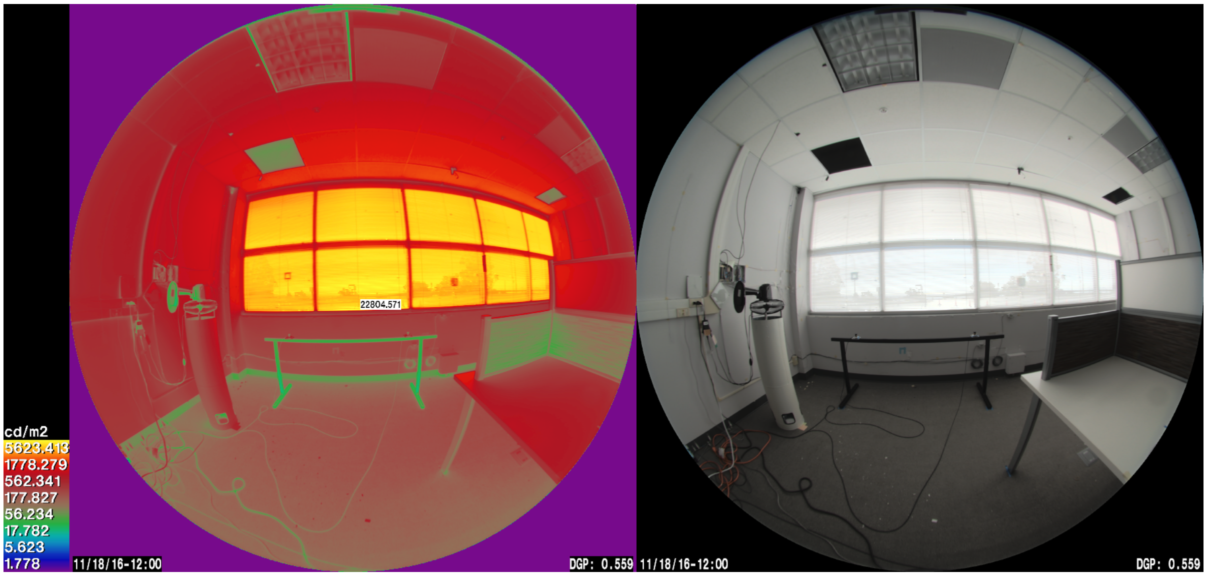
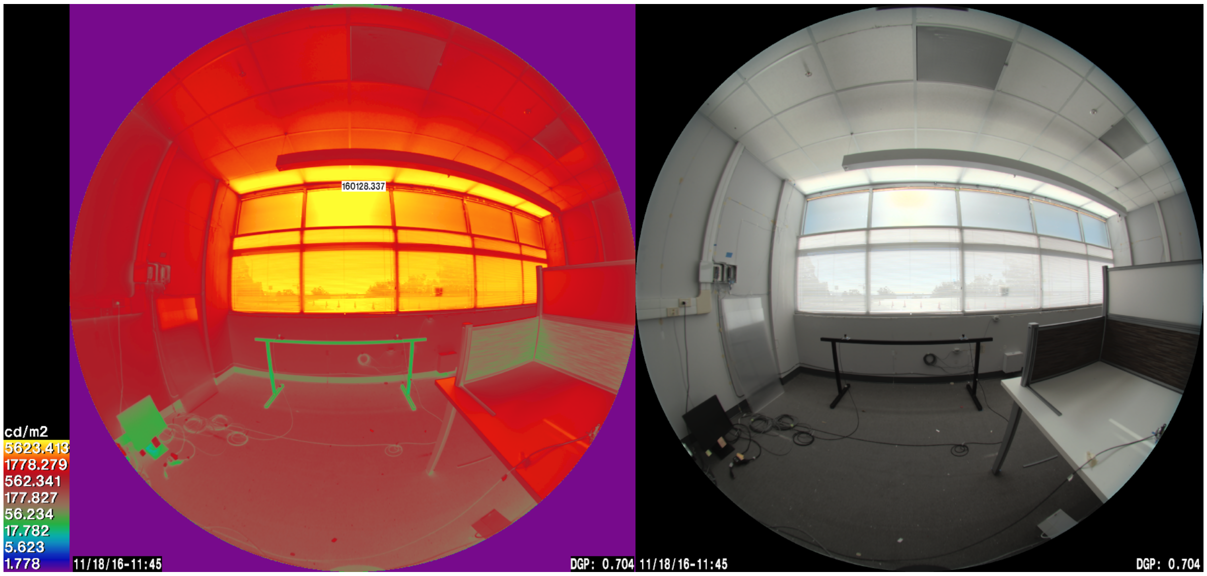
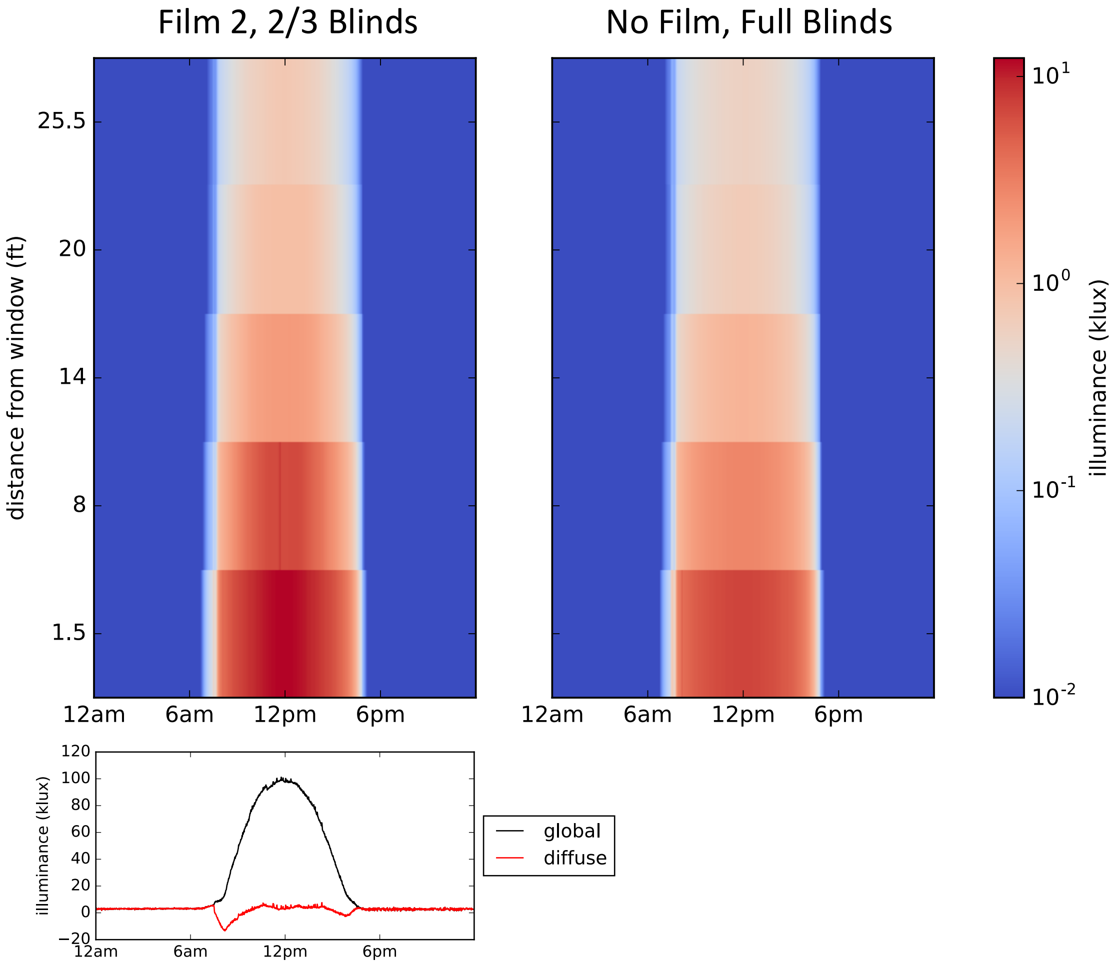


Figure D-3: November 18th, 12:00 pm, HDR Imaging for Film 2, Partial Blinds, No Lights Condition



These images are provided for a visual reference of the two conditions. In addition, Licor photosensor readings were taken in these two cells over the course of the day as shown in Figure D-4.

Figure D-4: November 18th, Photosensor Data by Heat Map Comparing Film 2, Partial Blinds, with No Film, Full Blinds. No Lights On for Either Case.



Film 2, 2/3 Blinds

No Film, Full Blinds

In Figure D-4, the plot on the lower left side shows the exterior illuminance pattern for the day, indicating a clear, sunny day. The data utilized for this analysis used the two center sensors located in the center of the cell, averaged for each distance listed from the window. The cell interior illuminance distribution for each case shows very high interior light distribution during all daylight hours at the locations closer to the window. The light levels are well above the required 100lux IES standard for egress conditions, and also much higher than the 300 and 500 lux minimum conditions set for the workplane illuminance. There does appear to be some increase in light levels in the case with the film, however in the no film case the light levels are also still well above the conditions targeted, indicating that there would be no additional hours of dimming that the system would see for this case when using the film during occupied hours.

Figure D-5: November 18th, Photosensor Data Charts Comparing Film 2, Partial Blinds, with No Film, Full Blinds. No Lights On for Either Case

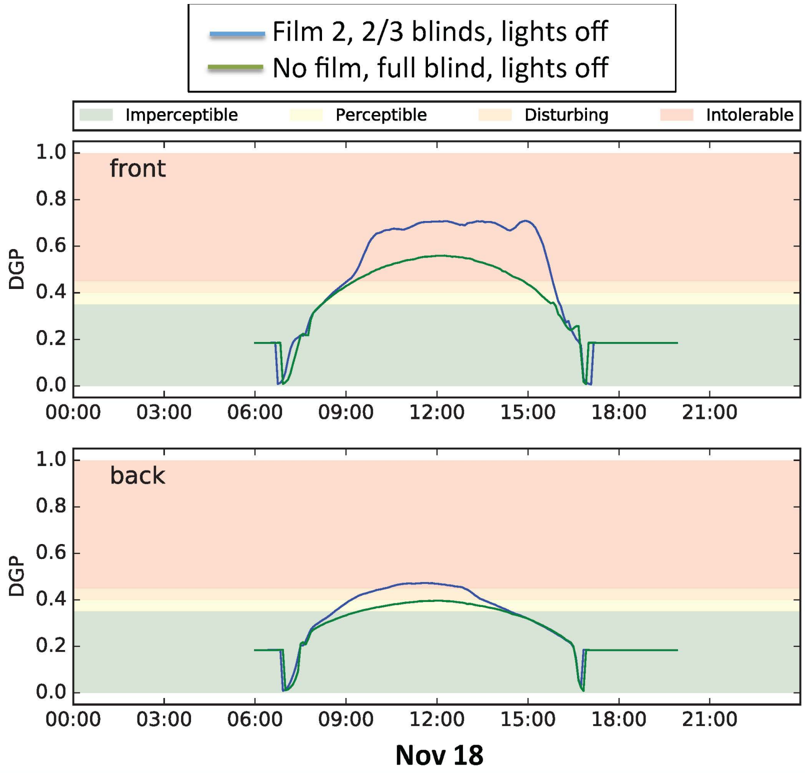
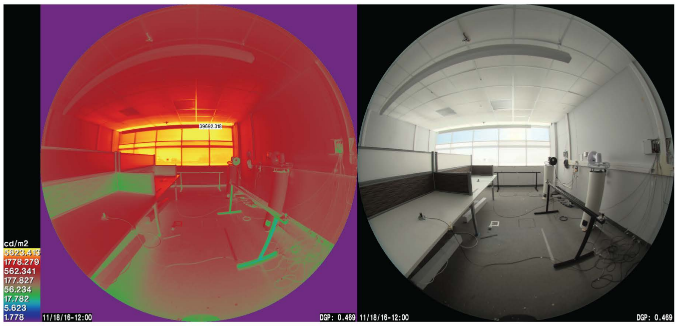
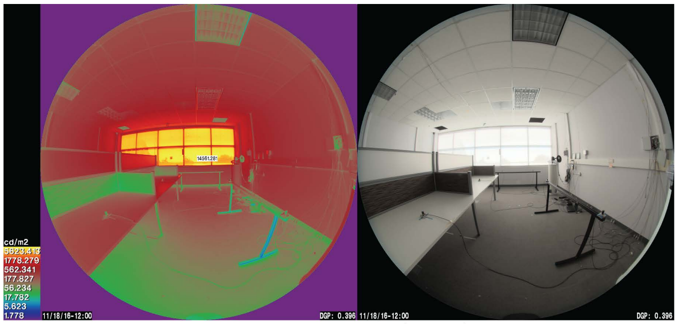


Figure D-6: November 18th, Photosensor Data Charts Comparing Film 2, Partial Blinds, with No Film, Full Blinds. No Lights On for Either Case



HDR images at back, 12:00 – Film 2, 2/3 blinds, lights off



HDR images at back, 12:00 - No film, full blinds, lights of

Figure D-7: Energy Usage Comparison, With Film 2 and with No Film, Utilizing Zonal Lighting Controls at 500 lux

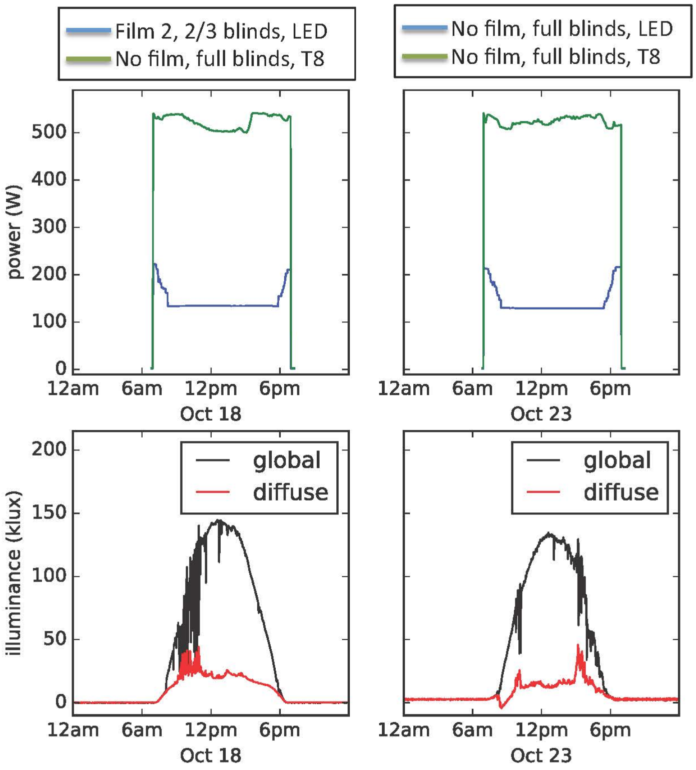


Figure D-7 illustrates the following results across two days of similarly sunny conditions, as illustrated in the lower outdoor illuminance graphs:

October 18th

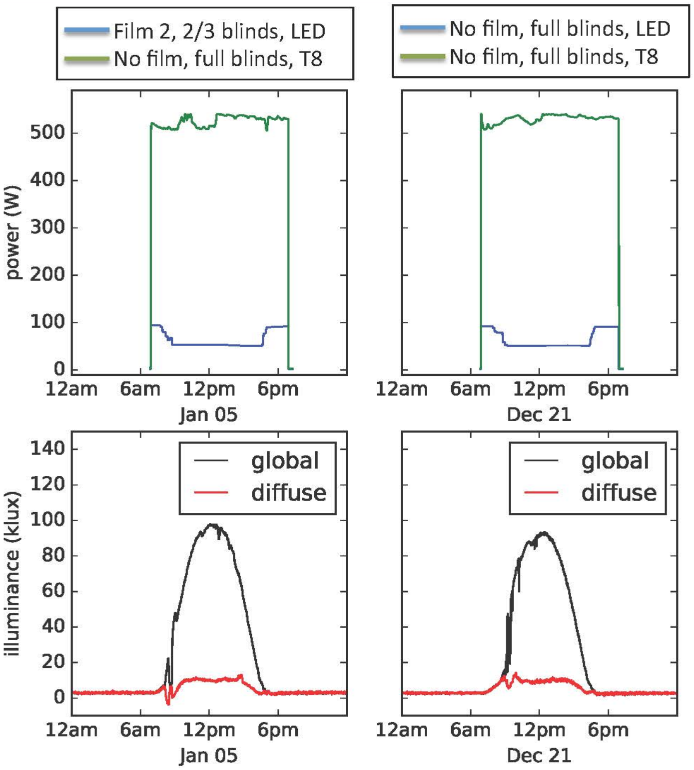
- Film 2, 2/3 blinds, LED: 1676 Wh
- No Film, full blinds, T8: 6068 Wh
- % savings = **72.4%**

October 23rd

- No Film, full blinds, LED: 1666 Wh
- No Film, full blinds, T8: 6077 Wh
- % savings = **72.6%**

This instance indicates only a 0.2% difference in energy use between the two conditions, illustrating as described earlier that the Film 2 has no significant impact on energy savings results. This result was further documented in Figure D-8, where the same analysis was conducted this time for two conditions that made use of the workstation specific lighting condition.

Figure D-8: Energy Usage Comparison, With Film 2 and with No Film, Utilizing Workstation Specific Lighting Controls at 500 lux



January 5th

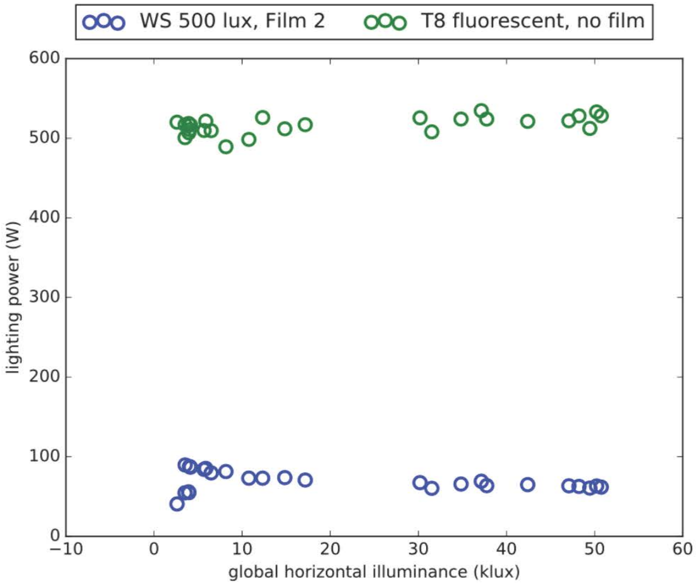
- Film 2, 2/3 blinds, LED: 743 Wh
- No Film, full blinds, T8: 6088 Wh
- % savings = **87.9%**

December 21st

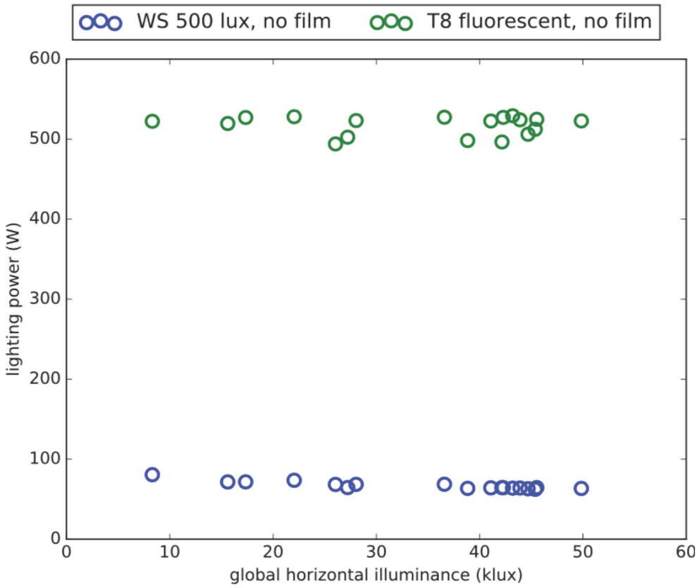
- No Film, full blinds, LED: 752 Wh
- No Film, full blinds, T8: 6146 Wh
- % savings = **87.8%**

This instance indicates only a 0.1% difference in energy use between the two conditions, illustrating once again that the Film 2 has no significant impact on energy savings results.

Figure D-9: Savings vs Exterior Illuminance, Daily Average Lighting Power and Global Horizontal Illuminance for Period of 7am-7pm



Oct 6 - 9, Dec 6 - 11, Jan 4 - 19



Dec 20 - Jan 2, Jan 20 - 24

Note: All lighting tests were done against Xcel's T8 baseline. In order to compare the Film 2 contition to a condition without the film installed, a comparison needed to be done on dates with similar exterior illuminance trends. Note the energy savings impact of the LEDs and the workstation specific lighting system outweighed the minimal incremental benefits of the daylight redirecting film.

Conclusion and Recommendations for Future Daylight Redirecting Film Applications

As seen from the results provided, the daylight redirecting film does not provide significant additional energy savings when incorporated into a workstation specific and LED lighting system as compared to T8 general lighting without film. It was also observed that some periods of intolerable glare were observed for both the film and no film conditions, as notd for conditions facing the window during sunny winter periods.

While the application studied did not elicit favorable results for the current system design, it should be noted that the daylight redirecting film did provide greater light distribution, particularly at the ceiling plane, and consequently lowered the contrast ratio in the space. Consequently, the daylight redirecting film may have more advantages when the specific application and design are targeted for site conditions, e.g.:

- Contrast ratio in space is taken into account and lower light output is tuned at light fixtures for 'on' at 100%
- May have additional advantages in lower window to wall area conditions
- Additional benefit may be derived from use of a separate photosensor provided at the ceiling plane to better capture daylight benefits

Overall, the daylight redirecting film may be a good fit for new construction energy efficiency incentive programs where additional design assistance can be provided, and Xcel is interested in this application. However, due to additional application costs and reduced return on investment the film is not currently suited for 'plug & play' prescriptive retrofit programs targeted in this current project.

Appendix E: FLEXLAB Test Results, Energy Savings – Detailed

General

This Appendix details the energy savings, interior illuminance impacts and exterior global illuminance values for each of the workstation specific lighting system tests. Several tests were conducted across a range of seasonal conditions representing a range of solar conditions. The following results document tests at both the 300 and 500 lux tuned minimum outputs at the workplane, as indicated. Each test also documents whether a daylight redirecting film was installed, or not, for the indicated test. Refer to Appendix D for detailed discussion of the impacts of the daylight redirecting film on the test results. In general, the film was documented to have no significant impact on overall lighting system energy use, with minimal increase in daylight penetration, but at levels well above the light level minimum at the workplane, and consequently not impacting further dimming of artificial lighting energy use in the cells. In summary, Tables E-1 and E-2 document the 'as tested' results with the energy savings as follows.

Table E-1: Summary FLEXLAB Test Energy Savings Results, As Tested, 2 Rows Dimming

WS Lux Minimum	Dates	% Energy Savings Over Baseline
300	10/3/16 – 10/6/16	93-94%
300	9/29/16 – 10/3/16	92-93%
500	10/6/16 – 10/9/16	89-92%
500	12/6/16 – 12/11/16	83-88%
500	12/14/16 – 12/20/16	83-87%
500	12/20/16 – 1/2/17	85-87%
500	1/4/17 – 1/19/17	83-88%
500	1/20/17 – 1/24/17	86-87%

Table E-2: Summary FLEXLAB Test Energy Savings Results, As Tested, 3 Rows Dimming

WS Lux Minimum	Dates	% Energy Savings Over Baseline
300	10/3/16 – 10/6/16	93-94%
300	9/29/16 – 10/3/16	93%
500	10/6/16 – 10/9/16	89-92%
500	12/6/16 – 12/11/16	82-88%
500	12/14/16 – 12/20/16	82-87%
500	12/20/16 – 1/2/17	84-87%
500	1/4/17 – 1/19/17	82-88%
500	1/20/17 – 1/24/17	86-87%

The test results in Tables E-1 and E-2 are documented directly from FLEXLAB testing, for both the 300 lux and 500 lux minimum workstation light levels. During these tests, the lighting controls system was used in an 'out of the box' condition. It can be seen from the test graphs that follow, Figures E-1 through E-5 that the workstation specific lighting system power dimmed to a lower level of approximately 30 watts while in full dimming mode. This indicates that the dimming controls were not tuned to allow for full energy reduction while at 100% dimming. This is a condition that has been experienced in other LBNL lighting tests, and indicates a need to tune these systems in the field, and verifying performance across the range of settings, in order to achieve the energy reduction expected.

In order to understand the impact this artificial minimum lighting power has on the overall system savings, Figures E-6 through E-15 are presented which include data to post-process the FLEXLAB results to show savings had the lighting controls system dimmed to the desired full light reduction level. This study was conducted twice, once to study the impacts of just dimming the first 2 rows of lights from the window, and the second to contrast this with dimming all 3 rows of lights from the window. The results are summarized in Tables E-3 and E-4. In general, it can be seen that nearly all of the energy savings are experienced with the first 2 rows of lights dimming only. This may suggest that only workstations within the first 20ft of window areas should be considered for an incentive program.

Table E-3: Summary FLEXLAB Test Energy Savings Results, Adjusted to Allow for Full Dimming – 2 Row Dimming Study

WS Lux Minimum	Dates	% Energy Savings Over Baseline
300	10/3/16 – 10/6/16	98-99%
300	9/29/16 – 10/3/16	98-99%
500	10/6/16 – 10/9/16	95-97%
500	12/6/16 – 12/11/16	83-94%
500	12/14/16 – 12/20/16	83-94%
500	12/20/16 – 1/2/17	87-94%
500	1/4/17 – 1/19/17	82-95%
500	1/20/17 – 1/24/17	90-94%

Table E-4: Summary FLEXLAB Test Energy Savings Results, Adjusted to Allow for Full Dimming – 3 Row Dimming Study

WS Lux Minimum	Dates	% Energy Savings Over Baseline
300	10/3/16 – 10/6/16	98-99%
300	9/29/16 – 10/3/16	98-99%
500	10/6/16 – 10/9/16	95-96%
500	12/6/16 – 12/11/16	82-94%
500	12/14/16 – 12/20/16	83-94%
500	12/20/16 – 1/2/17	86-94%
500	1/4/17 – 1/19/17	82-94%
500	1/20/17 – 1/24/17	89-94%

Last, one test was conducted in FLEXLAB to understand the relative impact of the workstation specific lighting system in terms of energy savings as compared to a zonal level (general) lighting system that incorporated daylight dimming. The results of this test are documented in Tables E-5 and E-6, which have been adjusted to allow for full dimming and have been presented to compare results for dimming 2 rows of lighting versus 3 rows. While this test was only conducted once during a seasonal period of relatively low sun angles, it is apparent that there is a substantial increase in energy savings for the workstation specific lighting system when compared to the more traditional zonal lighting approach. The major drivers for this savings are from the reduced LPD experienced by the workstation specific lighting system, along with a greater level of daylighting savings due to more granular, fixture level dimming controls.

Table E-5: Summary FLEXLAB Test Energy Savings Results, Comparing General (Zonal) Lighting Controls to Workstation Specific Lighting, Adjusted to Allow for Full Dimming – 2 Row Dimming Study

Workstation Lux Minimum	Dates	% Energy Savings Over Baseline
500	1/25/17 – 1/31/17	67-80%

Table E-6: Summary FLEXLAB Test Energy Savings Results, Comparing General (Zonal) Lighting Controls to Workstation Specific Lighting, Adjusted to Allow for Full Dimming – 3 Row Dimming Study

Workstation Lux Minimum	Dates	% Energy Savings Over Baseline
500	1/25/17 – 1/31/17	71-82%

A discussion of visual comfort for all tests is documented in Appendix F.

FLEXLAB TEST RESULTS – 300lux and 500lux Minimum Cases, As Tested, 2 Rows Dimming

Figure E-1: WS 300 lux Test Results, 2 Front Rows Dimming Only (10/03/16 – 10/06/16)

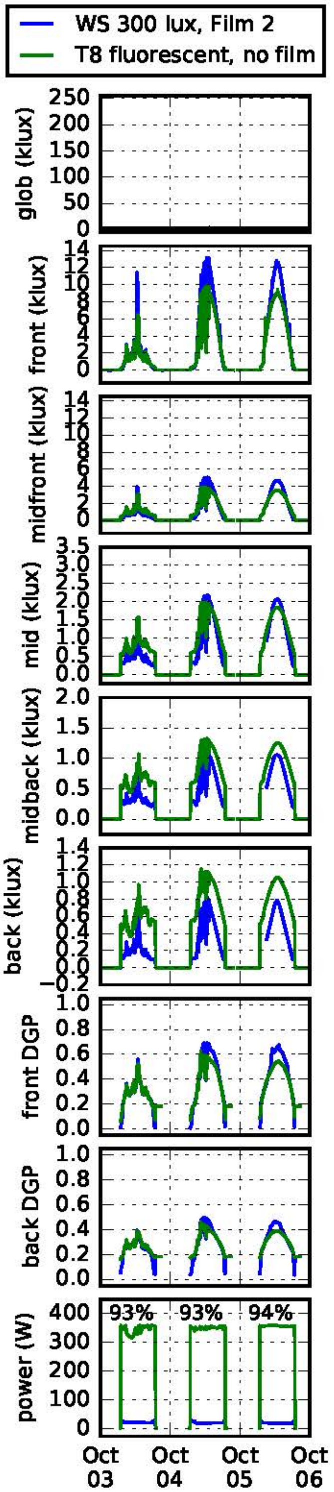


Figure E-2; WS 300 lux Test Results, 2 Front Rows Dimming Only (09/29/16 – 10/03/16)

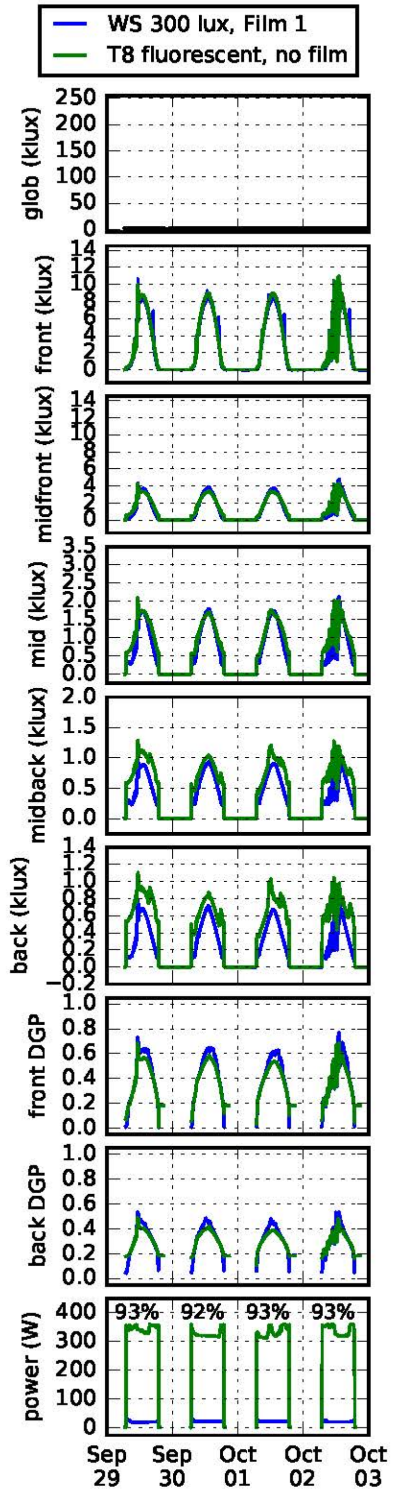


Figure E-3; WS 500 lux Test Results, 2 Front Rows Dimming Only (10/06/16 – 10/09/16; 12/06/16 – 12/11/16; 01/04/17 – 01/19/17)

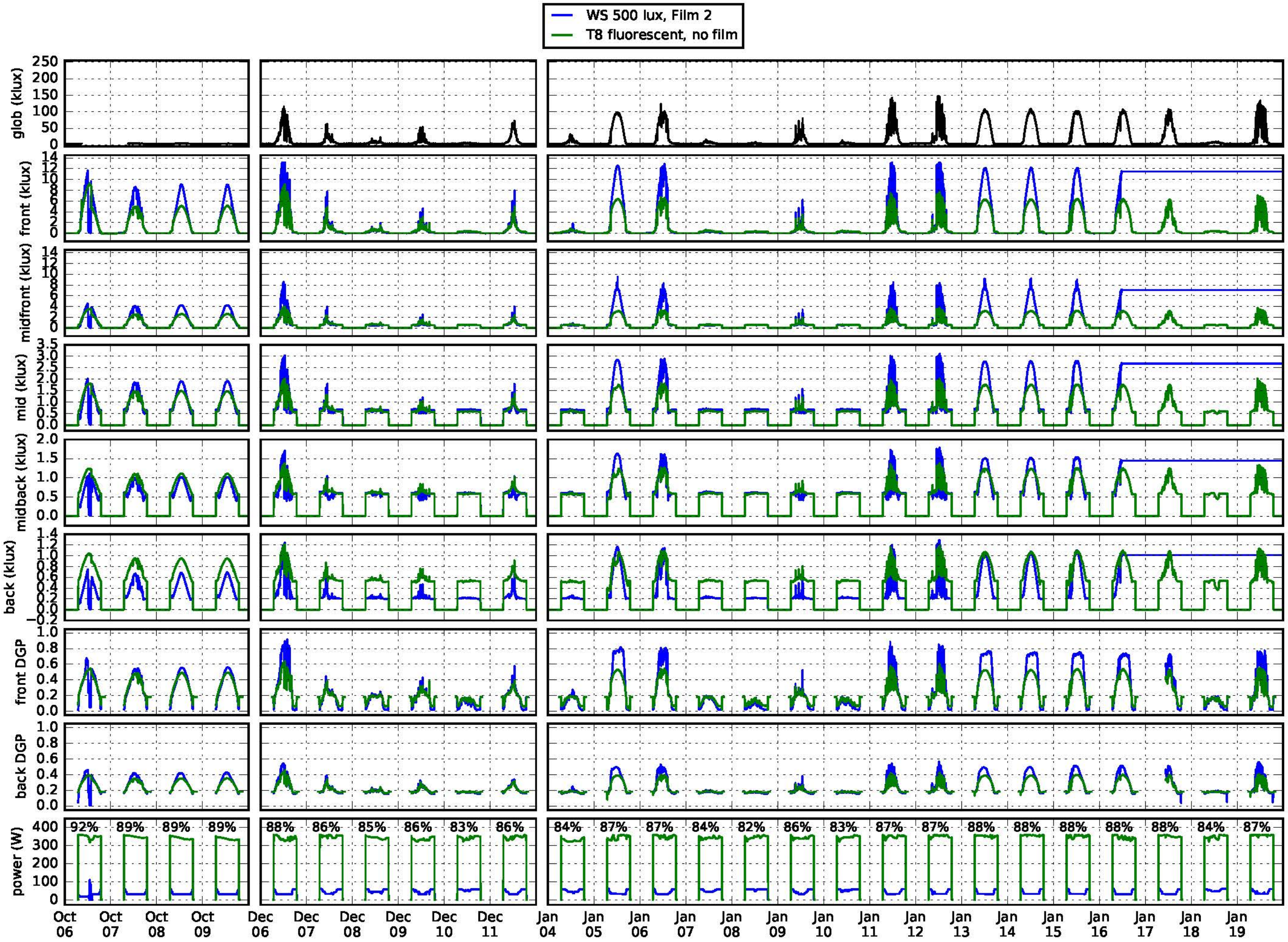


Figure E-4: WS 500 lux Test Results, 2 Front Rows Dimming Only (12/14/16 – 12/20/16)

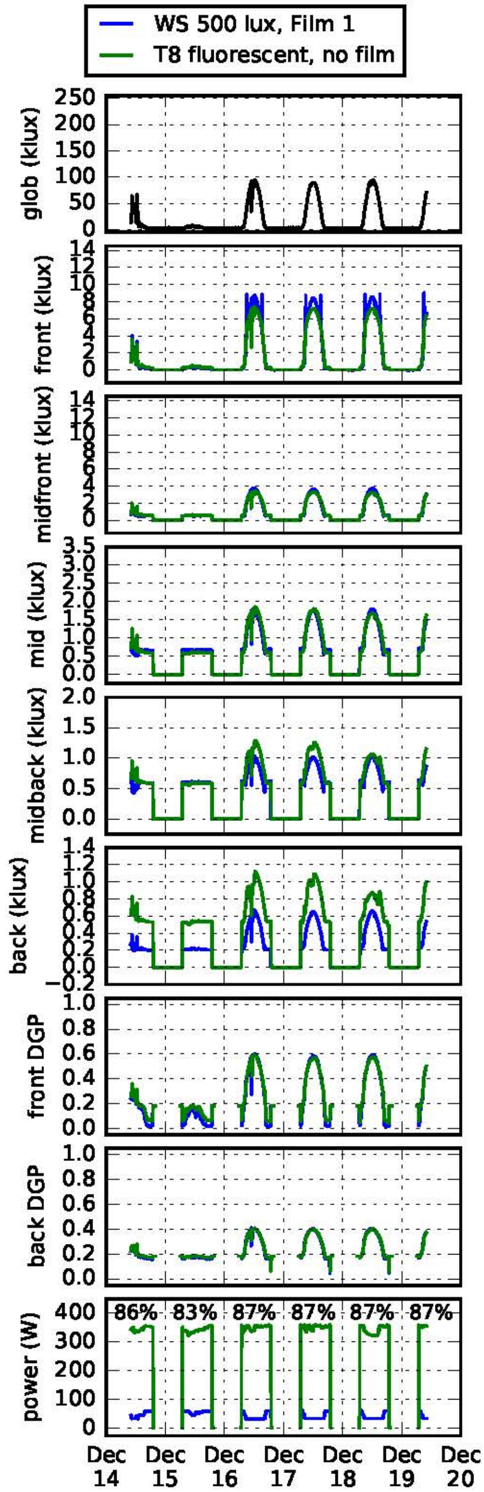
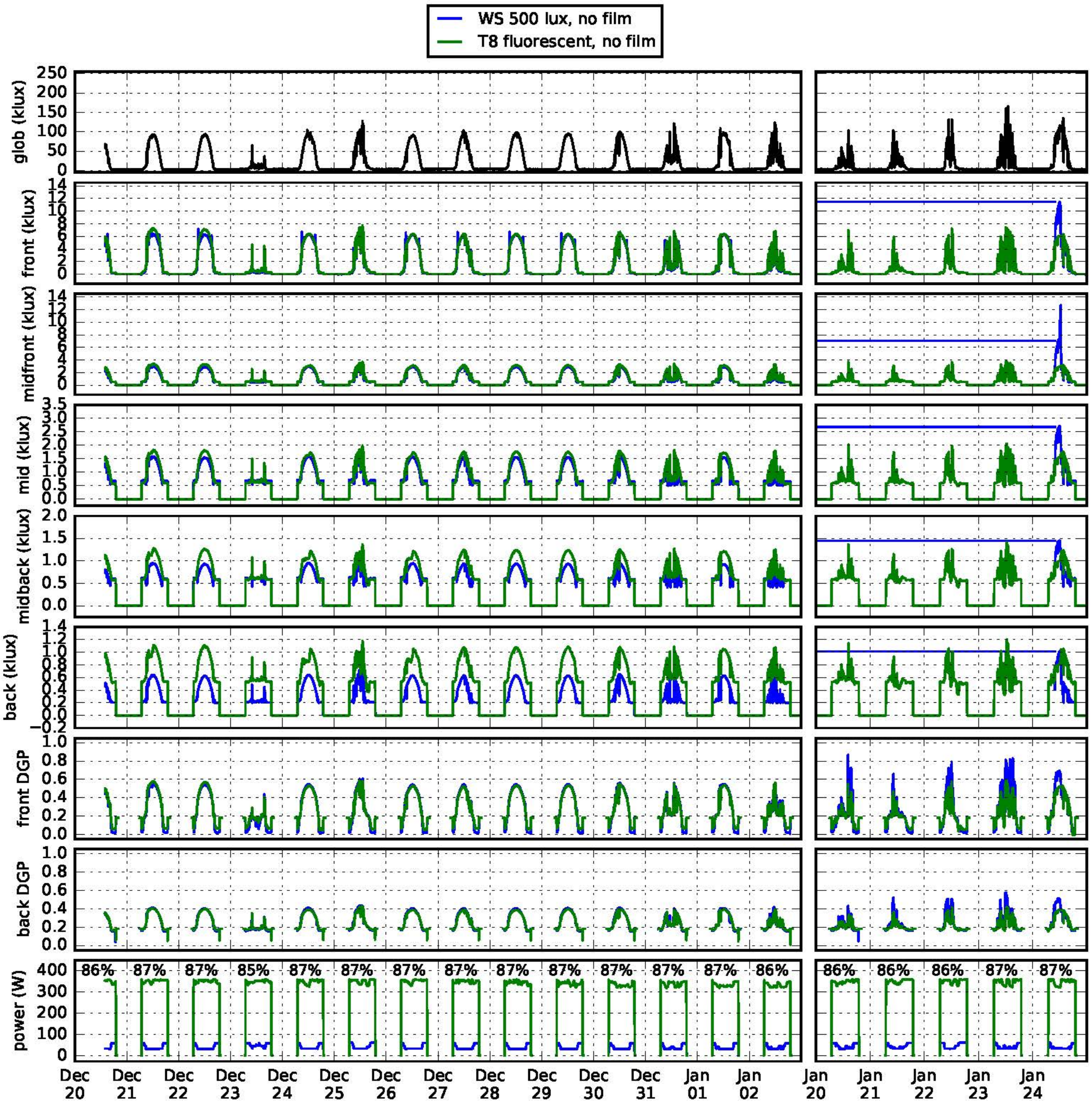


Figure E-5: 2 WS 500 lux Test Results, 2 Front Rows Dimming Only (12/20/16 – 01/02/17; 01/20/17 – 01/24/17)



FLEXLAB TEST RESULTS – 300lux and 500lux Minimum Cases, As Tested, 3 Rows Dimming

Figure E-6: WS 300 lux Test Results, 3 Front Rows Dimming (10/03/16 – 10/06/16)

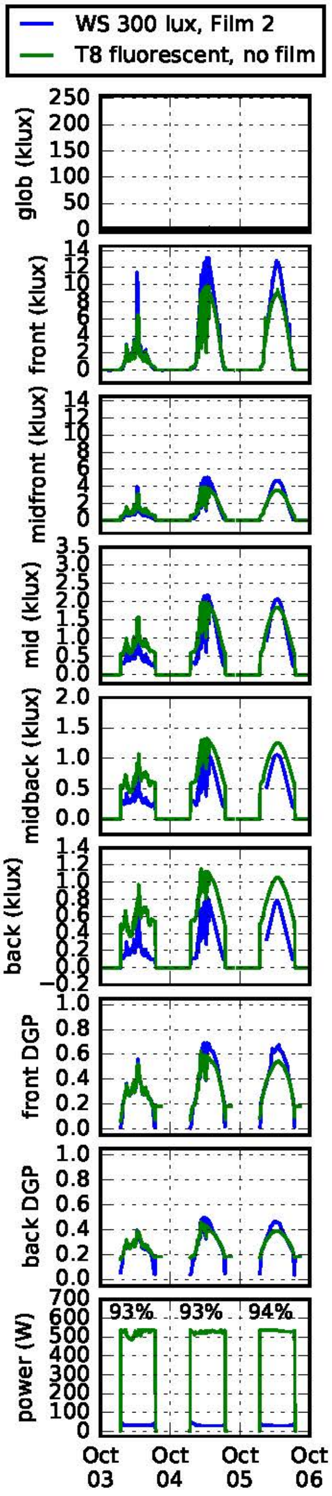


Figure E-7; WS 300 lux Test Results, 3 Front Rows Dimming (09/29/16 – 10/03/16)

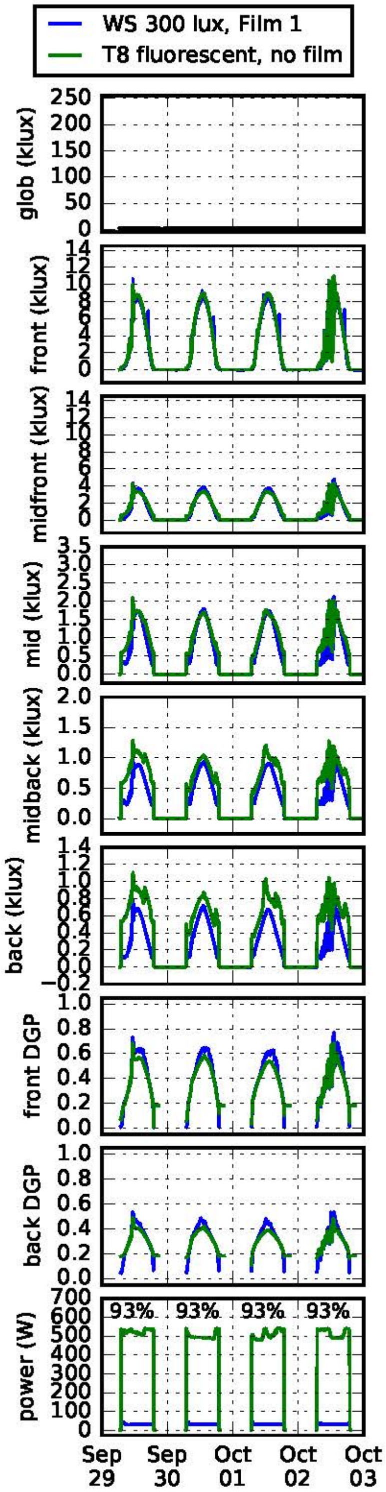


Figure E-8; WS 500 lux Test Results, 3 Front Rows Dimming (10/06/16 – 10/09/16; 12/06/16 – 12/11/16; 01/04/17 – 01/19/17)

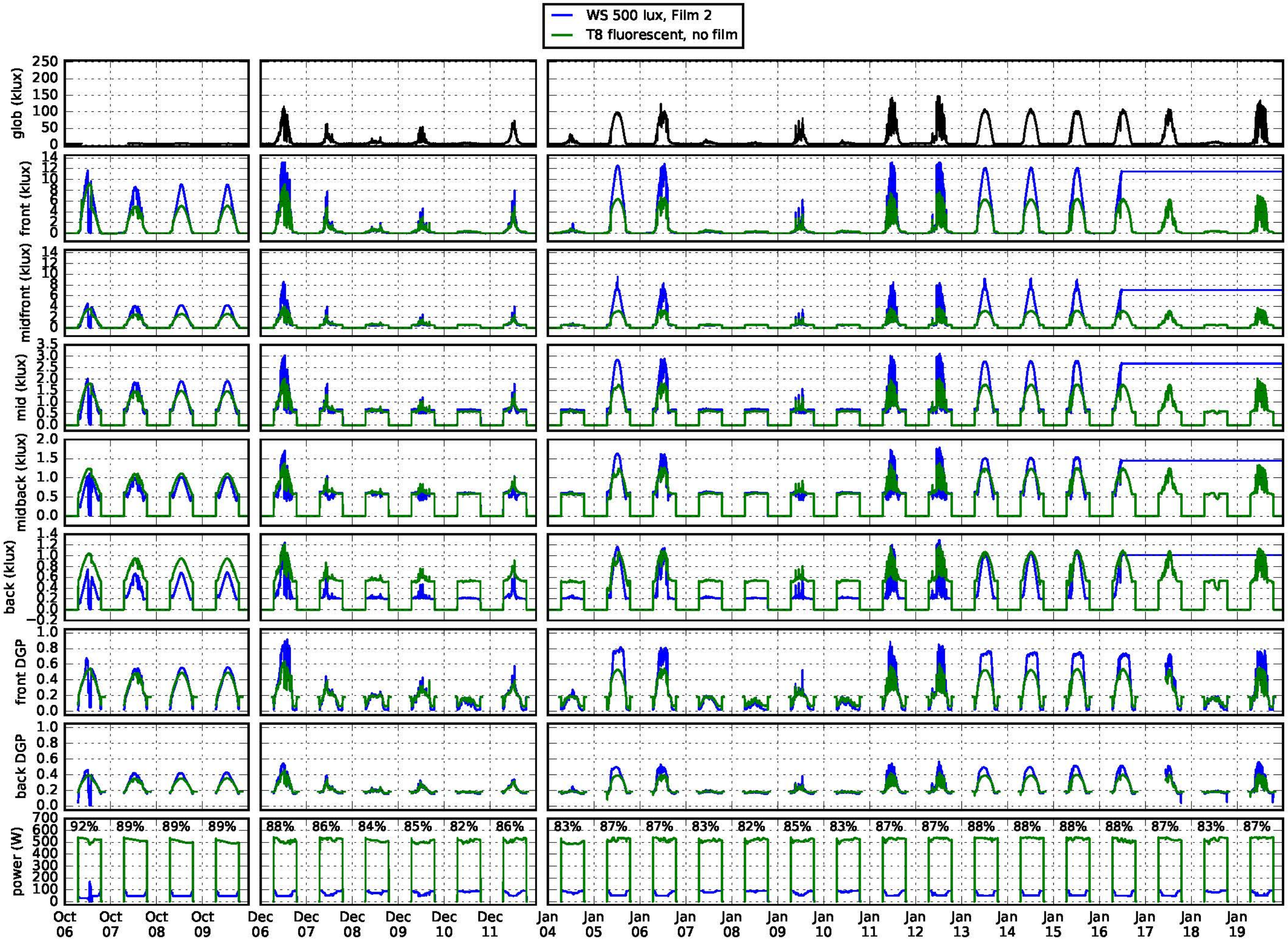


Figure E-9: WS 500 lux Test Results, 3 Front Rows Dimming (12/14/16 – 12/20/16)

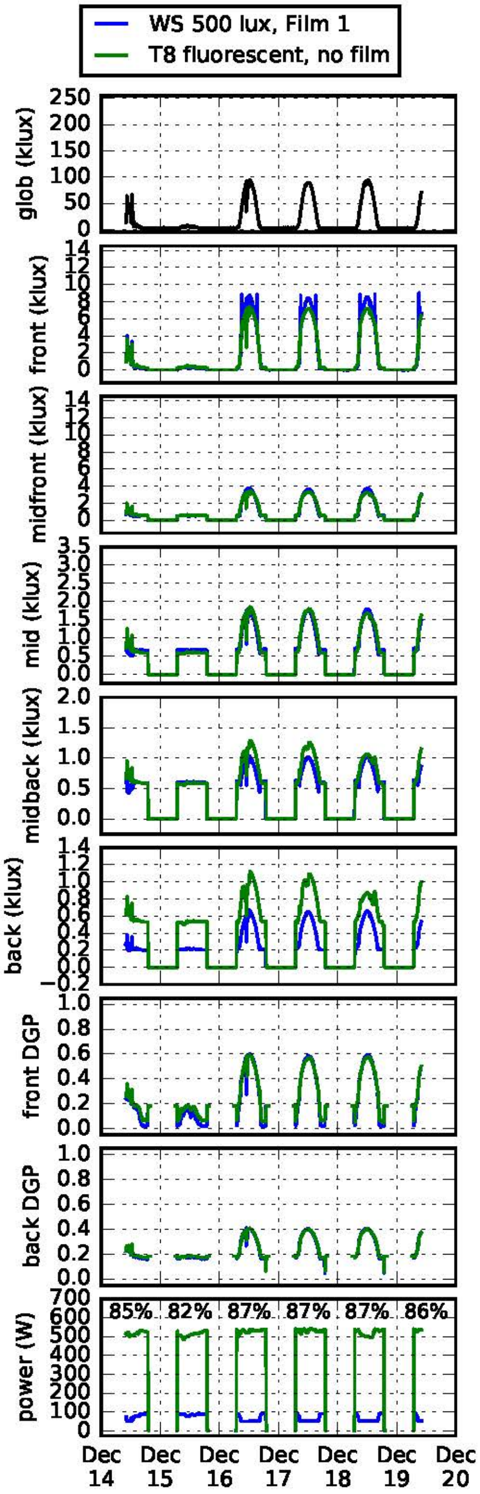
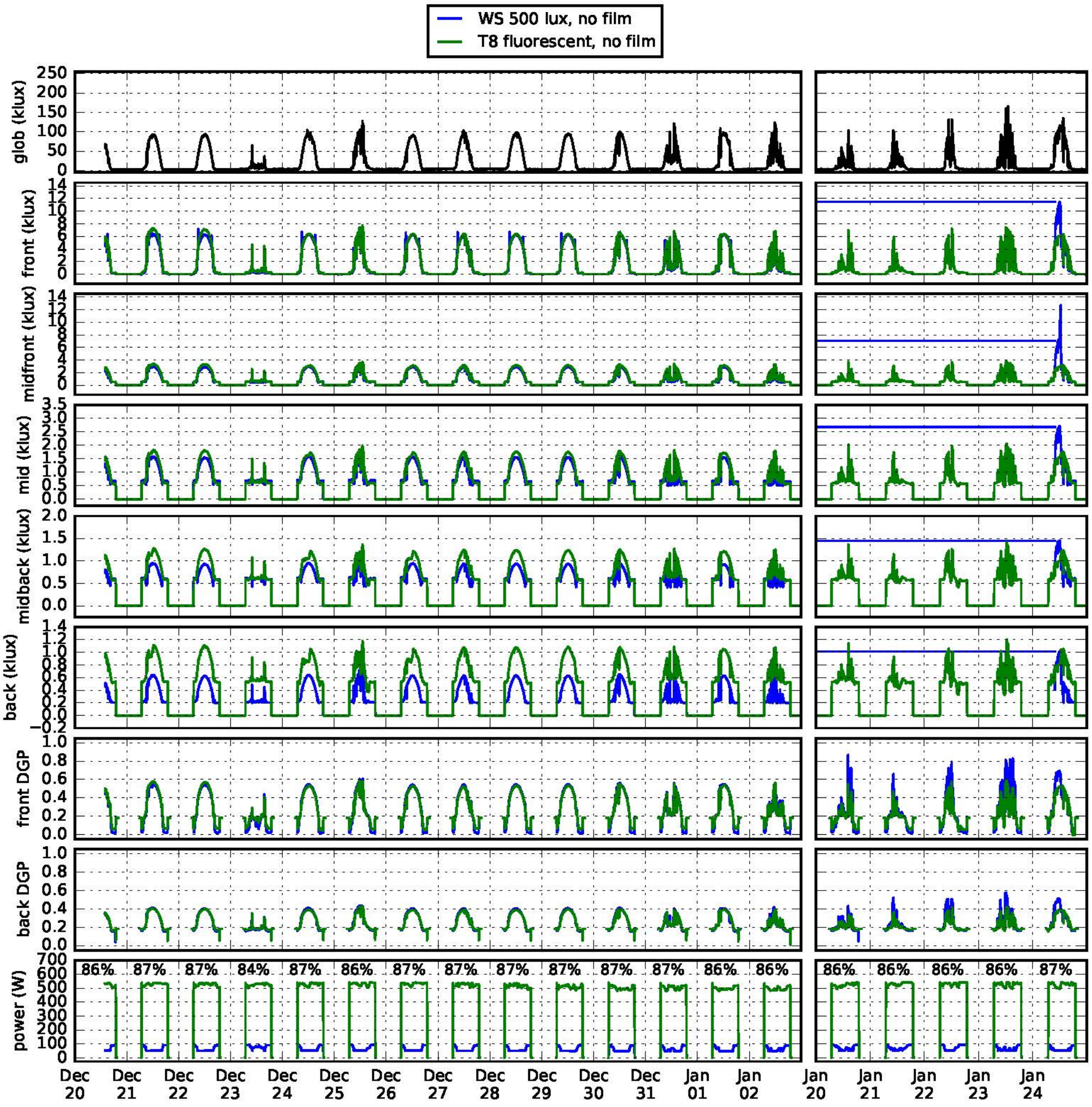


Figure E-10: 2 WS 500 lux Test Results, 3 Front Rows Dimming (12/20/16 – 01/02/17; 01/20/17 – 01/24/17)



FLEXLAB TEST RESULTS – 300lux and 500lux Minimum Cases, Adjusted to Allow for Full Dimming, 2 Row and 3 Row Dimming Studies

As described earlier, and can be seen from the previous test results, the lighting system did not dim completely during periods of adequate daylighting, creating artificially higher energy use than would be necessary. The following plots have post processed the FLEXLAB test data to determine what the energy use reduction would have been, had the system dimmed completely. These plots should be taken as the full potential for the workstation specific lighting system to save energy. Note that the interior illuminance plots have not been adjusted accordingly, however are presented again to provide a rounded picture of the test condition. It is not expected that the dimming of the lights to full off would have had significant impacts on the interior light levels beyond those shown.

In addition, an exercise was completed to capture the impact of having only the first 2 rows of lighting in the space, to a depth of ~20ft from the window, as compared to having all 3 rows of lighting dim, to a depth of ~25ft from the window.

FLEXLAB Test Results, Adjusted for Full Dimming, 2 Rows Dimming Results

Figure E-6: WS 300 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (10/03/16 – 10/06/16)

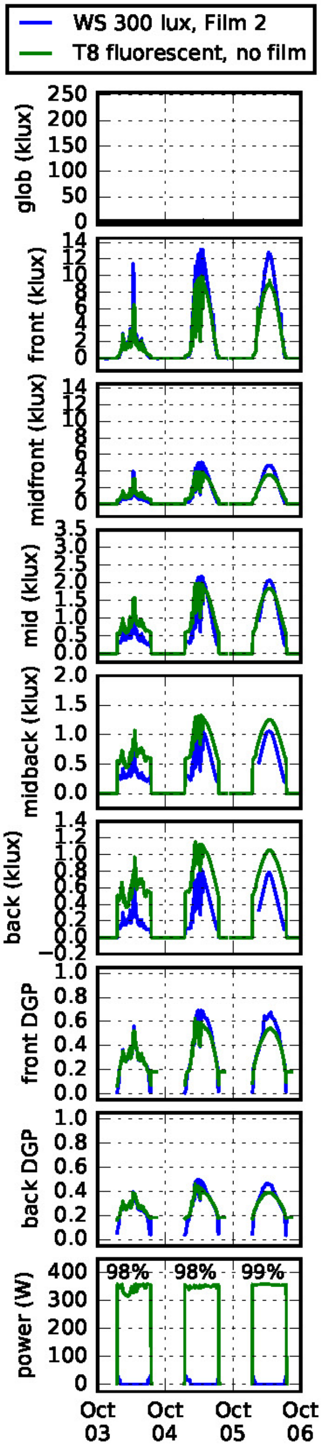


Figure E-7; WS 300 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (09/29/16 – 10/03/16)

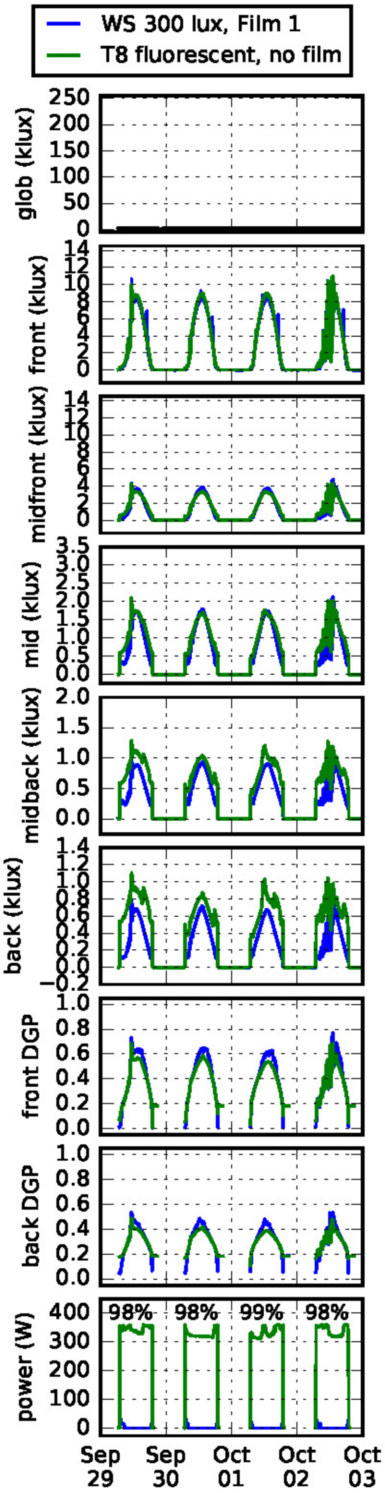


Figure E-8; WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (10/06/16 – 10/09/16; 12/06/16 – 12/11/16; 01/04/17 – 01/19/17)

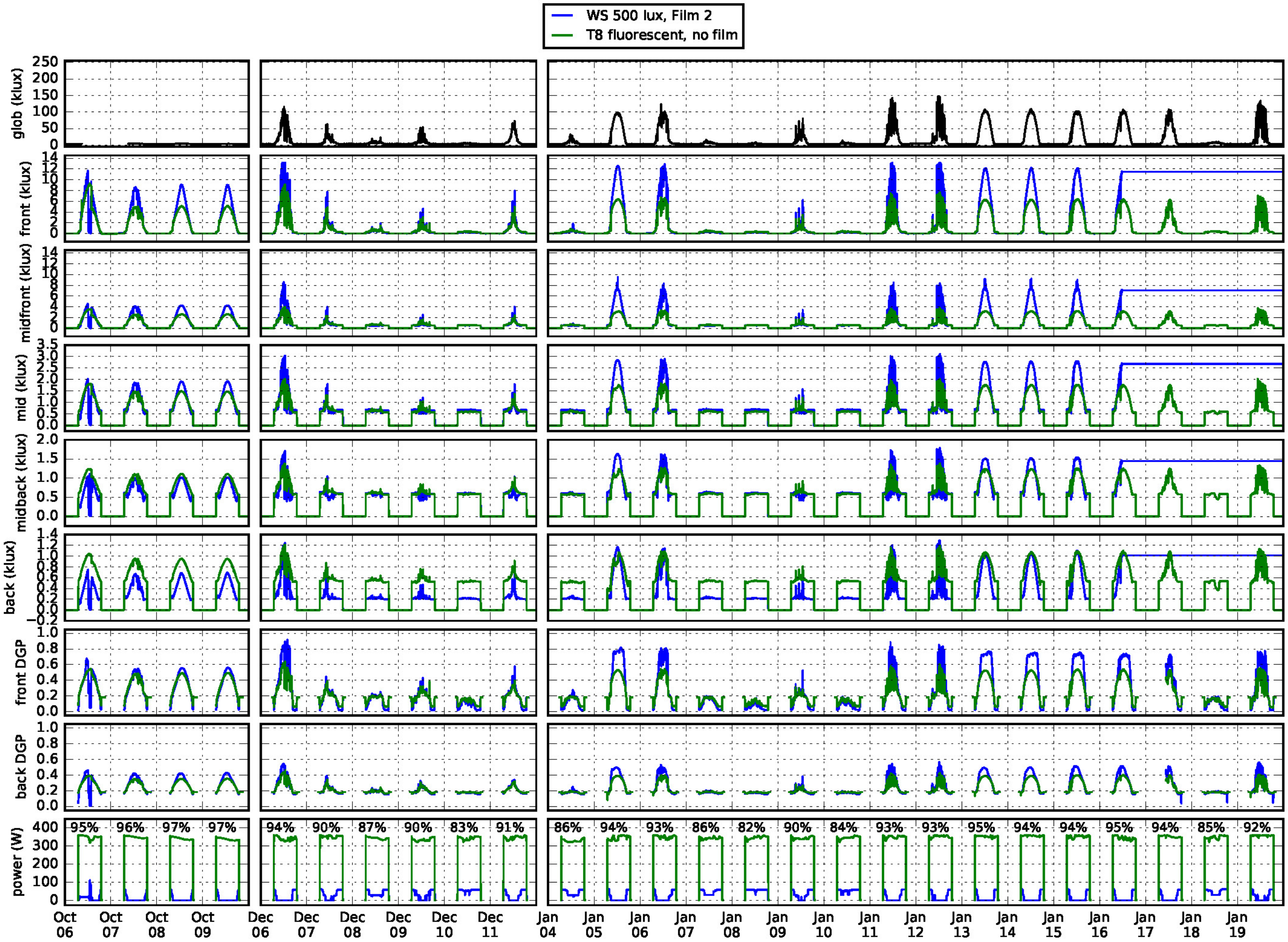


Figure E-9: WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (12/14/16 – 12/20/16)

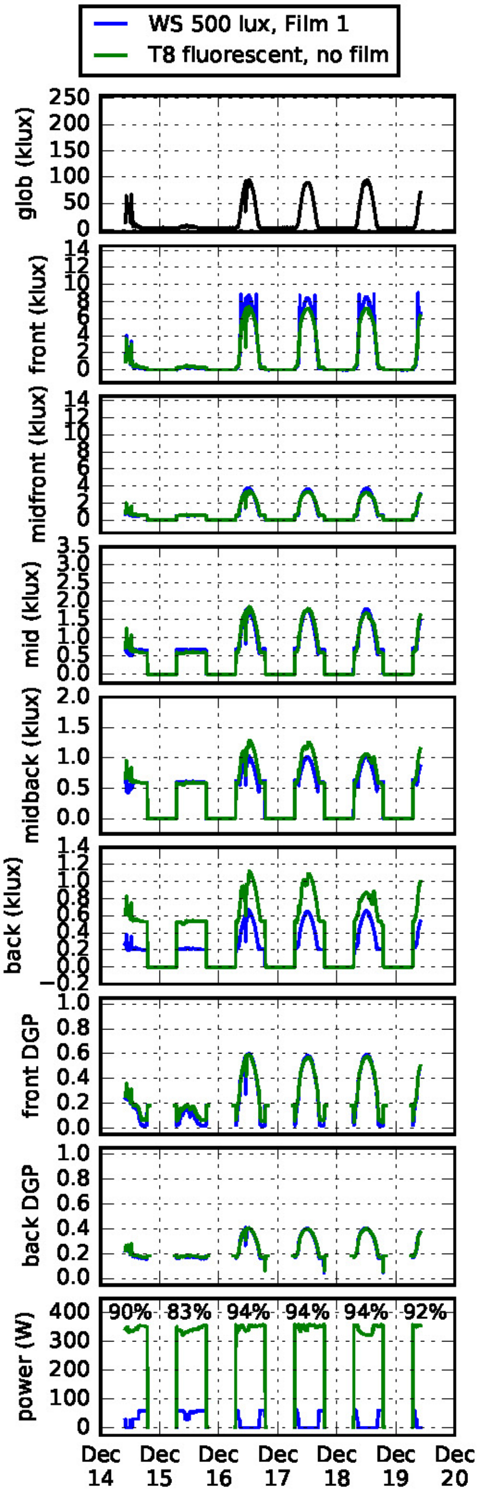
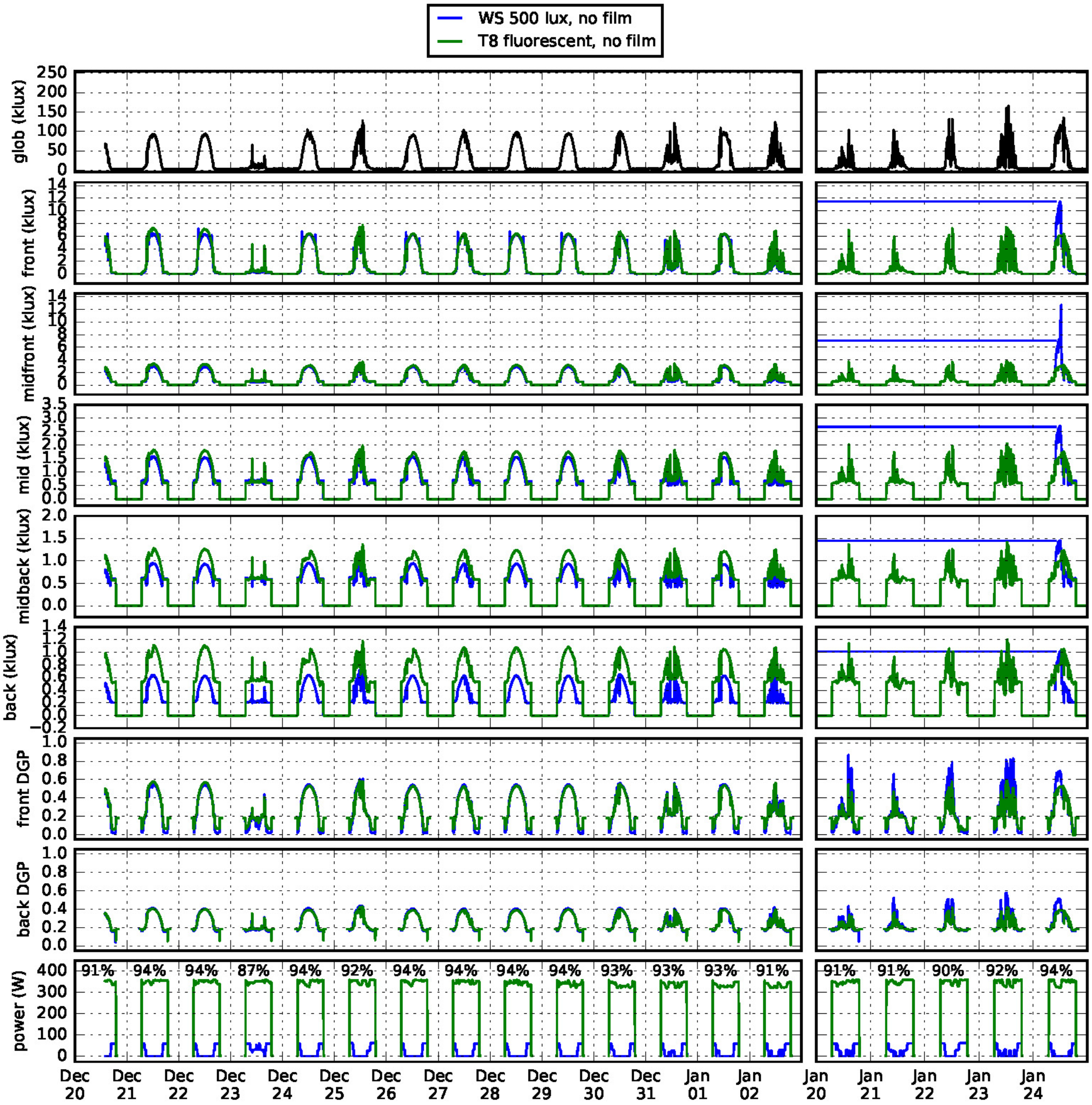


Figure E-10: 2 WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (12/20/16 – 01/02/17 ; 01/20/17 – 01/24/17)



FLEXLAB Test Results, Adjusted for Full Dimming, 3 Rows Dimming Results

Figure E-11: WS 300 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (10/03/16 – 10/06/16)

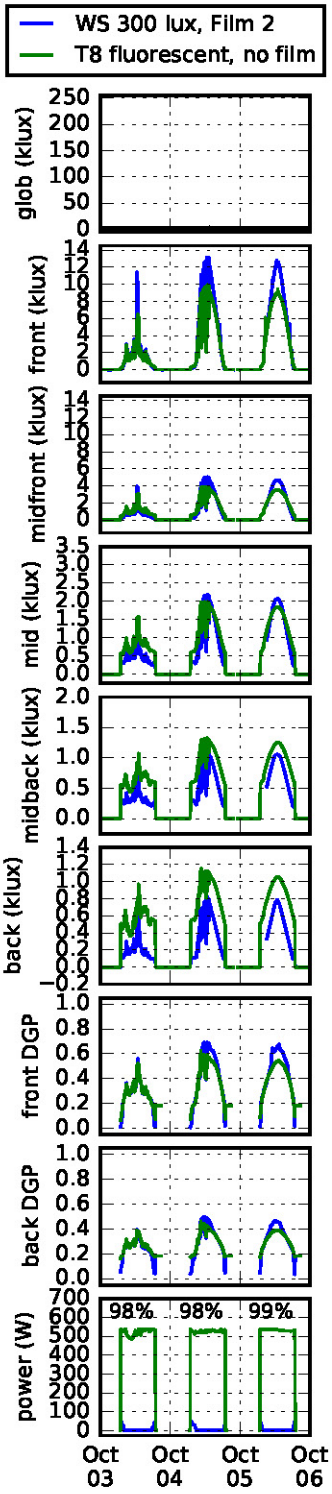


Figure E-12: WS 300 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (09/29/16 – 10/03/16)

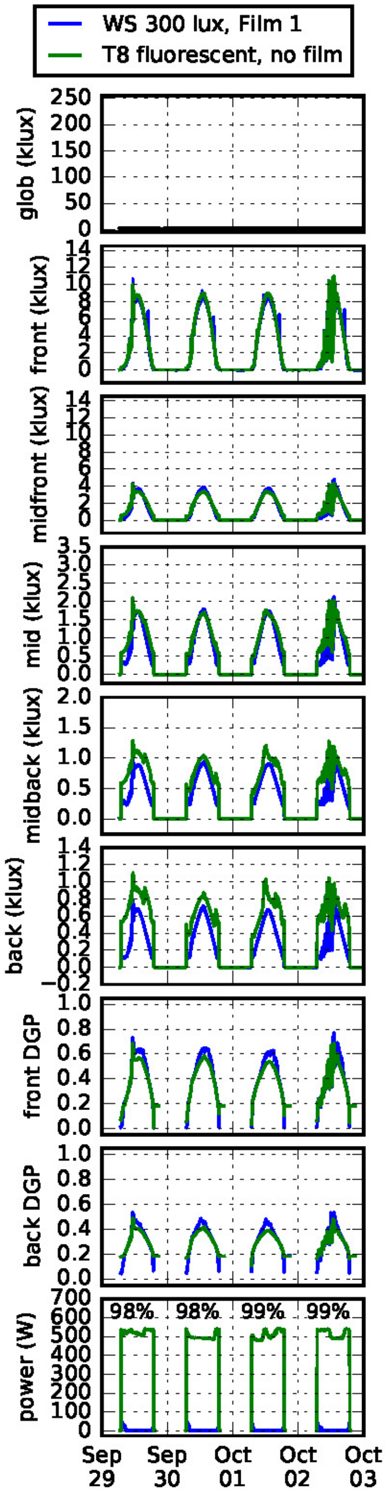


Figure E-13: WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (10/06/16 – 10/09/16; 12/06/16 – 12/11/16; 01/04/17 – 01/19/17)

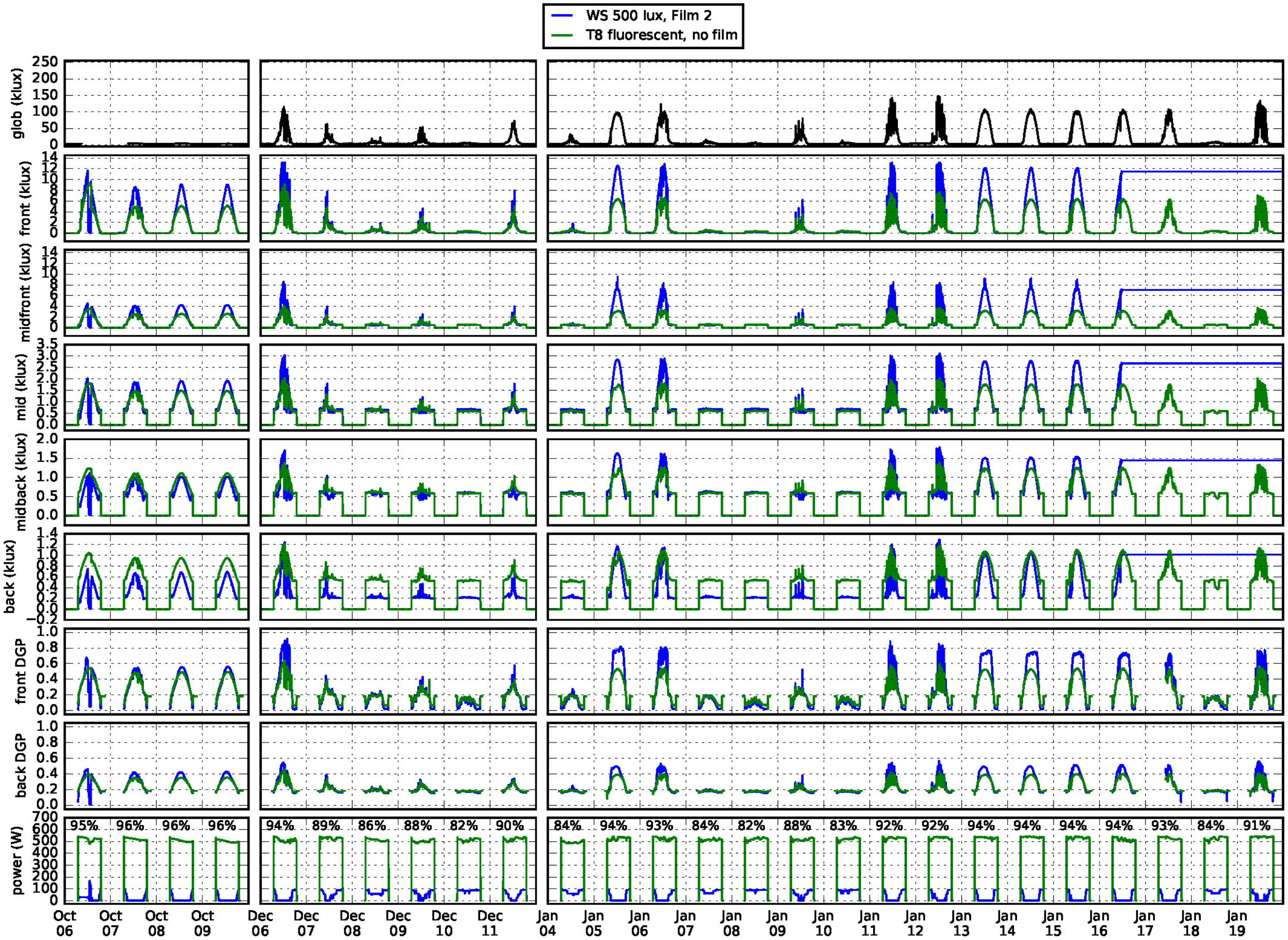


Figure E-14: WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (12/14/16 – 12/20/16)

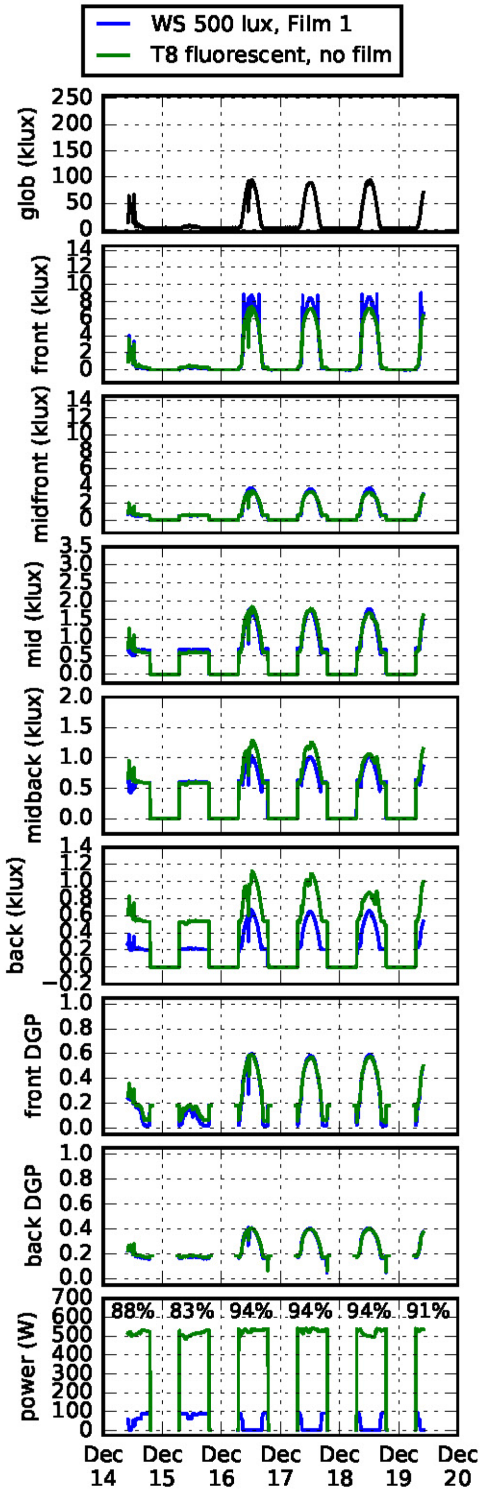
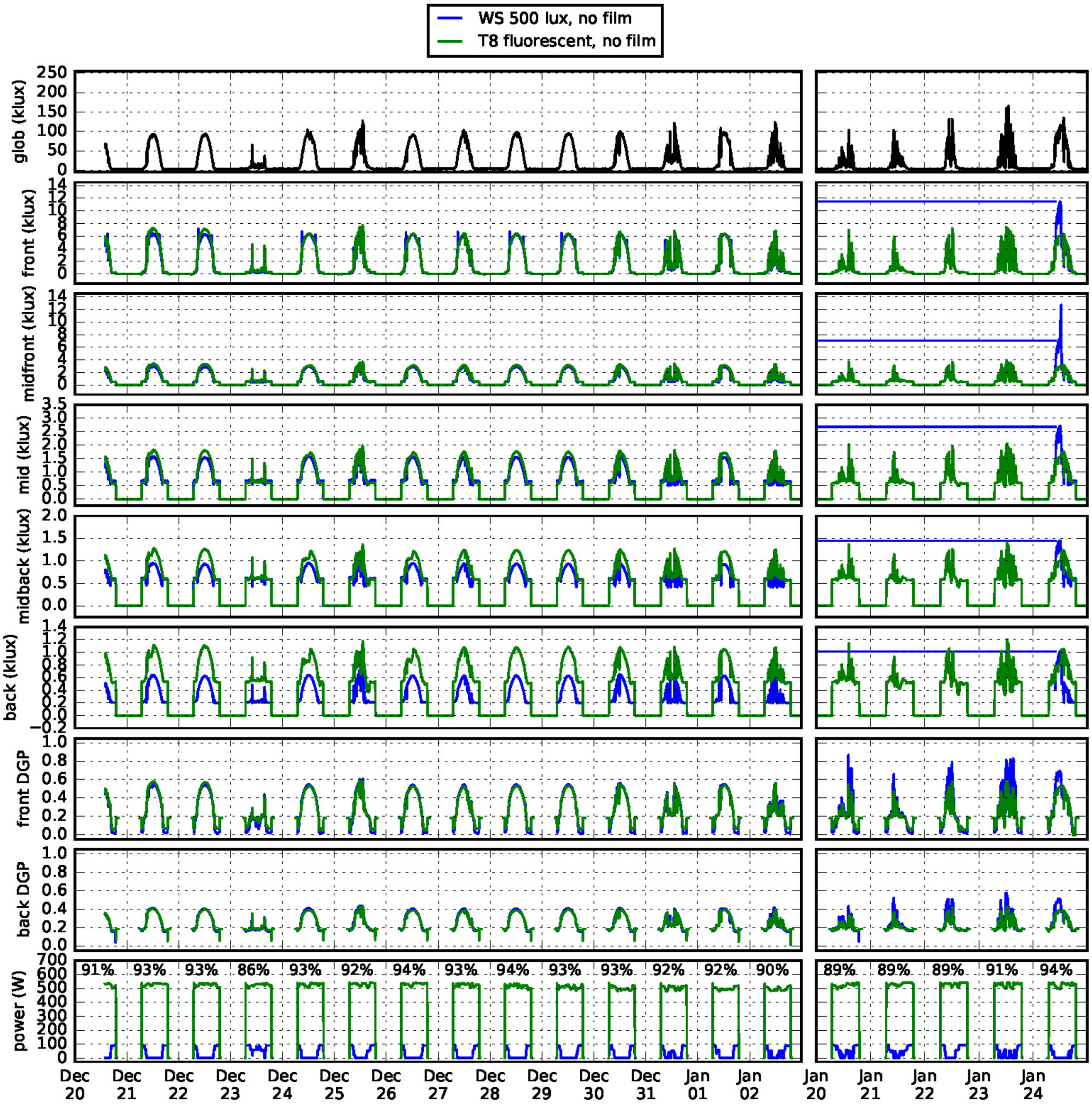


Figure E-15: WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (12/20/16 – 01/02/17; 01/2/17 – 01/24/17)



FLEXLAB TEST RESULTS – Comparing Workstation Specific Lighting to General (Zonal) Lighting Controls, 500lux Minimum Cases, Adjusted to Allow for Full Dimming, 2 and 3 Row Dimming Studies

Figure E-16: Comparing General (Zonal Lighting) Controls to Workstation Specific Lighting, Both With Daylight Dimming 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 2 Front Rows Dimming Only, (01/25/17 – 01/31/17)

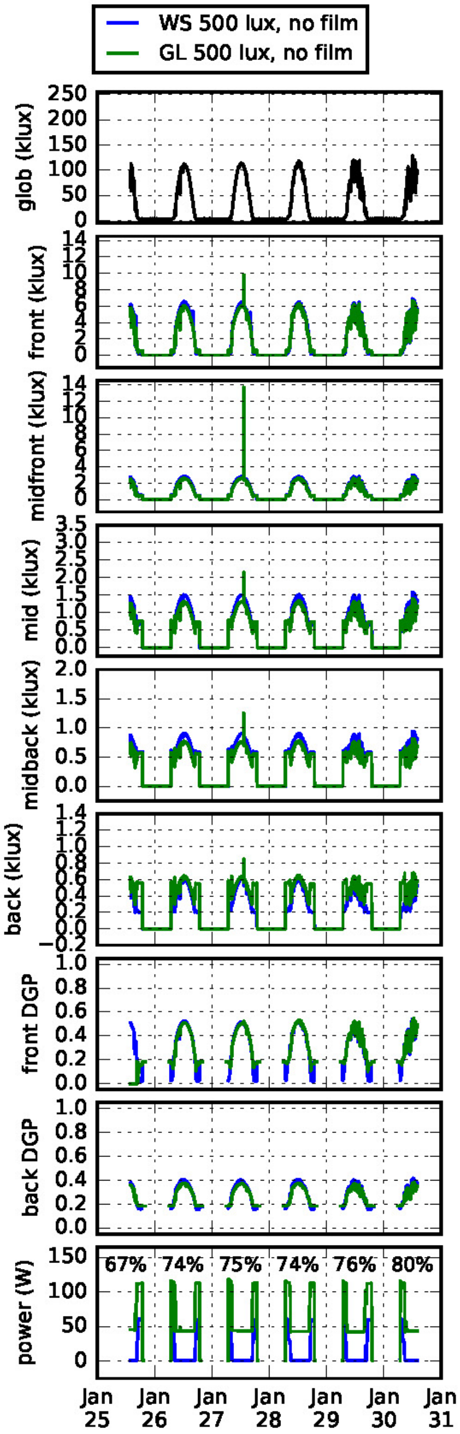
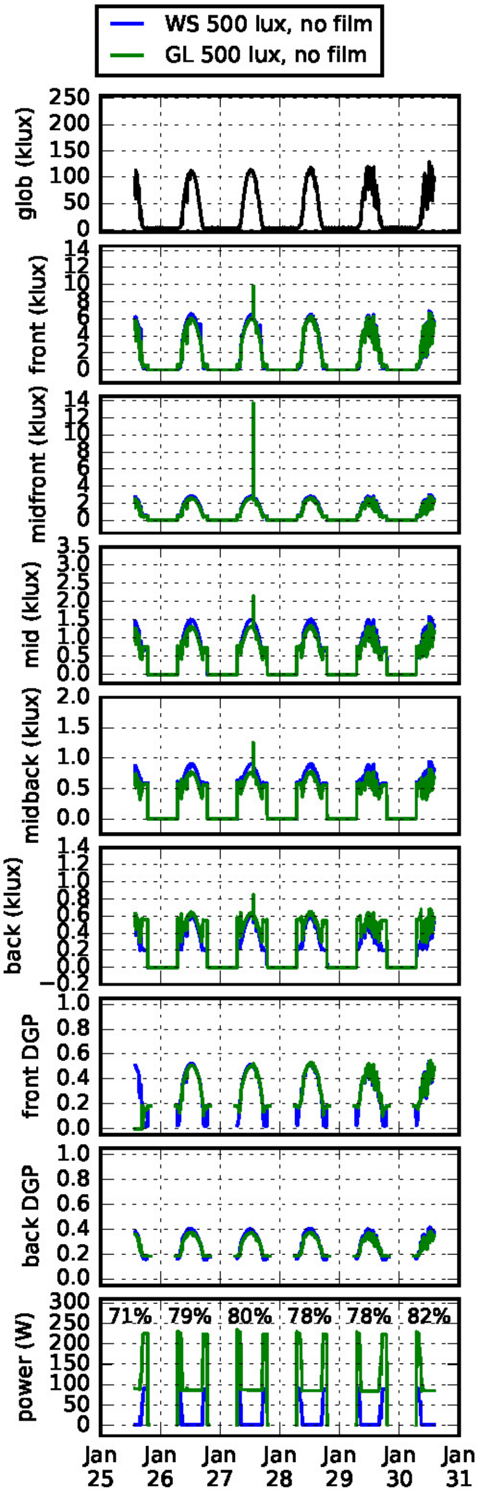


Figure E-17: WS 500 lux Test Results, Adjusted to Allow for Full Dimming, Study for 3 Front Rows Dimming, (01/25/17 – 01/31/17)



Appendix F: FLEXLAB Test Results, Visual Comfort - Detailed

For the Beyond Widgets experiments, our visual comfort analysis was comprised of two primary metrics; illuminance (lux; lumens / m^2) and glare (daylight glare probability).

Figure F-1: Licor photometric sensor (top); HDR camera package for glare measurement (bottom)

In the FLEXLAB cells where the Beyond Widgets reference and test lighting and shade system packages are installed, we monitor average illuminance at the task plane (2.5' above floor level) from an array of photometric sensors. These detect the quantity of light (lumens / m^2) at the height of primary importance to occupants, the workstation, or task plane.

Most lighting design criteria are centered around recommendations for illuminance levels at the task plane. The Illuminating Engineering Society (IES) *American National Standard Practice for Office Lighting* [IES RP-1-12, 2012][19] is the most – referenced standard in the U.S. For office environments the standard practice for many years, and IES's recommendations, had been to design lighting systems to an average maintained illuminance of 50 foot-candles (fc), around 540 lux. This standard pre-dated the prevalence of computer-based desk work most common

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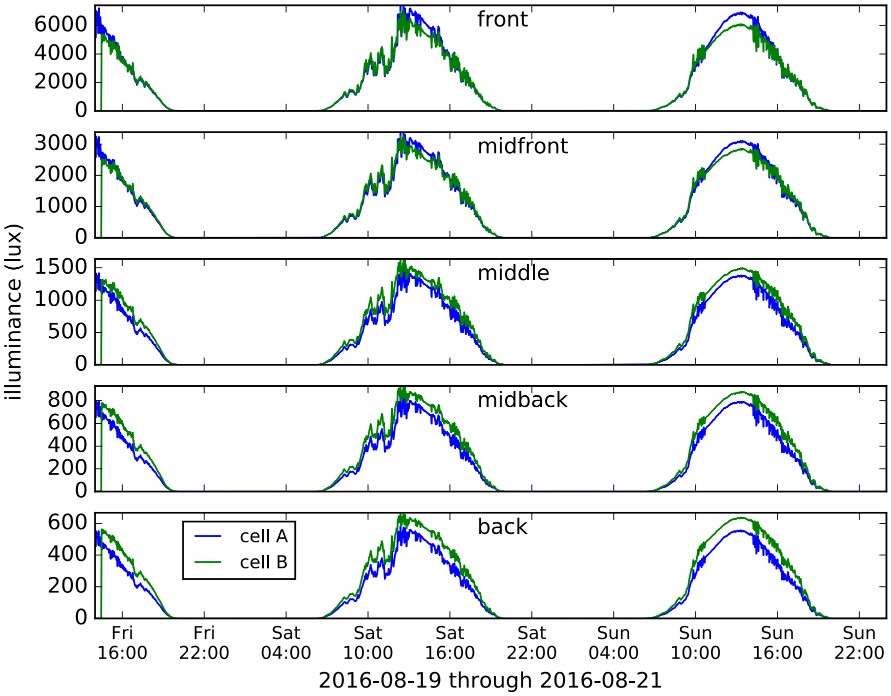
[19] https://www.ies.org/store/recommended-practices-and-ansi-standards/american-national-standard-practice-for-office-lighting/

today; more recently the recommendations for light levels for the average office worker (based on age, visual tasks performed, and other factors) are 30 foot-candles (around 320 lux) for most typical offices. This guidance recognizes that much of the modern office job involves work on a back-lit computer monitor, where high levels of lighting from overhead sources are not as necessary.

Illuminance monitoring

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) around the clock; at selected locations throughout the test space. The FLEXLAB data acquisition system records and reports these values in near-real time.

Figure F-2: Example plot of illuminance data from Licor sensor grid and FLEXLAB data acquisition system



The distribution of the photosensors in the test cell was as shown in Figure F-3, with the sensors being located in a grid, at approximately 4 ft on center between the sensors.

Figure F-3: Licor sensor configuration for Xcel workstation specific lighting system tests

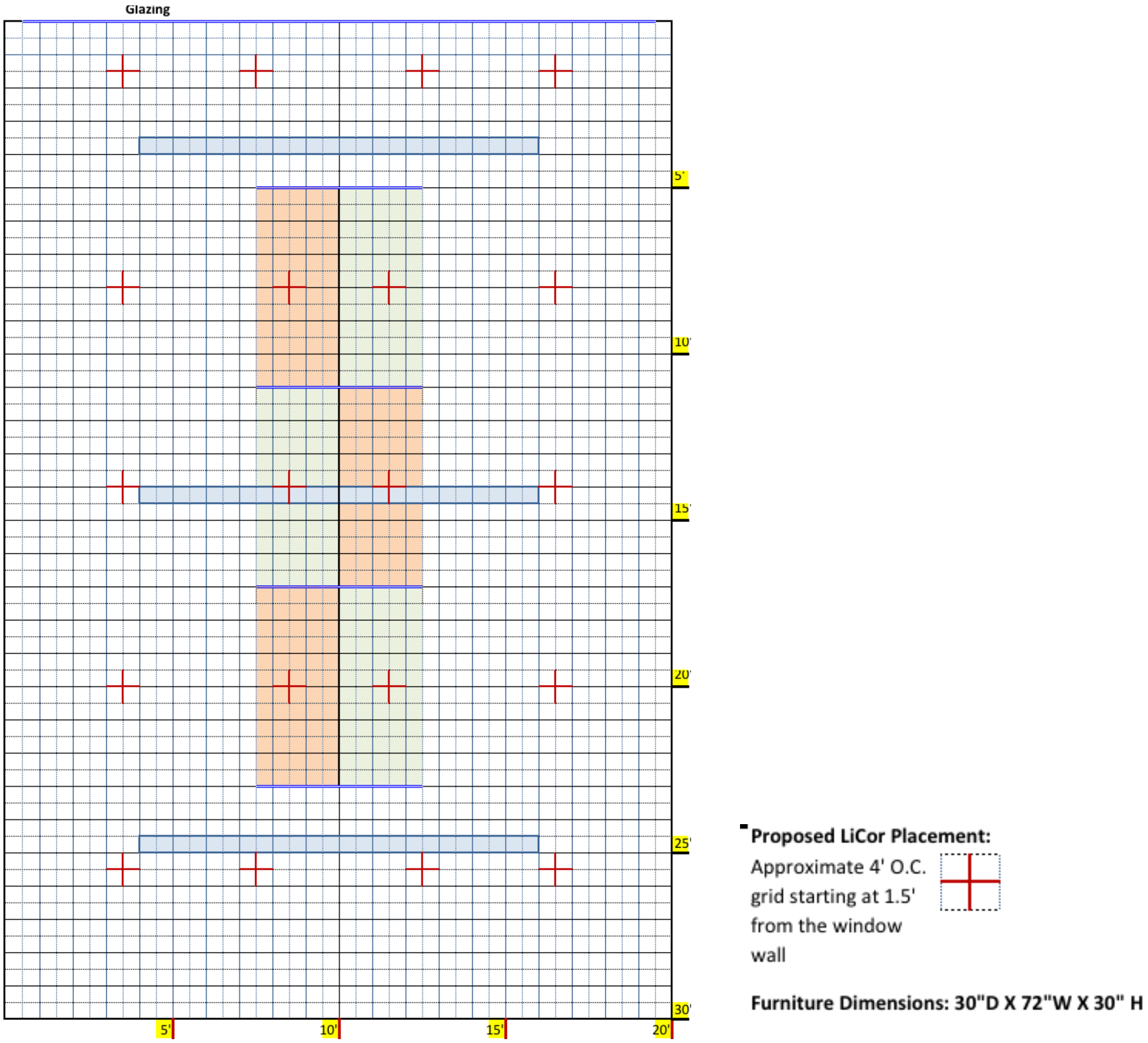


Figure F-4 provides a viewing of the test cell interior, where photosensors can be seen located on the center of each desk, as well as mounted on rails in the egress pathways around the workstations.

Figure F-4: The Licor photosensors are arrayed in the test space along a grid covering the desks and on the stands visible on either side of the workstations

Commissioning of the lighting systems

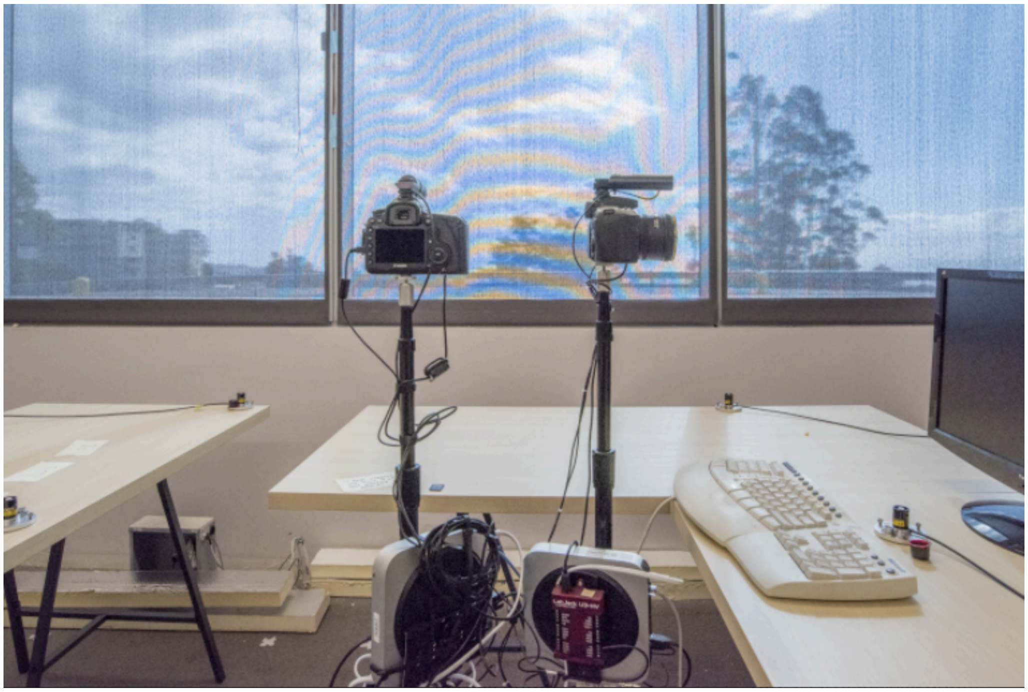
Dimmable lighting systems for the Beyond Widgets experiments were installed consistent with typical lighting design practice in commercial office environments; with respect to fixture densities (square feet per fixture), light level set points (illuminance at the task plane), and controls. Fixtures in the controls network (both reference and test cells) were assigned schedules of operation to match an expected occupancy period of 6AM – 6PM. The dimmable lighting systems were then commissioned to meet the desired average illuminance set point; either 300 lux or 500 lux, depending on the experiment. This was achieved by an iterative commissioning process. We start by averaging the illuminance measurements from the photometric sensors arrayed in the test cell at full output. This is done at night so that only illuminance from the electric lighting system is considered. The light fixtures are then dimmed in concert through the controls software, and the average illuminance at the new setting is calculated. This process is repeated until the setting corresponding to the desired average illuminance is achieved, and this value is programmed into the controls software as the “standard” operating level.

If the lighting controls include photosensors to dim the lights based on available daylight, the daylighting set point is also commissioned at this time. Essentially with the lights delivering the desired task plane illuminance, and absent any additional light (daylight) the daylighting set point is fixed. This programming tells the photosensor, on the ceiling or on the individual fixtures, facing down, that the light level it measures at this state is the desired level. The fixtures operate at this level until daylight enters the space and the closed-loop daylighting photosensor(s) sense(s) the higher levels and dim the lights, seeking the set point. When sufficient daylight enters the space such that the electric lights can dim no further, the system holds the fixtures at the lowest level until the daylight sensor. The sensitivity, maximum dimming level, response rate for each fixture or row of fixtures ("gain setting"), integrating period, etc. are all programmed in the controls system logic.

Glare monitoring

Glare is characterized in the FLEXLAB by the daylight glare probability (DGP) index, which relies on high resolution, field-of-view HDR luminance images to assess glare. DGP is measured and recorded via a combination of digital SLR cameras, illuminance sensors, and connected CPUs, as described and illustrated below. LBNL's Windows team has years of experience with luminance monitoring for visual comfort and glare analysis and has helped developed the High Dynamic Range (HDR) photography tools that monitor and characterize glare in the FLEXLAB.

Figure F-5: Example setup of HDR camera, sensor and processor packages for glare analysis in FLEXLAB



The 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, as illustrated in the example above. The premise of measuring glare at these locations is that if a lighting and shade system meeting minimum criteria for DGP at these locations, it is likely that those criteria are met elsewhere in the space as well.

Hemispherical field-of-view luminance measurements were taken throughout each study day 6AM to 6PM 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), and connected to / 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 (hdrcaposx). Four to seven images were taken per time interval depending on the brightness of the scene.

Daylight Glare Probability (DGP) Analysis Details

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 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.[20] DGP was calculated using the *evalglare* software[21] 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. Discomfort glare classes were defined based on these ratings.

Figure F-6: Suggested definition of daylight glare comfort classes[22]

Max DGP of 95% of period		Avg DGP of 5% of period	Class	Meaning
≤ 0.35 imperceptible		≤ 0.38 perceptible	A	Best
		> 0.38	B	Good
≤ 0.40 perceptible		≤ 0.42 disturbing	B	Good
	and	> 0.42	C	Reasonable
≤ 0.45 disturbing		≤ 0.53 intolerable	C	Reasonable
		> 0.53	Discomfort	Discomfort
> 0.45 disturbing		> 0.53	Discomfort	Discomfort

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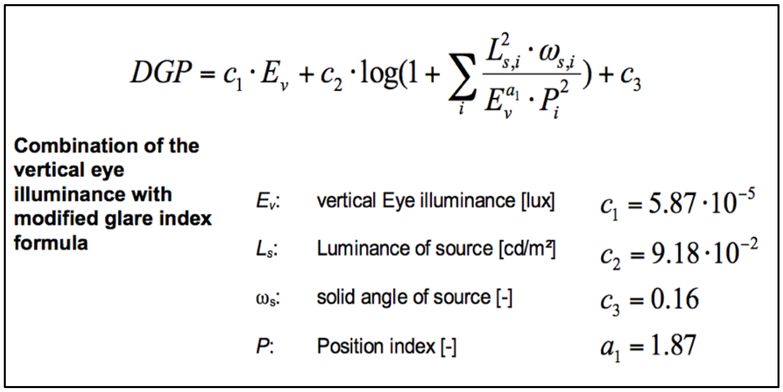
[20] Wienold J, Christoffersen J., Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras, Energy and Buildings 38 (7): 743- 757, 2006.

[21] Wienold J. evalglare version 1.0, September 2012, Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany.

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

Figure F-7: DGP Equation[23]



$$DGP = c_1 \cdot E_v + c_2 \cdot \log(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{a_1} \cdot P_i^2}) + c_3$$

Combination of the vertical eye illuminance with modified glare index formula

E_v: vertical Eye illuminance [lux] $c_1 = 5.87 \cdot 10^{-5}$

L_s: Luminance of source [cd/m²] $c_2 = 9.18 \cdot 10^{-2}$

ω_s: solid angle of source [-] $c_3 = 0.16$

P: Position index [-] $a_1 = 1.87$

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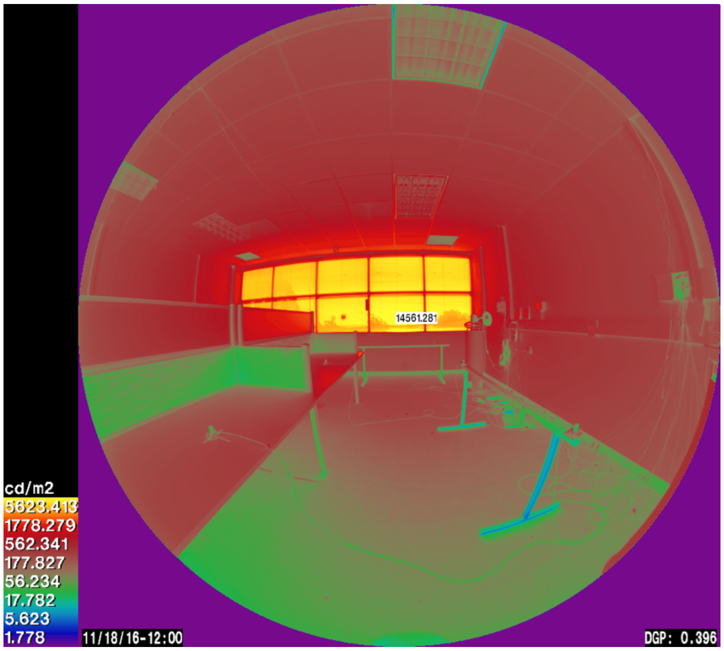
[23] https://www.radiance-online.org/community/workshops/2014-london/presentations/day1/Wienold_glare_rad.pdf

Figure F-8: This time-stamped image is 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 F-9: 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.



FLEXLAB Test Illuminance Results Details

The illuminance results for the workstation specific lighting system are presented as follows. For each case, the photosensor readings are presented related to their distance from the window. Note that the sensors located 1.5ft and 25.5ft from the window were located in the egress pathways around the workstations, and not on the workstations themselves. Consequently the target lux level for this position is the IES egress pathway illuminance minimum of 100 lux as noted previously. The target for the photosensors on the workplane is presented for each case as either 300 or 500lux.

The photosensor data presented is the average of the middle two sensors located that distance from the window. Refer to figure F-3 for the map of photosensor locations used in testing.

In all cases, it can be seen that the illuminance levels throughout each test case meet or exceed the minimum illuminance levels as set by IES or for the minimum levels desired at the workplane. As expected, increased light levels occur closer to the window, and at significant levels that may cause glare issues at times. These averages are taken throughout all test periods during occupied hours. An assessment of glare follows these results in the next section.

Figure F-10: Workstation Specific Lighting System, Illuminance Distribution, 300lux minimum workplane case with Film 1.

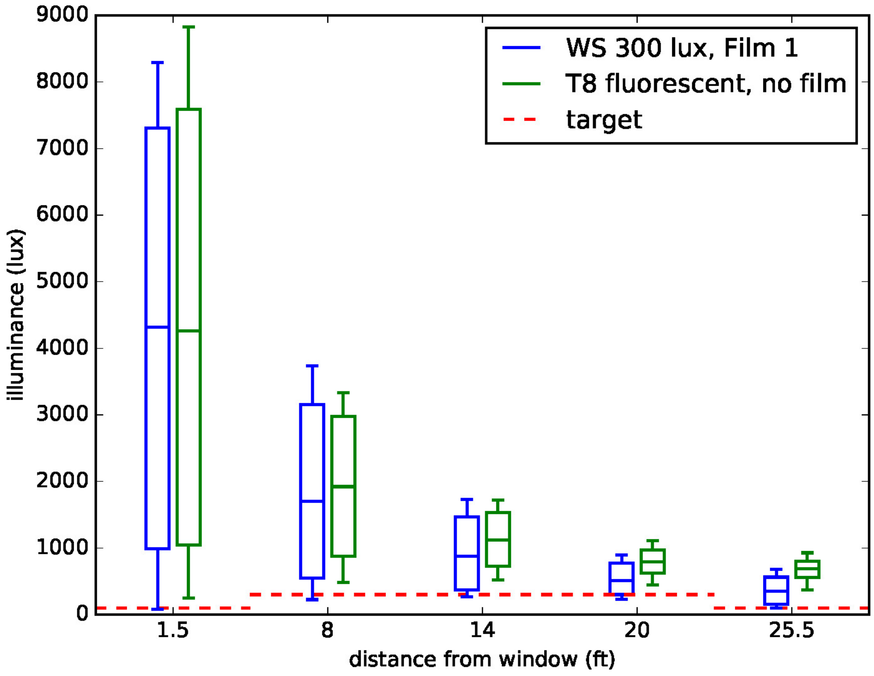


Figure F-11: Workstation Specific Lighting System, Illuminance Distribution, 300lux minimum workplane case with Film 2.

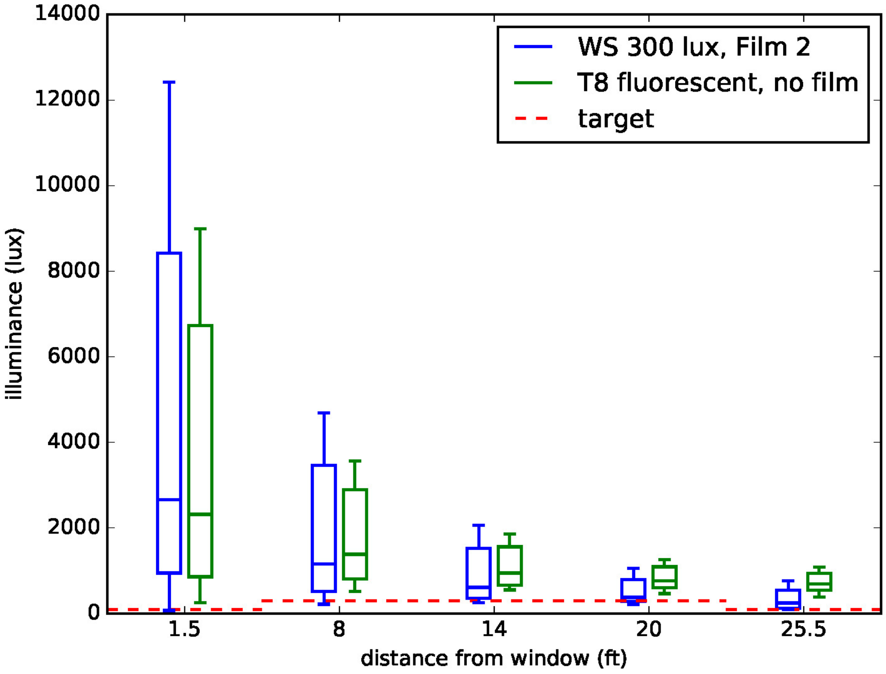


Figure F-12: Workstation Specific Lighting System, Illuminance Distribution, 500lux minimum workplane case with Film 1.

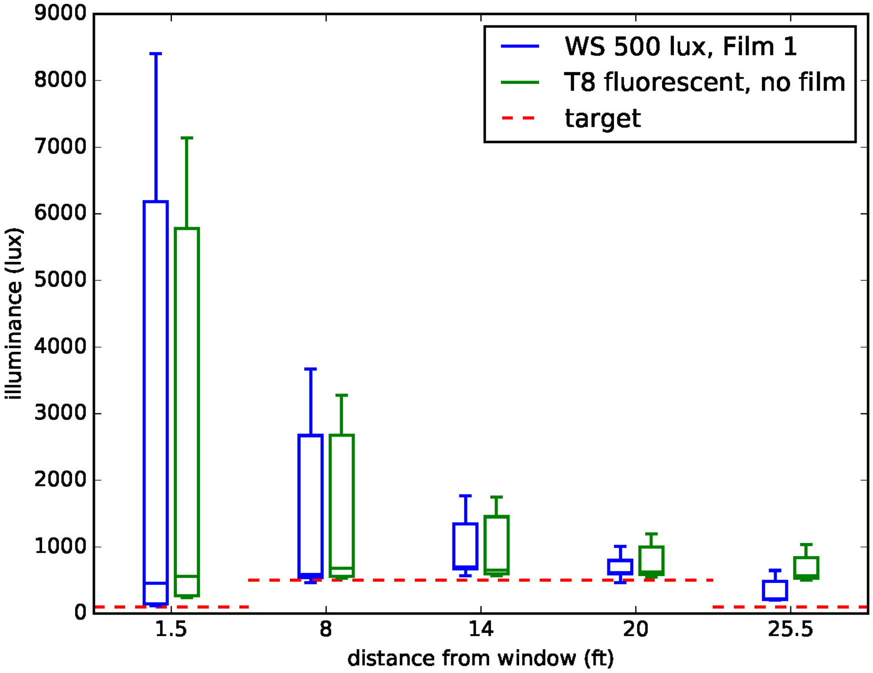


Figure F-13: Workstation Specific Lighting System, Illuminance Distribution, 500lux minimum workplane case with Film 2.

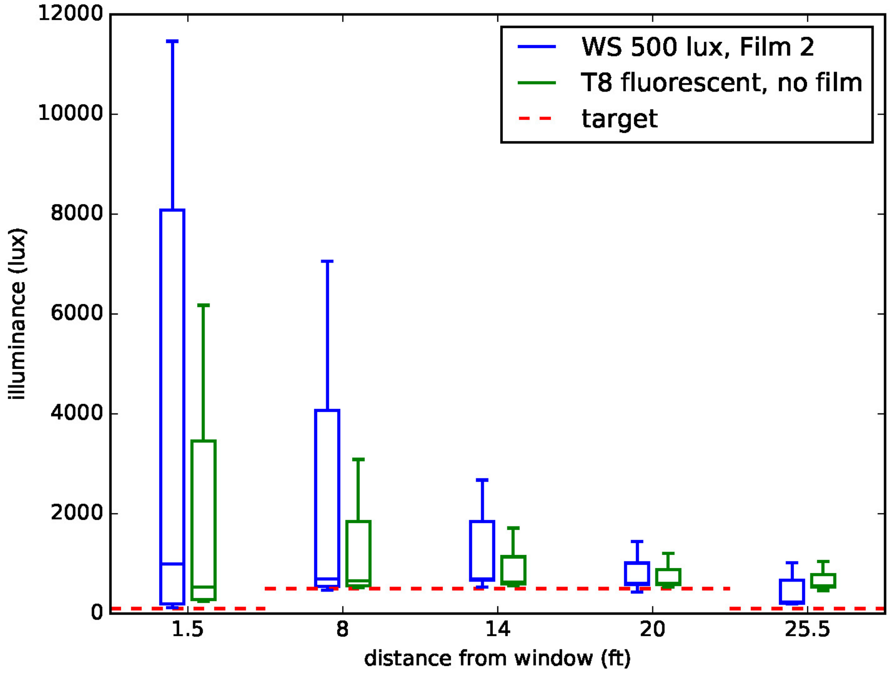
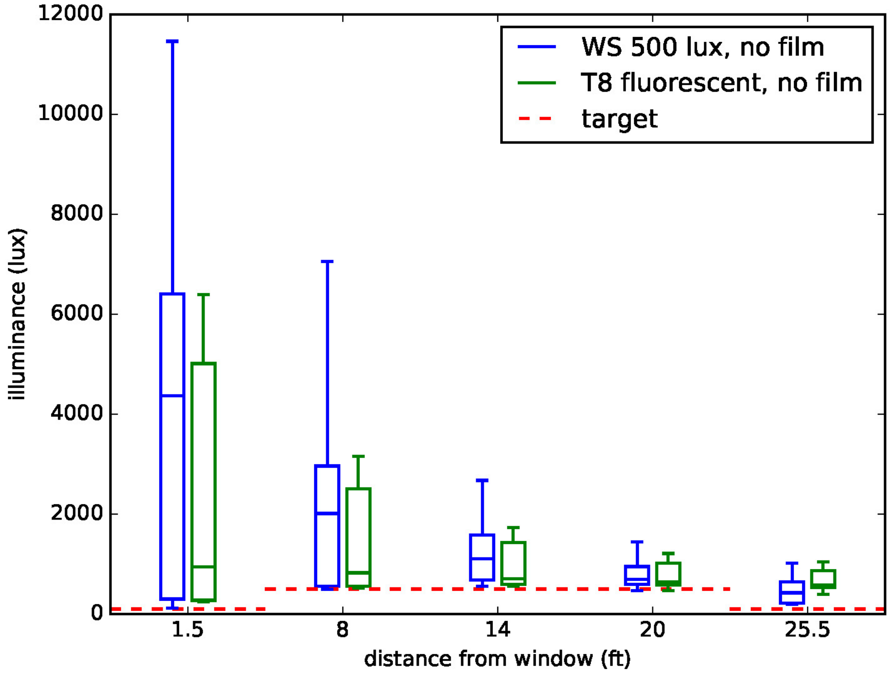


Figure F-14: Workstation Specific Lighting System, Illuminance Distribution, 500lux minimum workplane case with No Film.



Daylight Glare Probability (DGP) Test Results Details

The Daylight Glare Probability (DGP) results for the workstation specific lighting system are presented as follows for select test periods. The DGP data is plotted using a bar chart for each test date, with the % time that the test data was calculated to be in each of the Imperceptible, Perceptible, Disturbing and Intolerable ranges as previously defined. Note that only test data from the periods of 7am to 7pm are presented. For each test condition the presence and usage of any interior venetian type blinds is noted. In general, it will be noted that both the base case cell and the workstation specific system cell experienced periods of higher DGP values than an occupant might desire. This condition is commonly experienced with unshaded windows regardless of the interior lighting system design. As a result, it would be recommended to include manual or automated shading in the space to enable visual comfort throughout occupied hours for the targeted system.

Workstation Specific Lighting System, 300 lux Tuned Maximum Output Level

Figure F-10: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 300lux Maximum Output. Film 1 test condition.

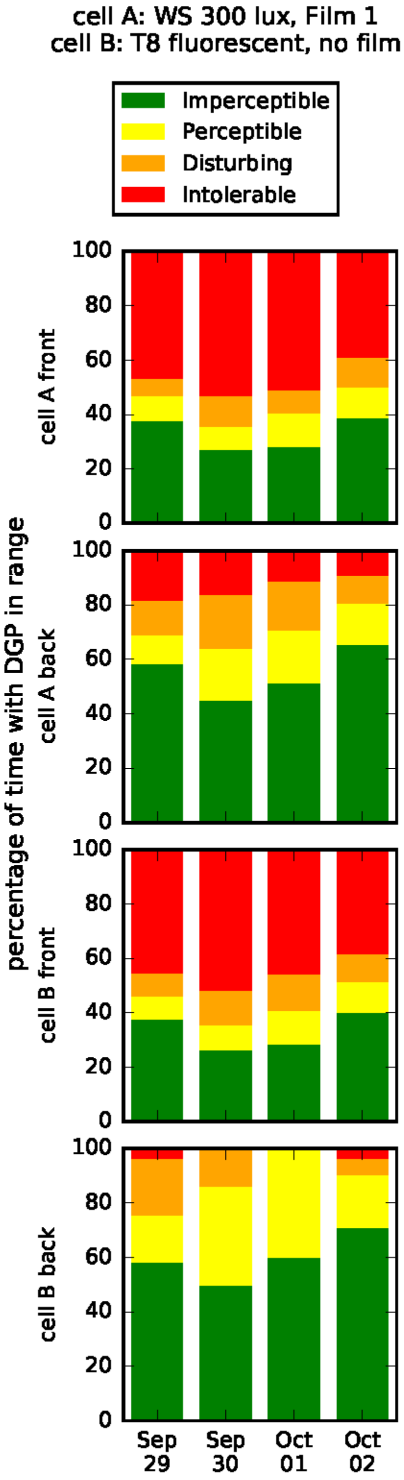
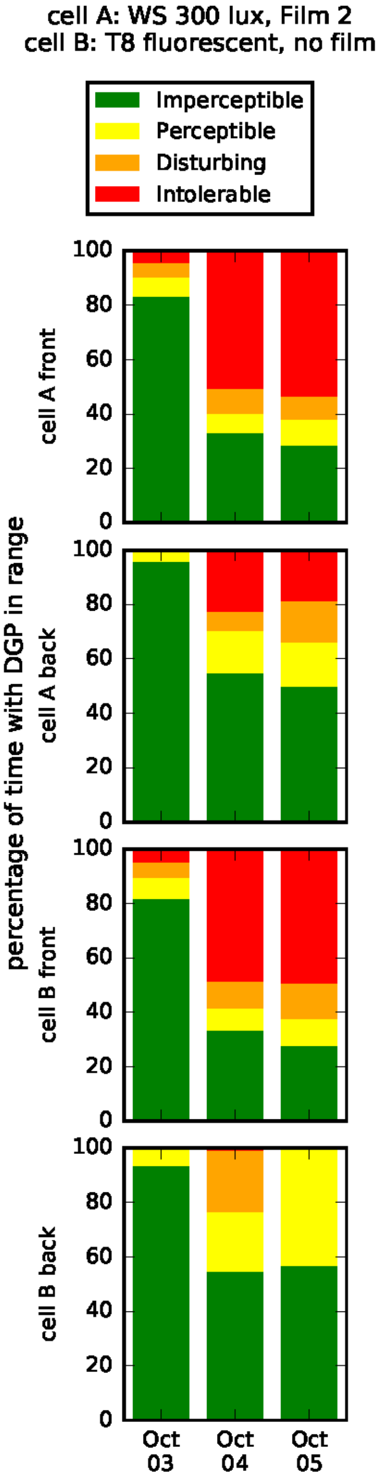


Figure F-11: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 300lux Maximum Output. Film 2 test condition.



Workstation Specific Lighting System, 500 lux Tuned Maximum Output Level

Figure F-12: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 500lux Maximum Output. No film test condition.

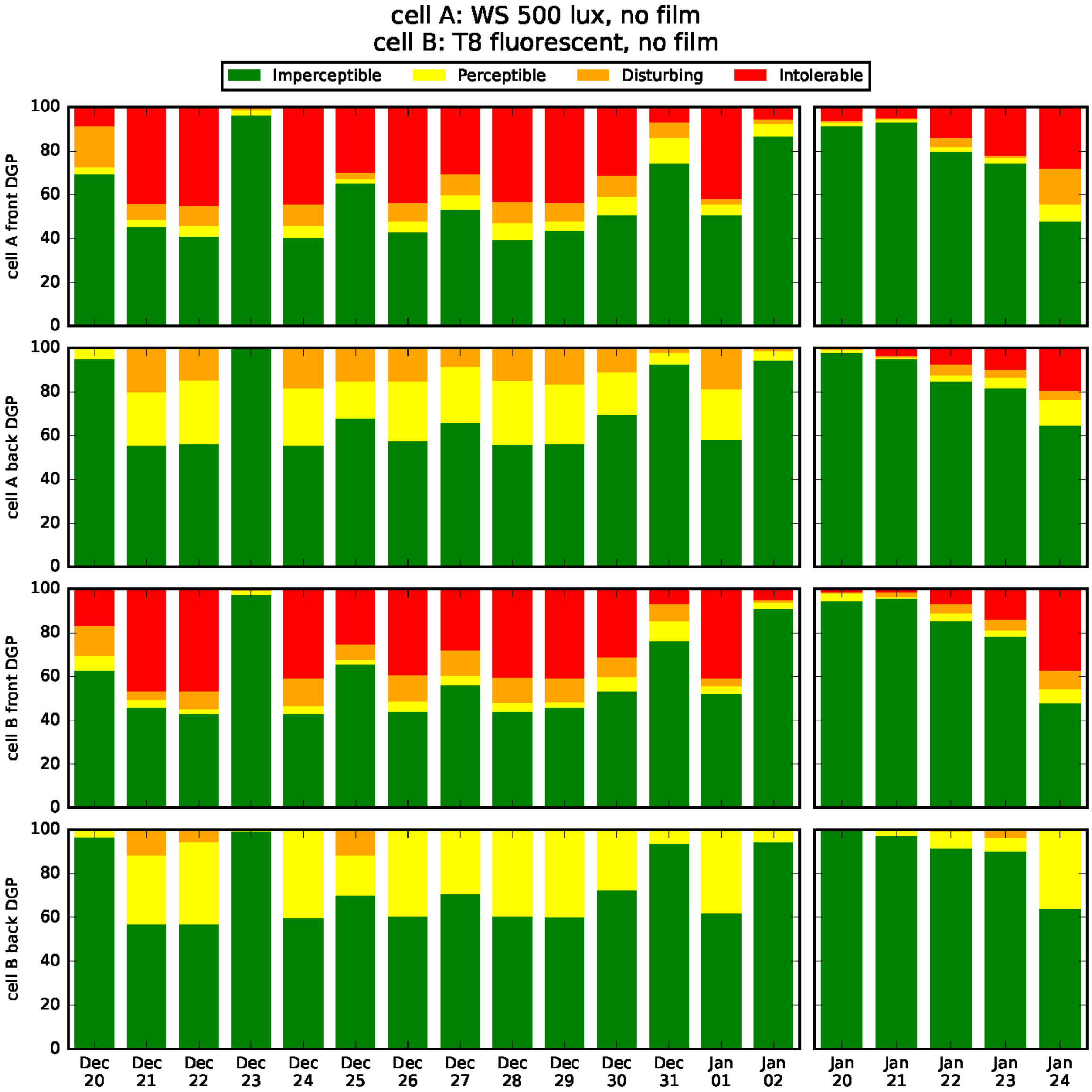


Figure F-13: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 500lux Maximum Output. Film 1 test condition.

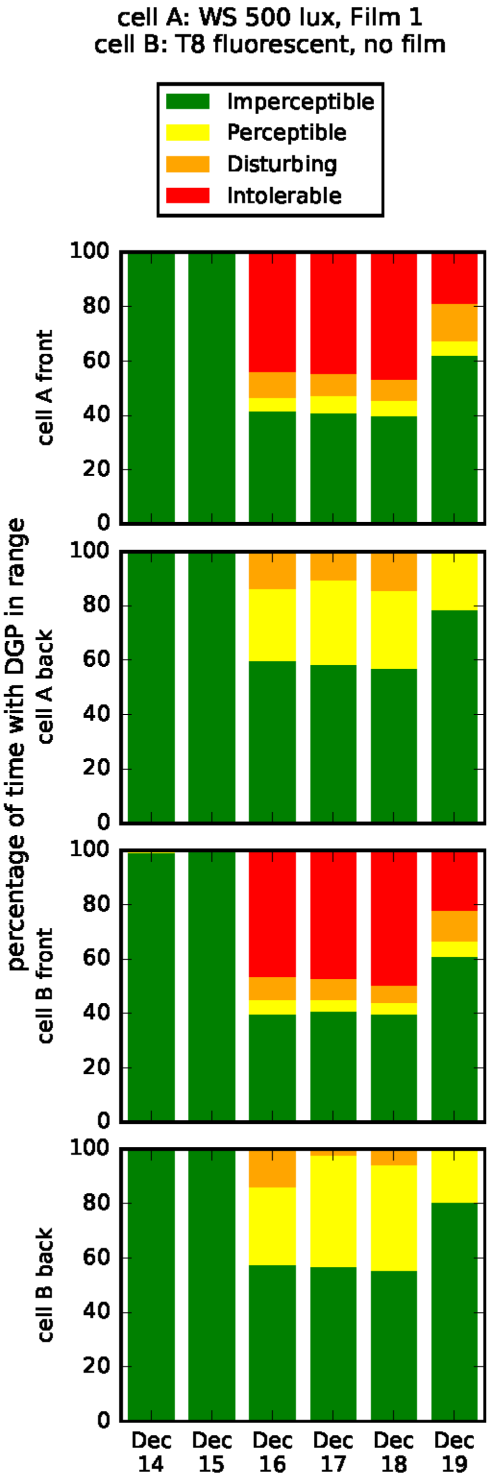
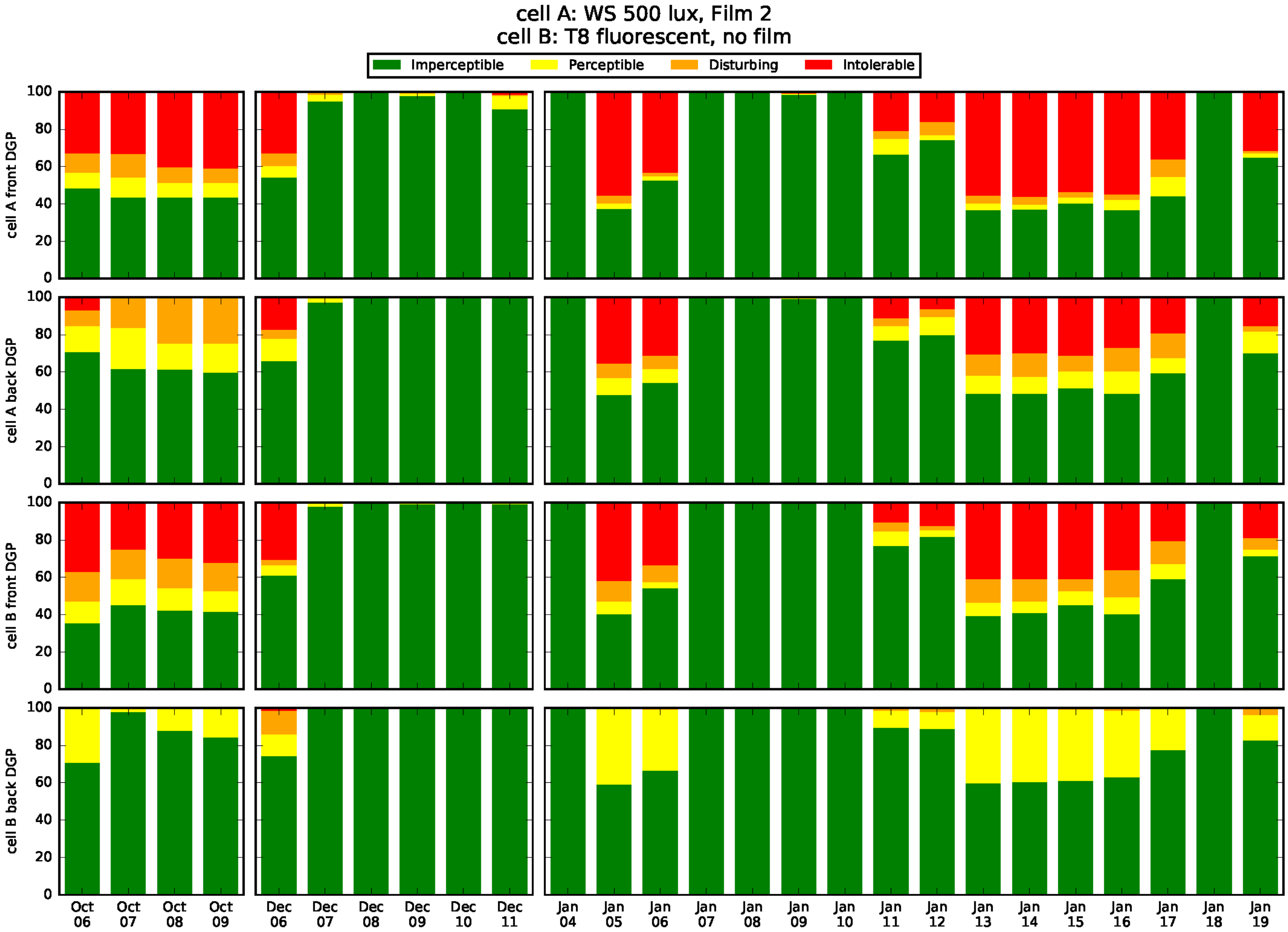


Figure F-14: Test Results % Incidence for Levels of DGP for Workstation Specific Lighting System, Tuned for 500lux Maximum Output. Film 2 test condition.



Appendix G: Workstation Specific Lighting – Occupant Density Range Assessment

FLEXLAB testing of the workstation specific lighting system was conducted for a space condition that represented the maximum occupant density allowable by code, and consequently represented the high end of potential installed LPD for this system given that one light fixture would be required per person. This condition was based on the 2015 International Building Code, Design Occupant Load per Table 1004.1.2 for a Minimum Floor Area Allowance per Occupant of 100 gross square feet per person for Business areas.

An assessment was also conducted using simulation to understand what the potential impact of LPD would be for a less densely occupied space, and consequently whether it would impact potential energy savings. For this exercise, a maximum area per person of 150 gross square feet per person was selected, which would translate into 4 workstations in the FLEXLAB test area.

For the assessment, an AGi computer model of the lighting environment in the reference and test cell of the FLEXLAB was built in order to evaluate electric lighting levels at the task plane (the desks) and at the floor for different lighting and furniture configurations. The model was built to the same dimensions and scale as the FLEXLAB environment. Reflectances of the main surfaces in the space were set to mimic those of the actual surfaces in the space as well.

Room Dimensions: 30 feet deep, 20 feet wide, 8 foot ceilings.

Desks: 2.5 feet tall, 2.5 feet wide (per workstation), 6 feet long (per workstation), 18 feet long (6-workstation option), 6 foot long clusters (x2) (4-workstation option).

Partitions: 2-foot tall, with 1 foot of opaque fabric and 1 foot of transparent acrylic.

Surface Reflectances:

- Walls 0.65
- Ceiling 0.86
- Floor 0.5
- Desk surface 0.85

Computer files called *.ies* files are available for most commercially available light fixtures.[24] These files characterize the quantity of light output and spatial distribution of that light output for the fixture based on standardized lab measurements. This information can be used in a lighting model to represent the fixtures' performance in the modeled space, and light levels (illuminance) resulting from fixture locations and orientation in the space can be calculated at any given point(s) within the modeled environment.

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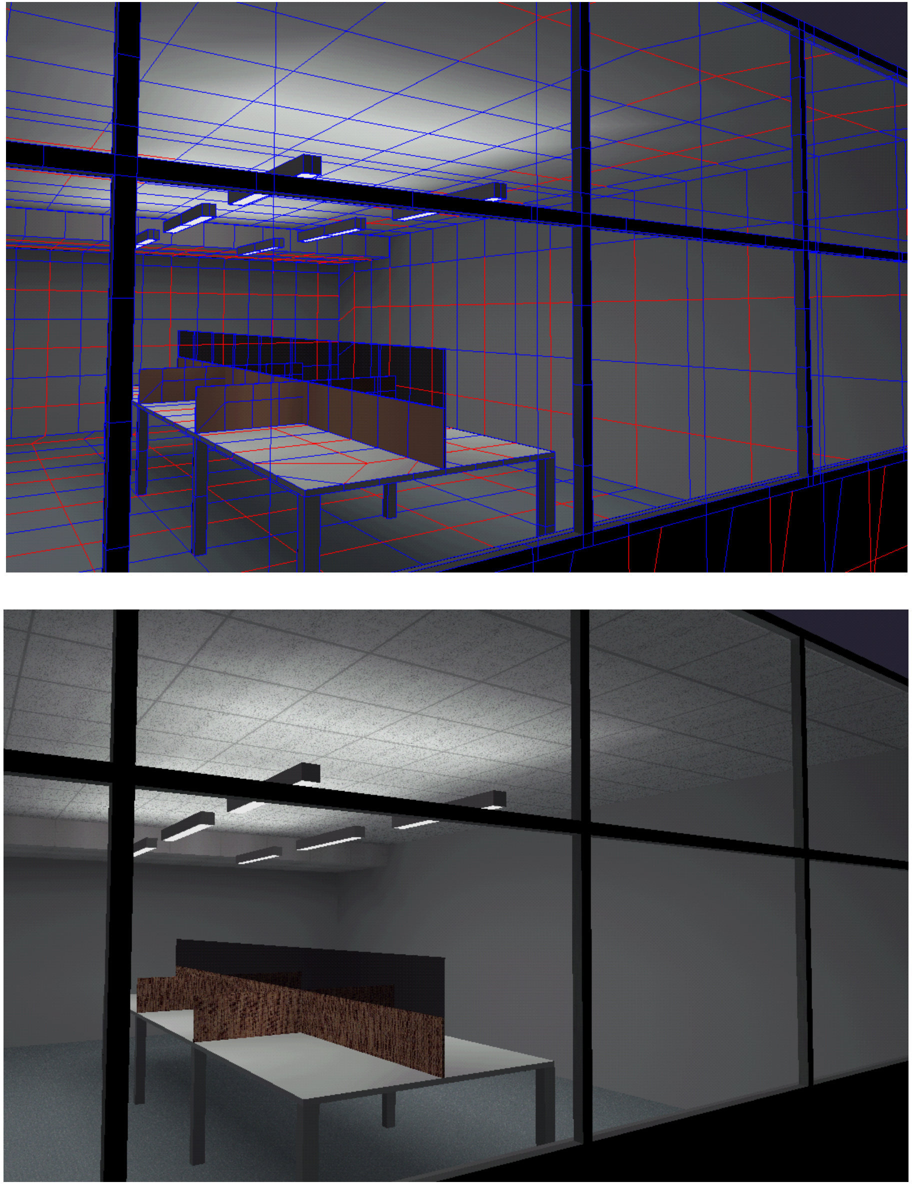
[24] The *.ies* file for the 4-foot suspended LED fixture used in the FLEXLAB and in the model was: FINELITE HP-4-ID-4ft-H-H-835; [TESTLAB] INDEPENDENT TESTING LABORATORIES, INC. [ISSUEDATE] 02/09/17 [_ABSOLUTELUMENS] 6134

Figure G-1: Snapshots of AGi Modeled Environment



In the FLEXLAB, workstation - specific lighting using direct-indirect LED pendant fixtures was installed and tested over 6 workstations as depicted in the rendering above. The lighting system was operated for periods of time at 2 different illuminance set-points; 300 lux and 500 lux.[25] For workstation - specific lighting, the design goal was to achieve the workstation illuminance setpoint (300 lux or 500 lux at the task plane) as well as provide adequate lighting in the areas surrounding the desks. This was determined to be an average illuminance level of

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[25] Due to commissioning precision, the latter set point actually resulted in average illuminance from electric lighting closer to 600 lux.

at least 100 lux at the floor based on IES lighting recommendations for transition spaces in offices, with a contrast ratio of no more than 3:1 (task plane: floor illuminance).[26]

Light levels calculated from the AGi lighting model were compared with measured results (fixture power and illuminance) from the FLEXLAB during lighting system commissioning. Light levels at locations not measured during FLEXLAB testing (principally, floor-level measurements) were also computed with the model.

The computer model was also used to evaluate lighting performance for a fixture and furniture configuration not tested in the FLEXLAB; a lower - occupant density option with 4 workstations instead of 6. Average illuminance calculated from points in the computer model were found to be within 1% to 5% of average illuminance calculated from measured points in the FLEXLAB. All light levels for the analysis were for electric light - only (at night, in the absence of day lighting).

Results for the higher and lower density workstation – specific lighting measurements and modeling are tabulated below. Following the table are illuminance results (floor- and desk-level) and rendered images from each model run. Each image represents a one-time illuminance result based on running the model solely for electric light output in the absence of daylighting. In reality luminance levels will be higher than shown during daylight hours.

The workstation measurements are taken at the working plane, and the floor level measurements are taken at the floor.

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[26] See IES RP-1-12 *American National Standard Practice for Office Lighting*; Table 32.2: Office Facilities Illuminance Recommendations for "transition spaces" such as passageways and entrances.

Table G-1: Workstation and Egress Lux Levels for Range of Occupant Densities – Comparison of FLEXLAB Test Data and AGi Modeling Results

	Attributes					Measured @ FLEXLAB			Modeled in AGi			Calculated Results			
	Cell area (ft^2)	Fixture count	Fixture length (ft)	Num. of Occ.	Ft^2 / occ.	Fixture Watts	Avg Lux (all meas pts.)	Avg Lux (desk only)	Avg Lux (desk only)	Avg Lux (floor)	Desk: Floor Avg Lux	Total ln. ft. of fixture	Total Fixture Watts	Watts /ft of fixture	Watts $/ft^2$
6 Workstations, 500 lux setpoint	600	6	4	6	100	30	304	**591**	563	197	2.86 :1	24	180	7.5	0.30
6 Workstations, 300 lux setpoint	600	6	4	6	100	16	151	**289**	297	104	2.86 :1	24	96	4.0	0.16
4 Workstations, 500 lux setpoint (model only)	600	4	4	4	150	*41*	n/a	n/a	589	201	2.93 :1	16	163	10.2	0.27
4 Workstations, 300 lux setpoint (model only)	600	4	4	4	150	*21*	n/a	n/a	307	105	2.92 :1	16	85	5.3	0.14

*values in italics estimated

Figure G-2: AGi Model results, 4 workstation configuration – 500 lux setpoint

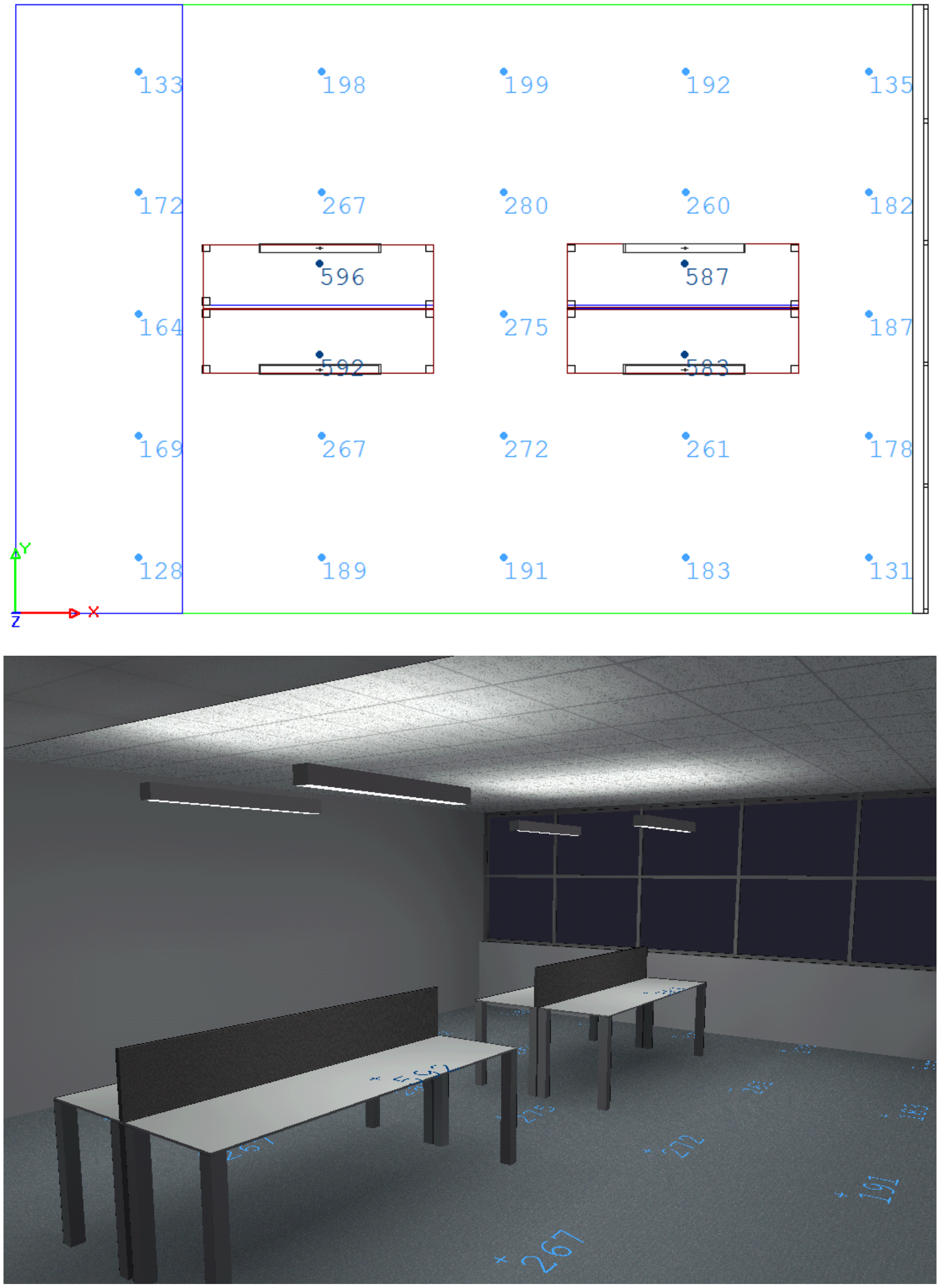


Figure G-3: AGi Model results, 4 workstation configuration – 300 lux setpoint

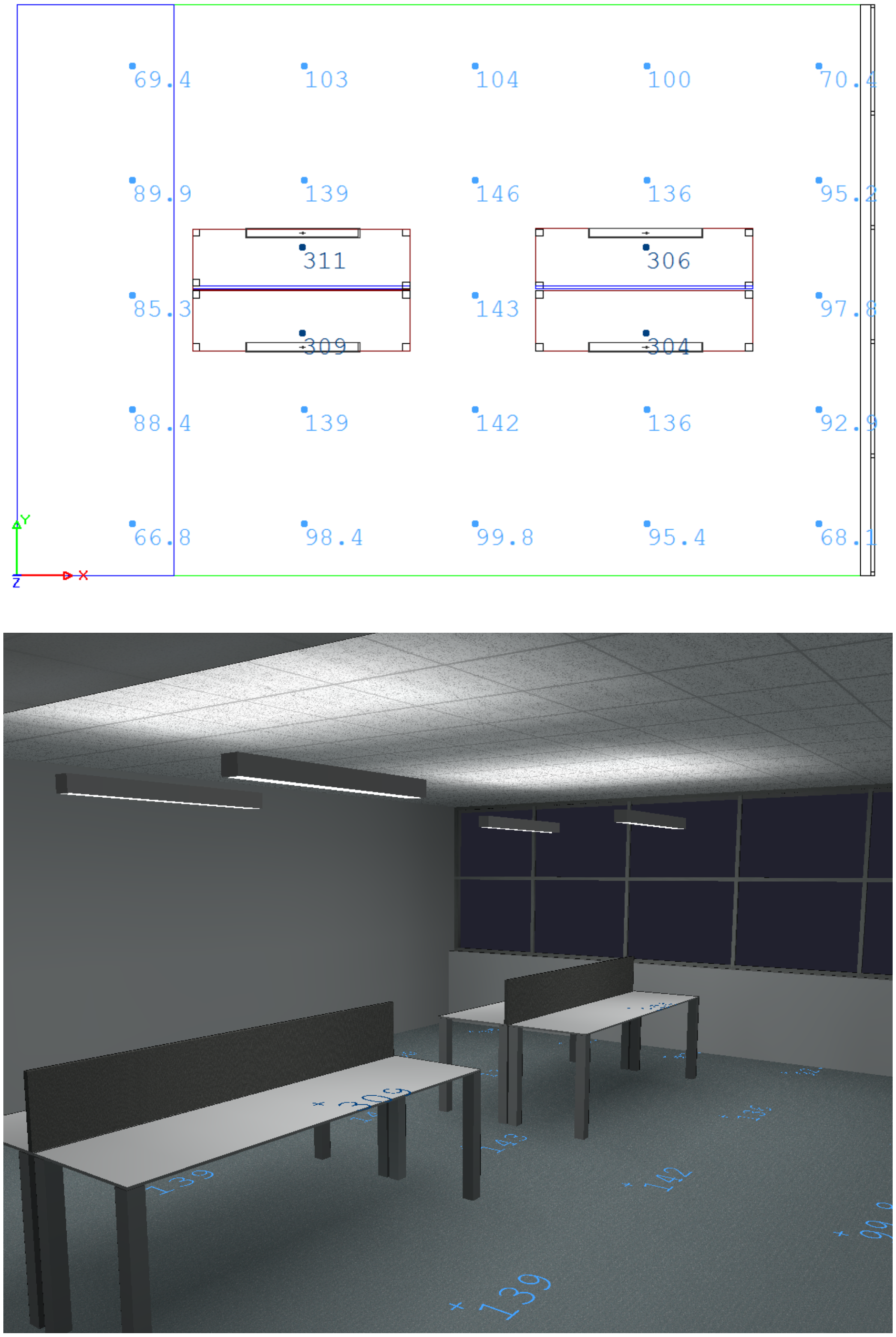


Figure G-4: AGi Model results, 6 workstation configuration – 500 lux setpoint

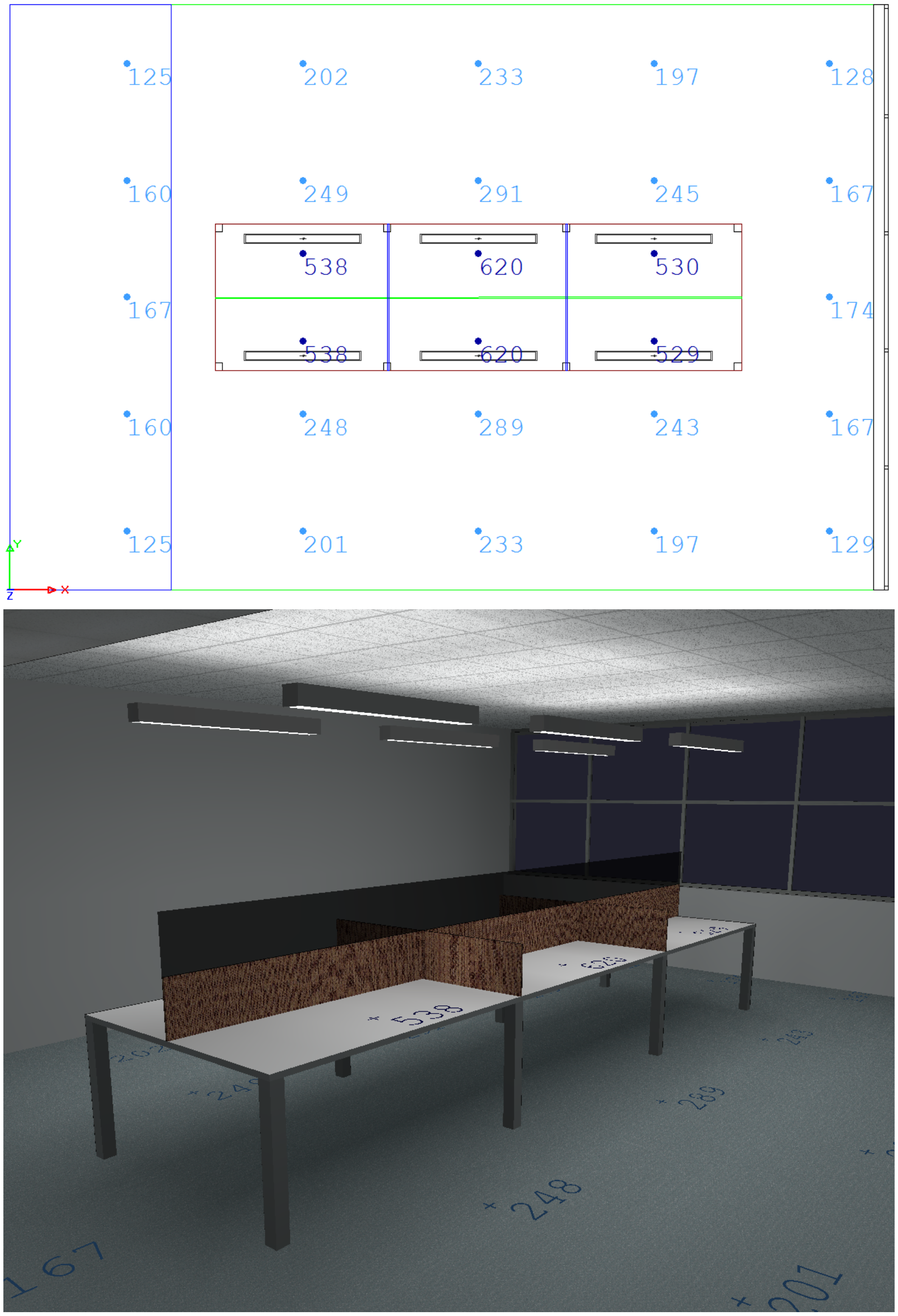
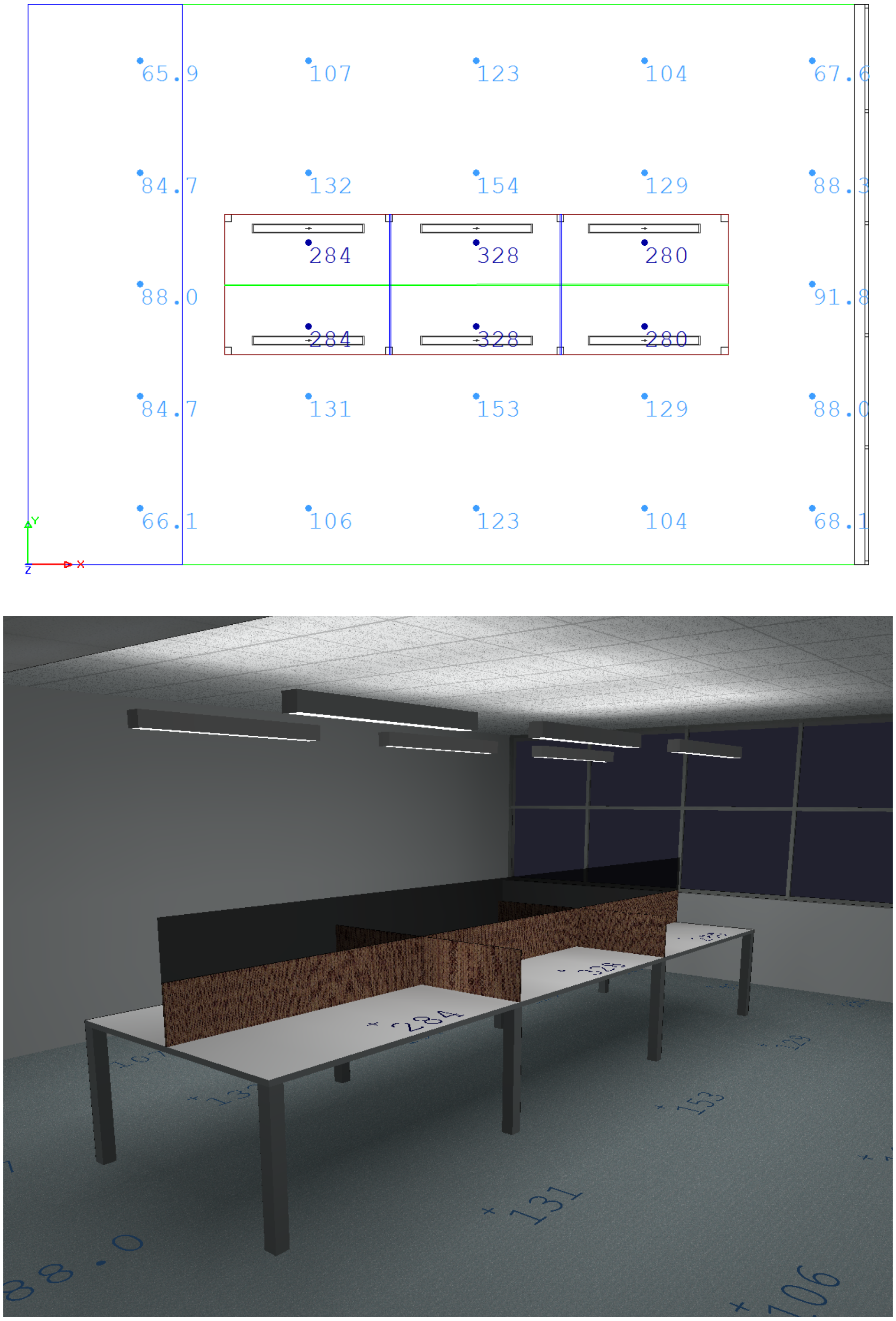


Figure G-5: AGi Model results, 6 workstation configuration – 300 lux setpoint



Appendix H: Market Segmentation Analysis

The following market analysis was conducted for the original system consisting of a daylight redirecting film, coupled with workstation specific lighting and daylight dimming controls. The report is included for reference only as it pertains to descriptions of the market analysis structure and process. All results for this system do not apply to the current workstation specific lighting system with daylight dimming controls, as the system installed cost and energy savings data has been modified. Please refer to Appendix J for an updated market analysis of key performance metrics, utilizing the same methods and process as described herein.

“BEYOND WIDGETS” SYSTEMS ENERGY EFFICIENCY – MARKET SEGMENTATION

Potential for Adoption of System-Based Utility Energy Efficiency Programs

Lawrence Berkeley National Laboratory

Date: February 23, 2016, Amended May 9, 2016

Table of Contents

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 to be considered in this study and the best building types (i.e., market segments) applicable to these systems. The systems and segments are shown in Table 15.

Table 15. 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 lighting upgrade and integrated zone-level daylighting and lighting controls Package 2. Integrated, enterprise-level networked lighting and 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, develop "adoption curves", 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[27] 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[28]. 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 of lighting widgets, in the northeast for example that estimated approximately 13% adoption of high efficiency LED lighting and controls over 10 years.[29]
- Shorter payback times, through market cost reductions or utility intervention saturation may range between 24% and 43% over 10 years.

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[27] 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.

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

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

The total technical potential of energy savings for each utility partner in GWh is in Table 16.

Table 16: 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**[30]	**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 17 and Table 18.

Table 17: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.04	1.13	1.98	1.19
Southern California	1.11	1.23	2.17	1.28
ComEd	0.28	0.25	NA	NA
Xcel Colorado	0.79	1.09	0.68	1.09
Xcel Minnesota	0.28	0.37	0.24	0.36

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.

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[30] No package 2 was specified for ComEd.

Table 18: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.42	1.35	2.38	1.32
Southern California	1.54	1.48	2.63	1.43
ComEd	0.53	0.44	NA	NA
Xcel Colorado	1.15	1.59	0.78	1.25
Xcel Minnesota	0.40	0.54	0.27	0.42

The total economic potential of energy savings (as filtered by a TRC ≥ 1.0) for each utility partner is presented in Table 19 (RET) and Table 20 (ROB).

Table 19: 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 20: 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 21 and Table 22. These tables represent the minimum estimated level of savings achievable for a systems based utility programs over a 10-year period.

Table 21: 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 22: 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	**6/8**	**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. Similar to widget-based equipment, 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.

2 INTRODUCTION

2.1 Background and Objectives

With funding from the US Department of Energy (DOE), Lawrence Berkeley National Laboratory (LBNL) is currently leading a "Getting beyond Widgets" research project to advance systems-based energy efficiency measures in US commercial buildings.[31] This effort seeks to expand utility incentive programs beyond the traditional focus on individual "widgets" (i.e., components) in order to unlock deeper energy savings from energy-efficient systems such as lighting measures with advanced controls.

As part of this effort, LBNL engaged DNV GL to estimate the market potential for specific energy-efficient systems selected and defined by LBNL and three utility partners:

California Publicly Owned Utilities (CA POUs) though out the state
Commonwealth Edison in Illinois (ComEd)
Xcel Energy in Minnesota and Colorado (Xcel)

Table 23 shows the market segments and system packages selected for each utility partner.

Table 23. Study targets

Market	Segment	System Packages
CA POUs	Offices	Package 1. Plug-and-play overhead lighting and automated plug load control system Package 2. Overhead lighting and / or networked controls changeout and automated plug load control system
ComEd	Offices and Schools	Package 1. Automated shading (roller) with integrated lighting controls
Xcel	Offices	Package 1. Zonal HVAC controls with lighting upgrade and integrated zone-level daylighting and lighting controls Package 2. Integrated, enterprise-level networked lighting and lighting controls, daylight redirecting film, and HVAC controls

The objective of this study is to identify which market segments (e.g., offices, schools) and sub-segments (e.g., large offices owned by the tenant) provide the greatest potential for cost-effective energy savings from the specific systems. This information will help LBNL gain a better understanding to target systems-based programs to market segments and sub-segments.

2.2 Study Approach

To develop the market profile for these systems DNV GL conducted the following tasks as part of this study:

1. **Segment the market.** Starting with the applicable data set(s) for each utility partner (e.g., data on all Xcel Office customers), we further divided the data into sub-segments based on factors such as building size (small or large), vintage (new or old), and ownership (owned or leased). See Section 3.1 for a discussion of the methods and assumptions used in this task.

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[31] See https://cbs.lbl.gov/getting-beyond-widgets-enabling-utility-incentive

2. **Estimate the market size.** To determine the market size, we calculated the technical and economic potential for the selected systems in the applicable market segments. In this study, “technical potential” is defined as the total square footage available to install each system, and “economic potential” is defined as the amount of technically feasible square footage for which a system is economically viable from the utility’s perspective. See Section 3.2 for a discussion of the methods and assumptions used in this task; see Section 4.1 for related findings.
3. **Conduct expert interviews**. We conducted market actor interviews to further understand the target markets and assess adoption for each market segment and sub-segment. See Section 3.2 for a discussion of the methods and assumptions used in this task; see Section 4.4 for related findings.
4. **Assess the adoption (achievable) potential.** Using the results of the economic potential analysis and “adoption curves” developed with input from the expert interviews, we estimated the percent of square footage in each market segment and sub-segment likely to adopt the selected systems over a 10-year timeframe. See Section 3.2.3 for a discussion of the methods and assumptions used in this task.
5. **Prioritize the market segments.** We ranked the market segments according to their “adoption potential” and other criteria developed from the expert interviews.

A summary of study findings and recommendations is provided in Section 5, Conclusions and Recommendations. The appendices of this report include tables of findings for technical potential, economic potential, and estimated achievable potential for these systems over time under different pricing scenarios.

3 METHODS AND ASSUMPTIONS

This chapter discusses the methods and assumptions we used to:

Segment the market
Estimate technical, economic, and achievable potential for each system
Conduct the expert interviews

3.1 Market Segmentation

3.1.1 Criteria for Market Segmentation

To develop the savings potential analysis, we disaggregated the utility partners' target markets into sub-segments using the following criteria:

Building type: As defined by the utility partners
Size: Small or large is defined differently for each utility partner:

- CA POUs: the CA POUs selected one building type: offices. Offices were defined as small or large based on building square footage. Offices occupying less than 50,000 square feet were classified as small, and offices occupying 50,000 square feet or more were classified as large. This is consistent with the square footage classifications used in the California Commercial End-Use Survey (CEUS).
- ComEd: Come Ed selected two building types: offices and schools. All of these building types were defined as small or large based on energy demand. Buildings with less than 100 kW of demand were classified as small, and buildings with demand greater than 100 kW were classified as large.
- Xcel Energy: Xcel Energy selected one building type: offices. Office definitions were small or large based on annual energy usage. Offices using less than 2,000,000 kWh per year were classified as small, and offices using 2,000,000 kWh/year or more were classified as large. This is consistent with the definition used in other potential studies commissioned by Xcel Energy in Colorado and Minnesota.

Ownership type: Own vs. rent
Vintage: old vs. new Vintage is defined differently for each area:

- For California we used 1978, the year Title 24 came into effect, as the delineation between old and new buildings.
- Minnesota adopted ASHRAE 90.1 in 1977 and we used this as the cutoff between old and new. Regions tend to perform similarly due to practices of regional contractors and equipment distributors so we applied the same cutoff to ComEd in Illinois and Xcel in Colorado.

Existing system configuration: multiple packages based on systems described in Table 23.
Climate and geography:

- CA POUs: We segmented California into two regions: north and south. The systems included in the study are not weather sensitive and are applicable throughout the state.
- ComEd: the entire service territory is contained within one climate zone, which is the International Energy Conservation Code (IECC) climate zone 5.
- Xcel: Minnesota and Colorado territories are analyzed separately to reflect differences between the two regions in climate and geography.

Finally, lighting systems in this study were not weather sensitive.

3.1.2 Data Sources for Market Segmentation

DNV GL segmented the data in the manner described above using three sources of data: site-level information from the utility partners, site-level information from the CoreLogic database, and micro-data from the US Energy Information Administration's 2012 Commercial Buildings Energy Consumption Survey (CBECS). A description of these data sources and their applications in this study begin in the next section.

3.1.2.1 Site-Level Information – LBNL Utility Partners

DNV GL used the following data sources to segment each of LBNL's utility partner markets:

California POUs

- The California Public Utilities Commission recently sponsored a Commercial Saturation Survey (CSS) that collected building characteristics and energy equipment data from nearly 8,000 phone surveys and 1,400 site visits of non-residential customers. These data, collected from the investor-owned utility (IOU) service territories, populate a comprehensive database that can support numerous analyses needed for the market segmentation task. As the IOU and POU territories are often adjacent (or overlapping in the case of gas), we used this data source in the current analysis to support the development of saturation estimates.
- The CA POUs and LBNL staff provided the base system energy-use intensities (EUIs) and system savings.
- The California CEUS developed estimates of square footage and EUIs for various market segments in California. This data provided a crosscheck the data purchased from CoreLogic, discussed in section 3.1.2.2 below.
- LBNL provided information on the distribution of energy consumption, by building type, for each California POU (except for Los Angeles Department of Water and Power).
- The Northern California Power Agency provided detailed information on the commercial customers served by its member utilities. Although this was not a direct input into the model, this information provided us with a better understanding of commercial customers within the POU territories, and it and was used to cross-check other data used in the analysis.

ComEd

- DNV GL extracted data relevant to this market segmentation analysis from two ComEd potential studies, conducted in 2009 and 2013, and from the most recent Ameren Illinois potential study, which also contained extensive market research on the saturation of end-use equipment in Illinois.
- ComEd staff provided annual consumption and peak demand by North American Industry Classification System (NAICS) category.
- ComEd and LBNL staff provided the base system EUIs and system savings.

Xcel Energy

- DNV GL conducted Xcel Energy's recent demand-side management (DSM) potential studies, performing extensive analysis in both the Minnesota and Colorado service territories. This included customer saturation surveys—and saturation and energy-efficient equipment penetration input development—for use in our potential study analysis.
- Xcel Energy and LBNL staff provided the base system EUIs and system savings.

3.1.2.2 Site-Level Information – CoreLogic

The key to DNV GL's market segmentation approach was to start with a data source that could provide site-level information on the required segmentation variables: building type, size in square feet, occupancy type, and building vintage. This information, often not tracked in utility billing data systems, and the resulting sample sizes from saturation studies often do not lend themselves to further market segmentation beyond building type.

As such, we started our analysis for each utility partner using data collected and developed by CoreLogic, a company that maintains a comprehensive database of property and related financial information.[32] This database provided building square footage by ZIP code and contained fields for vintage, and limited ownership information for all identified building types. We used this information to segment the market as requested for each utility partner, and to allocate total square footage to each sub-segment.

One caveat to using the information provided by CoreLogic for market segmentation is that data quality varies from state to state and county to county. While data requested for California buildings were available with an "office" building type identifier, several counties in other states only differentiated between "Commercial," "Industrial," and "Residential" buildings. Additionally, ownership information was limited to a degree that prevented any meaningful segmentation by that category using the CoreLogic data. For these reasons, we supplemented CoreLogic with the 2012 CBECS micro-data, described below.

3.1.2.3 2012 CBECS Data

The US Energy Information Administration recently released micro-data associated with the 2012 CBECS survey. This data contains records about individual commercial buildings from all 50 states, broken into census divisions. With these data we generated segments by geographic region, principal building activity, square footage, and vintage. We used the more detailed building-level information (e.g., average ceiling height, window to wall ratio, heating and cooling delivery systems, and presence of a building automation system) to cross-check the regional-level market segmentation developed using the CoreLogic and CSS/CEUS data.

3.1.3 Developing Square Footage and Consumption by Sub-Segment

One of the primary steps in the market segmentation process was developing total square footage and site numbers by building type, size category, ownership category, vintage category, and geographic/climate area for each of the key market segments defined above. Our initial attempt to calculate these numbers was based on the CoreLogic data acquired for relevant utility territories in California, Colorado, Illinois, and Minnesota; however, this data did not provide all necessary information, requiring integrating the CBECS 2012 micro-data. We used the CBECS to address three specific problems with the CoreLogic data:

- Missing ownership category
- Counties where buildings were categorized as "Commercial", instead of having a more detailed "Office" designation. This was an issue for Colorado, Illinois and Minnesota, but not for California
- Counties where a large number of buildings had square footage listed as zero

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[32] http://www.corelogic.com

To address the first problem, we calculated the percentage of buildings owned versus rented for each market segment based on the census division containing the relevant state. We then applied these percentages to the site number and square footage values taken from the CoreLogic data.

To address the second two problems, we took the following steps:

1. We calculated average and median CoreLogic building square footage numbers by the market segmentation categories.
2. Where missing square footage, we used the CBECS data to estimate the percentage of missing buildings that should be large or small within each market segmentation category.
3. We imputed square footage for the buildings missing square footage based on the median square footage for each of the non-missing segmentation categories
4. Where county data identified buildings as "Commercial" instead of "Office," we used CBECS to estimate and allocate the percentage of "Commercial" square feet assigned to office buildings.

After allocating the sites by market segment, we then aggregated this site-level information in order to calculate square footage by market segment.

LBNL provided energy consumption information for each base system under review. DNV GL reviewed these data against CEUS and other studies of savings potential information we have developed to ensure the saturation and savings information used for this analysis was reasonable.

The systems that are the subject of this analysis are described in detail in Appendix A.

3.2 Estimating the Technical, Economic, and Achievable Potential

To assess the achievable potential associated with system-level energy efficiency installations, DNV GL started by using a similar approach for estimating the technical and economic energy savings potential for stand-alone equipment.

However, because we consider system-level approaches as conceptual or emerging technologies, determining final achievable potential was more involved than conducting benefit/cost ratios and payback calculations. The final achievable potential developed for these systems were from data collected from interviews of subject matter experts.

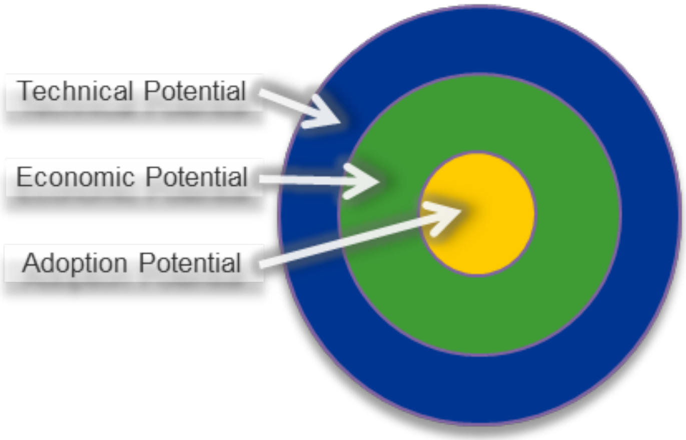
For technical and economic savings potential for each market segment and system, DNV GL used a bottom-up approach to processing building level data through our energy efficiency potential model, DSM Assyst. The analysis started with building data from CoreLogic for the targeted areas. We crosschecked these data against other publicly available data sets on commercial buildings, as described above. To determine the level of reasonableness for all regions of CoreLogic data, we analyzed the CBECS published by the US Energy Information Administration. For California we reviewed the Commercial CEUS developed by the California Energy Commission and the CSS developed by the California Public Utilities Commission.

Table 24 summarizes the types of potential we estimated, the source for each, and an overview of the relationship between these categories of potential. An illustration of this approach is in Figure 3-1.

Table 24. Sequence of potential categories

Category		Definition	Source
1	Technical potential	The complete penetration of all measure applications deemed technically feasible from an engineering perspective	DSM Assyst Modeling analysis
2	Economic potential	The technical potential of those energy conservation measures that are cost-effective when compared to supply-side alternatives	DSM Assyst Modeling analysis
3	Adoption potential	The amount of economic potential that could be achieved based on customers' likelihood to adopt the systems in response to specific marketing approaches and incentive levels.	Based on economic potential and results of expert interviews to determine adoption potential by system and market segment

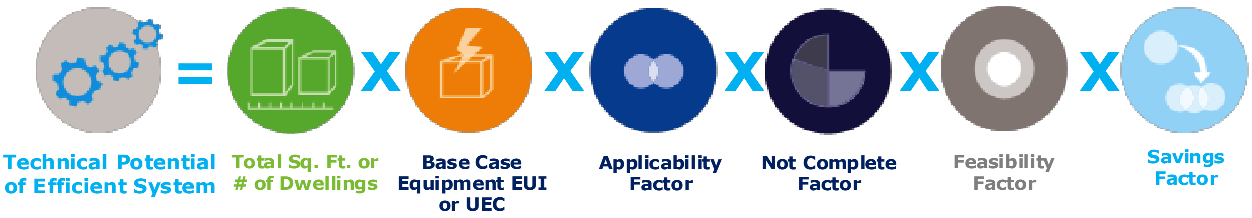
Figure 3-1. Relationship between economic, technical, and adoption potential



3.2.1 Technical Potential

As noted in Table 24, the analysis begins by estimating technical potential. Figure 3-2 shows a representation of the equation we used to estimate the technical potential for energy savings of the systems and market segments targeted in this study. Technical potential for peak demand reduction was calculated in a similar manner. Note that all elements of the equation are developed from inputs developed using the bottom-up data.

Figure 3-2. Technical potential estimation equation



Total square feet represent the total floor space for all buildings in the customer class.

Base-case equipment EUI (energy use intensity) or UEC (unit energy consumption) is the energy used per square foot by each base-case technology in each customer class. It is the energy consumption of the equipment being replaced, or affected by, the efficient technology.
Applicability factor is the fraction of the floor space that is applicable for the efficient technology in a given customer class.
Not complete factor is the fraction of applicable floor space not yet converted to the efficient measure. That is, one minus the fraction of floor space that already has the EE system installed.
Feasibility factor is the fraction of the applicable floor space that is technically feasible for conversion to the efficient technology from an engineering perspective.
Savings factor is the percent reduction in energy consumption resulting from application of the efficient technology. We utilize the percent savings applied to base energy use to ensure our savings estimates are correctly proportional to load.

3.2.2 Economic Potential

DNV GL estimated economic potential by identifying which measures and market segment combinations are cost effective. Cost effectiveness of energy efficiency projects is evaluated several ways. Customers evaluate investments in any capital equipment using simple or discounted payback calculations. Utilities evaluate potential programs based on their ability to generate positive values on four tests. These tests are:

Total resource cost (TRC): This compares the present value of avoided generation, transmission, and distribution against the present value costs to administer the program (excluding incentives) and the cost of the installed equipment. Equipment cost can be full or incremental to a baseline depending on the application (e.g., if the new equipment or system is replacing an active system (retrofit) or one that has failed (replace-on-burnout)).

Program administrator cost (PAC): This compares the present value of avoided generation, transmission, and distribution against the present value costs to administer the program, *including incentives*.

Participant cost (PC): This is the cost to the participant from participation in the program. Benefits are discounted bill savings and any rebates or other financial incentives. Costs are all related out of pocket expenses (equipment, disposal, additional operations and maintenance, any additional fuel costs, and customer time with program administration, if significant). This ratio very closely relates to discounted payback years.

Ratepayer impact measure (RIM): Expressed as a ratio, the RIM reflects the direction rates will change (via changes in utility revenues) due to the program. A RIM greater than 1.0 indicates that rates will go down because new utility revenues are greater than utility costs. In practical terms this ratio is net-present-value utility avoided costs divided by the sum of net-present-value customer bill savings, utility administrative costs, and utility incentives paid out.

Each utility assigns different levels of importance to these tests, but all start with the TRC. As a result, DNV GL used the TRC test to determine economic potential in the model. In other words, energy efficiency measures are cost-effective if they meet the minimum threshold set by the utility (e.g., a TRC greater than or equal to 1.0).

Using TRC as the threshold, we were able to estimate the square footage that provide the greatest potential for total savings and is cost-effective by program administrators. We use TRC instead of payback for one main reason: for utilities to claim savings for their efforts, they must demonstrate the degree to which they influenced the customer adoption decision and show that all customers benefit from the transfer of ratepayer funds to a few customers. A TRC greater than 1.0 is the first condition that needs to be satisfied. In contrast, if a project is deemed cost effective using payback measures, in theory the customer should elect to do this without intervention from a utility program. Any savings achieved by the utility might be deemed from free riders by regulators and the savings from these utility programs credit denied.

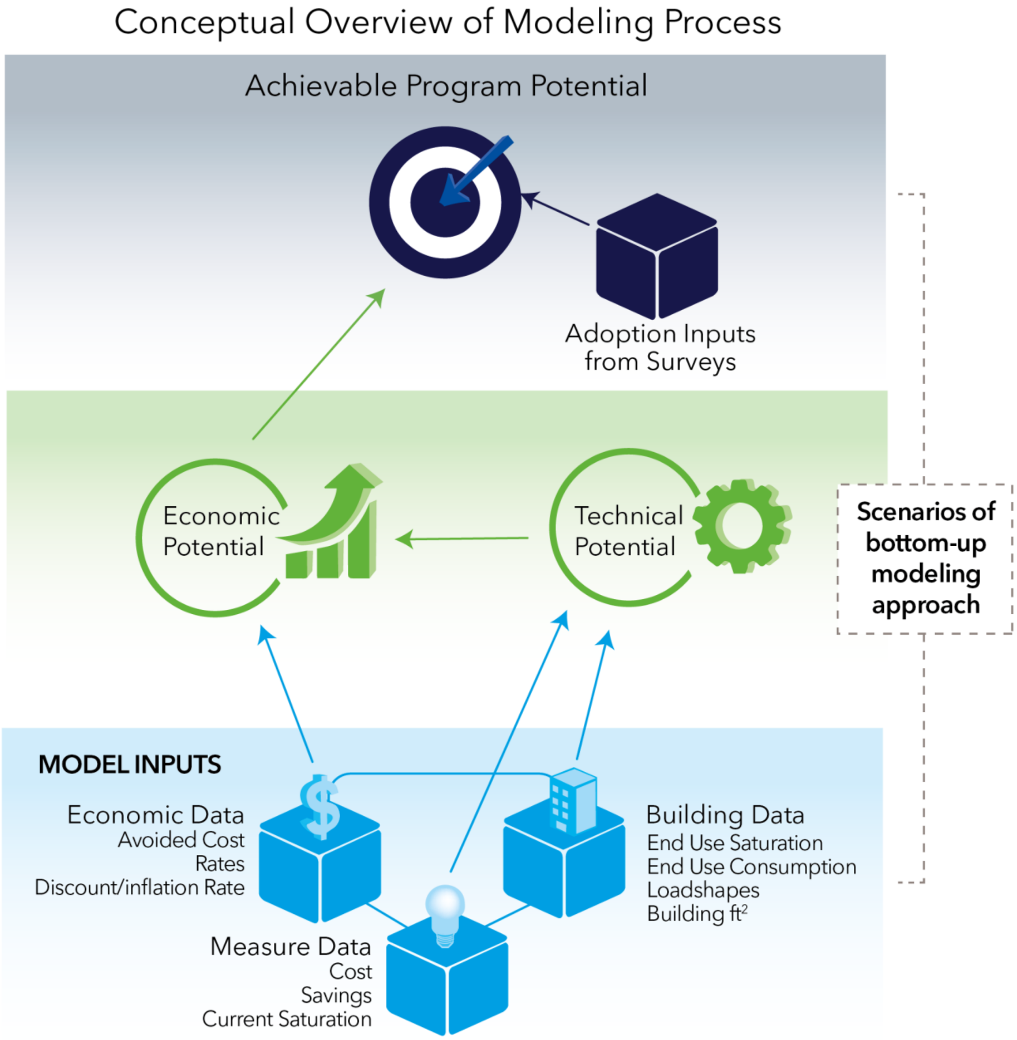
3.2.3 Achievable Potential

While the DSM Assyst model has a measure penetration module, the penetration curves in that module calibrate mainly to widget-based measures. Recalibration for system measures was not feasible due to data limitations. To compensate for this, DNV GL developed a penetration/adoption analysis that relied on expert judgment.

To develop adoption rates that vary by market segment and by program aggressiveness assumptions we used information developed from expert interviews. Programs can be used to increase customer awareness and the economic feasibility of the targeted systems two ways. They can fund awareness/education campaigns. They provide financial incentives for installations. They can do both simultaneously.

We applied the interview-derived adoption rates to the estimated economic potential to provide estimates of kW and kWh achievable potential expected under various intervention scenarios. Figure 3-3 provides a graphical representation of the modeling process.

Figure 3-3. Achievable potential overview



3.3 Interviews with Subject Matter Experts

DNV GL conducted two sets of interviews with subject matter experts to understand issues surrounding the adoption of energy-saving systems rather than individual components. As noted earlier, this information supported development of adoption curves for system-based measures; it also provided qualitative information about market opportunities and threats.

The first round of interviews included internal DNV GL experts from across the US who work with commercial customers and design lighting systems as part of program implementation. The second round targeted external experts on lighting system technologies. This included representatives from 13 market actor organizations: seven manufacturers/vendors, four solution providers, one architectural firm, and one market transformation organization. A listing of all interviewees is in Appendix B. The interview guide is in Appendix C.

Among the internal experts, there was no experience-based awareness of the specific systems described in the prep document. All were aware of the system concepts and had specific knowledge of advanced control systems for one end use only. For this reason, we changed the presentation of our question topic to "integrated control systems" and defined these as systems that control more than one end use with some degree of automation.

The in-depth interviews covered the following topics:

Respondent perspective: The role of the respondent, their experience in relevant fields, and their organization's position in the marketplace were used to gauge the reliability and accuracy of their opinions.

Current status of system approaches: Respondent estimates of the existing level of awareness of system approaches, their benefits, their penetration into the marketplace, and of programs promoting them were used to determine the baseline market acceptance and to inform the analysis of barriers and opportunities.

Benefits of Systems: Promoting energy efficiency solely for its own sake has proven limiting over time. System approaches are likely to provide benefits beyond energy savings that can inform program design, especially in terms of marketing and targeting promotion efforts.

Barriers and opportunities: A thorough understanding of the barriers to adoption facing market actors is essential for estimating the adoption potential over time and for the development of effective programs that support these systems.

Numerical estimate of adoption using three simple payback scenarios (two, five, and ten years): These estimates were the basis for the development of the numerical adoption curves used to estimate the adoption potential of system approaches.

Segmentation: The experience of the respondent pool promoting or selling these systems to their clients offered insight into the market sectors most and least likely to adopt them.

The project team developed the interview guide and administered it to the internal DNV GL expert pool. Interim results of this round of interviews were presented to LBNL for discussion. The guide was revised based on findings and refined direction from LBNL. The second round of interviews captured a range of market actors, primarily in the field of advanced lighting controls. A single DNV GL senior consultant administered these interviews. Interview duration ranged from 30 minutes to roughly 90 minutes, depending on the respondent's level of interest, knowledge, and involvement in the subject matter. The interview guide was adapted in real-time to respect respondent availability limitations and to reduce redundancy once clear trends developed for topics other than the core adoption questions.

3.3.1 Sample

The first round sample was pre-selected based on knowledge of DNV GL's organizational capability. We developed the second round sample using input from DNV GL staff and by on-line searches for additional vendors and manufacturers based on search terms such as "advanced lighting control," "building automation systems," and "energy management systems." In most cases, the survey respondents were discovered through a series of screening calls to the identified organization. Overall, we contacted thirty-eight individuals by telephone and/or electronic mail. Thirteen agreed to participate, for a response rate of approximately 34%.

3.3.2 Analysis

After the completion of the first round interviews, the DNV GL team performed a preliminary analysis and submitted the interim findings to LBNL for review.[33] We performed a second round of analysis after the completion of the second round interviews. This analysis consolidated the finding from both rounds of interviews. An overview of the processes for developing adoption curves and for analyzing, the qualitative responses, including TRC values are in the following sections.

The interview collected data points for hypothetical program years 2, 5, and 10 under three different scenarios of program effort, represented by simple project payback times of less than 1 year, less than 2 years but more than 1 year, and more than 2 years. Respondents were asked to consider the “eligible market” defined as that portion of the building stock that would undertake significant retrofits or renovations during a program year. It became clear from the responses however, that some respondents used the entire building stock as the reference point instead of the eligible market. Rather than attempting to calibrate the respondent during the interview, the DNV GL team decided to normalize the data as a separate step. The team normalized the data to both the unweighted average value (lower bound) and the analyst’s estimate (upper bound based on expert opinion) of the 10-year adoption potential for the eligible market. The point estimates at years 2, 5, and 10 became the reference points to develop annual estimates that roughly mirrored the S-shaped diffusion curves used to model market penetration of typical utility energy efficiency programs that offer financial incentives.

We aggregated Responses to qualitative questions, such as the respondents’ perspectives on barriers to adoption, by question and topic area and synthesized these into succinct findings. We reviewed the synthesized findings across question and topic area to check for consistency, and to identify trends in respondent answers. As the final step in the analysis for these factors, the DNV GL team distilled the salient points by topic; this information is in Section 4.4.

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[33] Submitted on 8/28/15 as “FirstRoundSummary150827.docx”

4 FINDINGS

4.1 Estimated Market Size

DNV GL determined the market size for the selected systems by estimating square feet. The technical and economic potential are reported in terms of energy savings, as described in Section 3.2. This section presents the findings from the analysis. Finally, all savings are reported in kWh for consistency.[34]

4.1.1 Technical Potential

Technical potential is the total savings possible from installation of these systems. The calculation of technical potential begins by identifying the total square feet available to install these systems. This step reduces total existing square feet by the area where the system is feasible and not installed already. For this analysis, we set feasibility and availability to 100%. We did not reduce available total square footage for two reasons. First, the target area was pre-selected for its feasibility. Second, we consider these systems as emerging and rarely present in the target markets.

The total square footage for these systems that is considered applicable, feasible, and not already installed for large and small facilities is reported in Table 25. Appendix E provides greater detail on the square feet of sub-segments.

Table 25. Total Square Feet Physically Available by Segment

State	Region	Building Type	Building Size	Square Feet
California	North	Office	Large	115,482,555
California	North	Office	Small	57,724,036
California	South	Office	Large	138,073,257
California	South	Office	Small	63,512,746
Colorado	Xcel	Office	Large	110,409,535
Colorado	Xcel	Office	Small	59,324,205
Illinois	ComEd	Education	Secondary	125,854,781
Illinois	ComEd	Education	Primary	4,014,785
Illinois	ComEd	Office	Large	120,473,777
Illinois	ComEd	Office	Small	58,060,881
Minnesota	Xcel	Office	Large	36,644,435
Minnesota	Xcel	Office	Small	28,970,902

Figure 4-1 presents the technical energy potential in kWh across regions for the different system packages. Technical potential for kW savings is presented in Figure 4-2. An important caveat is that these savings estimates are not additive. The model assumes the installation of only one system (Package 1 or

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[34] 1.0 million kWh is equal to 1.0 GWh.

Package 2) across all the available square footage in each segment. In reality, a combination of these two systems is more likely. In addition, the kWh and kW potential presented in these charts applies to both the replace-on-burnout (ROB) and retrofit early-retirement (RET) scenarios.

Figure 4-1: Technical potential in kWh

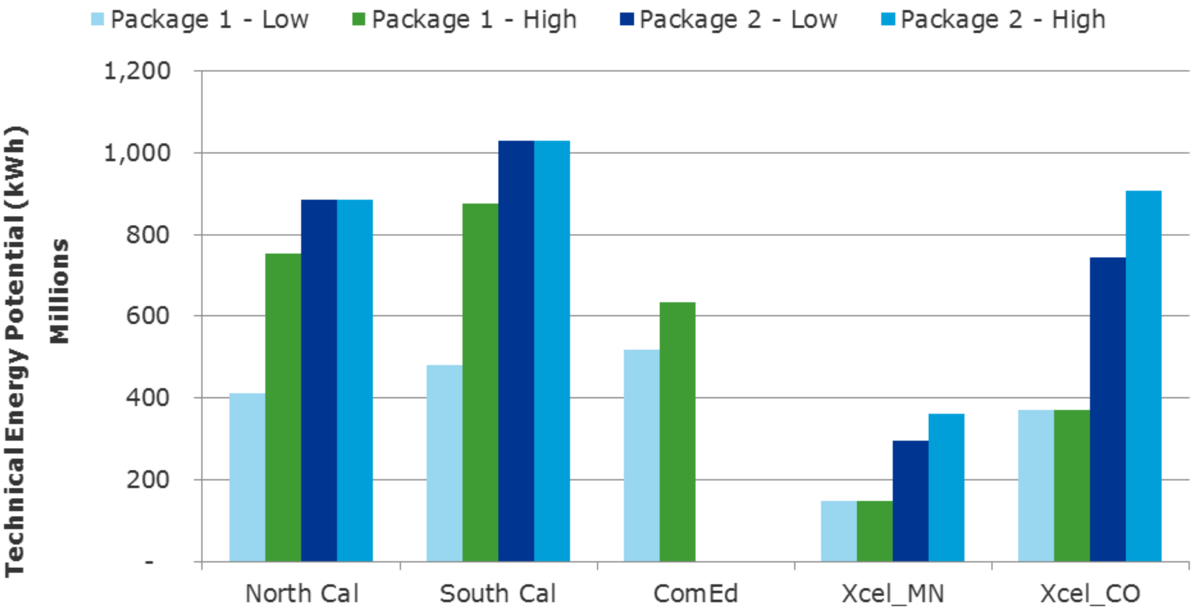
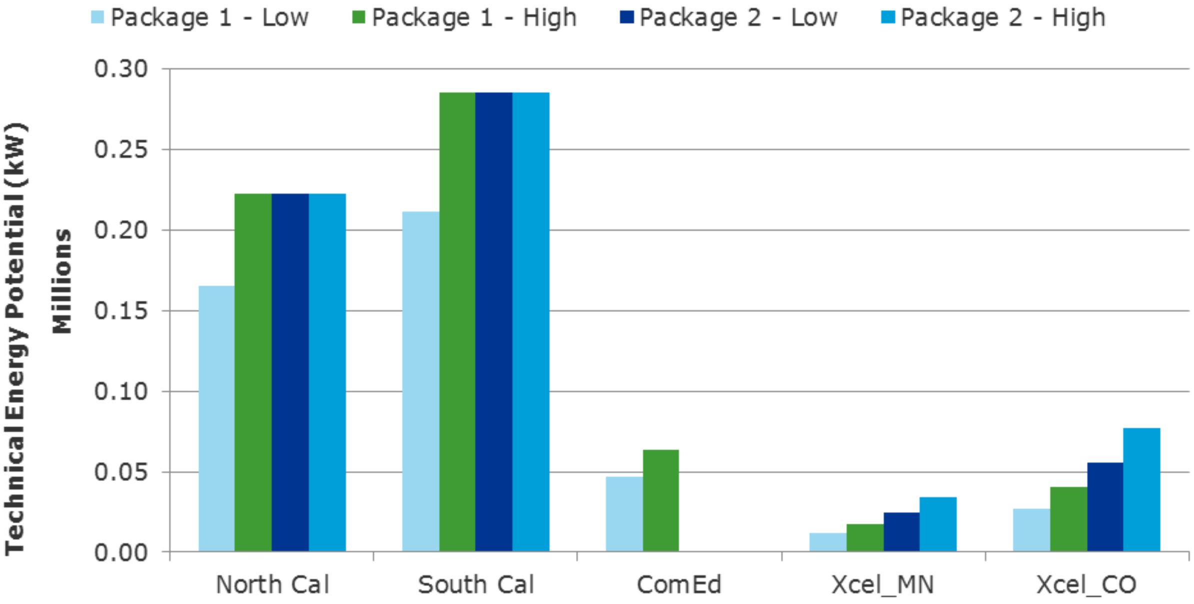


Figure 4-2: Technical potential in kW



The square feet available remain the same in each region and for each package. The potential kWh and kW savings represent the range of savings associated with each package. For example Package 2 for California provides the same energy savings but at two different costs. The result is that the Package 2 (High and Low cost) savings potential is the same.

As noted earlier, a critical interpretation of this savings potential graph is that Package 1 and Package 2 are not additive. Each package applies to the same physical square feet. Another way to interpret this is that Package 2 - High represents the maximum technical savings potential and Package 1 - Low represents the minimum technical savings potential for these systems.

4.1.2 Economic Potential

DNV GL estimated the amount of square footage that is economically viable from the utility's perspective using the TRC discussed earlier. When TRC for an integrated lighting system was greater than or equal to 1.0 the applicable square footage became part of the economic potential. Since market segments were narrowly defined and there are no competing technologies as part of this analysis, if a system was economically viable the economic potential was equal to the technical potential.

In both the RET and ROB scenarios economic potential is from the perspective of the utility. A system is considered cost-effective if the TRC ratio is greater than or equal to 1.0. In utility 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 17 and Table 18.

Table 26: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.04	1.13	1.98	1.19
Southern California	1.11	1.23	2.17	1.28
ComEd	0.28	0.25	NA	NA
Xcel Colorado	0.79	1.09	0.68	1.09
Xcel Minnesota	0.28	0.37	0.24	0.36

Table 27: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.42	1.35	2.38	1.32
Southern California	1.54	1.48	2.63	1.43
ComEd	0.53	0.44	NA	NA
Xcel Colorado	1.15	1.59	0.78	1.25
Xcel Minnesota	0.40	0.54	0.27	0.42

When we defined Economic Potential in section 3.2.2 the definition of TRC included the costs to administer the program. For this analysis, we included a program administration cost of 10 cents per kWh.[35] This cost is a DNV GL estimate of typical program costs across the country and was held constant across all utility partners. We included an estimate of program cost to provide a more inclusive cost effectiveness value. Actual utility administrative costs for a systems based program will vary. Without

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[35] This value can be adjusted in the Excel workbook model.

streamlined assessment tools to target buildings, more efficiently these costs may be greater than widget based programs due to the complex nature of selling and incentivizing systems compared to widgets.

4.1.2.1 Scenarios

The next step is to identify the amount of whole building square feet where the TRC value is 1.0 or higher and where installation of integrated systems is feasible. To understand the extent and type of opportunity available the TRC calculation uses two costing scenarios. The first scenario is a retrofit situation (RET). The second scenario is a replace on burnout scenario (ROB). We noted earlier that this analysis does not include competing systems. Where TRC is equal to or greater than 1.0, economic square feet are equal to technical square feet.

Table 28. Whole Building Square Feet Available and Considered Cost Effective

State	Region	Building Type	Size	Square Feet - RET	Square Feet - ROB
California	North	Office	Large	115,482,555	115,482,555
California	North	Office	Small	57,724,036	57,724,036
California	South	Office	Large	138,073,257	138,073,257
California	South	Office	Small	63,512,746	63,512,746
Colorado	Xcel	Office	Large	110,409,535	110,409,535
Colorado	Xcel	Office	Small	59,324,205	59,324,205
Illinois	ComEd	Education	Large	-	-
Illinois	ComEd	Education	Small	-	-
Illinois	ComEd	Office	Large	-	-
Illinois	ComEd	Office	Small	-	-
Minnesota	Xcel	Office	Large	-	-
Minnesota	Xcel	Office	Small	-	-

Even though the available square feet may be the same, energy savings under each scenario is different. Interestingly, less available square feet does not guarantee less economic potential. A much higher economic potential could exist for ROB than RET due to the lower incremental ROB cost. As a result, the difference in economic potential could be great enough to offset the availability of the square feet.

The amount of cost effective square feet available is shown in Table 28. Economic potential (kWh savings) for RET is shown in Figure 4-3.The economic potential for ROB is illustrated in Figure 4-4.

Figure 4-3 presents the economic energy potential in kWh at the whole building level across segments and different system packages under a RET full cost scenario. The ROB incremental-cost scenario is shown in Figure 4-4. Again, these savings estimates are not additive. The assumption selection and installation will be for one system package only across all of the available square footage for each segment.

Figure 4-3: Economic potential kWh (RET)

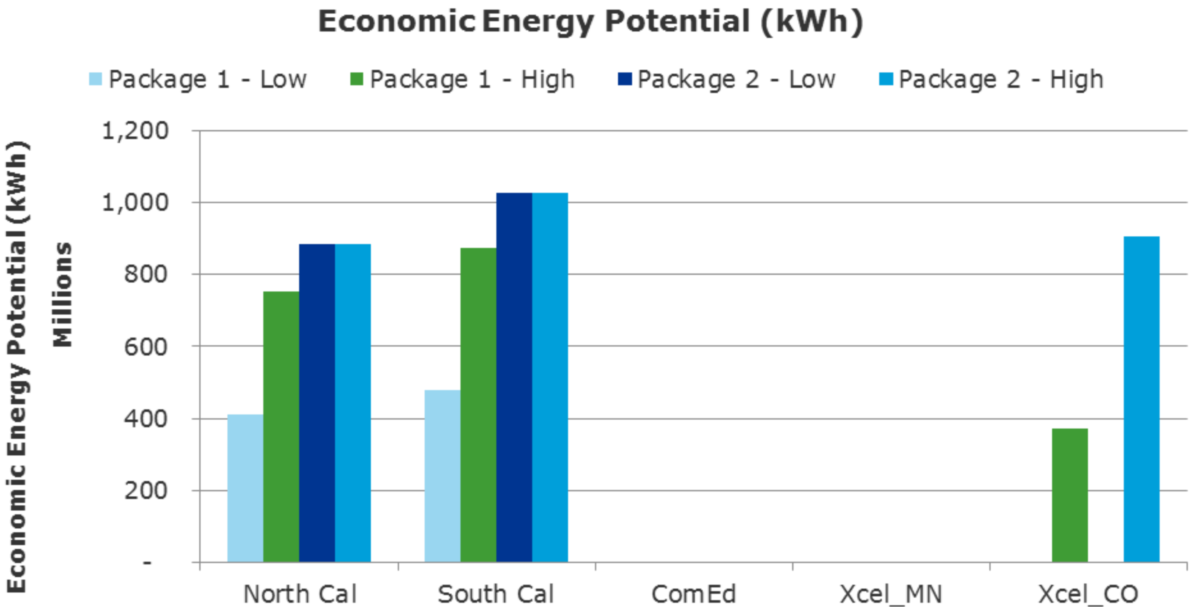
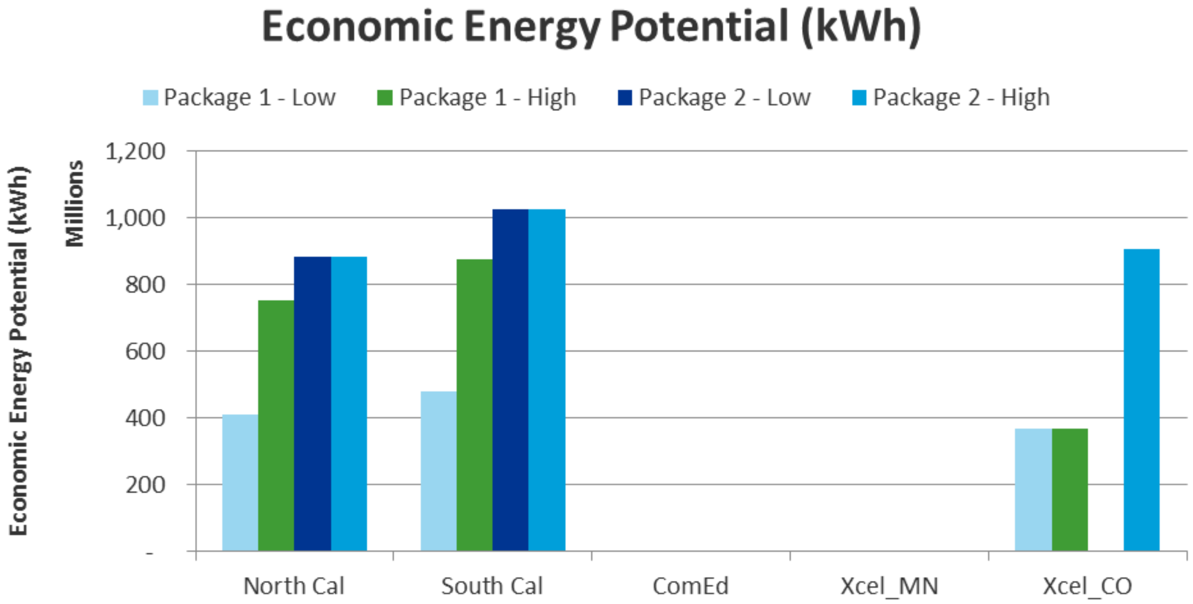


Figure 4-4: Economic potential kWh (ROB)



For the graphs it is easy to see that in California these systems are considered cost effective for both the RET and ROB scenarios. Similarly, Package 1 and 2 are economically viable for Xcel Colorado, but not Xcel Minnesota. The ComEd package was not cost effective for any segm7ents.

4.2 System Achievable Potential

Once technical and economic potential are identified, the next step to calculating energy savings is determining how much of the economically viable square footage would adopt these systems (vs widgets) and the period this is expected to occur. In this section, we develop the adoption curves and present the savings potential at year 10 of a program.

When estimating achievable potential, RET and ROB scenarios are treated differently. A retrofit application implies the replacement of functioning equipment. All applicable square footage is available each year since a retrofit can be performed at any time. For ROB scenarios, the equipment must fail before initiating a replacement. Failure can occur for any reason, but our assumption is that equipment is at the end of its useful life. In this analysis, we apply the estimated system life of 15 years to develop applicable square footage estimates. The implication is that in these ROB scenarios only 1/15 of the available square footage is available to install an integrated system in any given year.

In this study, we consider the systems as an "emerging technology." As used here, "emerging technology" refers to the fact that systems installations are a new way of approaching building operations and are not a common market practice. As such, there is little or no historical data to incorporate into an estimate of future adoption. To compensate for this lack of market data, criteria and thresholds for adoption were determined through interviews with experienced program implementers, lighting designers, vendors, and manufacturers with familiarity of regional and national markets. Through these interviews, DNV GL generated a set of adoption curves and applied these to the economic potential developed use the DSM Assyst model, as discussed in Section 3.2.3.

4.2.1 Adoption Curves

Adoption curves were generated using responses collected in interviews with subject matter experts. Table 29 and Table 30 show market adoption of systems under different customer simple payback scenarios. Since this estimated curve is from interviews, we provide the upper and lower bounds. A key observation is that when payback is two years or more, customer adoption drops off dramatically, reaching somewhere between 13% and 20% over a 10-year period where Y1 is the first year of program implementation and Y10 is the tenth year.

Simple payback greater than 2 years is the proxy for any payback greater than 2 years. In our interviews, we also asked respondents for estimates at 5 and 10 years. The consensus was that adoption begins to decrease as payback approaches 2 years and drops significantly for any time greater than 3 years.

Table 29. Cumulative achievable market penetration (upper bound)

Payback	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
≤ 1 yr	1%	4%	7%	10%	15%	20%	25%	31%	37%	43%
≤ 2 yr	1%	2%	4%	7%	10%	14%	18%	23%	28%	33%
> 2 yr	0%	1%	2%	4%	5%	8%	10%	13%	17%	20%

Table 30. Cumulative achievable market penetration (lower bound)

Payback	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
≤ 1 yr	1%	3%	5%	7%	10%	14%	18%	22%	26%	30%
≤ 2 yr	1%	2%	3%	5%	7%	10%	13%	16%	20%	24%
> 2 yr	0%	1%	1%	2%	4%	5%	7%	9%	11%	13%

4.3 Energy Savings Achievable Potential

Energy savings is calculated by multiplying the energy saved per square foot for each system by the square feet of interest. For example, calculating the energy savings possible from the technical potential provides an upper possible bound of potential savings, but does not necessarily provide a realistic estimate of the savings that will be achieved by a utility program or even market forces. Similarly, economic potential provides an estimate of total savings considered economically viable, but does not provide information on what is likely to be achieved.

There are no historical data to calibrate the adoption of these systems to utility programs or market activity. The systems by themselves (with no utility incentives) have a simple payback ranging from a low of 5.4 years in to a high of 22 years under a RET scenario. This range is driven by the combination of estimated bill saving and the installed equipment cost. DNV GL estimated cumulative potential annual energy savings for each system package using the middle payback estimate of greater than 1 year, but less than or equal to a two-year payback scenario. We chose the customer's simple payback instead of discounted payback as the criteria for adoption. We understand that customers that are more sophisticated or those contemplating projects requiring large capital amounts may use discounted payback as adoption criteria. Simple payback however is a common metric used by most businesses to screen and adopt capital expenditures. It also represents a more conservative view of payback and therefore will not overstate system adoption. We applied there adoption factors to the economic potential developed in the prior step.

This analysis includes multiple combinations of system savings and cost estimates (high/low), building size (small/large), vintage (old/new), ownership (rent/own) and situation (RET/ROB). DNV GL ran each of these scenarios through its DSM Assyst model. To allow LBNL to develop customized scenarios we developed an interactive scenario tool for use in future analysis[36].

In this report, we walk through two sets of output from this tool. Although we forecast savings under RET and ROB scenarios using three simple payback periods, the results reported here are from the middle period (≤ 2 years) where payback is greater than 1 year and less than or equal to 2 years. In other words, this assumes that through a combination of decreasing costs of integrated systems and utility rebates the customer's simple payback is about 2 years. The RET scenario is presented first and is followed by the ROB scenario.

4.3.1 RET

A retrofit application implies the replacement of functioning equipment. Each successive adoption year shows the cumulative total savings for that year (i.e. in year two, total adoption includes installed square feet from year 1 plus installed square feet from year 2). This section provides the 10-year cumulative lower achievable bound (LAB) and upper achievable bound (UAB) energy savings for each package reviewed for each utility partner. Where systems are cost effective across service territories the cumulative savings are more a function of available square feet than differences in markets at the regional level.

Achievable potential in all office buildings for Northern and Southern California is shown in Figure 4-5 and Figure 4-6 respectively. The savings for both configurations of Package 2 are the same because the high and low packages differ by cost and not by savings per square foot.

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[36] The DNV GL Potential Studies Evaluation Tool is a Microsoft Excel workbook

Figure 4-5: Northern California office RET lower and upper achievable kWh

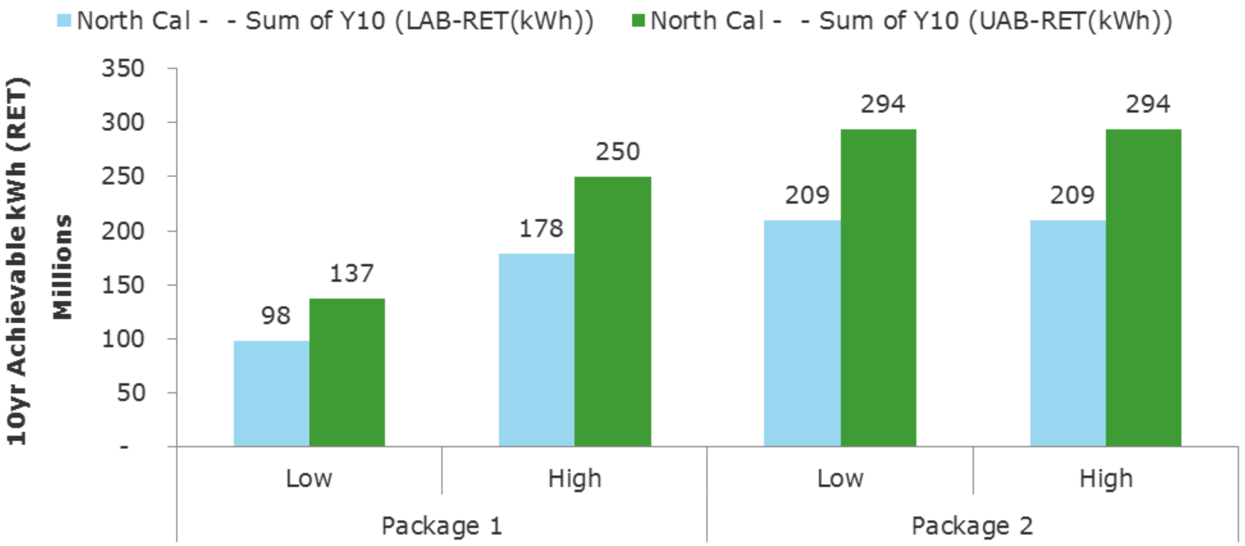
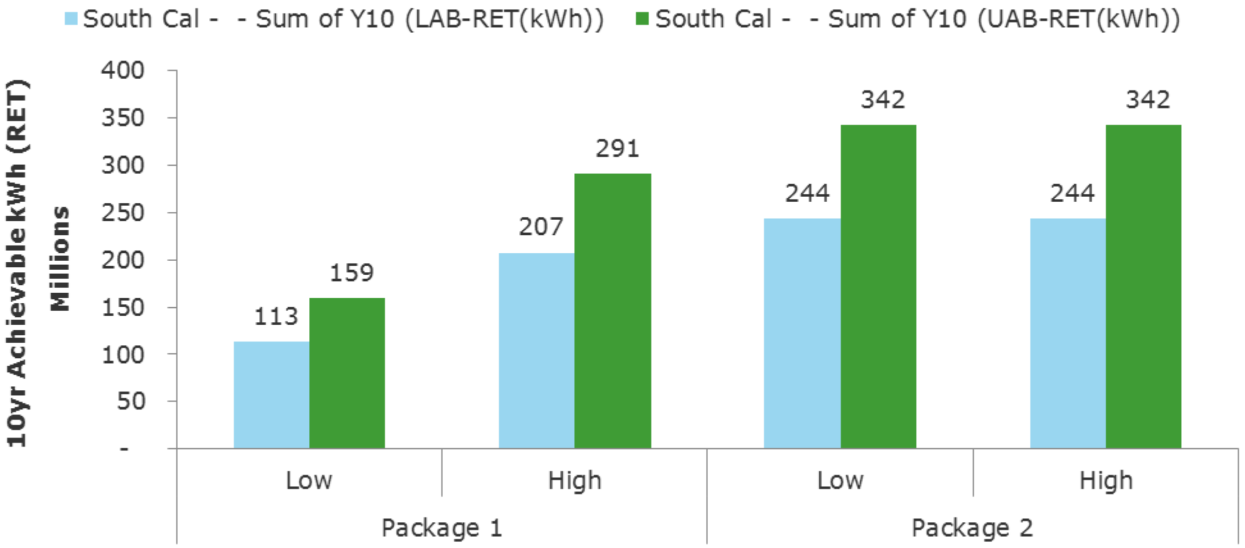


Figure 4-6: Southern California office RET lower and upper achievable kWh



Graphs of the adoption curves for Northern and Southern California are presented in Figure 4-7 and Figure 4-8.

Figure 4-7: Adoption curves for Northern California (kWh RET)

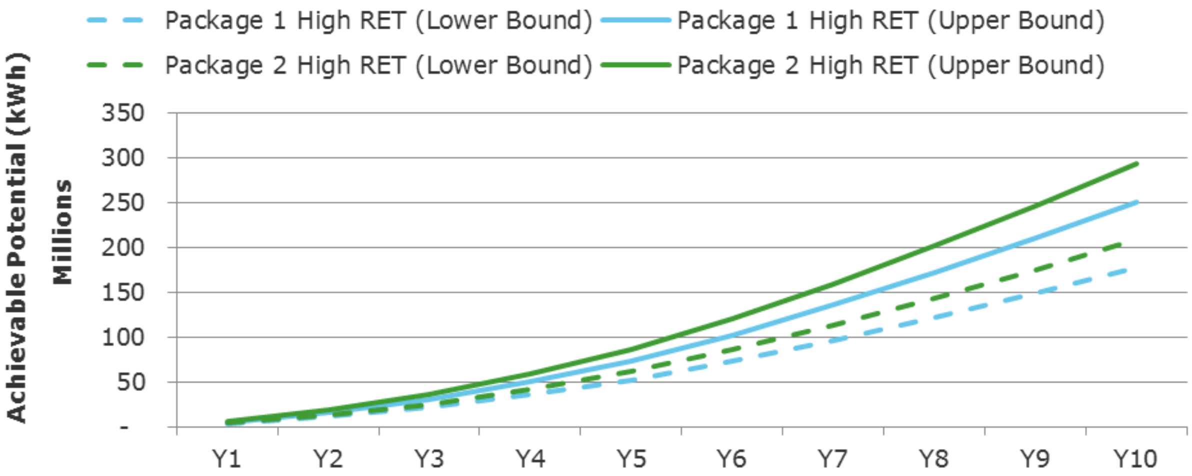
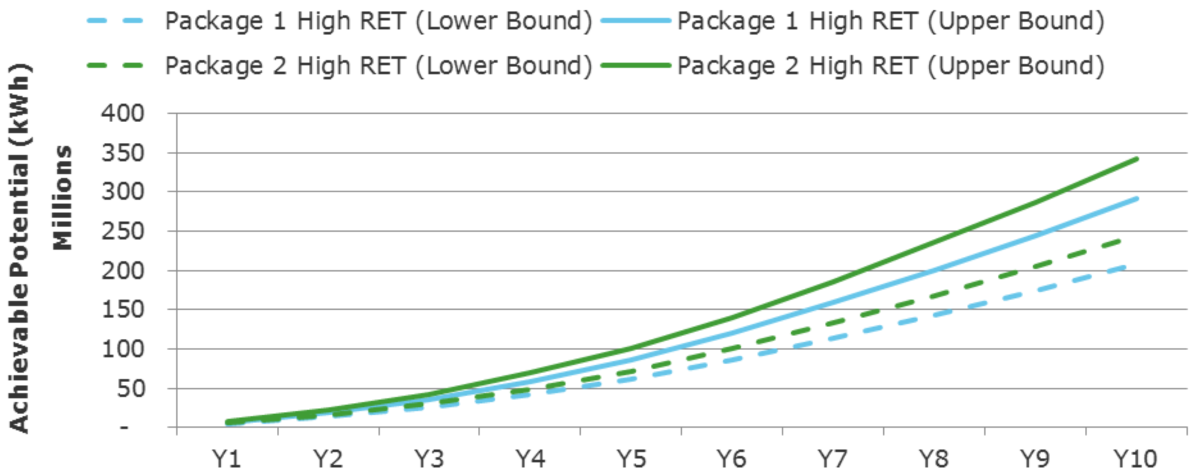


Figure 4-8: Adoption curves for Southern California (kWh RET)

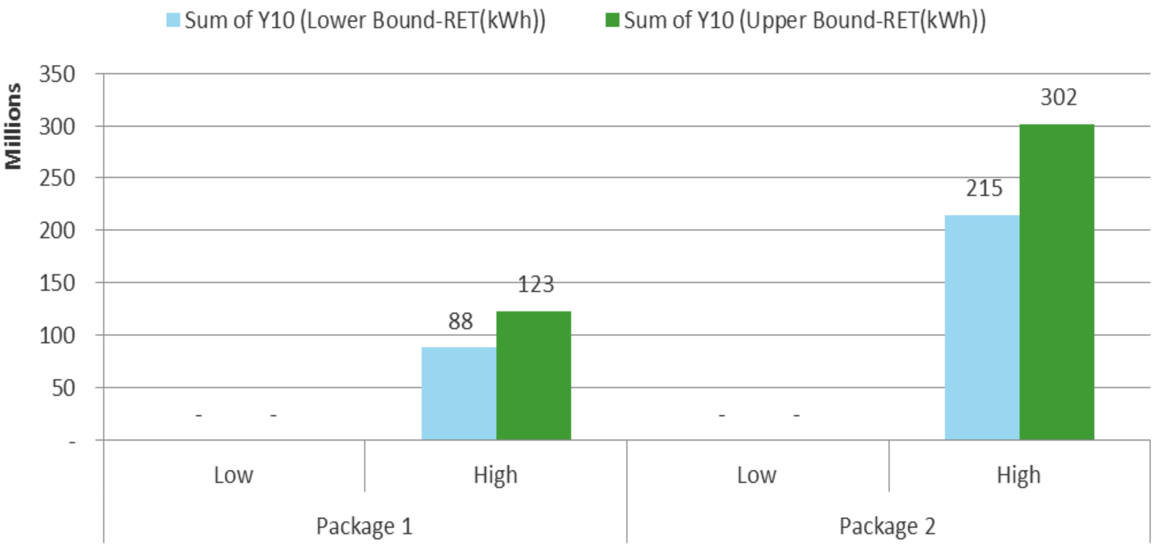


One interesting point shown in these graphs is that the potential exists for Package 1 (at the upper achievable bound) to save more energy than Package 2 (at the lower achievable bound).

No charts or graphs in this section for the ComEd service territory. These systems are not cost effective in a retrofit scenario for neither educational facilities nor small or large office buildings. For packages that are not cost effective using TRC criteria, we assume these systems are not offered as part of a program and no savings will result. See appendix I for ComEd scenarios with TRC criteria of zero.

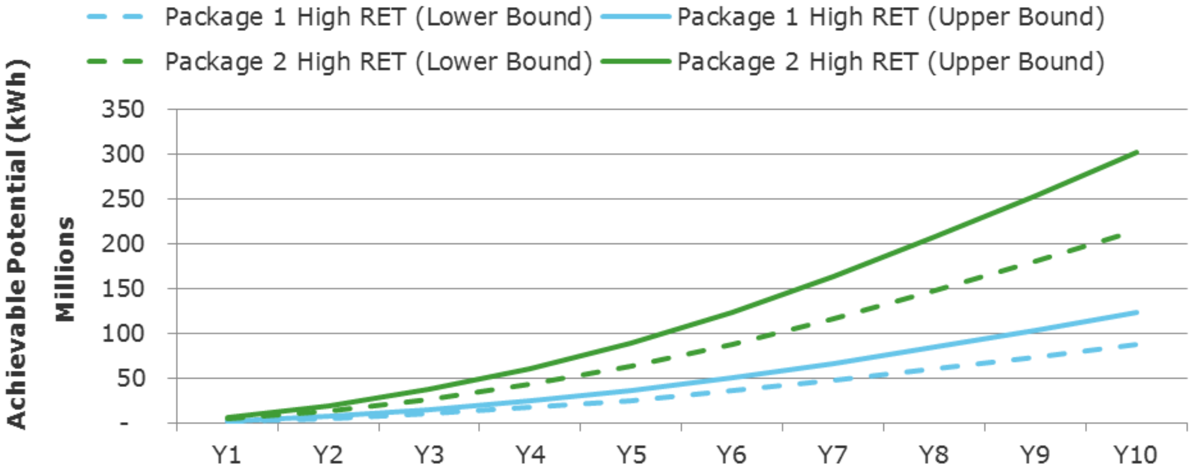
The next chart (Figure 4-9) show potential savings for office building in Xcel Colorado's service territory.

Figure 4-9: Xcel Colorado office RET lower and upper achievable kWh



For Xcel Colorado, the low cost low savings versions of package 1 and 2 package are not cost effective and therefore, show zero savings. The reason the high package is cost effective and the low package is not is due to the relationship between costs and savings. In package 2, a higher system energy savings offsets the high system cost. In package 1, the savings from the system is not sufficient to offset the cost of the system. The adoption curves for Package 1 and 2 (high) are shown in Figure 4-10. This graph illustrates the fact that even at lower market adoption rate Package 2 possesses more potential for savings than Package 1.

Figure 4-10:Xcel Colorado adoption curves (kWh RET)



No chart or graph is presented for Xcel Minnesota. In this service territory, neither package 1 nor package 2 met the TRC cost effectiveness threshold. TRC was the first filter for assessing utility program achievable potential. When a program is evaluated as not cost effective the assumption is that the utility will not implement the program and so, no savings will be achieved. See appendix I for Xcel scenarios with TRC criteria of zero.

4.3.2 ROB

Energy savings potential under a ROB scenario is always lower than a retrofit scenario due to the availability of applicable square footage. For ROB, the equipment must fail before initiating replacement. Failure can be for any reason, but for purposes of forecasting the assumption is that equipment is at the end of its useful life. In this analysis we apply an estimated life for the base widgets of 15 years and use this to develop the applicable square footage estimates by year. The implication is that in these ROB scenarios only 1/15 of the available square footage comes available to install an integrated system in any given year. The reported savings represent the cumulative savings for a particular year.

While there may be less square footage available in any given year, ROB scenarios typically have higher TRC values than RET scenarios because with ROB only the incremental cost of the system over a base widget is factored into the TRC test. In RET scenarios use the full cost of the equipment because there is no requirement to install replacement equipment.

Figure 4-11: Northern California office ROB lower and upper achievable kWh

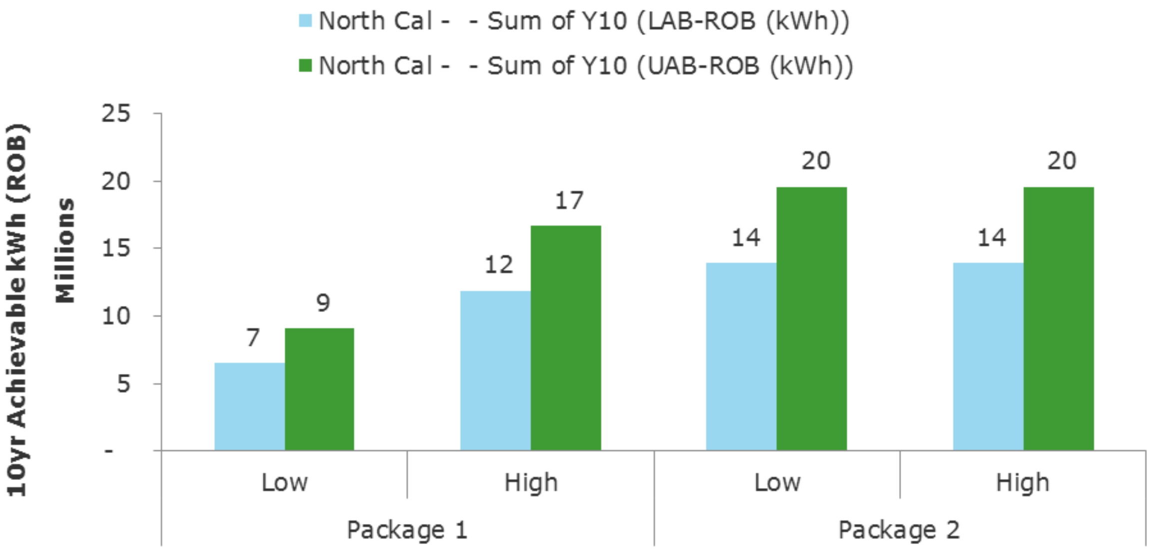
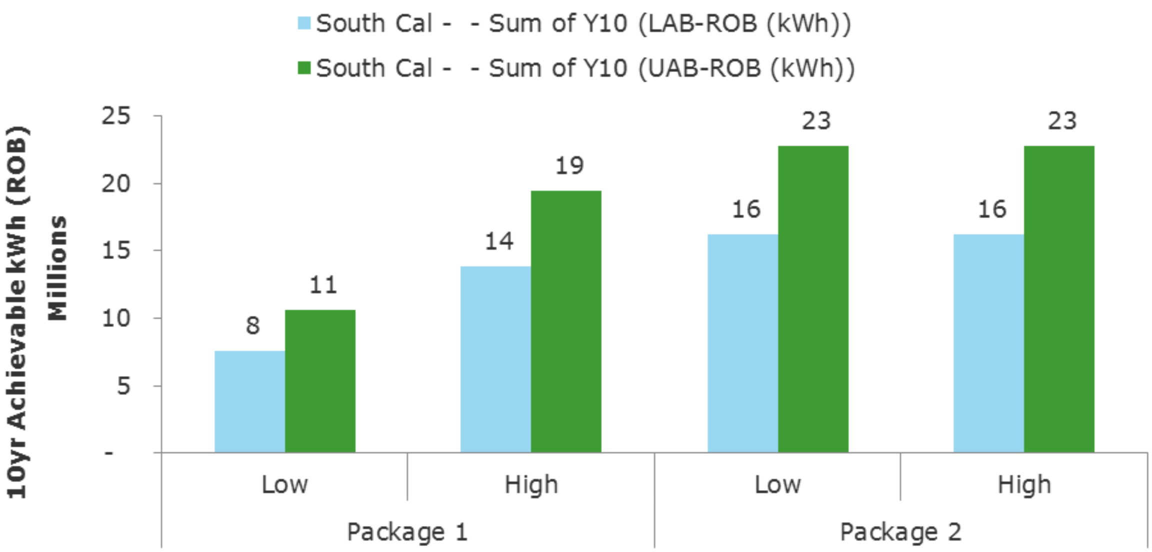
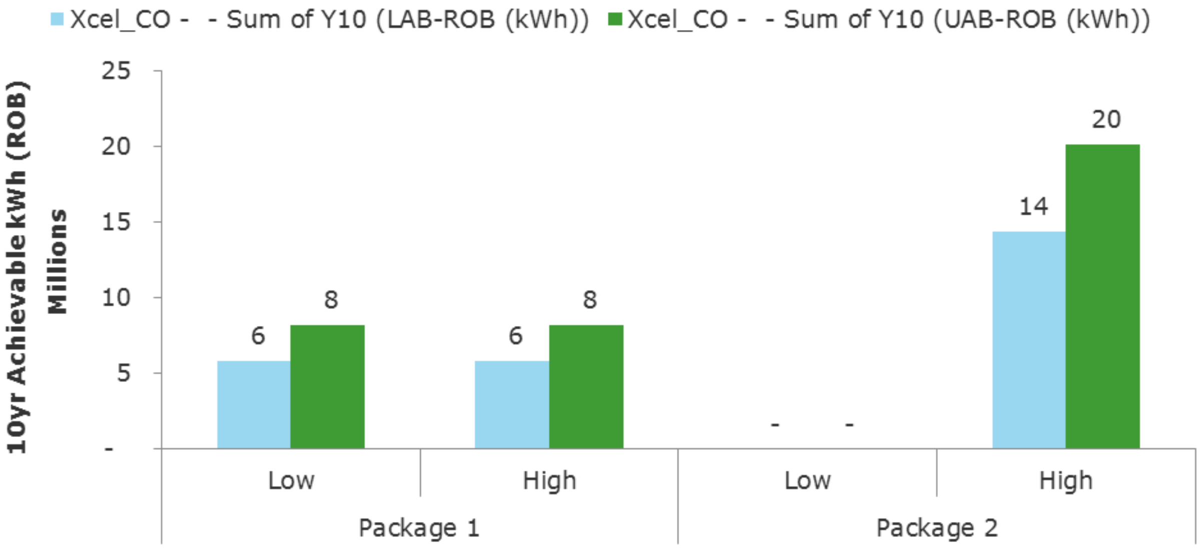


Figure 4-12: Southern California office ROB lower and upper achievable kWh



Similar to the RET scenario no chart for achievable potential is presented here for ComEd. In this service territory package 1 did not meet the TRC cost effectiveness threshold under the ROB scenario given ComEd's low avoided costs.[37] Again, when a program is evaluated as not cost effective the assumption is that the utility will not implement the program and so, no savings will be achieved. Utilities may offer programs not passing the TRC ration test for other strategic reasons. Appendix I includes estimates of savings potential for these types of programs.

Figure 4-13: Xcel office ROB lower and upper achievable kWh



Similar to the RET scenario no chart is presented for Xcel Minnesota. In this service territory neither package 1 nor package 2 met the TRC cost effectiveness threshold under the ROB scenario. When a

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[37] Incremental costs for the systems are shown in Appendix D. They are the difference between the widget costs and the system full cost

program is evaluated as not cost effective the assumption is that the utility will not implement the program and so, no savings will be achieved.

4.4 Market Perspectives

This section summarizes the findings of the expert interviews conducted for this study. The findings should be considered within the context of the following key points.

With a few exceptions, the promotion of systems approaches to energy efficiency is not widespread in the marketplace. Based on the first round of interviews, the research team decided to focus on "intelligent control systems," a generic term that incorporates advanced lighting controls (ALC) and advanced building automation systems (A-BAS), as a proxy for system approaches. These technologies interact with at least one typical "widget" measure, are an essential component of systems approaches, and in general are familiar to market actors. The key difference is that A-BAS systems are more likely to be enterprise wide, while ALCs may be site specific.

In general, responses related to adoption potential, awareness, barriers, and other key indices were closely aligned, regardless of whether the expert was associated with the ALC or A-BAS space.

The most significant difference related to the payback period. Stakeholders in the A-BAS space perceived customer tolerance for a higher payback threshold (~5 years) than those in the ALC space (~2 years). This difference is attributable to the differences in complexity, cost, sophistication of potential customers, and benefits between A-BAS and ALC installations.

As the market currently operates, opportunities to install intelligent control systems, for the most part, do not exist except in new construction or in cases of substantial building alterations of the controlled measures.

4.4.1 Awareness

Most respondents differentiated between awareness of the existence of intelligent control systems, which was seen as generally high, and a solid understanding of the potential benefits of these systems, which was generally considered low.

Awareness is "horrendous - low, low. Less than 5% (of the potential end-users are) aware of true capability."

"In general everyone is familiar … but not aware of everything they (these systems) can do."

The respondents perceived that design professionals are aware of these systems, but are unable to present a strong value proposition in a convincing manner. They highlighted significant gaps in general market awareness regarding the benefits of these systems and of third-party validation of system performance.

4.4.2 Penetration

Respondents were asked to estimate the portion of new C&I construction and the portion of existing buildings that would have intelligent control systems installed in the next year. For new construction, the answer varied by context, with Title 24 building codes in California substantially increasing expected adoption for new construction. The continuum of what constitutes an "intelligent control system" was also an issue in this discussion.

"Maybe 20%-30% in California due to Title 24, the rest of the country 5%"

"Less than 1% of buildings built if you exclude motion sensors"

The highest estimate for installation of intelligent control systems in new construction over the next year was 30%, with low estimates in the single digits.

Respondents expected even fewer installations of these systems in existing buildings than in new construction, with a high estimate of 5% of the eligible market and a low estimate of 0.5% or less. The Design Lights Consortium (DLC) estimates that advanced lighting controls are present in less than 3% of all C&I buildings. A review undertaken by the DLC of data from four efficiency programs found advanced network controls in less than 1% of all lighting retrofit projects.

The respondent pool mentioned a few energy efficiency programs that provide incentives for the incorporation of intelligent control systems in measure- level projects (e.g., layering advanced lighting controls onto LED re-lamping projects). Multiple respondents mentioned Eversource in Massachusetts & Connecticut, AEP Ohio, and Consumers Energy of Michigan in this regard. Most respondents differentiated the following market sectors in terms of awareness and adoption:

For California, Title 24 was mentioned frequently as a driver toward intelligent controls.

Other markets in the Northeast and Northwest are moving toward intelligent controls or system approaches.

The municipal-university-school- hospital sectors, as well as geographically diverse organizations with significant space requirements (e.g., some chain stores), have higher adoption rates than many of the other sectors.

Warehouses, large industrial spaces, and parking garages have been relatively receptive to advanced lighting controls due to high savings potential and the possibility of capturing non-energy impacts.

4.4.3 Barriers

Intelligent control systems face the following barriers to adoption, according to respondents:

- Cost. These systems have a relatively high entry cost in terms of basic assets required for implementation. These assets include the processing unit, control interface, and network capability.
- Uncertainty of benefits. The benefits of these assets are not susceptible to estimation on a per-unit basis, vary greatly depending on facility and control strategy, may include a substantial portion of non-energy benefits, and are not easily calculated. The respondents actually found this to be the greatest barrier, as shown by the representative quotes below:
- “Biggest barrier is the perception that there are not savings from controls, there is not a need for intelligence. The education gap is the first biggest barrier to adoption.”
- “Perception is the greatest barrier, the high level perception that controls are bells & whistles, which is an industry self-inflicted wound.”
- “We can't project the savings, once you have information that intelligent control systems can develop, you can really save.”
- Complexity. These systems are more complex. They require thorough and ongoing commissioning and user education. Contractors in are often not knowledgeable about them. These factors lead to less than optimal user experiences and resistance in the supply chain. In the words of one respondent, control systems “Have a stigma among contractors, they don’t have familiarity with them, they add tremendous padding to the labor price on installation, which is a huge barrier to entry.”
- Operational disruption. Installation of a facility-wide system may be more disruptive than the installation of widgets, especially in cases were wired networks are necessary. Wireless networked systems are significantly reducing this difference and are increasing in availability.
- Absence of unified standards. Intelligent controls system manufacturers have yet to settle on a consistent standard. There are some standards that many systems can use, such as BACnet, a data communication protocol for building automation systems. However, inter-operability, plug-and-play functionality, and the ability to swap out components based on availability or preference is still lacking.

- Perverse incentives. A decision maker driven by short-term financial considerations comparing the payback of a widget-based project (e.g., LED retrofit) with that of a system-based project (e.g., LED retrofit and intelligent control system) will see a substantially longer payback for the system, even though the total return on investment of the latter might be many times greater. Utility programs typically provide incentives favoring the short-term certainty that component replacement provides.

The first cost of intelligent control systems is undoubtedly a barrier. However, in the view of the respondents to this research effort, it is not the greatest barrier. The greatest barrier is the absence of information and education about the already-realized potential of these systems to save energy and to provide other ancillary benefits.

4.4.4 Opportunities

According to respondents, intelligent controls systems have a substantially greater return on investment than simple widget-based projects. Respondents reported energy savings of approximately 85% or greater due to the installation of advanced lighting controls. They also noted non-energy benefits from these systems, such as increased operational control, enhanced occupant satisfaction, space utilization optimization, reduced maintenance/outage costs, and real-time measurement and verification of system performance. In their opinion, the full potential of these systems has been neither fully explored nor fully documented. Below are the benefits noted by respondents:

- "The biggest thing is the quality, not so much the quantity of light, the ability to improve quality of light and improve spaces for inhabitants."
- "The short timer settings on occupancy sensors drive people nuts. Intelligent systems are controllable and rampable."
- "Maintenance reductions, less down time, less wear and tear, being proactive with facility."
- "There are tons of other benefits (of ALCs) that are hard to quantify, inter-operability with building management systems, benefits in classroom or office on productivity, hospitals (improve) circadian rhythm for better sleep, LEED points for control of light levels."
- "An entire new value stream (from A-BAS) is available when buildings become active nodes on the grid, essentially (they become) dispatchable."

Respondents suggested program interventions to overcome the barriers noted above. We grouped the suggested intervention strategies into three major categories: information, education, and appropriate support.

Information. Information developed by utilities and other independent third-party organizations would help overcome the uncertainty barrier. This information could include a comprehensive database of case studies across a wide variety of market segments, quantification of a variety of non-energy benefits, and the establishment of objective standards like the DLCs Commercial Advanced Lighting Controls Networked Lighting Controls Specification. These efforts could increase certainty and credibility.

- "Relevant industry case studies. Garner the whole value of energy savings and functional benefits."
- "Third party verified case studies would help."
- "The real market challenge is having trusted resource on the site."

Education and training. The respondents felt that education was sorely lacking across the stakeholder chain. They noted that manufacturer representatives who have intelligent controls systems in their product lines might not be aware of them, that contractors do not have sufficient knowledge to successfully install them, and that users may not preserve the knowledge necessary to operate them. This is on top of the low awareness of the full range of benefits these systems can

provide. Respondents reported that the value of efficiency programs' education on these systems was on the same order as program incentives.

They also noted that the systems are getting both smarter and more user-friendly, so perhaps the education can focus more on benefits and less on operation in the near future.

- "Think of the average car with all the microprocessors, and yet my 86 year old mom can still drive the car."

Appropriate support. One respondent noted that, recently, "the whole retrofit market in California came to a screeching halt; anything that you do that could trigger Title 24 won't be incentivized." Others noted that incentives for LEDs without the requirement of advanced lighting controls might effectively postpone the acquisition of significantly greater energy savings and non-energy benefits for decades.

- "Utility incentives that push harder on advanced system. There should be dis-incentives of non-intelligent systems."
- "Great piece some utilities offer are bonus incentives for comprehensive measures."

5 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the overall findings, opportunities, and threats to programs offering systems-based incentives, along with recommendations to help any future programs operate more effectively.

Conclusion 1: Ample potential exists to deploy systems-based energy efficiency programs for lighting in commercial office buildings. As expected, segments with the largest amount of square feet produce the most savings.

Recommendation 1: Advanced lighting systems should begin to be included as part of utility energy efficiency portfolios. Additional work will need to be done before these systems can move from a custom application to a more standardized one.

Conclusion 2: Even though the components of these systems exist today and are considered "off-the-shelf," combining them into a complete system is not common practice. Utility incentives programs can be most effective in situations when current payback periods are longer than customer investment thresholds. In addition to reducing payback times using financial incentives, utility programs can increase customer awareness and educate decision makers on the benefits of system-based approaches versus widget-based change outs.

Recommendation 2: To increase uptake of the systems approach, utility programs need to include an educational component to increase awareness among designers and contractors of lighting systems.

Conclusion 3: Installation of systems tends to be related to a major event that results in a remodel and therefore creates a "replace on burnout" decision path rather than a retrofit decision path.

Conclusion 4: Systems save energy, but are sensitive to utility avoided costs. The driver of economic potential was more about differences in avoided costs than by differences in system costs or savings.

Recommendation 3 & 4: Utility program should target the ROB market and use incremental cost to determine cost effectiveness for these programs.

Appendix A. System Detailed Descriptions

This appendix provides detailed descriptions of the "Beyond Widgets" projects selected for the three LBNL utility partners.

California POU Customer System Technology Specification

This section provides a summary description of the system selected for the California Publicly Owned Utilities (CA POUs)-LBNL "Beyond Widgets" project: Plug loads and lighting occupancy controls, with task and ambient lighting retrofits. This section includes the system features, technology packages, site requirements, and likely energy savings impacts. It will be used as the basis for developing detailed technology specifications, savings metrics and M&V approaches, and FLEXLAB testing plans.

The target market is currently anticipated to be commercial office space.

System Features

The following are features of the proposed systems energy efficiency program package. A suite of technology package options will be developed from these features, which will be pursued for testing, validation and program implementation guidance development.

Lighting and Lighting Controls

Occupancy controls

- Switches on in response to occupancy at the zone level
- Controlled to background/ambient level

Daylight dimming

- Electric lighting output reduces in response to natural light availability
- Applies particularly to retrofits where Title 24 is triggered

Task lighting and ambient lighting upgrade

- Installation of schedule and occupancy-based control task lighting and desktop equipment at workstation level
- Overhead lighting relamping or light fixture replacement to achieve ambient light level condition

Plug Load Controls

Occupancy control

- Operates in response to occupancy at zone level (overhead lighting) or individual workstation (plug loads) level
- Occupant preferences accommodated via override and sensitivity settings

Networked Controls System

Lighting and plug load controls scheduling, occupancy and reporting functions

Occupant Feedback System

Occupant engagement and awareness strategies for persistence of energy savings

The technology packages will be developed to ensure that there is more than one equivalent commercially available product source for each package.

System Performance Specification

Ambient (Overhead) Lighting and Lighting Controls

The overhead lighting retrofit should comprise some or all of the following elements:

1. Light fixtures
2. Lamps
3. Dimming ballasts or LED drivers
4. Panel and remote mounted load control relays and dimmers
5. Power supplies
6. Routers, controllers, processors and servers
7. Analog and digital input and output modules
8. Emergency lighting control

The primary objective is to control overhead lighting output by either a) lighting power density de-rating via lamp change-out or b) tuning existing lamps for a lower lumen output. This approach is consistent with a strategy known as task / ambient lighting, where background lighting is provided by ceiling mounting fixtures and task–specific lighting is provided on-demand by personal desktop lamps. Illuminance at the workplane should be based on current IESNA recommendations and user preferences. Primary control shall be in response to occupancy.

Additional specific requirements:

1. Light fixture (or luminaire) may be either in-ceiling or surface-mounted ‘troffer’ (available in various dimensions) or ceiling hung ‘pendant’ fixture
2. Lamps for use in retrofit projects should have a minimum rated lamp life of 68,000 hours[38]
3. Minimum initial delivered lumens will vary according to number of lamps, but a rough guide should be for 1’ x 4’ to provide 1500 initial lumens, and for 2’ x 4’ to provide 3000 initial lumens. 2’ x 2’ fixtures should provide 2000 initial lumens. The minimum Luminaire Efficacy Rating (LER) should be at least 110 lm/W.
4. Where drivers are installed or replaced, efficiency rating for driver technologies should be 0.83 (digital ballasts) and >80% (LED drivers)
5. For projects that incorporate dimming elements of lighting controls, related to institutional tuning, daylight dimming and demand response, electronic ballasts or LED drivers shall be capable of providing flicker-free dimming from 100% to 5%. Step dimming from 100% to at least one present level between 70% and 10% should be an available option TO support appropriate tuning according to site requirements / user preferences. There should be no phase-cut dimming. Communications protocols such as DALI, DMX/RDM, Zigbee and EnOcean are among the viable options
6. For systems with integrated lighting controls, this may comprise some or all of: occupancy sensors, photosensors (daylight dimming), lumen management and load shedding capability
7. Where implemented, all networked system 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[39] are maintained. The control system should be capable of controlling multiple zones

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[38] L_{70} (LED) or based on 12-hour start with instant start ballast (fluorescent)

[39] For example, for commercial offices, 30 footcandles on the workplane.

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.

Occupancy-Based Plug Load Control, including Task Lighting

Plug load control and occupancy-based task lighting shall comprise the following elements:

1. Block of controllable electrical sockets
2. Resettable circuit breaker
3. Power-on indicator light
4. Desktop LED task light

The primary objective is to control plug loads according to usage patterns defined by a) user / building operating schedules and / or b) occupancy at individual work locations. The objective is to minimize operating hours for office plug loads, particularly desktop equipment such as computers and monitors. Provision of task lighting powered via the APS aims to meet task level illuminance requirements while allowing lower ambient lighting LPD.

Additional specific requirements:

1. The blocks of sockets should consist of at least four power outlets – this will enable management of all common desk-based plug loads (computer / laptop, monitor, task light) The instructions for installation and operation should be intuitive and simple to understand – it should be possible for someone not previously familiar with the technology to make modifications to control settings.
2. Optional - Remote access and control may be provided for controllable outlets via a web-based interface, and will allow programming of individual outlets according to user preferences, including, but limited to schedule.
3. Control options shall include one or more of the following:
    - Schedule / timer
    - Master outlet-based control
    - Remote manual switch
    - Remote occupancy sensor - this sensor could either be a) part of the APS package or b) utilize occupancy signals from the appropriate sensor that is part of the overhead lighting controls package.
4. The LED task light should have a manual on-off switch

Note that the impact on HVAC systems operation will be estimated / measured, however, integration and optimization of HVAC performance with the system described above is not an objective for this project's system.

Technology Packages

The intent is to allow a range of different component technology options that meet the system features described above. The program incentives would be paid based on system performance rather than component performance or features. The technical requirements for each component are summarized below, followed by technology packages that will be selected for testing.

At least two packages are being considered, for review and feedback from the California POUs – a package that targets lower cost, minimally invasive installation, such as localized wireless or other stand-alone controls interventions, and another package that targets small cost technologies that might be slightly more involved to install, but could unlock deeper energy savings, such as networked controls and feedback.

Technology Package 1

Package 1 provides a low cost option, focusing on stand-alone controls with non-automated means of feedback and savings persistence guidance.

Technology Description

Overhead (ambient) lighting will be a lamp or fixture replacement with reduced lighting power density and lower lumen output. Local load sensing controlled power outlets, with task lighting providing required light levels at the task area.

Lighting and Lighting Controls System

The functional performance requirement is for the overhead lighting system to provide ambient / background lighting so that overall lighting energy use is minimized.

Primary control mode shall be in response (in real time) to:

Zone-level occupancy
Schedule controls

Representative technologies meeting description:

1. Overhead lights - Luxul linear LED replacement tube, recessed or pendant fixture
2. LED task lights - Tambient Boston Light

Plug Load Controls System

The functional performance requirement is plug loads to be controlled at the workstation level so that workstation plug load energy use is minimized. Control shall be implemented via schedule or occupancy sensor signal

Primary control mode shall be in response (in real time) to:

1. Cubicle-level occupancy sensor signal
2. Pre-programmed work schedules
3.

No secondary control inputs are envisioned.

Representative technology meeting description:

Autani Smartlet

Targeted Measurements

This technology package will not automate or trend the collection of controls data. However, measurements will be taken as a result of the package features, including:

plug load use schedule
plug load energy
lighting circuit energy

Technology Package 2

This package provides a small cost option, focusing on networked controls with automated means of feedback and savings persistence guidance.

Technology Description

Overhead (ambient) lighting will be a lamp or fixture replacement with reduced lighting power density and lower lumen output. Task lighting will supplement illuminance requirements in the work area. Local occupancy sensors will control overhead lighting (zone) and controlled power outlets (cubicle), including desktop task lighting.

Lighting and Lighting Controls System

The functional performance requirement is for the overhead lighting system to provide ambient / background lighting levels so that overall lighting energy use is minimized.

Primary control mode shall be in response (in real time) to one or a combination of:

Workstation occupancy
Schedule controls

All workstation level occupancy sensors shall be configured to reflect occupancy of workstation specific areas, and installed in a semi-permanent fashion (e.g. affixed to furniture system), to discourage relocation of sensor.

Representative technologies meeting description:

Overhead lights - Philips SpaceWise
LED task lights - Tambient Boston Light

Plug Load Controls System

The functional performance requirement is for occupancy sensors to control plug loads at the workstation level so that workstation plug load energy use is minimized. Control shall be implemented via workstation specific occupancy sensor connected to workstation level plug loads. Occupants may adjust timeout, occupancy sensor sensitivity and direction of sensor viewing angle. No overrides at the occupant level are envisioned.

Primary control mode shall be in response (in real time) to:

Pre-programmed work schedules
Workstation level occupancy sensing

No secondary control inputs are envisioned. All workstation level occupancy sensors shall be configured to reflect occupancy of workstation specific areas, and installed in a semi-permanent fashion (e.g. affixed to furniture system), to discourage relocation of sensor.

Representative technology meeting description:

Telkonet EcoGuard

Targeted Measurements

This technology package will not automate or trend the collection of controls data. However, measurements will be taken as a result of the package features, including:

Workstation occupancy
Plug load use schedule
Plug load energy
Lighting circuit energy

Candidate Site Requirements

Standard set of commercial office equipment of 1990's/00's era, e.g. laptops, desktop computers, flat screen monitors, etc.
9-10ft floor-to-ceiling height with dropped ceiling/plenum
Existing overhead lighting system with T12 or T8 light fixtures, either lay-in or pendant hung
Overhead lighting system zone covers the same area as the workstations incorporating task lighting and plug load controls (i.e. the existing lighting controls don't impact adjacent spaces such as conference rooms)
Existing switch based or networked lighting controls, without daylight dimming
Network access to workstations for occupant level feedback software or network access to a common display for workstation area feedback
Average daily occupancy a minimum of 8 hours a day, 5 days a week

Energy Saving Impacts

Baseline Case

The California POUs use California's Title 24 Energy Code as their baseline for comparison for all energy efficiency Demand Side Management Programs. This presents a number of challenges for utilities in the state, since on a prescriptive and component based level it is difficult to develop technology offerings that are substantially higher energy savings over Title 24 to justify an incentive program. This systems level technology package provides a distinct advantage in this respect, as energy savings are greater at the system level.

The relevant prescriptive elements of California's Title 24 Energy Code are as follows for plug loads and lighting respectively.

Lighting and Lighting Controls

Scheduling, institutional tuning, occupancy based operation and daylight dimming to be implemented in office areas.

Plug Loads

Circuit controls for 120-volt receptacles for office workstation equipment (PCs, local printers, task lighting), which incorporate the capability to implement on-off schedules. Plug-in power strips with occupancy based control do not qualify under the current Code.

Proposed Technology Packages Energy Savings

Energy savings arising from advanced lighting controls are expected to reach approximately 38%.[40] Implementing a task ambient strategy are generally expected to surpass this, with measured energy savings of between 30-60% depending on the baseline.

Energy savings arising from load sensing (proxy occupancy control) and occupancy sensor control of power strips is indicated as being between 10-23% of connected plug loads.[41,42]

HVAC Impacts

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[40] http://eetd.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf

[41] http://www.gsa.gov/portal/mediaId/197383/fileName/GPG_Plug_Load_Control_09-2012.action - includes all common office equipment items, excluding kitchen area appliances.

[42] http://aceee.org/files/proceedings/2012/data/papers/0193-000277.pdf

In addition to the savings demonstrated within the plug loads and lighting systems, impacts on cooling energy reduction are also of interest. These interactive effects are less well studied in case studies and other technology reports.

References

No references were provided for this case study.

ComEd Project System Description

This section provides a summary description of the system selected for the ComEd-LBNL "Beyond Widgets" project: Automated interior shading integrated with lighting and HVAC controls. This section includes the system features, technology packages, site requirements, and likely energy savings impacts. It will be used as the basis for developing detailed technology specifications, savings metrics and M&V approaches, and FLEXLAB testing plans.

System Features

The key features of this system – automated shading integrated with lighting and HVAC controls - are as follows:

Automated Shading: The automated interior shading element will be either roller shades or venetian blinds. The functional performance requirement is for the shades/blinds to control solar gain through perimeter windows so that envelope-related thermal loads are minimized while meeting daylighting requirements. In occupied areas, occupants will always have the option to override the shading system. In unoccupied perimeter areas, the shades will 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.

Technology Packages

The intent is to allow a range of different component technology options that meet the system features described above. The program incentives would be paid based on system performance rather than component performance or features. The technical requirements for each component are summarized below, followed by technology packages that will be selected for testing.

Automated Shading

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

1. Shading element – roller shades (various fabric options) or venetian blinds. Roller shades should have an openness factor between 1-3%. The exterior reflectance should be greater than 60%.
2. Motor for shades/blinds operation, and housing for blinds when retracted.
3. Keypads to enable user control and override of automatic operation.
4. Routers, controllers, processors and servers.
5. Control system that utilizes an automated, computer server-based control system with the ability to receive inputs from multiple occupancy sensors and photo sensors. The control system should have the capability to interface with HVAC control system. The system should allow for at least 3 shade height

settings for roller shade (including fully raised and fully lowered), and at least 3 height settings (similarly as for roller shades) and 2 slat positions (fully open and closed) for venetian blinds.

6. Sensors for control inputs
7. Programming software

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

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.

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.

All control inputs shall be configured to reflect each site's specific characteristics and requirements. Users should always have the option to override the automated control.

<u>Automated lighting controls</u>

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

1. Digitally addressable ballasts or LED drivers
2. Panel and remote mounted load control relays and dimmers
3. Power supplies
4. Routers, controllers, processors and servers
5. Analog and digital input and output modules
6. Group/scene and manual zone controls
7. Occupancy/vacancy sensors
8. Photosensors
9. Integral time clock control
10. Emergency lighting control
11. 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.

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[43] are maintained. 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).

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

HVAC Controls

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

1. BACnet control communications
2. Variable frequency drives on fan and pump motors
3. Modulating valves on heating/cooling loops
4. Outdoor air temperature reset
5. Networked mechanical equipment controllers

Optional control input:

1. 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**
- **CO2 sensor signals**

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

Technology Packages for Testing

In order to evaluate the savings, specific technology packages need to be specified and tested. It is not feasible to test all possible technology packages as there are too many permutations and combinations of components. Therefore, the project team will be testing 2-3 technology packages that approximate the range of savings and likely program offerings for this measure (Table 31).

Package 1 represents a basic package with roller shades, integrating shading and lighting controls. Package 2 represents a basic package with venetian blinds. Package 3 represents the fully integrated package with roller shades, integrating shading, lighting and HVAC controls.

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[43] For example, for commercial offices, 30 footcandles on the workplane.

Table 31. Technology packages that will be tested in FLEXLAB

Components	Pkg 1	Pkg 2	Pkg 3
Shade element			
- Roller	X		X
- Venetian blinds		X	
Shade control			
- Solar only	X	X	
- Solar + Occ. + HVACmode			X
Lighting type			
- LED pendant	X	X	X
Lighting control			
- Continuous dimming + Occ	X	X	X
HVAC control			
- Tstat	X	X	
- Tstat + occ. ventilation			X
Window glass type			
- Low-e	X	X	X
Window orientation			
- South	X	X	X
- East	X	X	X
- West	X	X	X
Window-wall ratio			
- 40%	X	X	X

Candidate Site Requirements

The likely minimum site requirements for the system are:

10 ft floor-to-ceiling heights with dropped ceiling / plenum for routing of power and communications.

Air-based delivery systems with hydronic supply.

BACnet or similar architecture to support inter-communications

HVAC operation based on thermal setpoint control strategy consistent with ASHRAE 90.1

BMS with trend facility (or alternative i.e. for RTUs?)

Additional requirements for preferred sites:

Moderate to large windows (window-wall ratio > 40%).

Clear or low tint glazing (double/triple).

Digitally addressable dimming ballasts or LED drivers.

Minimum of 8 hours average daily occupied hours.

Perimeter constitutes significant proportion of total floor area (~>25%)

Open office partitions 4 ft. or less.

Better to have open office on perimeter than closed office.

Energy Saving Impacts

Baseline Case

The Illinois Technical Resource Manual for Energy Efficiency (TRM) version 3.0 specifies the following baselines:

New construction: Building code or federal standards.

Retrofit: Existing equipment or the existing condition of the building or equipment

Per the Energy Efficient Building Act in Illinois, the Capital Development Board (CDB) is required to review and adopt the most current version of the International Energy Conservation Code within one year after its publication date. The Code will then become effective within 6 months after it is adopted by CDB. The 2012 IECC Took Effect in Illinois on January 1, 2013. Generally, major renovations trigger code compliance.

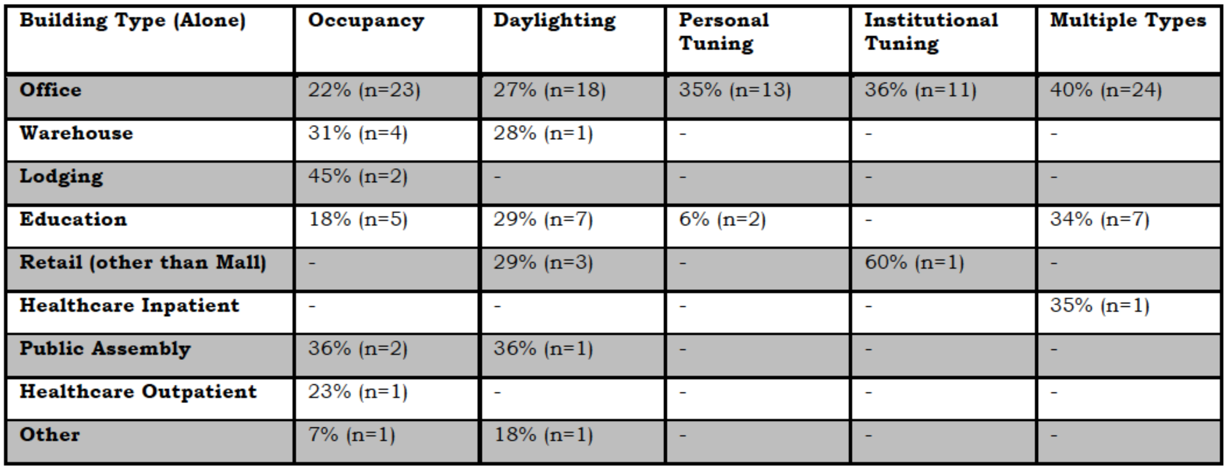
For the purposes of this project, the baseline for comparing the technology packages will comprise of the following:

Manually operated interior shading
T-8 Troffer with scheduled control
Low-e double glazing
40% window-to-wall ratio
VAV HVAC system with scheduled thermostatic setup/setback control.

Proposed Technology Package Savings

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 32).

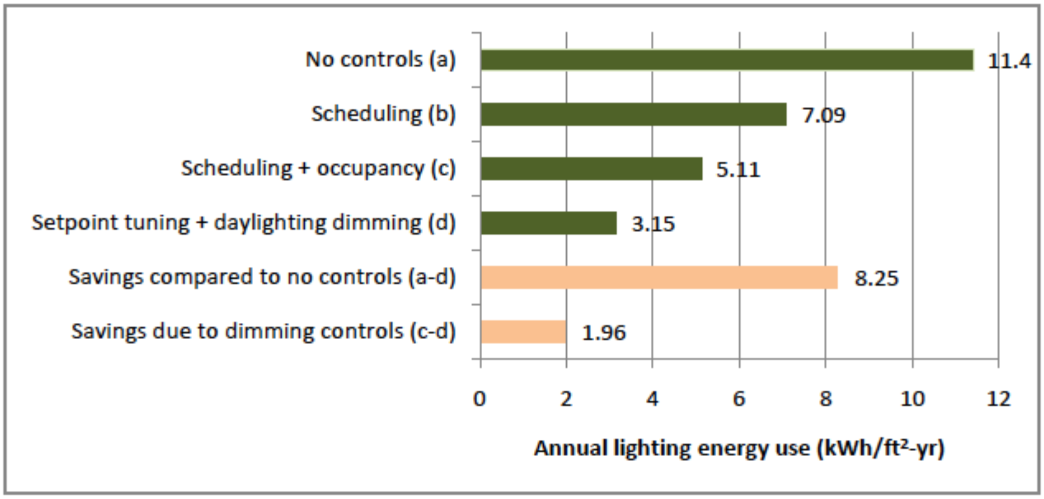
Table 32. Energy savings from LBNL meta-analysis of lighting controls studies (Williams et al. 2011)



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 (**Error! Reference source not found.**). 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 hard-wired systems) serve as an added incentive to increase adoption.

Figure 5-1. Lighting energy use savings in the New York Times headquarters building (Lee et al. 2013)



References

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

Xcel Energy Systems Performance Specification

This section provides a summary description of the system selected for the Xcel Energy-LBNL “Beyond Widgets” project: Integrated HVAC control system with enterprise-level, intelligent networked lighting controls, combined with enhanced daylighting controls (when appropriate, using daylight-redirecting window film and deep daylight dimming to take advantage of interactive HVAC effects).

This section includes the system features, technology packages, site requirements, and likely energy savings impacts. It will be used as the basis for developing detailed technology specifications, savings metrics and M&V approaches, and FLEXLAB testing plans. The target market is large and small commercial offices.

System Features

The following are features of the proposed systems energy-efficiency program package. A technology package options suite will be developed from these features, which will be pursued for testing, validation and program implementation guidance development.

Key aspects for systems selection are their level of functionality (individual autonomous control; enterprise-level, zone control; enterprise-level, intelligent granular control) and their integration with other building systems through additional sensor types tied to the lighting control system. This systems approach requires a different perspective on assessment and validation depending upon levels of functionality; with an emphasis less on installed product and more on performance/outcome, e.g., kWh/sf/year. Projects will include a HVAC energy savings assessment from lighting efficiency improvements as well.

HVAC Controls:

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

1. BACNet control communications
2. Variable frequency drives on fan and pump motors
3. Modulating valves on heating/cooling loops
4. Outdoor air temperature reset
5. Networked mechanical equipment controllers

Optional control input:

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

Functional performance requirement:

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**

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.

Example operational modes:

1. Thermal setpoint
2. Calculated solar gain based on shading position (optimized for daylighting)
3. Maintenance override
4. Occupancy/vacancy

Automated lighting controls for daylighting and occupancy sensing:

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

1. Digitally addressable ballasts or LED drivers
2. Panel and remote mounted load control relays and dimmers
3. Power supplies
4. Routers, controllers, processors and servers
5. Analog and digital input and output modules
6. Group/scene and manual zone controls
7. Occupant/vacancy sensors and controllers
8. Daylight responsive sensors and controllers
9. Integral time clock control
10. Emergency lighting control
11. Utility "demand response" control

Functional performance requirement:

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.

Photosensors and controls shall be programmed to ensure minimal lamp cycling (and associated reduced lamp-life and occupant distraction) due to varying daylight levels and should be capable of easy recalibration to accommodate changes in environment/preferences. They should be calibrated to ensure that IES guidelines or code standards are maintained. Occupant sensors may control lighting at the zone or individual workstation level. Lighting output should be adjusted to user requirements (lamp output tuning relative to maximum rated output).

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

- **Occupancy**
- **Workplane illuminance (measured directly or calculated from measured reflectance)**

Example operational modes:

1. Scheduled
2. Occupied/vacant
3. Daylight dimming

Notes on Integration of Systems

Operation of automated lighting controls shall take also into account energy optimized performance of daylighting dimming controls to ensure minimal glare issues arise than necessary.

Occupancy control shall be at the individual cubicle or private office level in order that control signals may appropriately control the local lighting levels or HVAC operation according to a) verified energy performance and/or b) occupant preferences.

Daylight-redirecting window film for extended daylighting

The building glazing system may comprise some or all of the following components:

1. Daylight redirecting film (applied to interior glass surfaces) that brings natural light deeper into the building's interior by changing the light's direction as it passes through windows. The film redirects light toward the ceiling, reducing the need for artificial light throughout the day.

Technology Packages

The intent is to allow a range of different component technology options that meet the system features described above. The program incentives would be paid based on overall integrated, system performance rather than component performance or features. The technical requirements for each component are summarized below, followed by technology packages that will be selected for testing.

In order to evaluate the savings, specific technology packages need to be specified and tested. It is infeasible to test all possible technology packages, as there are too many permutations and component combinations. Therefore, the project team will be testing three technology packages that approximate the range of savings and likely program offerings for this measure.

Package 1: represents a basic package with zonal HVAC controls, integrating zone-level daylighting and lighting controls.

Package 2: represents an enhanced package with daylight-redirecting window film, integrated networked, zone-level lighting controls, luminaires with integral occupancy and photosensors, and HVAC controls.

Package 3: represents the fully integrated package with daylight-redirecting window film, integrated networked, highly granular lighting controls, a dense sensor configuration (workstation-specific luminaires with integral occupancy and photosensors) and HVAC controls.

Candidate Site Requirements

The likely minimum site requirements for the system are:

- **10 feet, floor-to-ceiling heights with dropped ceiling/plenum for routing of power and communications.**
- **Air-based delivery systems with hydronic supply.**
- **BACNet or similar architecture to support inter-communications**
- **HVAC operation based on thermal setpoint control strategy consistent with ASHRAE 90.1**
- **BMS with trend facility (or alternative i.e., for rooftop units (RTUs))**

Additional requirements for preferred sites:

- **Moderate to large windows (window-wall ratio > 40%).**
- **Clear or low tint glazing (double/triple).**
- **2nd or 3rd generation linear fluorescent lamps and ballasts with zonal control or scheduling.**

- **Minimum of 8 hours daily average occupied hours.**
- **Perimeter constitutes significant proportion of total floor area (~>25%)**
- **Open office partitions 4 ft. or less.**
- **Better to have open office on perimeter than closed office.**

Energy Saving Impacts

Baseline Case

For Colorado, the minimum compliant building with the absence of energy modeling compared to ASHRAE 90.1-2010 code as modified or local code when more stringent. The EDA Modeling Protocol is based on a utility modified version of the ANSI/ASHRAE/IESNA Standard 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings utilizing Appendix G.

For Minnesota, code is based on the 2012 International Energy Conservation Code® and ANSI/ASHRAE/IES Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings. All prescriptive measures utilize the energy savings calculations listed in the State of Minnesota Technical Reference Manual For Energy Conservation Improvement Programs, Version 1.2, Effective: January 1, 2015 – December 31, 2015, which specifies the following baselines:

- **New construction: building code or federal standards.**
- **Retrofit: existing equipment or the existing condition of the building or equipment**

Baseline Building Selection:

The building selected for this study is based on an office building with a typical 2'x4' acoustical grid ceiling.

Floor Area: 25,000 sqft. (typical per story)

Ceiling Height: 9'-0"

Windows:

- **Sill Height: 2'-6"**
- **Top of Window: 8'-0"**
- **Glazing/Façade Area Ratio: 40%**
- **Glazing Type: Double Low-e Tvis = 0.65**
- **40% window-to-wall ratio**
- **Manually operated interior shading**

Interior Space Planning:

- **The floor used for this study used two different strategies for space planning to compare the energy effects of:**
- **A traditional space plan with perimeter private offices located near the windows and interior open offices**

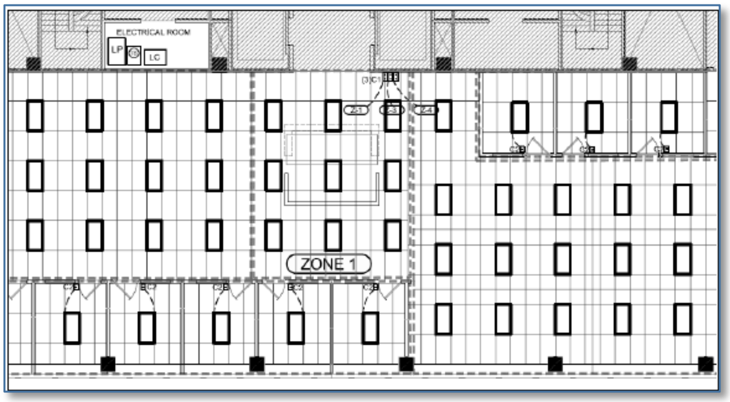
For the purposes of this project, the baseline for comparing the technology packages will comprise of the following:

Lighting and Control System Design

- **T-8 Troffer with scheduled control**
- **Existing Luminaire: 2'x4', 3-lamp T8, recessed parabolic troffer**
- **Existing Layout: 8' x 8'**
- **Resulting Task-plane Illuminance: 55 footcandles average**
- **Target Task-plane Illuminance: 35 footcandles average**

- **ASHRAE minimum control zone: 2,500 sqft.**

Figure 5-2. Typical recessed 2'x4' fluorescent luminaire layout (8'x8')



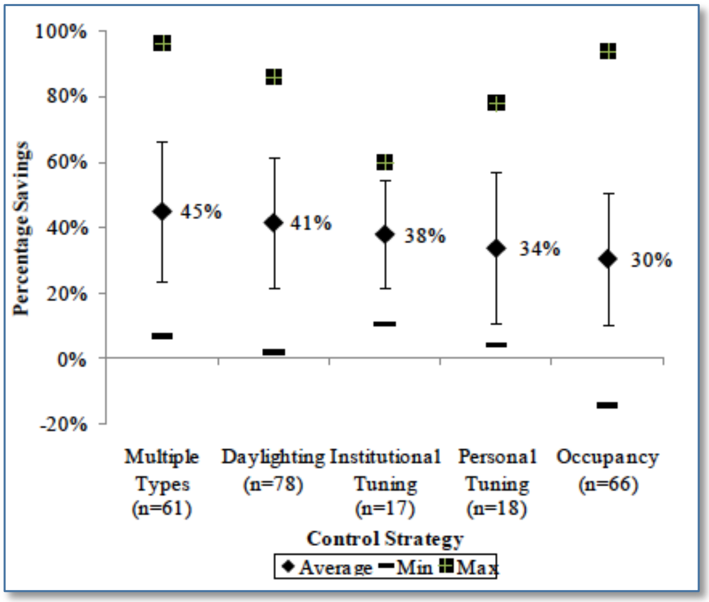
HVAC and Control System Design

- **VAV HVAC system with scheduled thermostatic setup/setback control.**

Proposed Technology Package Savings

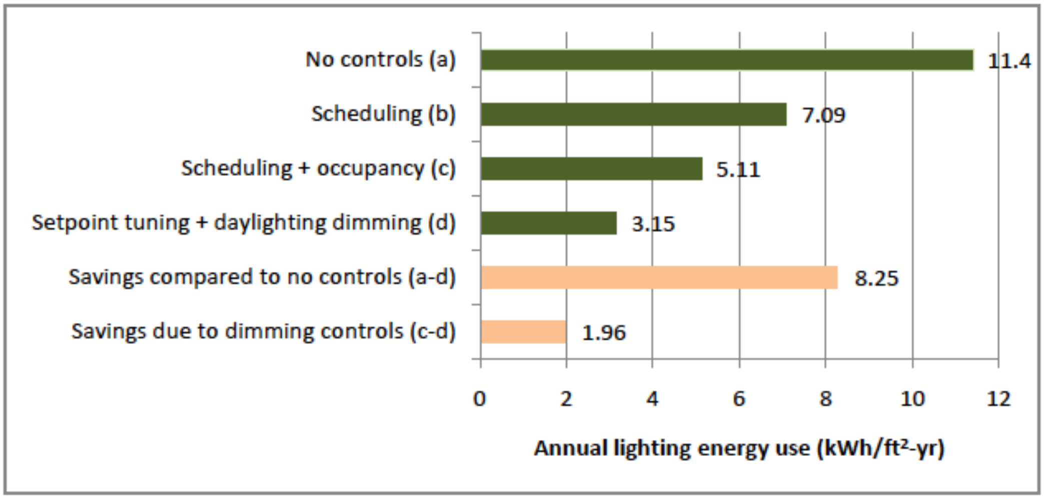
Daylight-based dimming is a proven but underutilized energy-efficiency technology, particularly within the context of utility programs, which mostly cater to prescriptive component-based efficiency measures. An LBNL study (Williams et al. 2012) showed that for offices, daylighting alone yielded an average lighting energy savings of 41% (N=78 projects), institutional tuning yielded 38% average savings (n=17), personal tuning, 34 % average savings (n=18), and occupancy provided 30% average savings (n=66) (**Error! Reference source not found.**).

Figure 5-3: Average energy savings (%) by control strategy (Williams, et al. 2012)



Adding enhanced daylighting with light-redirecting window film extends the effective daylighting zone and therefore, the potential energy savings associated with daylight dimming and HVAC controls, 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 5-4). Improved daylighting practices employing automated shades, in this case, 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 hard-wired systems) serve as an added incentive to increase adoption.

Figure 5-4. Lighting energy use savings in the New York Times headquarters building (Lee, et al. 2013)



Employ a systems level approach to lighting incorporating greater control granularity, dense sensor networks (wired or wireless), and fewer luminaires (optimally task-oriented, i.e., workstation-specific fixtures) that enables much greater energy savings and enhanced functionality.

Notes on Systems Measurement and Verification (M&V)

LBNL intends to employ a graduated approach to M&V with respective accuracy and savings metrics.

Purpose of metrics: M&V

- **Lighting kWh during on-hours.**
- **Zonal cooling kWh during on-hours (scheduled occupancy hours). Calculated from VAV airflow, system pressure and SAT. Central plant and air handler effects are highly dependent on rest of building and therefore, difficult to measure specific zonal impacts. (Fan energy may be an exception)**
- **Zonal heating kBtu during on-hours. Calculated from reheat and/or perimeter heating flow/temps. Does not capture savings at central plant. (Pumping energy ~ 2-way or 3-way valves)**
- **Chiller plant kWh – consider using average kW/ton.**
- **Boiler kBtu – consider average % efficiency.**
- **kWh/sf/yr for relevant zones.**
- **kWh/sf/yr for whole bldg.**

Performance metrics:

- **Workplane illuminance**
- **Spectral distribution-CCT**
- **Air temp**

- **Glare index**

9.1.1.1.1.1.1.1 References

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. LBNL-6023E

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, Lawrence Berkeley National Laboratory. Page, E, Erik Page & Associates, Inc. May 2012. Quantifying National Energy Savings Potential of Lighting Controls in Commercial Buildings. LBNL-5895E

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

Appendix B. Listing of Interview Participants

Table 33 lists the DNV GL staff interviews by name and title for the internal adoption potential interviews. The external interviews (Table 34) are listed by company name and role in the market for integrated systems. One small architectural firm agreed to talk to us on the condition of anonymity. These responses represent a wide array of market actor perspectives.

Table 33. DNV GL internal respondents

Name	Title
Max Neubauer	Consultant, Policy Advisory and Research
Ryan Ollie	Engineer, Program Development and Implementation
Angela Xanders	Senior Consultant, Program Development and Implementation
Ben Huntington	Consultant, Policy Advisory and Research
Blake Herrschaft	Senior Engineer, Sustainable Buildings and Communities
Jarred Metoyer	Head of Section, Engineering West

Table 34. External subject matter experts

Company	Role
Ameresco	Solution provider
Anonymous	Architect
Design Lights Consortium	Market transformation
Digital Lumens	Manufacturer
Eaton/Cooper	Manufacturer
Encelium/Sylvania	Manufacturer
Enlighted	Advanced lighting systems
Facilitec	Solution provider
Johnson Controls	Manufacturer
Leading Edge Design Group	Solution provider
Schneider Electric	Manufacturer
Siemens	Manufacturer
Universal Devices	Solution provider

Appendix C. Market Actor Interview Guide

Based on findings from interviews with DNV GL internal experts, the market actor interviews focused on "integrated systems". These were defined as a system that controls more than one end-use with some degree of automation.

During the in-depth interviews, these questions serve as a guide for the discussion. The interviewer may probe certain areas more in one interview than another, or may collect responses in an order other than the one provided in the guide.

1. Preliminary

1. In a few words, please summarize your experience and expertise with regard to integrated control systems.
2. Does your company have/ Do you specify a proprietary systems, or do you have detailed knowledge of a specific system or technology

2. Awareness

3. How would you characterize the awareness of integrated control systems in the market place, for example relative to awareness of efficient lighting or heating? As a percentage of eligible customers?
4. What approach do you think programs could take to increase awareness of integrated control systems?
5. Does this differ from key measures (LED lights) for example, and if so, how?

3. Penetration

6. Are you aware of any energy efficiency programs that are promoting integrated control systems or comparable? If so, where and how?
7. Are there any market segments in particular that might more readily adopt integrated control systems? Any that you identify as particularly resistant? Why?

4. Barriers

8. What kind of barriers to adoption do integrated control systems face that are different from those facing specific end use measures, such as efficient lighting or HVAC equipment?
9. Are there any approaches to overcoming barriers that might be particularly useful for promoting integrated control systems?
10. [IF NOT PREVIOUSLY MENTIONED] – What specific barriers might efficiency programs have to overcome to increase adoption of integrated control systems in existing buildings? How might they do so?
11. What features of integrated control systems are particularly worth promoting?
12. Historically it has been relatively easy to encourage vendors to promote higher efficiency measures in their core business line. What might encourage them to promote integrated controls systems if they are not in their product line?

5. Decision Making

13. How does the decision making to install integrated control systems differ from the decision making to install just one of the component measures?

14. If integrated control systems can be shown to offer substantially greater benefits, including non-energy benefits, what benefits do you think would be most attractive to decision-makers? [Prompt if necessary "Substantially greater energy savings, reduced demand charges, increased productivity, increased comfort, increased sales "]

6. Adoption Forecast

15. What percentage of new commercial and industrial buildings will have integrated control systems installed in the next twelve months?
16. What percentage of existing commercial and industrial buildings will have integrated control systems installed in the next twelve months?
17. Assuming a comprehensive marketing effort and a simple payback of less than 2 years but more than one year less what percentage of eligible customers would install integrated control systems in the two years of the program? In the next five years? In the next 5 years? In the next 10 years?
    a. What if the payback were greater than 2 years?
    b. Less than a year?
18. Assuming that an average adoption rate can be determined for integrated control systems across all C&I market segments. Would you expect the adoption rate to be higher or lower, and by how much in terms of percentage, for the following type of decision makers:
    a. Those who own their buildings?
    b. Those that lease buildings?
    c. Small building owners?
    d. Large building owners?
    e. Old building owners?
    f. New building owners?

7. Next Steps

19. Now that you've heard all the questions, can you recommend anyone else we should talk with?
20. Are there any questions I haven't asked that I should have?

8. Conclusion

Thank you for your time. Please contact me if you think of anything about these systems you would like to add.

Appendix D. System Assumptions Used in This Study (all values are whole building level)

Msr ID	Measure Name	Building Type	Energy Savings %	Peak Reduction %	Widget Cost ($/sqft)	System full cost ($/sqft)	System EUI (kWh/sqft)	System Life (yrs)	Widget Life (yrs)
CA POU_Package 1_Low	Plug load and lighting controls	Office pkg1	17.0%	18.0%	$0.80	$2.80	13.10	10	15
CA POU_Package 1_High	Plug load and lighting controls	Office pkg1	23.0%	18.0%	$0.80	$4.70	17.70	10	15
CA POU_Package 2_Low	Plug load and lighting controls	Office pkg2	27.0%	18.0%	$0.80	$4.50	17.70	15	15
CA POU_Package 2_High	Plug load and lighting controls	Office pkg2	27.0%	18.0%	$0.80	$7.70	17.70	15	15
ComEd_Package 1_Low1	Shading/lighting	Med Office	9.0%	2.0%	$1.81	$3.24	13.10	15	15
ComEd_Package 1_High1	Shading/lighting	Med Office	12.0%	3.0%	$2.05	$4.23	13.10	15	15
ComEd_Package 1_Low2	Shading/lighting	Large office	9.0%	10.0%	$1.22	$2.19	17.70	15	15
ComEd_Package 1_High2	Shading/lighting	Large office	12.0%	16.0%	$1.46	$2.93	17.70	15	15
ComEd13	Shading/lighting	Medical	NA	NA	NA	NA	NA	NA	NA
ComEd_Package 1_Low4	Shading/lighting	Primary School	20.0%	22.0%	$1.70	$3.06	7.46	15	15
ComEd_Package 1_High4	Shading/lighting	Primary School	23.0%	23.0%	$2.04	$4.10	7.46	15	15
ComEd_Package 1_Low5	Shading/lighting	Secondary School	13.0%	12.0%	$0.47	$1.37	12.26	15	15
ComEd_Package 1_High5	Shading/lighting	Secondary School	14.0%	13.0%	$0.66	$2.03	12.26	15	15
Xcel_Package 1_Low	Integrated lighting+HVAC controls, redirecting film	Office pkg 1	17.5%	10.0%	$0.80	$2.50	11.70	15	15
Xcel_Package 1_High	Integrated lighting+HVAC controls, redirecting film	Office pkg 1	17.5%	15.0%	$0.80	$2.50	11.70	20	15
	Integrated lighting+HVAC controls,								

Appendix E. Technical Potential Sub-Segments

Table 35: Technical potential for California POUs by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
California POU	North	Office	Large	New	Rent	48,319,755
					Own	11,334,264
				Old	Rent	36,091,175
					Own	19,737,361
			Small	New	Rent	9,335,001
					Own	4,392,941
				Old	Rent	23,317,930
					Own	20,678,164
	South	Office	Large	New	Rent	65,016,080
					Own	15,250,685
				Old	Rent	37,369,853
					Own	20,436,639
			Small	New	Rent	18,036,621
					Own	8,487,821
				Old	Rent	19,603,801
					Own	17,384,503

Table 36: Technical potential for ComEd by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
ComEd	N/A	Education	Secondary	New	Rent	6,874,073
					Own	59,287,702
				Old	Rent	5,799,969
					Own	53,893,037
			Primary	New	Rent	35,667
					Own	1,440,225
				Old	Rent	367,427
					Own	2,171,466
		Office	Large	New	Rent	13,394,048
					Own	4,641,318
				Old	Rent	86,210,612
					Own	16,227,800
			Small	New	Rent	6,019,057
					Own	3,941,280
				Old	Rent	24,681,526
					Own	23,419,017

Table 37: Technical Potential for Xcel Colorado sub-segments

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
Xcel CO	N/A	Office	Large	New	Rent	59,960,349
					Own	19,640,524
				Old	Rent	15,057,792
					Own	15,750,870
			Small	New	Rent	17,917,087
					Own	11,849,287
				Old	Rent	6,644,474
					Own	22,913,358

Table 38: Technical potential for Xcel Minnesota by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
Xcel MN	N/A	Office	Large	New	Rent	19,267,994
					Own	4,869,088
				Old	Rent	5,404,635
					Own	9,102,718
			Small	New	Rent	9,537,684
					Own	6,794,375
				Old	Rent	5,691,286
					Own	6,947,556

Appendix F. Economic Potential Sub-Segments

Table 39: Economic potential for California POUs by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
California POU	North	Office	Large	New	Rent	48,319,755
					Own	11,334,264
				Old	Rent	36,091,175
					Own	19,737,361
			Small	New	Rent	9,335,001
					Own	4,392,941
				Old	Rent	23,317,930
					Own	20,678,164
	South	Office	Large	New	Rent	65,016,080
					Own	15,250,685
				Old	Rent	37,369,853
					Own	20,436,639
			Small	New	Rent	18,036,621
					Own	8,487,821
				Old	Rent	19,603,801
					Own	17,384,503

There is no economic potential table here for ComEd since none of the system configurations or applications passed the TRC test.

Table 40: Economic potential for Xcel Colorado by sub-segment

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	Square Footage
Xcel CO	N/A	Office	Large	New	Rent	59,960,349
					Own	19,640,524
				Old	Rent	15,057,792
					Own	15,750,870
			Small	New	Rent	17,917,087
					Own	11,849,287
				Old	Rent	6,644,474
					Own	22,913,358

There is no economic potential table for Xcel Minnesota since none of the system configurations or applications passed the TRC test.

Appendix G. Achievable Potential kWh (Package 2)

These tables provide the kWh savings for systems deployed in the service territories of ComEd, Xcel Colorado and Xcel Minnesota. For all tables the abbreviations for “Lower Achievable Bound” and “Upper Achievable Bound” are LAB and UAB respectively. The table values include the following conditions:

- Package 2 - high cost, high savings
- Replace-on-burnout (ROB) situation
- Retrofit (RET) situation
- 2-year payback
- Cumulative savings in year 10

Table 41: California POU achievable kWh (Package 2)

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kWh – ROB LAB	kWh – ROB UAB	kWh – RET LAB	kWh – RET UAB
CA POU	North	Office	Large	New	Rent	3,891,471	5,461,713	58,372,060	81,925,699
					Own	912,814	1,281,143	13,692,212	19,217,139
				Old	Rent	2,906,632	4,079,484	43,599,481	61,192,254
					Own	1,589,564	2,230,968	23,843,466	33,464,514
			Small	New	Rent	751,802	1,055,160	11,277,028	15,827,407
					Own	353,789	496,546	5,306,837	7,448,192
				Old	Rent	1,877,928	2,635,689	28,168,926	39,535,334
					Own	1,665,333	2,337,309	24,979,991	35,059,636
	South	Office	Large	New	Rent	5,236,123	7,348,944	78,541,840	110,234,162
					Own	1,228,226	1,723,826	18,423,395	25,857,396
				Old	Rent	3,009,611	4,224,016	45,144,172	63,360,241
					Own	1,645,881	2,310,009	24,688,219	34,650,132
			Small	New	Rent	1,452,594	2,038,728	21,788,908	30,580,923
					Own	683,574	959,402	10,253,604	14,391,023
				Old	Rent	1,578,808	2,215,871	23,682,120	33,238,064
					Own	1,400,075	1,965,018	21,001,126	29,475,264

The graphs illustrate the savings between package 1 and 2 in the ROB scenario. Even though package 2 is more expensive, this package has the potential to achieve more savings than either configuration of package 1.

Figure 5-5: Northern California adoption curve kWh (ROB)

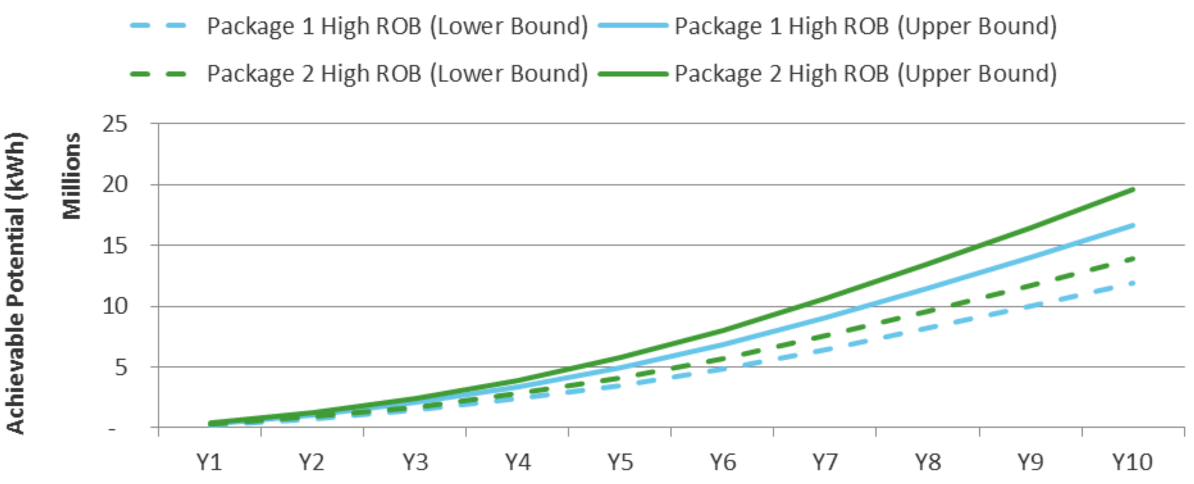
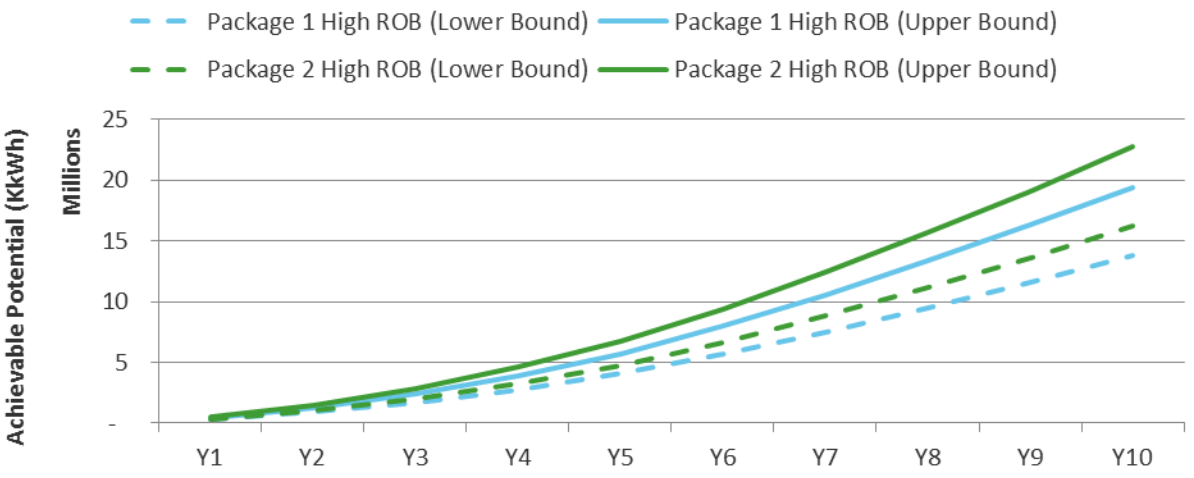


Figure 5-6: Southern California adoption curve kWh (ROB)



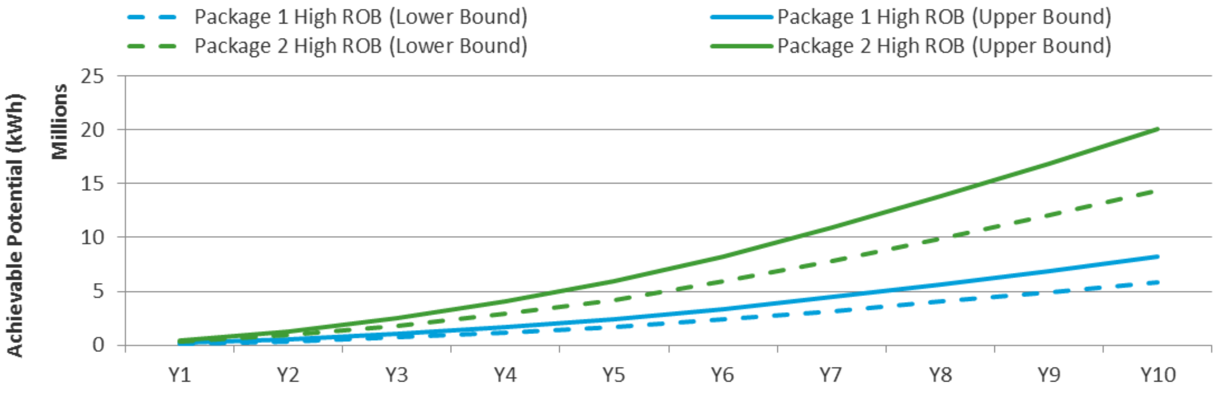
Interestingly the savings in Northern and Southern California are very similar. This result is driven by the fact that both regions of the state have very similar distributions of square feet in the office building segment. For both regions, the largest segment for savings is newer large office buildings that are leased to tenants

There is no kWh achievable potential table here for ComEd since none of the system configurations or applications passed the TRC test.

Table 42: Xcel Colorado achievable kWh (Package 2)

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kWh – ROB LAB	kWh – ROB UAB	kWh – RET LAB	kWh – RET UAB
Xcel CO	N/A	Office	Large	New	Rent	5,063,535	7,106,716	1,356,221	1,903,468
					Own	1,658,604	2,327,865	24,879,062	34,917,982
				Old	Rent	1,271,601	1,784,704	19,074,019	26,770,553
					Own	1,330,130	1,866,850	19,951,955	28,002,744
			Small	New	Rent	1,513,063	2,123,597	22,695,947	31,853,961
					Own	1,000,649	1,404,420	15,009,738	21,066,300
				Old	Rent	561,113	787,527	8,416,694	11,812,904
					Own	1,934,989	2,715,773	29,024,828	40,736,601

Figure 5-7: Xcel Colorado adoption curve kWh (ROB)



There is no kWh achievable potential table here for Xcel Minnesota since none of the system configurations or applications passed the TRC test.

Appendix H. Achievable Potential kW (Package 2)

These tables (Table 43 though Table 44) provide the kWh savings for systems deployed in the service territories of ComEd, Xcel Colorado and Xcel Minnesota. For all tables the abbreviations for "Lower Achievable Bound" and "Upper Achievable Bound" are LAB and UAB respectively. The table values include the following conditions:

- Package 2 - high cost, high savings
- Replace-on-burnout (ROB) situation
- Retrofit (RET) situation
- 2-year payback
- Cumulative savings in year 10

Table 43: California POU achievable kW (Package 2)

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kW – ROB LAB	kW – ROB UAB	kW – RET LAB	kW – RET UAB
CA POU	North	Office	Large	New	Rent	982	1,378	2,845	3,994
					Own	230	323	1,339	1,879
				Old	Rent	733	1,029	11,001	15,440
					Own	401	563	6,016	8,444
			Small	New	Rent	190	266	2,845	3,994
					Own	89	125	1,339	1,879
				Old	Rent	474	665	7,108	9,976
					Own	420	590	6,303	8,846
	South	Office	Large	New	Rent	1,454	2,041	6,051	8,493
					Own	341	479	2,848	3,997
				Old	Rent	836	1,173	12,537	17,596
					Own	457	642	6,856	9,623
			Small	New	Rent	403	566	6,051	8,493
					Own	190	266	2,848	3,997
				Old	Rent	438	615	6,577	9,231
					Own	389	546	5,832	8,186

There is no kW achievable potential table here for ComEd since none of the system configurations or applications passed the TRC test.

Table 44: Xcel Colorado kW achievable potential

Utility	Region	Bldg. Type	Bldg. Size	Vintage	Own or Rent	kW – ROB LAB	kW – ROB UAB	kW – RET LAB	kW – RET UAB
Xcel CO	N/A	Office	Large	New	Rent	429	602	6,437	9,034
					Own	141	197	2,108	2,959
				Old	Rent	108	151	1,616	2,269
					Own	113	158	1,691	2,373
			Small	New	Rent	128	180	1,923	2,700
					Own	85	119	1,272	1,785
				Old	Rent	48	67	713	1,001
					Own	164	230	2,460	3,452

There is no kW achievable potential table here for Xcel Minnesota since none of the system configurations or applications passed the TRC test.

Appendix I. Achievable Potential (ComEd & Xcel MN)

ComEd and Xcel Minnesota programs were not cost effective using the TRC ≥ 1.0 threshold. These utilities may decide however to offer integrated systems as part of their portfolio to affect market transformation. Technical potential remains the same from the earlier analysis. This appendix provides achievable potential using the same approach used for the main report. The difference however, is that the TRC threshold was set to zero. No segments filtered out and, as a result, the achievable potential for ComEd and Xcel MN was calculated using technical potential as the base. The results are the achievable potential these utilities might expect if they eliminate or significantly reduce the TRC threshold.

In Figure 5-8 and Figure 5-9, a threshold of TRC ≥1.0 is the basis for the potential shown for the California POUs and Xcel Colorado. For ComEd and Xcel MN the potential is based on a TRC ≥ 0 threshold.

Figure 5-8: Economic Potential RET

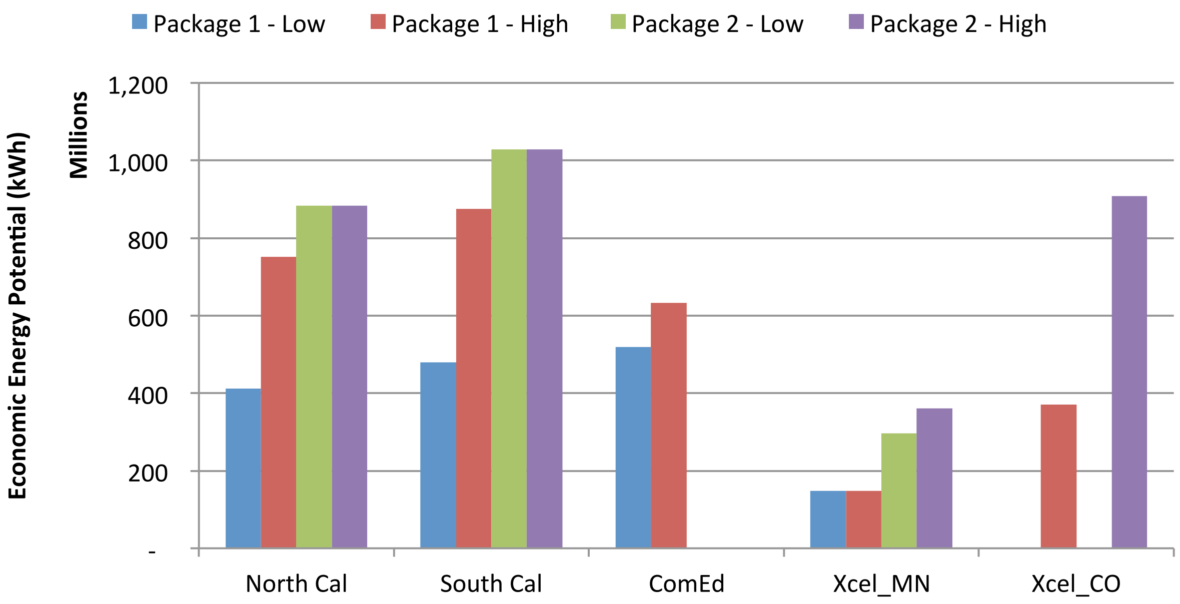
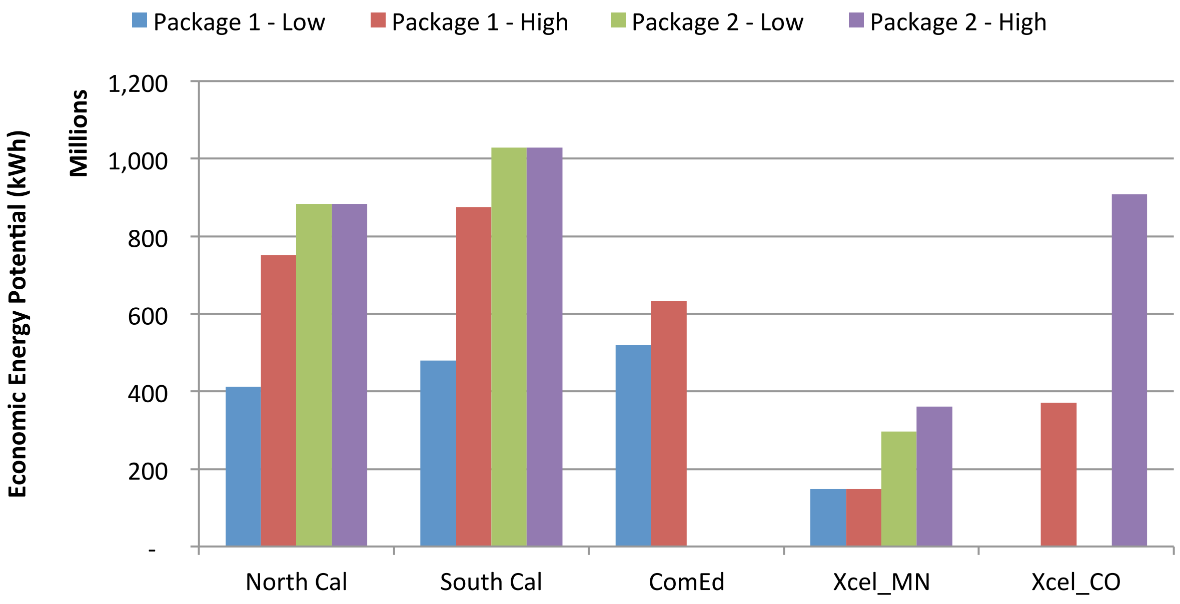


Figure 5-9: Economic Potential ROB



The cumulative adoption potential of energy savings for each utility partner is presented in Table 19 (RET) and Table 20 (ROB). The tables include low and high forecast bounds. The majority of the savings in the cumulative adoption for ComEd is due to office buildings (69%), followed by secondary schools (30%) and then primary schools (1%).

Table 45: Cumulative Adoption for RET (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
ComEd	**123/150**	**172/210**	**NA**	**NA**
Xcel Minnesota	**35/49**	**35/49**	**70/98**	**86/120**

Table 46: Cumulative Adoption for ROB (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
ComEd	**8/11**	**10/14**	**NA**	**NA**
Xcel Minnesota	**2/3**	**2/3**	**5/6**	**6/8**

Appendix J: Updated Market Analysis for Workstation Specific Lighting System

The market analysis presented in Appendix H was reevaluated for the updated systems selection of the workstation specific lighting system with daylight dimming controls. The same methodology was followed as described in Appendix H. For the market analysis update, the following system descriptions were used to define system related metrics:

Table J-1: Updated Workstation Specific System Descriptions

Market	Segment	System Packages
Xcel	Offices	Package 1. Workstation specific lighting fixture upgrade with fixture (local) daylighting and lighting controls Package 2. Workstation specific lighting fixture upgrade with enterprise-level networked daylighting and lighting controls

Key metrics that were updated included revising the system cost to include workstation specific lighting fixtures and controls replacements. Whole building potential energy savings were also adjusted for each of the medium and large commercial office environments. The revised market assessment also made use of FLEXLAB test results where available, for energy savings figures as shown in Tables J-2 and J-3.

Table J-2: Updated Workstation Specific System Whole Building Metrics - Minnesota

Msr ID	Measure Name	Energy Savings %[44]	Peak Reduction %	System full cost ($/sqft)[45]	Whole Building EUI (kWh/ sqft)[46]	System Life (yrs)
Xcel Package 1_Low	Integrated workstation-specific lighting, daylight dimming controls	6.0%	4.3%	$3.32	11.20	20
Xcel Package 1_High	Integrated workstation-specific lighting, daylight dimming controls	18.0%	9.5%	$3.54	22.74	20
Xcel Package 2_Low	Integrated workstation-specific lighting, daylight dimming controls	6.0%	4.3%	$5.34	11.20	20
Xcel Package 2_High	Integrated workstation-specific lighting, daylight dimming controls	18.0%	9.5%	$5.70	22.74	20

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[44] Source: FLEXLAB test data results, refer to Section 4

[45] Source: FLEXLAB test fixture cost data, plus controls data

[46] Source: FLEXLAB test data results applied to DOE Reference medium and large commercial building models

Table J-3: Updated Workstation Specific System Whole Building Metrics - Colorado

Msr ID	Measure Name	Energy Savings %[47]	Peak Reduction %	System full cost ($/sqft)[48]	Whole Bldg EUI (kWh/ sqft)[49]	System Life (yrs)
Xcel Package 1_Low	Integrated workstation-specific lighting, daylight dimming controls	6.0%	4.6%	$3.32	11.04	20
Xcel Package 1_High	Integrated workstation-specific lighting, daylight dimming controls	17.0%	10.1%	$3.54	21.83	20
Xcel Package 2_Low	Integrated workstation-specific lighting, daylight dimming controls	6.0%	4.6%	$5.34	11.04	20
Xcel Package 2_High	Integrated workstation-specific lighting, daylight dimming controls	17.0%	10.1%	$5.70	21.83	20

The following tables present the updated analyses and results for the key performance metrics. Table J-4 outlines the technical potential for energy savings for the system in each of the two markets.

Table J-4: Technical potential (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	119.9	671.5	119.9	671.5
Xcel Minnesota	48.4	295.0	48.4	295.0

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

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[47] Source: FLEXLAB test data results, refer to Section 4

[48] Source: FLEXLAB test fixture cost data, plus controls data

[49] Source: FLEXLAB test data results applied to DOE Reference medium and large commercial building models

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 Tables J-5 and J-6. It should be noted that utility rates used for MN were \$0.07/kWh, and were \$0.08/kWh, with escalation rates applied for applications in later years. The avoided cost stream average for Xcel Colorado was used at \$0.07/kWh and at \$0.03/kWh for Minnesota. This large variation in supply side avoided costs creates markedly different value propositions for utility incentive programs in each market area. In general, these rates are lower than found in other markets, and so TRC values in other markets may also be significantly higher than presented here.

Table J-5: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	0.29	1.27	0.20	0.80
Xcel Minnesota	0.10	0.44	0.06	0.28

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 (ROB) out scenarios the TRC are higher because the equipment cost used in the test is 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.

Table J-6: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	0.38	1.63	0.20	0.90
Xcel Minnesota	0.13	0.57	0.07	0.32

The total economic potential of energy savings (as filtered by a TRC ≥ 1.0) for each utility partner is presented in Table J-7 (RET) and Table J-8 (ROB).

Table J-7: Economic Potential for RET (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	-	671	-	-
Xcel Minnesota	-	-	-	-

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. Refer to full report in Appendix H for further details.

Table J-8: Economic Potential for ROB (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	-	671	-	432
Xcel Minnesota	-	-	-	-

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 Tables J-9 and J-10. These tables represent the minimum estimated level of savings achievable for a systems based utility programs over a 10-year period.

Table J-9: Cumulative Adoption for RET (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	0/0	159/223	0/0	0/0
Xcel Minnesota	0/0	0/0	0/0	0/0

Note: (lower bound / upper bound)

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

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Xcel Colorado	0/0	10/15	0/0	7/10
Xcel Minnesota	0/0	0/0	0/0	0/0

Note: (lower bound / upper bound)

Overall, the Colorado market's utility rate and potential for system energy savings in the medium and large commercial market is significant, and meets the TRC>1.0 test for program cost effectiveness, and should be considered for incentive program development. As described earlier, while the MN market does not currently meet the same TRC test for this system, technical potential is still significant and the program may be considered valuable to pursue from a portfolio program perspective.