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Integrated Daylighting Systems

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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I. Executive Summary

A. INTRODUCTION

This report summarizes an assessment of integrated daylighting systems (IDS) at 13 Federal building sites in California, Nevada, Illinois, Indiana, and Washington, D.C. These Federal buildings were retrofit between 2009 and 2012 as part of the U.S. government's American Recovery and Reinvestment Act (ARRA).

Lighting is often the single largest end use in commercial buildings and directly impacts heating and cooling, total energy use and load shape so it is an important focus of GSA's energy efficiency programs. Windows and their associated external and internal shading systems help "shape" the quantity and quality of daylight and sunlight entering the building, which also varies with climate, site, orientation and other building parameters. "Daylight dimming" as an electric lighting control strategy is implemented via set point tuning – regulating electric lighting output according to target light levels at the work location – and daylight dimming – allowing electric lights to dim dynamically in response to available natural light. As a result, electric lighting supplements daylight when needed, rather than operating at a constant level. The consequence is a reduction in electric lighting operation, which results in energy savings.

IDS have the potential to save significant energy in the perimeter areas of buildings. This perimeter area is also referred to as the daylit zone, and is defined here as being within the distance of two times the maximum window height from the window wall. Single story spaces can be entirely daylighted with skylights, but were not examined in this study. Other daylighting benefits are more difficult to quantify but include: providing building occupants with a pleasant, dynamic, and more comfortable working environment; and the psychological and physiological benefits associated with a direct connection with views outdoors.

The barriers to implementing IDS cost-effectively are varied and complex:

- As the market for advanced lighting controls that include dimming remains small, project implementation costs remain high.
- Installation and commissioning practices are not straightforward – appropriate resources must be committed to ensure performance according to design intent, to maximize energy savings and return on investment and to meet the requirements of building occupants.
- Appropriate and broadly accepted methods of valuing non-energy benefits of daylight are not currently incorporated into the overall economic cost-benefit analysis, undervaluing the overall proposition of daylight and IDS as a control strategy.
- The IDS at the selected sites utilize photosensors and electronic dimming ballasts to control fluorescent electric lighting, which was the preferred technology at the time of the study between 2012 and 2013. No LED-based lighting systems were measured – the results presented in this report reflect this unintended technology bias and should not be extended to IDS systems comprising LEDs, as the performance characteristics of LED technology are very different in terms dimming range, efficacy, and efficiency – some conclusions, particularly with respect to cost, may change.

B. SITE SELECTION

The participating sites were identified through a multi-stage vetting process. This began by querying a GSA buildings database to identify sites that had the required characteristics (such as windows of appropriate dimensions, low cubicle partitions and advanced lighting controls), and was followed by distribution of surveys to key contacts at potential candidate sites to determine site specifics, and finally completed via direct contact by phone to verify information provided at the various stages. From this, 13 sites were selected to take part in the study.

It is worth noting that this is not the conventional method of selecting sites under the Green Proving Ground. Typically, Green Proving Ground "demonstration" projects match technologies with partner sites, with the aim of demonstrating technical potential under favorable conditions. Here, retrofits were implemented as part of larger refurbishment programs. Had these installations followed the usual demonstration route, lighting energy savings associated with daylight dimming would likely have been greater, for two reasons. Firstly, the calibration and commissioning of the advanced lighting control systems would have focused specifically on optimizing performance of the daylight dimming elements of system operation. Secondly, lessons learned from reviewing early measured data and from review of implementation practices in the field could have been applied to system operations while still in the measurement and verification phase of the study, with resulting performance improvements recorded and included in the final results. Both would likely have further contributed to the compelling case for daylight dimming.

C. TECHNOLOGY EVALUATION

The site assessments comprise two levels of investigation. The first was a photometric characterization of all 13 selected GSA sites, in which light levels were recorded under various lighting output levels and different blinds and shade positions and physical characteristics of the site observed and measured. The second involved long-term monitoring of five of the 13 sites, where light metering and photography equipment was installed in offices, conference rooms and reception work areas to continuously record and log light levels. To measure lighting energy consumption at the five sites, power metering equipment was connected to the lighting circuits that served the study areas. Occupant surveys were conducted post-retrofit to determine building occupants' satisfaction with the lighting system, specifically their work area comfort level and their use of interior non-lighting systems, such as window blinds, impacting the use of natural daylight.

D. STUDY DESIGN AND OBJECTIVES

The aim of this study was to characterize the performance of IDS within GSA buildings and focused on four key objectives:

- From the 13 sites visited, understanding GSA's approach to implementation of IDS, including approach to retrofit interior design and workplace configuration.
- From the five sites at which detailed assessment was conducted, quantifying light conditions, energy savings and occupant satisfaction associated with the daylight dimming elements of the lighting system and understanding their interdependencies.

- Evaluating the costs and paybacks associated with the daylight dimming element of the lighting system at the five sites participating in the long-term monitoring.

- Analyzing the results across sites to provide recommendations for future deployment of IDS technology across the GSA portfolio.

Measured light levels were compared against Illuminating Engineering Society of North America (IESNA) recommendations on lighting levels required to meet visual comfort needs according to space type. These recommendations have been adopted by GSA's P100 Facilities Standards document. Traditional lighting controls use on-off switching for scheduling and occupancy-based control. This study focused on the energy savings made possible in terms of the two dimming control strategies that represent daylight dimming – setpoint tuning and daylight dimming and were compared to the installed lighting power baseline. Occupant satisfaction was assessed through the distribution of surveys to occupants of daylit zones in each of the five assessed buildings.

E. RESULTS

PHOTOMETRIC CHARACTERIZATION

Utilizing both natural and artificial light together, spot measurements taken over a single day indicated that the IDS at 13 sites supported light levels to meet the minimum performance requirements outlined in the P100 (30 foot-candles at the work plane for the office work areas and 10 foot-candles in non-work areas). Provision of task lighting was present at 3 of the 10 office sites, all in private office spaces.

Figure 1: Photometric snapshot results for assessed GSA sites

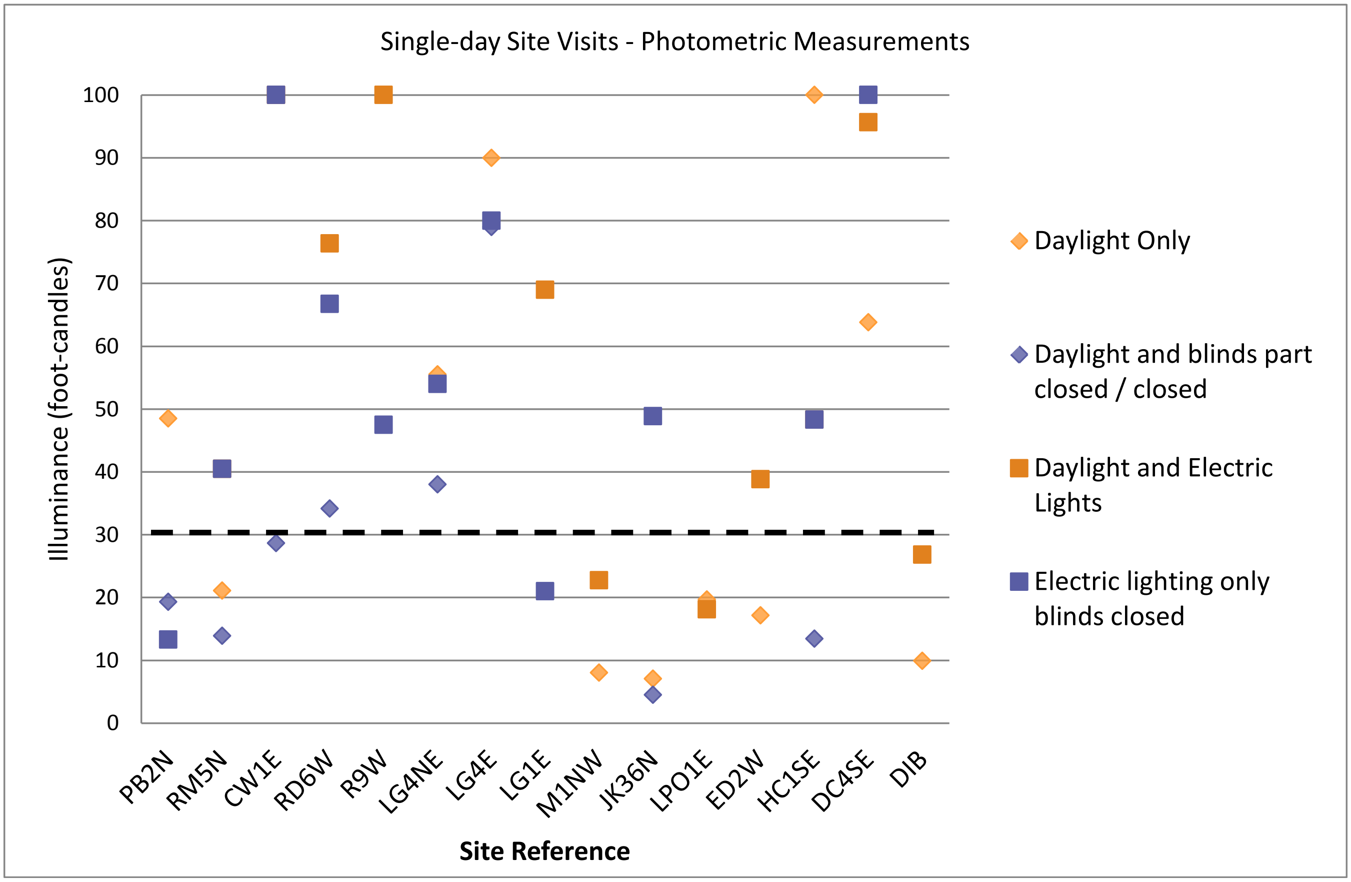


Table 1: Characterization of Photometric Results

	Methods of / capacity to meet P100 Lighting Levels					
Site Reference	Daylight Only (Measured)	Daylight Only (Calculated) Elec Light and Daylight – Elec light	Electric Light Only (Measured)	Unnecessary Electric Lighting (Measured / Calculated)	Default Blinds Position Closed (Offices)	Significantly exceeding P100
PB2N	Yes	-	No	Yes	Closed	No
RM5N	No	No	Yes	No	Part-closed	No
CW1E	No	No	Yes	Yes	Closed	Yes
RD6W	Yes	-	Yes		Closed	No
R9W	No	Yes	Yes	Yes	Closed	Yes

	Methods of / capacity to meet P100 Lighting Levels					
Site Reference	**Daylight Only (Measured)**	**Daylight Only (Calculated) Elec Light and Daylight – Elec light**	**Electric Light Only (Measured)**	**Unnecessary Electric Lighting (Measured / Calculated)**	**Default Blinds Position Closed (Offices)**	**Significantly exceeding P100**
LG4NE	Yes	-	Yes		Closed	No
LG4E	Yes	-	Yes		Closed	No
LG1E	No	Yes	No	Yes	Closed	No
*M1NW**	*No*	*No*	*No*		*None*	*No*
JK36N	No	No	Yes		Lowered / open	No
*LPO1E**	*No*	*No*	*No*		*Closed*	*No*
ED2W	No	No	Yes		Open	No
HC1SE	Yes	-	Yes	Yes	Closed	No
DC4SE	Yes	-	Yes		Open	Yes
*DIB**	*No*	*No*	*No*		*None*	*No*
Totals	6	2	2 (Offices Only)	5	9 (Offices Only)	3

* Non-office sites

Of the 13 sites visited for single-day site assessments, eight sites (offices) were capable of meeting necessary light levels with natural light alone during bright conditions. Of these eight sites, six were observed to support light levels at work locations above the recommended P100 lighting levels with daylight alone, although switching lights off required manual operation of wall switches at all but one site; lights were typically programmed to dim to a minimum light/power output but not switch off. Two of the eight sites were observed to be capable of utilizing natural light sufficiently to not require electric lighting during bright conditions. Lighting control systems at these two sites were not programmed to enable lights to switch off automatically, and had no operable switches to manually switch lights off. An assessment of electric lighting output identified three sites that were significantly over lit[1] – with the window shades closed; light levels were 67, 80, and 113 foot-candles respectively at these sites.

The interior design of occupied spaces varied among observed locations, in terms of office systems and furnishings that impact the utilization of natural light. The default window blind position was partly or fully closed at nine of the 10 office sites. At five of these office sites, the closed blinds resulted in the use of electric lighting where natural light alone would have been sufficient to meet P100 recommended light levels. At two of these five sites, electric lighting without natural light was unable to achieve P100 recommended light levels at the work plane.

A wide range of furniture types were present in terms of specification and color. For instance, in open office areas, cubicle partitions were installed both perpendicular and parallel to the window, were generally greater than 3 feet in height, and were medium-to-dark in color. This impacted the penetration and distribution of natural light, as the partitions channel (perpendicular) and block (parallel) light from the windows and the darker partition surfaces absorb natural light rather than reflecting it.

Of the 5 sites participating in the long-term monitoring portion of the study, data from 4 of them confirmed that over the course of the monitoring period, light levels measured at the work plane achieved or exceeded the IESNA recommended minimum, although in some cases electric light was the predominant source and in other buildings it was daylight, depending on design details.

Cross-referenced work plane light levels and external light level data, photographs of blinds position and lighting energy data showed that four sites were not making best use of available natural light and were consequently over-reliant on electric lighting.

ENERGY SAVINGS AND COST-EFFECTIVENESS

Energy savings and cost-effectiveness were assessed for five of the 13 sites in which long-term energy monitoring equipment was installed. The IDS at the five study sites, realized energy savings from a combination of daylight dimming (automatic modulation of light output in response to prevailing natural light conditions) and setpoint tuning (the maximum set light level assuming no natural light, and the level that lights switch on at). The installed lighting power density (LPD) varied by +/- 20% from the average across the sites, but was not the determining factor in energy savings. Average annual energy savings for IDS across the five sites was 1.35 kilowatt-hours per square foot.

At 3 sites, the energy savings emphasis was on daylight dimming – this can be attributed to less aggressive set point tuning and relatively well calibrated system operation. For the other 2 sites, setpoint tuning contributed greater energy savings than daylight dimming – demonstrating an aggressive approach to setpoint tuning and targeting a low operating LPD. In particular, the Ronald Dellums site, the dimming performance is heavily skewed towards implementation of setpoint tuning at a very low level, providing less opportunity for additional savings from dimming. The consequence is that daylighting dimming is less cost-effective than tuning plus dimming - energy cost savings from dimming are relatively low compared to the

[1] Assumed here to be 60 foot-candles, double the IESNA recommendation of 30 foot-candles.

cost of equipment, whereas tuning energy cost savings are relatively high, offsetting more of the equipment cost.

Energy savings from installation of LED-based systems overall would be greater, due to the significant reduction in installed lighting power density. Energy savings associated with daylight dimming would likely be significantly lower for the same reason – with less installed power these is less scope for power reduction through dimming.

Table 2: Lighting energy use and the energy saving impact of IDS control strategies

Site (FB – Federal Building, CH – Courthouse)	Installed lighting power density (W/ ft^2)	Setpoint tuning savings (kWh/ft^2/yr.)	Daylight dimming Savings (kWh/ft^2/yr.)	Total IDS energy savings (kWh/ft^2/yr.)	Simple payback (yrs.) daylight dimming *(tuning plus dimming)*	SIR daylight dimming *(tuning plus dimming)*
Ronald Dellums FB	1.74	1.1	0.3	1.4	17.6 *(10.9)*	0.63 *(1.03)*
Roybal FB	1.62	0.7	1	1.7	4.3 *(8.7)*	2.61 *(1.29)*
Cottage Way FB	1.35	0.3	1.1	1.4	4.9 *(10)*	2.3 *(1.12)*
Hammond CH	1.51	0.4	0.3	0.7	13.9 *(23.9)*	0.8 *(0.47)*
Dirksen FB	1.9	0	1.6	1.6	6.26 *(23.8)*	1.79 *(0.47)*
Average	**1.62**	**1.35**		**1.36**	**10** ***(15)***	**1.63** ***(0.88)***

Energy savings from daylight dimming resulted in an average payback period of 10 years. There was a broad spread in payback across study sites, ranging from 4.3 years to 17.6 years. For setpoint tuning and daylight dimming combined, average payback was 15 years, ranging from approximately 9 years to 24 years.

The assessment of cost-effectiveness was undertaken using the savings investment ratio (SIR) metric, where the implementation costs of the new systems are assumed to be paid off by the energy cost savings arising over the lifetime of system operation and from which a value equal to or greater than 1 indicates cost-effectiveness. Assessment of cost-effectiveness for daylight dimming indicated an average SIR value of 1.63. For setpoint tuning and daylight dimming together, the average SIR value was 0.88.

Initial costs (equipment, installation and commissioning) varied significantly across study sites and were a key factor in determining payback and cost effectiveness at all sites. One leading industry vendor has suggested that the current total installed cost of their advanced lighting control systems based on the use of fluorescent lamp technology (for systems that support setpoint tuning and daylight dimming) range from $0.50-$4.00 per square foot of floor space[2]. At the low end of this cost range (less than $0.77 per square foot), all the assessed sites would be cost effective, achieving an SIR equal to 1, whilst at the high end (greater than $2.28 per square foot) none of them would be. Comparing the assessed sites that are currently operating cost-effectively, the IDS becomes cost-effective at an installed cost of approximately $2.00 per square foot. For daylight dimming, sites that are currently operating cost effectively become so at an installed cost of approximately $1.40 per square foot.

As daylight dimming energy savings and costs for LED-based systems are different, paybacks would also be different – this study does not include any estimates of energy savings or resulting paybacks for LED-based fixture systems. While the fixtures are likely to be more costly, the dimming controls should be cheaper so cost and payback data will vary and will continue to change over time as systems mature.

Utility rates proved to be critical in determining cost-effective operation – utility rates for sites participating in the long-term monitoring study range from $0.08 - $0.13 per kilowatt-hour. At the time of writing, the average US electricity price for commercial customers was approximately $0.10 per kilowatt-hour. Assuming that this rate was applied to all sites with the initial costs associated with daylight dimming alone, three out of five sites would be cost effective; assuming full installation costs (for setpoint tuning and daylight dimming); one of the five monitored sites would be judged to be cost-effective.

The HVAC savings associated with reduced lighting operating hours were not evaluated in this study, and are therefore not reflected in the results for energy savings or cost effectiveness. AAs a general trend, reduced electric lighting consumption from the use of daylight control strategies should reduce the internal loads in the space, thus increasing heating season energy use and decreasing cooling. But specific numbers will vary with the many types of HVAC systems and control details and are beyond the scope of this study.

OCCUPANT SATISFACTION

Occupant satisfaction was assessed at the five sites participating in the long-term assessment. Results of the 22 question survey indicate that satisfaction with lighting and visual comfort of work spaces varies significantly, with a range of perceptions within individual sites and with differing degrees of overall occupant satisfaction across sites. The results suggest that the level of satisfaction relates to the presence of absence of available personal lighting controls, an inconsistent approach to occupant engagement by management and issues of incomplete commissioning of the control system. The surveys also report that more could be done to improve overall visual comfort levels. In examining the negative perceptions of the

[2] This cost range comes from 'Monitoring lighting energy savings from dimmable lighting controls in the New York Times Headquarters Building', (2013). It reflects vendor perspectives of costs due to the wide range of building characteristics that determine density of infrastructure, complexity of installation and other factors such as local labor rates.

lighting systems overall, performance of the IDS aspects (*e.g.* active dimming and impact of window blinds/shades operation) were among the least important elements contributing to dissatisfaction. Occupants were generally satisfied with their light levels at all sites. Where they were not satisfied, feedback was consistent in terms of three primary reasons: 1) with lighting being too dim, 2) absence of task lighting and 3) a perceived lack of influence over light level settings for ceiling-mounted fixtures. Occupants' feedback on the availability of lighting controls indicated similar sentiments. While the majority expressed satisfaction, over 45% (55 respondents) stated that the current arrangements did not meet their needs. These results may reflect a mixture of two different concerns: in some cases the lack of availability of suitable control options, and in others a lack of proper communication to occupants of what those options are and how to use them.

PROJECT IMPLEMENTATION

Interviews with project managers and facilities managers at three sites where commissioning of daylighting controls was completed by a third-party commissioning agent of record revealed a high level of satisfaction. Operational satisfaction was generally assessed in terms of completing key activities with little to no rework, and providing a full and transparent documentary record, consisting of a commissioning report, system operating manuals and a list of operational settings and protocols. However, when entities other than third party commissioning agents (e.g. control systems vendor, electrical contractor or GSA operations teams) completed commissioning tasks, the satisfaction rate was lower, due mainly to insufficient documentation provided at handover. This absence of documentation could compromise operations and future maintenance tasks and the ability to maintain proper system operation that supports persistence of energy savings according to design intent.

According to facilities staff at the 13 sites, building occupants were generally unaware of the lighting options available to them in terms of setting their local electric light levels. Only occupants of private offices were provided with manual controls for switching or adjusting their overhead lighting.

At present, the approach to system operation and maintenance varies across sites. Some managers rely on system warranties and vendor staff to complete maintenance tasks, while others have resident trained operations and maintenance teams to monitor and troubleshoot system issues.

F. LESSONS LEARNED AND RECOMMENDATIONS

Daylighting, or "integrated daylighting systems" as discussed here, has been specified and implement for many years as a design and energy saving strategy, although often with mixed success and outcomes. A small number of buildings are described in magazines and conferences with limited performance data suggesting that the energy savings potentials are real. But the very slow progress nationally toward producing larger and more reliable energy savings as part of visually comfortable work environments motivated GSA to examine some recently renovated buildings where the lighting and daylighting retrofits were undertaken as part of a broader renovation and efficiency program, without an explicit focus on deploying IDS. This study reveals a range of lessons learned from this implementation of IDS, which will help inform future efforts to enhance GSA workspace and meeting agency energy saving goals. These include:

- Greater focus on the end-user experience of lighting system operation is needed. To achieve high levels of occupant satisfaction with IDS and lighting systems, it is important that occupants a) understand how to utilize their lighting system and b) have access to thoughtfully designed systems that are responsive to their visual needs. As a matter of course, occupants should be engaged in the retrofit process, educated about their new lighting systems and trained on how to use them effectively to support their own performance and comfort requirements. Providing enhanced lighting controls to building occupants is one of the best routes to improving occupant lighting satisfaction, and may lead to greater energy savings. Dynamic dimming of electric lighting appears to enhance occupant satisfaction with overall lighting system performance.

- Commissioning IDS can be complex. As such, a thorough, well-documented commissioning process is essential to providing a control system that matches owner intent, operates effectively, and can be maintained over time. This includes training for operators and occupants to support effective use of the system and an understanding of its benefits. To help achieve this, it is suggested that an experienced third party commissioning agent be engaged as an observer early in the project development process. This will ensure a robust critical assessment of the implementation process and is more likely to identify potential performance issues early. Employing a third party agent for this task helps prevent the use of product-specific language and jargon that can make commissioning handover documents difficult to interpret and understand.

- Stipulate that all lighting and daylighting management control systems installed in GSA buildings should be accessible to and usable by the building operator. The lighting control system user interface should be simple and clear for use by trained operations and maintenance staff. The control system should produce sufficient real-time reporting of energy consumption by building zone so that the Facilities Management team or owner can track performance results on a continuous basis and assist in diagnostics when faults occur.

- Identify the preferred approach to operations and maintenance (*e.g.* trained in-house resources, subcontracts, or contracts with the product vendor). Current arrangements vary by site, with each of the above options having benefits and drawbacks. However, the most effective way to leverage the benefits of each option is to adopt it to the exclusion of the others. In doing so GSA would increase the cost-effectiveness of procurement (in the instances of subcontracts or vendor contracting), increase the value-added from resources provided for training and career progression in facilities and operations (where utilizing trained GSA personnel), contributing to a sharpened focus and increased capacity within GSA to continuously improve in this area.

G. CONCLUSIONS

As GSA strives to comply with mandated targets to reduce energy use intensity and Green House Gas (GHG) emissions, the demand to find innovative technologies that can deliver significant whole-building energy savings will grow. This study demonstrates that overall, integrated daylighting systems have the technical ability to achieve significant lighting energy savings while providing comfortable light levels and occupant satisfaction.

The results suggest that if the criteria for deployment were strictly to achieve energy and GHG reduction, irrespective of payback, IDS could be applied effectively in most buildings in every GSA zone and region. However, this study also shows that while lighting energy savings of approximately 28% over baseline conditions could be achieved for different office space types, these savings could not always be achieved cost effectively, even when coupled with relatively high utility tariffs of over $0.12 / kWh. With a nominal payback period of less than 10 years as a criterion, two studied spaces proved to be cost effective – one open office space and one private office. In these locations, IDS delivered 34% and 40% lighting energy savings and payback periods of approximately 8.5 years and 10 years, respectively. Other systems had either higher costs or lower savings and did not meet the 10 year target.

The IDS studied here were deployed in a range of space types, including non-work areas, controlled by a lighting management system manages and responds to photosensor input, and also utilized other non-daylight related advanced control strategies such as time scheduling and occupancy sensing. For deployment across GSA offices and other space use types, Integrated Daylighting Systems are best implemented at the zone level (e.g. open work areas containing multiple occupants with similar daylighting access), as this reduces unit equipment and installation costs and as a result of operating at the zone level, reduces the impact of occupancy / vacancy on the cost-effectiveness of system operation. The requirements of intelligent IDS should always be a design consideration when light fixtures, lighting controls, glazing and shading, and ceiling grids are being renovated or refurbished.

Other recommendations for design and operation of IDS include:

- Lighting may either be programmed to turn off when natural light is sufficient, or dim to a minimum. The former saves more energy, the latter results in longer lamp life. Occupant attitudes to both strategies vary by site, although switching lights on and off is widely reported as being distracting. When implementing a control protocol that switches lights off completely, lights should be dimmed to minimum setting and remain at this minimum continuously for a period of time (i.e. 5 mins) to ensure that lights are not turning on and off in response to unstable ambient light conditions (such as a cloudy sky).

- To maximize cost-effectiveness of controls and capture the largest energy savings, perimeter areas of buildings should be devoted to open office area designs and be staffed by high-occupancy workers.

- Lighting controls in IDS must be carefully calibrated in order that electric lighting operation is effective and efficient, and so that occupied spaces are not overly bright.

- Operational resources should be allocated to monitoring lumen output of fixtures, periodically test photosensor calibration and operation and correct drift, and cleaning sensors to maintain design operation.

- For implementation of IDS in private offices, an assessment of occupancy is recommended as a precursor. When occupancy rates are low, a simple occupancy switch with on-off control may be the most cost-effective solution, although the IDS energy savings may still be high. Dimming may still be desired for tuning purposes and can capture daylight-related energy savings. As lights in open office zones will be activated by the presence of single occupants, overall occupancy levels are less important in determining dimming savings in these spaces. However newer controls that can provide controllable workstation-specific lighting can provide light only when and where needed.

- Cost-effectiveness is improved by having individual photosensors control multiple fixtures since this will minimize materials and labor cost. There may be more opportunity for this in open office spaces than private offices as the floor areas that may reasonably be controlled by a single sensor are larger. In principle, for a west facing building with no nearby obstructions, it is conceivable that a single photosensor could control a row of light fixtures to a depth of 15 feet from the window, as long as shading is treated uniformly in the perimeter zone. The optimum ratio of sensor to fixtures is likely varied from location to location, depending on building characteristics and will change as new fixture integrated controls and wireless sensors capture more market share.

With careful planning, design, and implementation, Integrated Daylighting Systems can offer a cost-effective opportunity to reduce lighting energy in GSA buildings. As noted in the analysis, the building specific answers are dependent on the design of the existing lighting and control systems, the occupancy of the space, local electricity rates and other factors. A significant proportion of energy savings at 4 of the 5 monitored sites came from setpoint tuning, where the existing lighting system design allowed for significantly higher light levels at the workplane than those stipulated in P100 – reducing the light output with dimming control was part of meeting the required light levels, and also delivered energy savings versus maximum rated output. Where setpoint tuning is not necessary to achieve desired work plane illuminances, (such as the system at the Dirksen site), these additional savings will not occur and so IDS systems in these settings may have lower cost-effectiveness. It is therefore recommended that a policy of targeted deployment be adopted for potential retrofit projects, where existing lighting power density, light levels, and energy use intensity are high.

For whole-building modernization and new construction projects, the net costs associated with implementing IDS would be lower due to the incremental cost increase of including IDS in an advanced, integrated lighting control system with dimming. As the market for advanced controls matures, as LEDs have more market impact, and as wireless controls replace wired systems, it is anticipated that the marginal cost of materials and labor will be reduced. Consequently, IDS should be considered for implementation in all future new GSA buildings.

To support effective use of natural light, attention should be paid to the design, interior floor plan, furniture and partitions, and occupant behavior in day lit spaces. Glazing type, window size and location, shading system type and controls all influence daylight performance. Use of natural light is enhanced where occupants are motivated to adjust blinds regularly, either through training and education, or by resetting them to the open position periodically – activity that could be carried out by a maintenance or cleaning crew. GSA could also consider more widespread use of IDS-integrated automated shading to address this issue – since reliable dynamic shading allows natural light to be better utilized. Light colored furnishings and diffuse reflective wall surfaces enhance daylight use by reflecting light within the space. The height of cubicle partitions should be limited to three feet in height and ideally installed perpendicular to the window, although higher partitions with clear or translucent elements at the top can provide privacy and daylight. Finally, cost-effectiveness will improve as the market for advanced lighting controls continues to grow, pushing down equipment costs, and making contractor knowledge of implementation practices more widespread, and also reducing installing costs.

The high granularity of control inherent in the newer advanced lighting controls system provides additional opportunities for energy savings beyond those studied here. Data from occupancy sensors, particularly when associated with a workstation-specific lighting layout, could inform other systems (*e.g.* HVAC, ventilation to direct less air to unoccupied spaces). Since lighting accounts for 26% of electricity use in commercial buildings[3], control systems could also be programmed to coordinate with building level EMS and be involved in demand response events and other electric load management strategies in response to time of use electricity rates.

Finally, although it is less easy to quantify, a well daylighted space that provides view, some variation in light levels and color temperature, provides daylight to offset electric light without glare, are all desireable features for all new and existing GSA buildings.

[3] U.S. Energy Information Administration (EIA), available at http://www.eia.gov/emeu/cbecs/cbecs2003

II. Methodology

A. TECHNOLOGY DESCRIPTION

IDS represent a subset of technologies that may be installed as part of a comprehensive lighting and lighting controls package, and comprise the following equipment:

- A Lighting Management Control System (LMCS) that coordinates sensor information and building operations staff input to control and monitor lighting output and energy use.
- Digital dimming ballasts or LED drivers that control power to the luminaires in response to signals received from the photosensor and according to specified, pre-set light levels programmed into the LMCS.
- Photosensors that provide electronic signals to the ballast or drivers to control light output, allowing lights to adjust according to the availability of natural light.

The systems assessed in this study consisted entirely of fluorescent lamp-based lighting and lighting controls. As such the results should be interpreted as applying only to this technology, although the broader conclusions and recommendations also apply to IDS implemented in LED-based lighting systems.

In general, implementing IDS as part of an advanced lighting control system provides the opportunity for greater control over light levels. This added control may also provide greater comfort for occupants for the workspaces served in addition to economic savings from reduced electric lighting use.

Traditional lighting systems utilize manual switches or simple on-off scheduling controls. Occupancy sensors can either be used to control large zones within buildings, or sometimes, as with workstation-specific lighting, will control light operation according to occupancy of a single workspace. IDS provides an added capability: for set point tuning, allowing light levels to be set according to the preferences of occupants of building zones or offices and for daylight dimming – the active response from the electric lighting to existing natural light conditions, so when there is an abundance of natural light, electric light output can be reduced down or switched off. Through this operating mode, IDS reduce or eliminate the power requirements from lighting when it is not needed: this operation is what provides the energy savings.

The daylighting system operates through one-way communication from the photosensors to the electronic ballasts or drivers; signals sent from the photosensor indicate the light levels in the space. The calibrated light levels programmed into the LMCS and communicated to the ballast provide a reference against which the ballast controls power input to the light fixtures. When photosensor readings are higher than the LMCS setting, power to the lamps is reduced; when they are lower, power is increased. Photosensors initially are calibrated by exposing them indirectly to a range of light levels - typically once at night to set the minimum electric light baseline and again during the day to determine the daylight level that renders operation of electric lighting unnecessary. Using these calibration levels, plus possibly some intermediate settings, sensors can provide accurate signals to the ballast to vary power to maintain a programmed light level.

The sites assessed as part of this study had a range of fixtures, ballasts and lighting control systems. The majority of sites had recessed 2-by-2 troffers or 2-by-4 troffers containing two lamps and operated by a single outboard (not integrated into the fixture) ballast. One site had a combination of recessed troffers and occupant responsive pendant fixtures, the latter being located above the workspace. The pendants also comprise an integrated occupancy sensor and photosensor and are controlled by two inboard (integrated into the fixture) ballasts, one controlling the two lamps that provide the workstation task lights and one controlling operation of the ambient lighting lamp. One site had surface mounted troffers containing a single lamp each, operated by a single outboard ballast. For the ceiling troffers, photosensors control small lighting zones, typically between two and six light fixtures. For the pendant fixtures, the photosensor controls all lamps in the fixture.

Typically, primary control of lighting fixtures was by occupancy and then lamps would dim to reflect available daylight levels. In private office spaces, however, manual switches both activated the lights and provided an override to the occupancy sensors. Once the lights are activated, light output is controlled by signals from photosensors. Further details of fixtures and controls, including pictures of onsite examples, can be found in Appendix A.

BACKGROUND

Lighting accounts for 26% of the electricity used by commercial buildings in the United States and represents a large potential source of energy savings[4]. In the past several decades, energy savings typically have been achieved through widespread deployment of more efficient lamps and ballasts. Over the past five years, integrated daylighting systems have become commercially available from both industry leaders and startup companies. So far, they have achieved negligible market penetration in US commercial buildings and are a significant and largely untapped energy savings strategy[5]. Greater awareness of the available energy savings, the tightening of building codes and the advent of LED-based lighting systems for commercial buildings means that this is likely to change.

This study was designed to evaluate IDS through assessment of the photometric performance, energy savings, and occupant satisfaction associated with the technology and by isolating its performance from the other control strategies commonly utilized.

Implementation of IDS is a logical step in lighting control good practice as it accommodates the dynamic nature of natural light and takes advantage of its significant contribution to the illumination of a space. Lighting controls adjust for this natural light variation by controlling power to the electric lighting. The reduction in input power below that required to meet design light levels in the absence of daylight represents an energy saving.

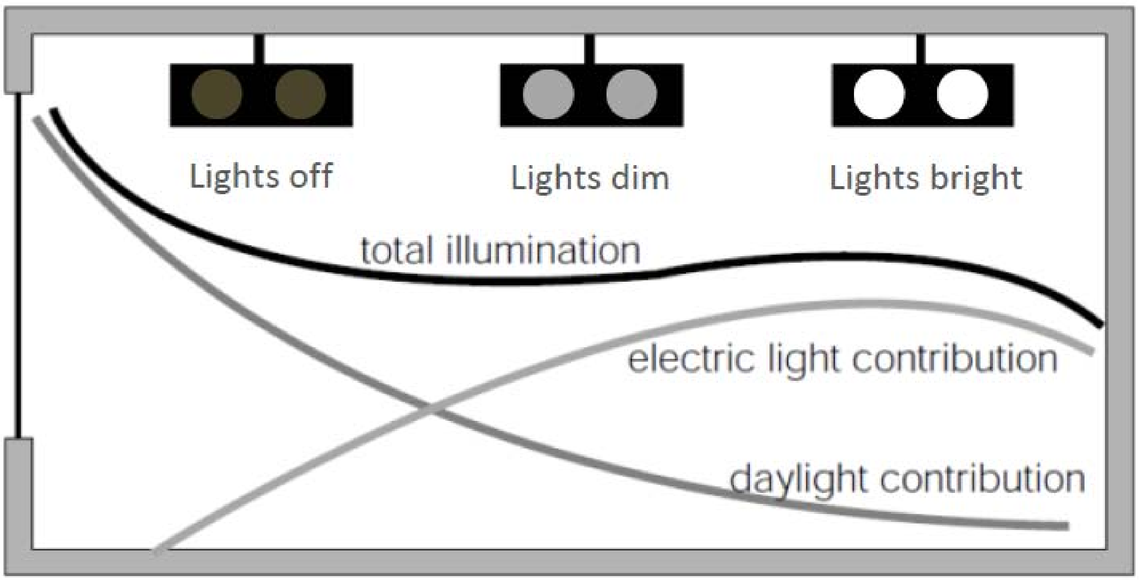
Ideally, IDS should operate so that the occupant experiences a near constant light level at the work plane, regardless of the proportion of light coming through the windows and from the electric lights respectively. At the same time, the change in electric lighting levels should barely be perceptible, so as not to be disruptive to concentration or to result in eye fatigue. In achieving these two objectives, it should provide

[4] Buildings Energy Data Book: 3.1 Commercial Sector Energy Consumption, available at http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/3.1.4.pdf

[5] Williams, A; Atkinson, B; Garbesi, K; Page, E; Rubinstein, F (2012)

the occupant with the appropriate light levels for their task.[6] Figure 2 illustrates the concept of the interaction between natural light and electric light at various distances from the window.

Figure 2: Section diagram of the day lit zone and use of electric lighting



In order to be deemed as achieving visual comfort, light levels incident at the work surfaces generated by IDS must be sufficient to allow people to perform their tasks safely and comfortably. Ambient lighting should also support visual comfort so that the occupants' eyes do not become fatigued by contrast between the workspace light levels and the light in their immediate local area. The Illuminating Engineering Society of North America (IESNA) recommends that office work locations have an average illuminance lighting level of approximately 30 footcandles.[7] This guidance is now reflected in GSA's P100 design guidance (the target illuminance level is 30 footcandles) and therefore is the benchmark against which sites are measured in this study.

MANUFACTURER CLAIMS

Forecasting energy savings with any accuracy for lighting systems is only possible once the site proposed for installation has been assessed. There are numerous factors that influence the energy savings that may arise from implementation of lighting control strategies and as a result vendors tend to a) estimate an energy savings range or a reasonable estimate for energy savings potential for the systems that they install and b) often indicate savings on the basis of performance of the integrated system, rather than for individual control strategies which it incorporates.

[6] This will vary by occupant, location relative to the window, and task type; thus, providing occupants with the facility to set light levels for their work space should be considered. Adoption of this approach is likely to deliver energy savings in and of itself.

[7] The Lighting Handbook, 10th Edition (Table 32.1, Reading and Writing)

Energy savings potential for daylighting varies and has been measured within a range of 40%-80% daily savings, based on the time of year and orientation with annual averages as high as 40%-50%. Daylight savings are typically estimated to be between 20%-60%[8] of lighting energy, and normally assume that daylight dimming is only a portion of an integrated lighting control system. However, vendor literature and marketing materials are careful not to imply that such savings are guaranteed – the tone of the material is focused on the "how" and not the "how much" – as suggested above, an estimate of energy savings is entirely dependent on local and building specific characteristics and therefore can only be determined upon detailed investigation of the site.

PREVIOUS STUDIES OF DAYLIGHTING

The following publications represent a small but significant portion of work completed in the study of daylighting design, and are important reference documents for this report.

- *Tips for Daylighting* (2013), Lawrence Berkeley National Laboratory
- *Daylighting Buildings in the 21st Century* (2006), International Energy Agency
- *Sidelighting Photocontrols Field Study* (2005), Heschong Mahone Group,
- *A Source Book on Daylighting Systems and Components* (2000), Lawrence Berkeley Laboratory
- *Automatic Lighting Control Demonstration: Long-term Results* (1991), Lawrence Berkeley Laboratory

MARKET ADOPTION

Currently the scope for adoption of IDS in the U.S. appears promising, although as described above it is likely to be one of a number of control strategies adopted as part of an integrated lighting design. Whether it becomes common practice to assess the effectiveness of each individual control option of these integrated systems remains to be seen, although feedback from facilities managers suggests that vendors currently offer all-inclusive packages without quantifying the cost effectiveness of each of the constituent parts. This is partly a result of the proprietary nature of integrated lighting control systems. Manufacturers build software and hardware platforms around one another; end users are often able to access only the overall lighting savings that arise from the whole system rather than a report of the cost-effectiveness of each separate control strategy. There are likely a number of reasons for this, chief among them that end users may not know what to do with this information were it provided. Greater flexibility of software would allow vendors and users to tailor data queries to meet their needs. To improve design and operating practice and consequently increase deployment, this level of sophistication in monitoring and reporting is encouraged here.

The recent rapid evolution in the lighting industry has seen LEDs emerging as a cost-effective alternative interior lamp technology, disrupting the commercial building lighting market and threatening to displace fluorescent systems. This change heralds significant uncertainty in terms of the future of systems based on fluorescent tubes and their cost – for instance, will manufacturers continue to fund further development of

[8] Williams et al, (2012). *Lighting Controls in Commercial Buildings.*

electronic ballast technology or will they direct commitment towards development of LED-compatible alternatives? More generally, it remains to be seen whether the arrival of LEDs as an alternative to fluorescent lamps will be a catalyst for installing lighting controls in commercial buildings. Regardless of the technology responsible for emitting the photons, indications are that any replacement of a commercial building lighting system will leverage installation of controls, as incremental costs of including them in an installation are marginal and the benefits potentially significant. Furthermore as Codes and Standards continue to tighten, the inclusion of controls in lighting systems designs will become commonplace.

RISKS

The greatest risks associated with IDS are the same as those for most building energy systems – the variables that affect their overall value proposition. The most fundamental risk would be where building occupants do not find the environment created by the dimming systems sufficiently comfortable for working – the ultimate recourse for action in this instance would be to deactivate the daylight dimming control strategy.

Other risks are associated with the technical performance of the system and variation in the economics that underpin its cost-effectiveness (or otherwise):

- Occupant behavior increasing electric lighting operation and reducing energy savings (*e.g.* blinds/shades closed)
- Fluctuations in local energy prices
- Poor lighting / daylighting design
- Inadequate glazing type, glazing area to admit sufficient daylight
- Inadequate sun control and glare control to manage direct sunlight and bright skies
- Occupant behavior reducing energy savings (*e.g.* blinds closed, task lighting)
- Poor commissioning before and after installation
- Poor maintenance , poor training
- Not engaging occupant needs

BARRIERS

The main barriers to implementation of IDS are the current low market penetration of integrated lighting control systems, reliable installation and commissioning of the systems, and the perception of initial costs of implementing lighting control being too high.

- Overall equipment costs are relatively high mainly due to the high prices of dimming ballasts – these items are currently a relatively low volume, custom product, but as take-up increases unit costs will come down. Future cost reductions of ballasts may be limited if the lighting industry invests more heavily in LED-based systems.

- Installation and commissioning costs are high because many contractors do not have experience with these systems. Daylight dimming control is inherently dynamic; consequently set-up, calibration, and commissioning is a complex exercise requiring multiple iterations and careful attention to detail. Improved sensors and wireless communications links will improve the installation and commissioning process. Only better training and greater experience with the technologies and good practices will improve effectiveness of teams implementing these projects.

- The perception of implementation cost being too high arises in part due to the two points above, but also the unrealistic expectations on payback from energy cost savings alone. Oftentimes, lighting system upgrades are associated with refurbishment programs, in which alternative options are assessed – under this framework, advanced lighting controls (including IDS) are likely to be a very attractive option.

Another significant barrier is the absence of an economic value that can be reasonably and consistently applied to the non-energy benefits of daylight. Some research suggests there are both physical health benefits associated with natural light, as well as psychological and productivity benefits but the literature is not definitive on this regard and there is little direct causal information that directly links design decisions to outcomes. Views from glare free windows are highly desirable office attributes but hard to quantify in value. Given that occupant salaries far exceed energy costs in all buildings this could provide an added economic rationale for ensuring that good daylighting is installed in buildings.

B. TECHNICAL OBJECTIVES

The objectives of this study were to characterize and understand the performance of IDS within GSA buildings and to assess the impact of building design on the use of natural light in place of electric lighting.

The study focuses on four key elements:

- Quantifying and understanding the energy savings, light conditions, and occupant satisfaction associated with the IDS elements.

- Evaluating the costs and paybacks associated with the daylight dimming elements of the lighting system.

- Assessing the project development, design and implementation process for IDS projects.

- Analyzing the results across sites to provide recommendations for future deployment of IDS technology across the GSA portfolio.

This necessarily involved undertaking a broad characterization of GSA buildings with regard to daylight design, in addition to a more detailed analysis of a smaller site sample from which more substantive, detailed results and conclusions could be drawn.

C. METRICS BEING MEASURED

The method adopted in this study with regards to site analysis was to complete a number of single-day site assessments to help select sites for further study and conduct deeper, long-term analysis at a subset of these sites. For the single-day site visits, in addition to the visual assessment, the only quantitative assessment carried out was for photometrics. A structured question and answer exercise was also conducted with the Building Manager, Lighting Project Manager or equivalent. For the long-term analysis at five selected sites, analysis of energy consumption, cost-effectiveness and occupant surveys were also completed.

PHOTOMETRICS

The objective of IDS is to maintain adequate light levels and acceptable lighting quality for building occupants, irrespective of whether the dominant light source is natural daylighting or electric lighting. Measuring light levels at or adjacent to the workplane and comparing this to the stated target light levels provides insight as to how successful the interaction between daylight and electric light is in meeting the illuminance requirements. Light levels are measured in the horizontal workplane at various distances from the window wall and at workstation locations. Additional measurements were made on vertical surfaces to better understand glare conditions and light distribution.

To provide lighting conditions that are supportive of most office work, values for horizontal illuminance should achieve the IESNA recommended level of 30 foot-candles at the work plane in office spaces and above 10 foot-candles in lobby and cafeteria areas. The assumption used in this study is that exceeding illuminances of 30 foot-candles while electric lights are operating may constitute a missed opportunity for energy savings.

ENERGY CONSUMPTION

Lighting power consumption and its variation according to available natural light revealed the patterns of lighting energy use in the measured day lit zones. By comparing actual energy consumption with that according to the preset maximum lighting output, energy savings were calculated for the monitoring period.

Preset light output levels were programmed into the lighting control system to provide a maximum power input / maximum light output threshold level for the electric lighting. The power requirement that achieves these preset levels will vary from site to site, and would have been to meet light levels specified by the P100 lighting guidelines, the tenant or the occupants of the lighting zone.

COST EFFECTIVENESS

The economic performance of the five long-term monitored sites was assessed using equipment and labor cost inputs for each installation where this information was available, local blended utility prices, and assumed energy cost reductions from energy savings offset implementation costs. In the absence of detailed site-specific information, assumptions have been used to derive cost estimates, typically on a dollar per square foot basis.

It should be noted that cost inputs typically reflect bid project costs that are several years old – this is particularly relevant to equipment costs which have been reduced as volume sales increase and technology state-of-the-art improves.

Cost effectiveness is measured here using three different methodologies: simple payback, savings investment ratio (SIR) and life-cycle cost (LCC).

OCCUPANT PERCEPTIONS OF LIGHTING SYSTEMS

The objective of installing a new lighting system is to create a safe and comfortable working environment for occupants. To measure their perspectives on the new systems, a survey containing questions on the various aspects of IDS revealed which elements of implemented projects were successful and which less so, from an occupant point of view. The questions focused on identifying how lighting is provided, the means of lighting and shading control, and specific questions on workplace lighting conditions.

D. DEMONSTRATION PROJECT LOCATIONS

The project locations were identified through a multi-stage vetting process. The first step was a detailed review of a GSA buildings database which contained details on the type and locations of installed systems and components within a large sample of GSA buildings.

Using the classification of IDS as described above (lighting systems that contained both photosensors and electronic dimming ballasts), 96 buildings were identified, and were scheduled to complete installation prior to the start of the study data collection period in April 2012.

The database analysis was followed by identifying key contacts at the 96 selected sites and distributing a preliminary online questionnaire, containing questions on basic site characteristics and requesting points of contact relating to the lighting systems. The responses to the first questionnaire provided a certain amount of self-selection from the sites –replies were interpreted as a willingness to engage further in the study, whereas no responses were interpreted otherwise. Finite project resources dictated that focus be devoted to those that responded, so from this initial ‘expression of interest’ a second, more detailed survey was distributed, focused on overall building characteristics and also containing specific questions regarding the building systems that relate to daylighting, such as windows, blinds and shading, and lighting controls. There were 40 responses to this survey in total. The final step in the screening process was a verification phone call to each of the 40 sites, during which the site main point of contact was asked several key questions: these reflected the need to confirm key details provided in the survey responses and to seek agreement / permission to undertake a brief site survey. The questions pertained to access to the building, permission to take photographs, permission to distribute occupant surveys and describing what the work would entail to the key contact.

Site selection for the study was based on effective use of project funds: which geographical locations were convenient and cost-effective to visit. The selected sites were either a) relatively close by or b) were part of a cluster of sites that could be visited during a single trip. On that basis, sites in California, Nevada, Chicago, Hammond, IN, and Washington DC were selected as the most appropriate.

III. M&V Evaluation Plan

A. FACILITY DESCRIPTION

The sites assessed as part of this study varied significantly in type and characteristics: entrance lobbies, conference rooms, private offices, open plan offices and reception work areas all were represented.

Site assessments were carried out at 13 different buildings in total. Five of these sites were revisited to install equipment that would continuously collect lighting and power data. Where possible, the IDS assessment was conducted in locations that were broadly representative of the majority of day lit areas.

As this study is concerned with how daylight is utilized as an alternative to electric light, the focus of assessment is on building perimeter areas, characterized here as the zone within the distance of two times the ceiling height from the window. Daylight rarely provides significant illuminance beyond this distance from the windows. In most sites, this was a maximum of 20 feet from the window to the rear wall; occasionally it was little further. One major exception was the lobby location in the Metcalf Federal Building in Chicago. This was a deep zone, as the windows extended from the floor to the 27 foot-high ceiling.

For the photometric characterization, measurements were taken at a minimum of one workspace and at a maximum of four work locations. This depended on the representative area type (i.e. private office or open office) and where access was granted for the site visit. This approach led to relatively focused study areas, with the exception of the largest study area which was approximately 1,000 square feet.

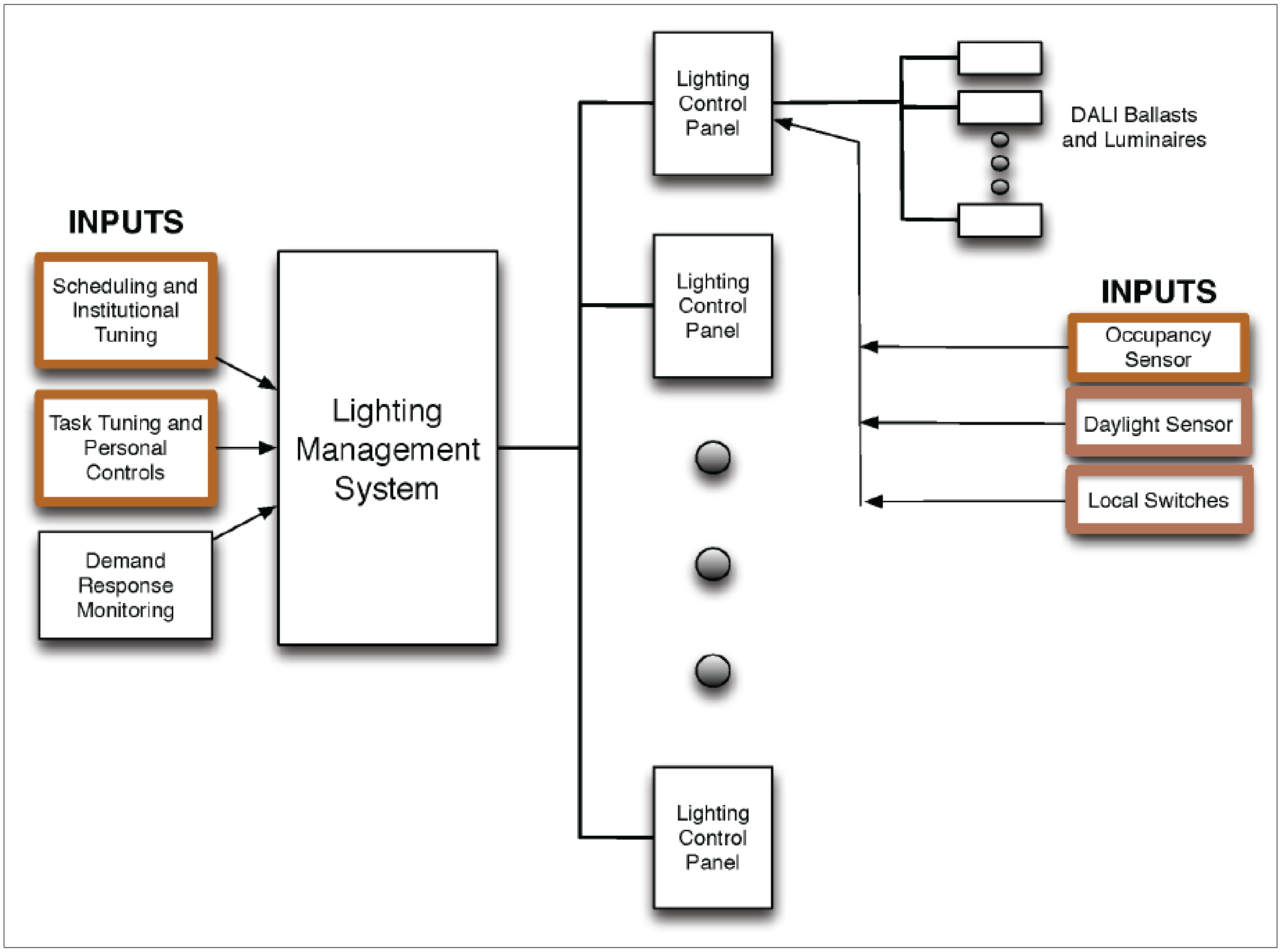
For the single-day site assessment measurements were recorded under the prevailing natural light conditions on the day of the visit, and under different lighting scenarios (for example, daylight only with blinds shut, daylight and electric lighting with blinds open).

At the long-term monitoring sites, the objective was not to specify the test conditions but to allow occupants to utilize their workspace environment in their usual manner in order to understand how the electric lighting controls were operating.

DIAGRAM OF THE TECHNOLOGY

A basic schematic of IDS and lighting control system is shown in Figure 3 below. It illustrates the nature of the system in which there are inputs from a centralized lighting control system, which establishes the overall conditions under which each of the control strategies function, and from remote sensors and switches, which operate local lighting according the appropriate control conditions. With regards to IDS, this translates into programming maximum lighting power input to meet preset light levels, and calibrating local photosensors to adjust lighting power according to available natural light.

Figure 3: Schematic design of one example of an IDS lighting management system. This study examines the effects of the highlighted control elements: scheduling and institutional tuning, task tuning and personal controls, occupancy sensors, local switches and daylight dimming



Two different approaches to dimming control are utilized in the IDS included in this study. At the 3 California sites, a Digital Addressable Lighting Interface (DALI) based control system was implemented. DALI is not only dimming control, rather it is a lighting control protocol, controlled and operated via digital signals from the controls system to the control modules (ballasts in this case) over low voltage communication wires. The ballast also communicates with the control system, supporting status reporting and monitoring. At the Chicago and Hammond sites, 'DALI-like' systems were installed, where almost identical functionality can be programmed, but it is the manufacturer's proprietary system rather than an industry standard.

The alternative is use of a 0-10V signal to control light output. 0-10V dimming systems are controlled and operated via analogue signals sent to the ballast. These signals set the operating conditions for the ballasts and can be controlled at the zone level – all of the lighting connected to a single circuit will dim to the same level, although they may be controlled by different sensors and therefore act independently.

There are pros and cons associated with both systems but the main comparisons are those of flexibility and cost of implementation.

The flexibility value proposition of DALI is based on the following:

- It allows each of the light fixtures to be independently addressed and controlled – once the system is installed and operating, lighting arrangements can be changed without any physical labor required as all changes can be implemented through a software interface.
- Its inherent flexibility and granular control of individual fixtures supports initiatives such as peak demand reduction or demand response, variation in daylighting and energy rate-based lighting control and billing of tenants in multi-occupancy buildings.
- Installations can be less expensive due to the simple wiring and absence of the need to hardwire different lighting zones, although additional communication wiring is necessary to support DALI operation.

0-10V systems do not offer the same level of flexibility but the hardware is currently cheaper – DALI ballasts are more expensive than 0-10V alternatives by up to a factor of two – and are simpler to operate, and in buildings or zones where light levels can be uniform, the flexibility offered by DALI systems may not be necessary. Additionally there is no burden on the operator to maintain a system database that is an integral part of a DALI-based control, and less skills and training are required for installation and operation of the lighting system. Unlike for new construction, where the low installation costs of DALI improve the economic case, costs associated with equipment removal in retrofit projects reduces this somewhat and so final system / protocol selection is inevitably a trade-off; a decision based on the requirements, specifications and constraints of each site.

FACTORS INFLUENCING SUCCESS OF IDS

The specifics of each site by definition impacted the nature of observations, for both site visit types. Daylighting design is inherently impacted by physical properties without and within the nominated buildings; these site specific factors are summarized in Table 3 below.

Table 3: Factors determining daylight availability within occupied work areas

Factors influencing results from outside the building	Factors influencing results from building design and site
• Latitude • Height of adjacent buildings / structures • Proximity of buildings / structures to site	• Façade orientation • Window size and maximum height • Presence of shades or blinds • Presence and orientation of partitions • Furniture and decoration • Timing of system commissioning[9]

[9] Daylighting Commissioning Report

These characteristics varied across sites, with a range of latitudes and climate types, window-to-wall ratio glazing areas and glass type, different approaches to providing shading as a result of the building design and orientation of the façade, and orientation of office furniture and cubicle partition height.

B. TECHNOLOGY SPECIFICATION

The technology specification varied from site to site and across manufacturers, which, for the sites in the study, consisted of systems installed by two vendors. The technology is a network of interacting devices that are configured and calibrated to achieve the desired effect, namely modulation of electric lighting in response to available natural light. The key individual devices and systems are:

- Photosensor
- Digital / electronic dimming ballast
- Lighting control system

At each of the study locations, IDS is secondary to activation of lights by occupancy sensors or manually-operated wall switches. The process of daylight dimming begins with a signal from the photosensor to the ballast, providing information on the current light levels. Photosensors typically are installed to monitor illuminance on a reference surface, for which the reference setting is calibrated to light levels at the workplane. The photosensor signal communicates the prevailing light condition–made up of daylight and electric light components–and whether it meets the light settings set in the LMCS. The ballast is able to adjust light levels according to whether or not the preset requirements are being satisfied: if the photosensor signal indicates overall lighting is too bright, the ballast will reduce power to the lamps; conversely, if it indicates that light levels are below those required, it will increase power input.[10]

Typically, ballasts will control one or two lamps, depending on how many are present in the luminaire itself. The ballast activates and modulates power to the lamps on the basis of signals from the photosensor in the space and according to data from the LMCS that sets maximum and minimum light levels. For IDS comprising LED lamps, an LED driver would be used in place of a ballast. For a more detailed summary of installed equipment, refer to the tables in Appendix A.

For design operation to be achieved, appropriate location and accurate calibration of the photosensor are paramount. Sensor calibration ideally should be completed once the day lit space is occupied, so that lighting system settings may be modified to reflect any lighting condition changes created by furniture and people. For the design operation to persist, photosensors must periodically be checked to see if they have gone out of calibration. They must also be cleaned regularly (every few months is sufficient) to avoid dust build up and consequent loss of sensitivity and accuracy. The likely consequence of not performing these tasks is a lighting control that does not meet its design intent, and could lead to unnecessary energy use. It is

[10] For LED-based systems, the same operating principles apply, with the main difference being in the equipment – the need for a ballast is removed and in its place is an LED driver, which is used to regulate the quantum and quality of power supplied to the LED lamps. In contrast to ballasts, LED drivers are typically integrated within the light fixture.

assumed here that this would be completed by the building cleaning crews, and involves little effort, assuming the sensors are wiped clean every two weeks – the cost of this activity is not included in the economic analysis presented here.

The lighting control systems assessed in this study have typically comprised continuous dimming with a minimum electric light level rather than switching off completely – two sites had programming that switched lamps off in response to daylight. An intermediate option is to program systems to dim to the lowest levels for a period of time and then turn off. Restricting operation to dimming control only may prolong lamp life, as constant switching on and off physically degrades the lamp. However, there is an energy penalty associated with this, since in order to provide the low end 10% light output, up to approximately 30% of maximum power is required, so even during bright conditions there would be lighting energy use. To minimize this penalty, ideally lights would be dimmed to the lowest level that does not compromise their operating lifetime.

EQUIPMENT AND INSTALLATION COSTS

The key cost inputs are for infrastructure over and above that required to support operation of the time scheduling, occupancy-based control and light level tuning controls protocols. This comprises two main items: photocells and the cabling that connect them to the ballasts for each fixture. For the cable cost, cost is calculated based on number of photosensors and number of fixtures. Not included in the costs of daylighting are software costs, lighting system controllers installed for each area / floor and home-run cabling.

Table 4: Equipment and Installation costs for IDS

Equipment / Installation Item	Equipment Cost ($)	Labor Cost ($)
Photosensor	46	50-63*
Cat5 cable	11 per linear foot (installed)	Included in equipment cost
Dimming ballast	25 each	0.3 / ft^2
Software	0.1 / ft^2	n/a
Programming	n/a	0.3 / ft^2

*Includes calibration

C. TECHNOLOGY ASSESSMENT

The IDS installed at each of the visited sites were part of implementing an overall integrated lighting control system at each site. These systems were installed prior to the start of the project and therefore no comparisons with the pre-existing lighting system could have been undertaken. The scope of the retrofit differs between sites: in some locations, only photosensors were added while in others there was a full lighting system replacement, including lamps and fixtures. In each case, the IDS were implemented in the perimeter area of the building.

D. TEST PLAN

The data collection, equipment monitoring and testing plan was devised by LBNL scientists in accordance with the project scope, and was separated into two distinct assessment methods. The first was a site characterization exercise, comprising a single, half-day site visit. The second was ongoing data collection with installed sensors and metering equipment. This two level approach to collection of information and data supports the general information gathered during the early questionnaires sent to GSA sites regarding their daylighting systems. The objective is to provide insight into GSA IDS installations to date at a high, meta, and detailed site analysis level. Through this approach, drawing conclusions from each sample type, it is possible to provide well-informed, appropriate policy recommendations.

The method adopted for the single-day visits was developed and discussed during two 'test' site visits carried out in a single location within the LBNL campus, and honed to ensure an efficient and effective data and information collection framework.

The approach for the long-term monitoring was determined to some degree by the characteristics of each site in terms of the size of the monitored area, the number of measured work spaces and what space type was typical within the building. The scope for monitoring at each location also was affected by the physical constraints of monitoring equipment, in that light sensors must be wire-connected to the data collection devices and the wiring placed some constraints on location of sensors.

The fieldwork was carried out by LBNL engineering and scientific personnel who were familiar with the equipment being installed, the purpose for each measurement taken and with the methodology adopted. These personnel were involved in development of the data collection plan.

SITE SELECTION

Preliminary site selection was undertaken on the basis of information contained within a GSA buildings database. Sites were selected on the basis of a multi-stage screening process. The first screen was based on the presence of two equipment types at the prospective candidate sites: photosensors and electronic dimming ballasts and that the lighting project was anticipated to be completed during the site surveying period, between April and September 2012. The database contained 90 buildings that met these criteria.

Points of contact for all 90 buildings were confirmed, and these individuals received a brief online questionnaire, requesting basic details about the building and identifying a technical contact involved in the implementation of the new lighting systems. 48 responses were received. The technical contact received a more detailed questionnaire, which focused on specifics of IDS and other building systems that impact the use of natural light. There were 33 responses to this questionnaire. All 33 respondents were contacted by telephone to verify the information provided.

A sample of 13 sites was selected on the basis of information provided through the questionnaire survey and verification process and also with the target of visiting as many sites as possible given the scope of and constraints on the project in terms of time and funding. This included focusing on nearby locations and those where more than one site could be assessed during a single trip (multiple sites per city).

TECHNOLOGY DEPLOYMENT

The new IDS observed at each location visited consisted primarily of newly installed sensors and installation of new communications wiring. New lighting fixtures were installed at some sites, but at many, existing fixtures remained as the lamp specification often did not change. Fixture and circuit layouts were modified in one open office location such that light fixtures were located above individual cubicles.

The systems used a wide range of luminaires (technical details are summarized in Appendix B). To operate these luminaires, dimmable ballasts were controlled by a Lighting Management Control System (LMCS). The most commonly observed luminaries were recessed 2x4 or 2x2 fixtures, installed in open office areas, private offices, conference rooms, and other similar room types. The pendant fixtures installed in one open office area provided both upward-directed (ambient) light and downward-directed (task) light; the up-light and down-light components had separate ballasts and were individually controllable. Lights were either operated by a manual wall switch (private offices) or turned on to a preset level when an occupant entered their workspace. Electric light output then adjusted automatically according to available natural light.

ANALYSIS METHODS

To satisfy the scope of the project and provide both a broad overview and a more detailed analysis of IDS projects in GSA buildings, a two-tier assessment was used for this study: the first to gather information on a number of GSA buildings as a representative sample of those for which IDS were being implemented, and the second to undertake detailed analysis of a subset of these to provide greater insight regarding the 'success' of implemented IDS projects.

This 'broad and deep' approach leads to the identification of strategic, general management and technology decisions currently practiced, and determines the degree to which they are consistent with meeting objectives of lighting system energy savings, cost-effectiveness, occupant comfort and efficient and effective project implementation processes. The assessment process is outlined below.

The first comprised a series of high-level site assessments, each completed over the course of a few hours, and consisting of:

- Metering of light levels throughout the designated daylit area under various lighting and shading conditions
- Measurement of physical characteristics of the daylit space
- Recording of lighting system specifications (fixtures, lamps, and sensor types, numbers and locations)
- Observation of access to daylight arising from current occupant workspace behaviors (i.e. operation of lights or blinds)
- Interview with Building Manager, Lighting System Project Manager or equivalent to discuss project implementation, from design through commissioning, occupancy and operation.

Detailed descriptions of the single-day site visits, including summaries for all 13 assessed locations can be found in the Appendices.

The second, more detailed level of assessment incorporates the assessment tasks completed in the first, with the additional recording of temporal data over a period of between one and five months (depending on the site):

- Monitoring of light levels at the workplane within the daylighting project area
- Recording of use of blinds and shades by occupants
- Metering of lighting system energy use
- Distribution of survey to building occupants occupying zones where IDS is implemented

This two-tier approach to analysis is complimentary in that the first supports analysis of a significant number of sites at a high level, and the second allows a deeper dive into the intricacies and nuances of IDS operation. The insights from one level are instructive in drawing conclusions from the other. The analysis results are presented separately for each method so as to be clear for the reader. When drawing conclusions and lessons learned from the project sample, all of the results and observations are considered together.

LONG-TERM MONITORING

The remainder of the body of this report focuses on the sites at which data was collected over a period of time - monitoring equipment was installed and remained in place for a period of between six weeks and five months.

A priority output from the single-day site visits was to hold discussions with facilities managers to clarify whether long-term data monitoring was acceptable both from the point of view of the occupants, who have to work around the installed equipment, as well the organization, which may be wary of the potential inconvenience or perceived security implications of supporting the project.

The scope for understanding daylighting systems based on long-term monitoring and data collection was significantly greater, as much more detail would be provided than was possible from the single day visits. Data collected would represent the dynamic interaction between daylight and electric lights. It would reflect diurnal, and to a certain extent, seasonal, changes in natural light levels and illustrate the degree to which installation of daylight controls for electric lights had been successful. In addition to the information collected from the single-day visits, the following data and information was collected during the long-term monitoring:

- Illuminance levels at the workstation (vertical and horizontal), with photometers installed atop computer monitors, and collected at the frequency of one reading per minute per sensor.
- Illuminance (vertical) levels at the window, monitoring outdoor light conditions, collected at the frequency of one reading per minute.
- High dynamic range photographs, assessing the brightness of the occupied spaces, glare and also monitoring the use of blinds over the monitoring period, collected at a frequency of 7 images per 30 minutes, with the photographs being taken over a 15 to 20 second period.

- Illuminance levels at the camera location (vertical), which can be correlated to the window illuminance data to determine daylight penetration, collected at the frequency of one reading per minute.
- Power metering on electric lighting circuits for the monitored area, collected at the frequency of one reading per five minutes.
- Where possible, data for the central lighting management control system (LMCS) was used to monitor the operation and performance of individual fixtures.
- Occupant surveys, focused on understanding the degree to which lighting at each site meets the occupant requirements, what lighting characteristics are preferred and what it is about their lighting that people don't like.

Table 5 contains details of the long-term monitoring sites.

Table 5: Long-term monitoring site summary

Site	Location	Approximate floor area (ft^2)	Description of monitored work spaces	Type and number of assessed workstations
Ronald Dellums FB, Peace Corps, N tower, 7th floor, West façade	Oakland, CA	540	Open office plan and one private office	4 open office cubicles and 1 private office
Roybal FB and CH, Bankruptcy Court, 9th floor, East façade	Los Angeles, CA	670	Open office plan	6 open office cubicles
Cottage Way FB, GSA Directors Office, West building, 1st floor, South and West façades	Sacramento, CA	170	Private office	1 private office
Hammond CH, Clerk of the Court, IT Offices, 1st floor, East and South façades	Hammond, IN	810	Open office plan, private office conference room	1 open office cubicles and 2 private offices
Dirksen FB and CH, GSA Office, 2nd floor, West façade	Chicago, IL	940	Open office plan, private office and reception	3 cubicles and 1 private office and 1 reception work space

Every site that went forward for long-term monitoring and data collection was first assessed in a single day site visit, although the assessed sites were not always identical – for instance, in two locations (Hammond and Ron Dellums), the private office space assessed in the single-day visit was a small part of the site measured in the long-term analysis and for one other (Cottage Way), an office different to the one assessed during the single day site visit was made available as the long-term monitoring location.

At each site, photometers were installed atop the assessed workstation monitors, one measuring horizontal illuminance and one measuring vertical illuminance. A photometer was installed on the window, measuring the exterior natural light levels. A camera was positioned to take pictures of the window wall in the assessed space in order to monitor how any installed shading systems were operated, how much light penetrated the space, and to support the measurement of glare.

To measure energy, power metering equipment was installed in the electrical closet, measuring power on the lighting circuits that provided electric light to the monitored site. We also gathered power data for individual lighting fixtures, which enabled a correlation of measured light levels at the workstation with the operation of the corresponding overhead lights. This provided us with vital extra information, relating electric light operation to overall workstation light levels.

Correlating and comparing measured light levels at the window and in the workspace illustrates how well the exterior natural light levels translated into good use of daylight within the space. Assessing the power metering and LMCS data indicated whether electric lights were being activated, and whether electric lighting operation was well tuned to the available daylight.

The number of workspaces monitored at each site varied from a minimum of one to a maximum of six. The types of workspaces monitored also varied: light meters in were installed in reception areas, conference rooms, open plan office areas and private offices.

As all sites were visited after having completed installation of IDS, there was no opportunity to do a comparison against the pre-retrofit design; it was accepted at the outset that such a comparison would not be possible. For the site characterization surveys, no energy analysis was completed, as the information on energy savings and cost effectiveness have been provided by GSA.

For the long-term monitored sites, the energy baseline refers to a tuned light level to identify the energy threshold at which savings can be allocated to daylight dimming, and calculates savings compared to the operation of the existing lighting system in the absence of daylight dimming.

The site investigations at each monitoring location suggest that that normal occupant behavior cannot affect the measurements. To ensure this, the photometers were placed in locations clear of the work surface so that readings would not be compromised by paper and desk clutter.

The monitoring periods at the long term monitoring sites reflect the overall project schedule, and the time period for which GSA tenants were content to host the monitoring equipment.

METHODOLOGY FOR CALCULATION OF ENERGY SAVINGS

For an assessment of energy savings associated with daylight dimming, it is important to recognize the other elements of integrated lighting control and to outline the philosophy behind the allocation of energy savings among the various control elements.

The most fundamental light control is implementation of a time schedule. Under this regime, lights are switched off during unoccupied hours (predominantly night time and weekends). Lights will cease to operate after a certain time at the end of the working day–often after the daily cleaning crew have completed their rounds–and will be switched on in the early morning, to coincide with the arrival of the first workers or building maintenance staff. The energy savings from this measure is the difference between this scenario and one where the lights are on 24 hours a day.

Occupancy-based lighting control is becoming increasingly common and was present at all of our long-term monitored sites, although in some private office spaces there also were manual switches. The energy savings allocated to occupancy controls are those that occur when the workzone or workspace is vacant for sufficient time for lights to power down or off. Energy savings are calculated by the power saved over the total time for which the lights are powered down or off.

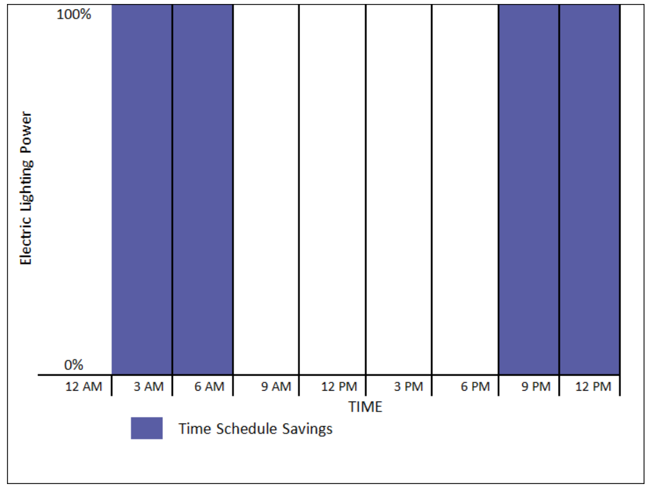
Institutional tuning of light levels reflects the need to turn lights down to meet the required workstation light levels, to meet either the design guidance or the occupant's requirements. To enable this measure, a 0-10V electronic dimming or DALI-type ballast must be installed to enable control of power to the lamps: the extra hardware requirement is what makes tuning follow occupancy control in the energy savings hierarchy. Anecdotal evidence suggests that meeting the design guidance of 30 footcandles at the workplane meant turning the electric lighting output down to around 50%. The fact that lights need to be dimmed to 50% to provide 30 footcandles indicates that the lighting system is overdesigned for the location – more fixtures / lamps are present than are necessary to properly illuminate the space. The energy saved by tuning is calculated from the difference between the tuned level output and installed lighting power output, minus those periods where occupancy-based control was in operation.

When calculating energy saving and associated costs for integrated systems or control strategies, it is important to define the extent and limits of the energy savings associated with each system or control strategy and allocate costs appropriately according to the equipment required to deliver those energy savings.

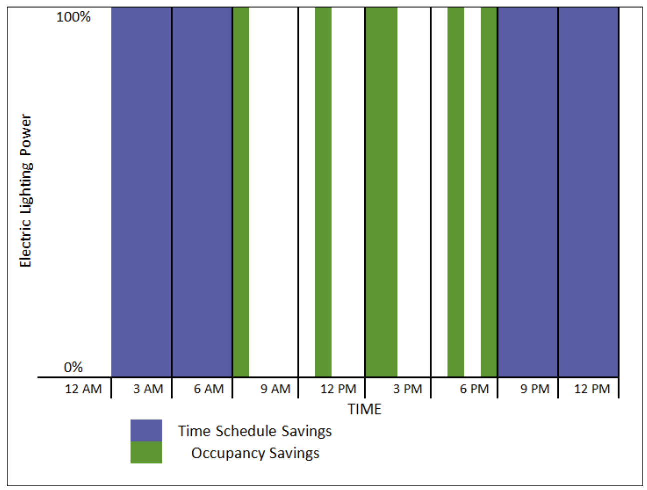
For control systems that implement various lighting control strategies, separating energy saved under one strategy from another requires understanding the sequence in which they are implemented. To quantify energy savings from daylight dimming, it is important to define the method used in allocating energy savings to other control elements of an integrated lighting system, namely time scheduling, occupancy-based control and high-end tuning. Figure 4 is a step-by-step explanation of how daylight dimming savings are calculated, an important part of which is recognizing energy savings that arise from other control strategies and ensuring that these are not included. Figure 5 is an enlarged version of the last graphic in Figure 4, showing a breakdown of energy savings by control strategy.

Figure 4: Concept Framework for Estimation of Daylight Dimming Savings

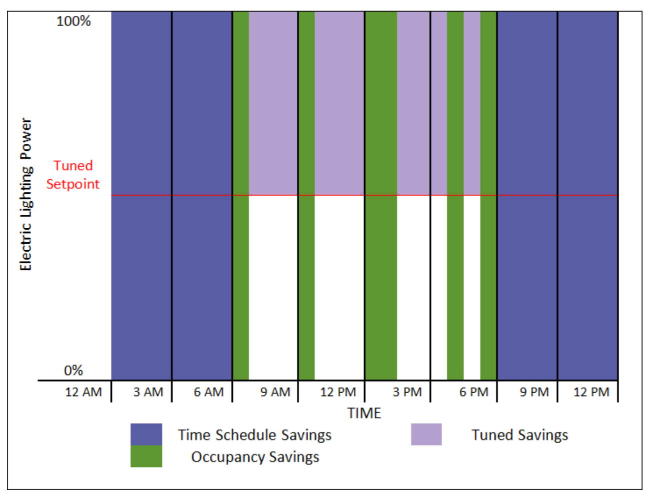
Energy savings allocated to time scheduling-based control arise from periods where the lights are off due to out of hours building vacancy.



Occupancy sensors-based energy savings arise from vacancy periods in work spaces during office hours, either at the zone or individual office / cubicle level, depending on the approach to installation adopted within each building or zone.



Energy savings from tuning / dimming of light levels to design illuminance requirements reflect the difference between the power used at 100% lighting output and that used at the tuned lighting levels. The tuned lighting output level is set at the individual site and in the first instance; the target is to meet the IESNA minimum light level requirements. Individual occupant preferences may cause this to vary within a single site.



Energy savings from daylight dimming occurs during periods when power consumption falls below that of the tuned lighting output. This is a response to available natural light which is sufficient to reduce the necessary output of electric lighting.

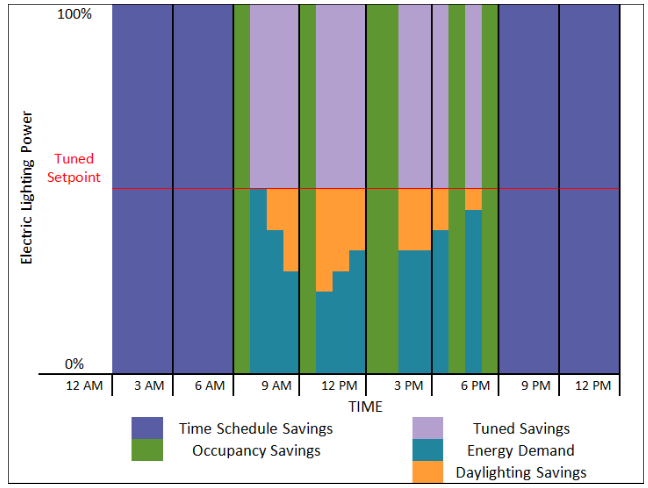
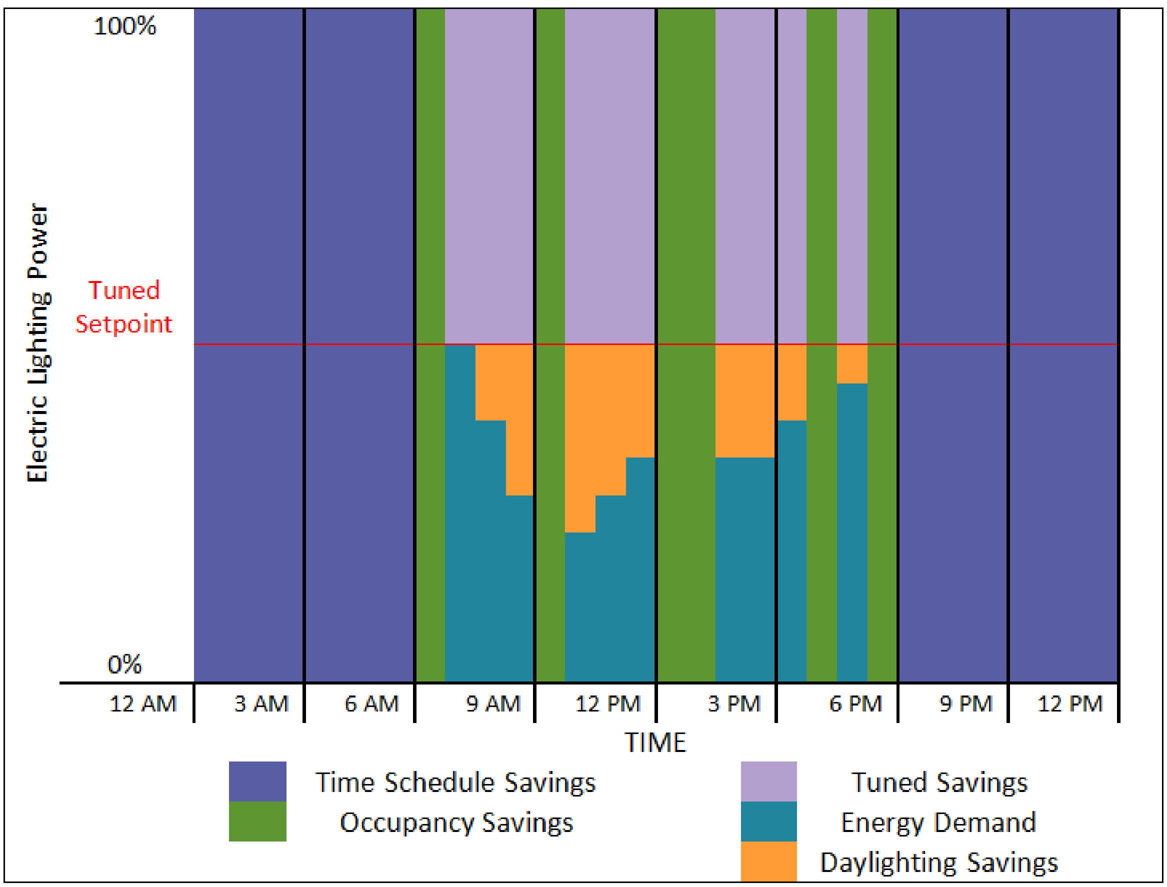


Figure 5: Definition and separation of lighting energy savings by control strategy



In this study, two energy savings calculations are completed for each site. The first assumes that energy savings from IDS come from daylight dimming alone. The second is calculated on the basis that both daylight dimming and high-end tuning require the same electronic dimming ballast hardware and therefore that both control strategies would be implemented together.

Energy savings results for the monitored period are extrapolated in order to provide an estimate of annual energy savings. These estimates are based on savings observed during periods around the solar equinox, which is assumed as the annual average in terms of available daylight.[11]

It is not clear that energy savings associated with the individual control measures were assessed in detail prior to installation of lighting systems at the assessed sites. Given the integrated nature of the systems and the variables (such as occupancy) that determine energy savings, this is unsurprising: the lighting system designer / vendor / installer is unlikely to go further than outlining a range of expected energy savings for any specific measure and may be conservative in estimating overall energy savings.

E. INSTRUMENTATION PLAN

INVENTORY OF LONG-TERM SITE MONITORING EQUIPMENT

Table 6 contains brief descriptions of equipment installed at each of the long-term sites. The photometers were installed at workstations, typically atop computer monitors adjacent to the workplane, and also at the window to record external light levels. A camera was located to record lighting conditions, monitor blind position and at some sites, used as a mounting location for a photometer. The power metering equipment was installed at the electrical panel, monitoring electric current on the relevant lighting circuit(s).

Table 6: Installed Data Monitoring Equipment

Measurement Type	Measuring Instrumentation	No. Installed	Range of Measurement	Measurement Frequency
Light levels – illuminance	Photometer	Varies per site (from 5 to 16)	0 – 100 Klux	1 per minute
Glare	Canon A570IS camera and Opteka Fisheye lens	1 per site	Visible spectrum radiation	7 bracketed photos every 30 minutes
Power metering	HOBOWare U30 Data logger	1 per site	N/a	Lighting circuit pulse counts every five minutes
Power metering	Current transducers	Depends on number of relevant lighting circuits	15A/20A depending on site	Lighting circuit pulse counts every five minutes

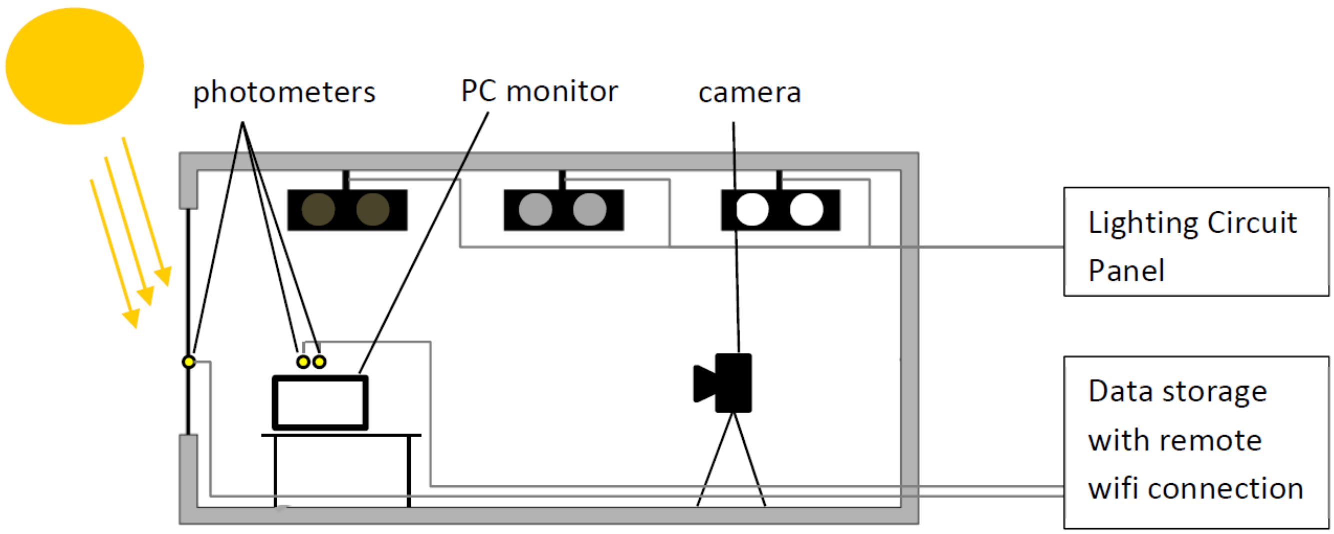
[11] Automatic Lighting Controls Demonstration, F. Rubinstein (1991). Analysis of the data suggests that extrapolating 1 month of data at the fall equinox month (equal number of working days either side of 21 September) has an error of between 13% and 17%, always underestimating savings. For two or more months of data this error falls to between 4% underestimate and a 4% overestimate.

Measurement Type	Measuring Instrumentation	No. Installed	Range of Measurement	Measurement Frequency
Power metering	Watt nodes	Depends on number of relevant lighting circuits	120-277V	Lighting circuit pulse counts every five minutes

ILLUSTRATION OF INSTALLED MONITORING EQUIPMENT

Figure 6 illustrates how monitoring equipment was installed and operated. Monitoring of light levels and power metering were entirely independent of each other and had to be correlated by time stamp, which were synchronized either before or during the monitoring period.

Figure 6: Section Drawing of Monitoring Equipment and Infrastructure



IV. Results

A. SUMMARY OF TECHNICAL OBJECTIVES

The objectives of this study were to measure the performance of IDS within GSA buildings in the terms of the following:

- Energy savings, light conditions and occupant satisfaction associated with the daylight dimming elements of the lighting system.
- Investment criteria associated with the IDS element of the lighting system, utilizing detailed equipment and labor costs and local utility rates.
- Assess the technical and economic performance of IDS to provide recommendations for future deployment of IDS across the GSA portfolio.

ENERGY SAVINGS - OVERVIEW

This study sought to determine whether energy savings achieved by the use of IDS were sufficient to justify more widespread installation. This required two types of analysis: quantification of energy savings and calculations of cost-effectiveness.

The analysis below includes two assessments of IDS. The first assesses the incremental benefits of daylight dimming alone–that is, only the dimming that takes place in response to dynamic variation of natural light. The costs associated with this option are also assumed to be incremental: only the equipment that is added to support daylight dimming beyond what is required for time scheduling, occupancy-based control and high-end tuning, as well as the labor required for installation and equipment calibration, is included in the cost breakdown. The second couples tuning and daylight dimming together as integrated parts of an IDS system. The energy savings associated with active dimming to a maximum light output (programmed into the system) and those associated with the daylight dimming are included here. For costs, the boundary is also redrawn. The equipment required to support tuning and dimming control strategies is included, including software costs and labor required for installation, calibration and programming.

A LIGHTING POWER

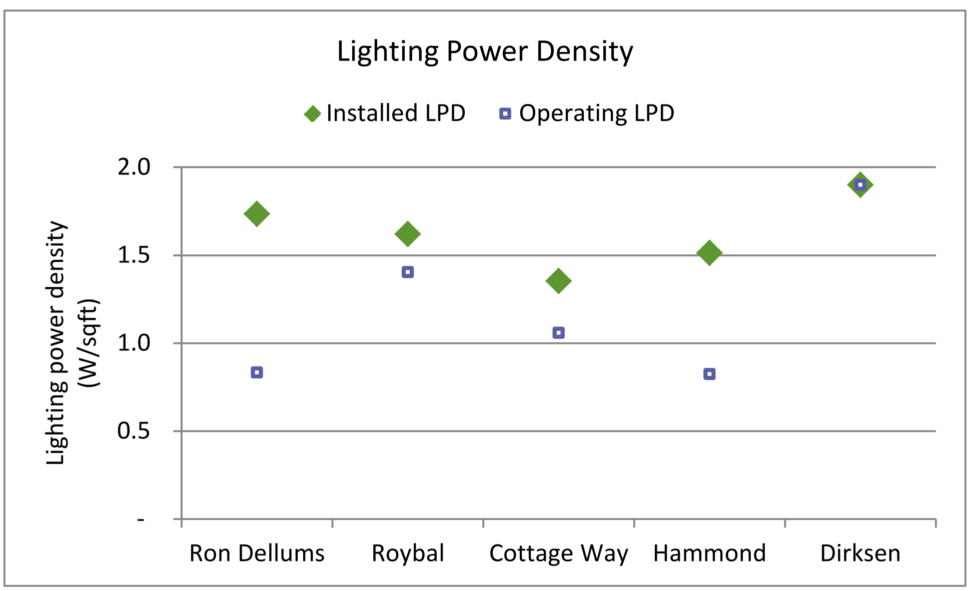
Table 7 presents the installed and operating lighting power densities (LPD) at the five monitored sites. It shows the variation in installed lighting power per unit area and the degree of tuning is represented by the difference between the installed LPD and the operating LPD. The site with the highest LPD – Dirksen – has not implemented any high-end tuning, so all of the dimming will be as a result of daylight dimming. All four other sites have implemented it to varying degrees.

Table 7: Installed and operating lighting power densities at long-term monitoring sites

Site	Installed Lighting Power (W)	Set point Lighting Power (W)	Floor Area (ft2)	Installed LPD W/ft^2	Set point LPD W/ft^2
Ron Dellums	930	447	540	1.74	0.83
Roybal	1078	934	670	1.62	1.4
Cottage Way	191	156	170	1.17	0.85
Hammond	958	698	810	1.51	0.83
*Dirksen	1778	1778	940	1.9	1.9

Figure 7 graphically illustrates the data presented in Table 7, mainly showing the magnitude of potential energy savings from set point tuning. The savings realized from tuning also depend on occupancy.

Figure 7: Installed and operating lighting power densities at long-term monitoring sites



B ENERGY USE INTENSITY

Table 8 presents the energy savings in terms of reduction in energy use intensity for both assessments: savings from daylight dimming only, or from a combination of tuning and daylight dimming. The measured data comprises a part-year period only – results were extrapolated to estimate annual energy savings. Note that the results data are subject to rounding.

Table 8: Lighting energy use intensity of advanced lighting control strategies and operating energy use intensity of electric lighting

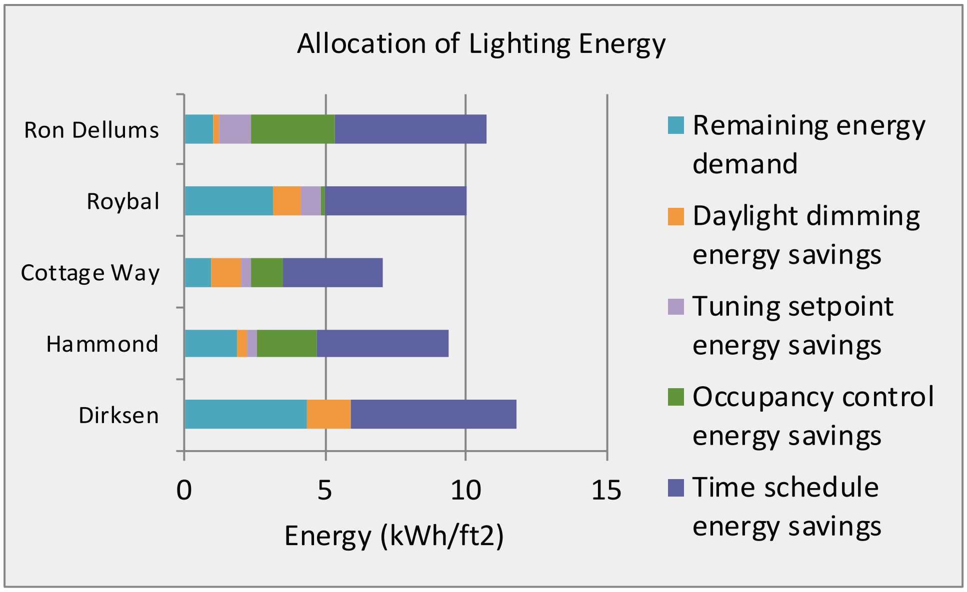
Site	Energy use, lights always on (kWh/ft²/yr.)	Schedule savings (kWh/ft²/yr.)	Occupancy Savings (kWh/ft²/yr.)	Tuning savings (kWh/ft²/yr.)	Daylight dimming Savings (kWh/ft²/yr.)	Energy use after all savings (kWh/ft²/yr.)
Ron Dellums	10.7	5.4	3	1.1	0.3	1
Roybal	10	5	0.2	0.7	1	3.2
Cottage Way	7	3.5	1.2	0.3	1.1	1
Hammond	7.3	3.6	2.1	0.4	0.3	0.9
*Dirksen	11.8	5.9	0	0	1.56	4.3

*Dirksen system is not tuned

C FUTURE ENERGY SAVINGS

Occupancy is clearly a determining factor in energy savings achieved from IDS – electric lighting must operate in the first place otherwise energy savings will be associated with one of the other control strategies. As Figure 8 shows, energy savings from occupancy-based control are significant. The data suggests that for Ronald Dellums and Hammond in particular, there is significant potential to increase daylight dimming savings through increasing occupancy.

Figure 8: Allocation of lighting energy



For the Roybal and Dirksen study sites, the greatest potential looks to through reduction in lighting energy use intensity, possibly through improved utilization of daylight.

Table 9: Greenhouse gas (GHG) emissions for regional and national average utility fuel mixes, in kg CO_2 eq/ft^2/year

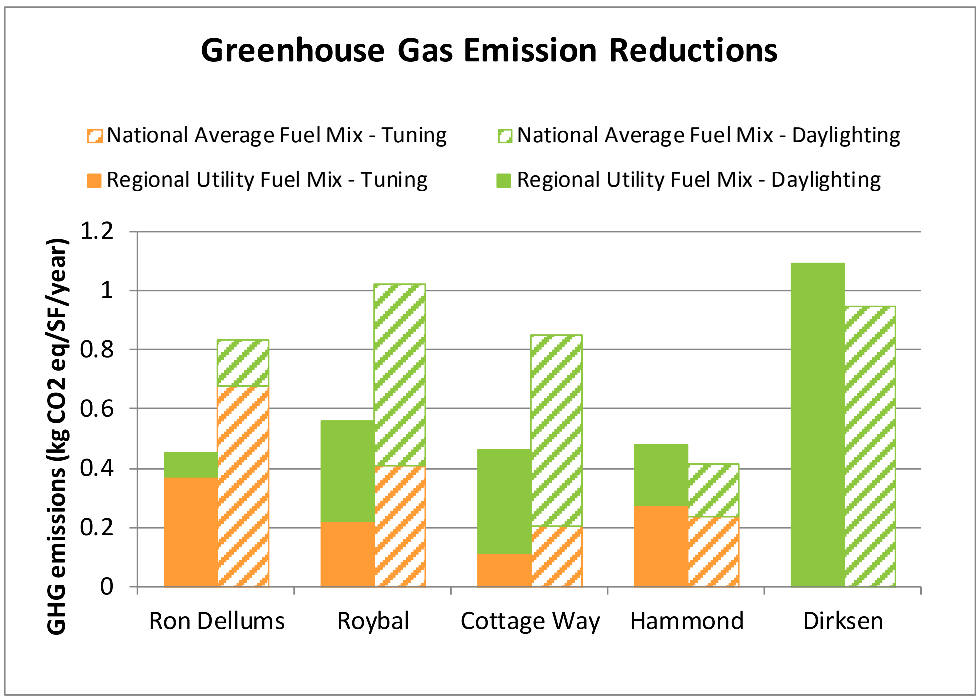
	Regional Utility Fuel Mix (kg $CO_{2\ eq}$/ft^2/yr)		National Utility Fuel Mix (kg $CO_{2\ eq}$/ft^2/yr.)	
Site	Daylight Dimming	Set point Tuning	Daylight Dimming	Set point Tuning
Ron Dellums	0.09	0.37	0.16	0.68
Roybal	0.34	0.22	0.62	0.41
Cottage Way	0.35	0.11	0.65	0.2
Hammond	0.2	0.28	0.17	0.24
*Dirksen	1.09	0	0.94	0
Total	3		4.1	

	Regional Utility Fuel Mix (kg $CO_{2\,eq}/ft^2/yr$)		National Utility Fuel Mix (kg $CO_{2\,eq}/ft^2/yr.$)	
Site	Daylight Dimming	Set point Tuning	Daylight Dimming	Set point Tuning
Average	0.6		0.8	

http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Table 9 contains the reduction in greenhouse gas emissions associated with the energy savings, measured both in terms of the regional utility fuel mix and the national average fuel mix. The regional utility fuel mix resulted in an average reduction of GHG emissions of approximately 0.6 kg $CO_{2\,eq}/ft^2$/year while the national average fuel mix resulted in an average reduction of approximately 0.8 kg $CO_{2\,eq}/ft^2$/year across the sites.

Figure 9: Results for greenhouse gas emission reductions as a result of energy savings from daylight dimming and set point tuning at each site



1. PEACE CORPS, 6TH FLOOR, RONALD DELLUMS FEDERAL BUILDING

The assessed site is in a west facing perimeter location in the north tower of the Ronald Dellums Building, consisting of a single private office of medium size and six open office cubicles. The view from the windows is unobstructed as all the adjacent buildings are four floors or lower in height. The structural pillars that protrude from the building envelope provide minimal shading from direct sunlight.

The curtain wall windows consist of untreated single glazing and have an internal window-to-wall ratio of around 0.75. Vertical blinds are present in all of the windows. In the private office, manual controls can be easily reached. In the cubicles, the controls are not easily accessible due to the presence of cubicle partitions: control wires hang between the window wall and the partition. Occupants have made their own adaptations to allow easy access to control wires.

The view from the cubicles is limited by presence of structural pillars and by the partitions, which limit direct light from the windows from a height below three feet. The partitions perpendicular to the windows also limit access to ambient natural light.

The private office has six recessed troffer light fixtures with two lamps each. The six cubicles each have a dedicated pendant lighting fixture consisting of task-focused downlight (2-lamps) and an indirect uplight (1-lamp). Both task and indirect lighting components dim to daylighting. Cubicles 1 and 2 were not included in the analysis as they were largely vacant throughout the study period. A plan drawing of the monitored space can be found in Appendix B.

The lighting controls in the private office are manual-on primary via a wall switch and then dimming to available daylight. For the cubicles, primary lighting control is occupancy-based and then dimming to available daylight for both the uplight and downlight components.

The site monitoring period consisted of 56 weekdays.

The lighting control system software was programmed in such a way that it is possible to review the tuning level of individual fixtures. Furthermore, lighting system software programming supports data download for the individual fixtures in the open office space; these could be monitored and assessed throughout the assessment period. The results presented in Table 10 show energy savings arising from each of the individual workspaces. Energy savings are calculated on the basis of daylight dimming savings alone (assuming a high-end tuning level of 50%) and for lighting energy savings from both tuning and daylight dimming together. The energy savings figures quoted are for a two month period from 12 August to 12 October. Table 10 excludes the assessment of Cubicles 1 and 2, which were known to be largely unoccupied (occupancy was less than 25%).

Table 10: Ronald Dellums Federal Building dimming energy savings

Control Strategy	Measured Energy Savings (kWh)	Estimated Annual Energy Savings (kWh)	Dimming Energy Reduction (%)
Daylight dimming	23.7	287	7.7%
Tuning and daylight dimming	123	740	25.7%

Table 11: Ronald Dellums EUI savings

Control Strategy	Baseline EUI ($kWh/ ft^2/yr.$)	Dimming EUI ($kWh/ ft^2/yr.$)	EUI Reduction ($kWh/ ft^2/yr.$)
Daylight dimming	1.25	0.99	0.26
Tuning and daylight dimming	2.37	0.99	1.38

2. BANKRUPTCY COURT, 9TH FLOOR, ROYBAL FEDERAL BUILDING

The assessed site is an east facing perimeter location of the Roybal Federal Building, and consists of eight open office cubicles. The view from the windows is unobstructed as all the adjacent buildings are significantly lower in height. The structural pillars that protrude from the building envelope provide minimal shading from direct sunlight.

The curtain wall windows consist of untreated single glazing and have an internal window-to-wall ratio of around 0.7. Venetian blinds are present in all of the windows, for which manual controls are easily accessible.

There is a clear sky view. The view from the cubicles is limited by presence of partitions greater than five feet in height, perpendicular to the windows and limiting access to ambient natural light from windows in other cubicle sections. The 14 troffer fixtures house two lamps each and are spread evenly across the ceiling space, not located to correspond with individual work cubicles.

The lighting controls are occupancy-based primary control for all 14 fixtures in the zone, and once activated, lamps dim to available daylight. A plan drawing of the monitored space can be found in Appendix B.

The site monitoring period consisted of 51 weekdays.

The lighting control system was programmed in such a way that supported review of light settings by fixture and energy data download from the LMCS for the monitored period. The energy savings results presented in Table 12 are calculated on the basis of daylight dimming savings alone (assuming a high-end tuning level of 50%) and for lighting energy savings from both tuning and daylight dimming together. The energy savings figures quoted are for a 9 week period from 23 August to 26 October. These figures are factored up to a 52 week period to represent annual energy savings.

Table 12: Roybal Federal Building dimming energy savings

Control Strategy	Measured Energy Savings (kWh)	Estimated Annual Energy Savings (kWh)	Dimming Energy Reduction (%)
Daylight dimming	117.5	679	31.8%
Tuning and daylight dimming	195.2	1128	33.8%

Table 13: Roybal EUI savings

Control Strategy	Baseline EUI (kWh/ ft^2/yr.)	Dimming EUI (kWh/ ft^2/yr.)	EUI Reduction (kWh/ ft^2/yr.)
Daylight dimming	4.17	3.15	1.02
Tuning and daylight dimming	4.84	3.15	1.69

3. GSA DIRECTORATE, 1ST FLOOR, COTTAGE WAY FEDERAL BUILDING

The assessed site is a private office in the southwest corner of the west block of the Cottage Way Building. The view from the windows is somewhat obstructed by the exterior concrete lattice structural supports and also by the architectural overhang. The structural pillars also provide some shading.

The curtain wall windows consist of untreated single glazing and have an internal window-to-wall ratio of around 0.8. Vertical blinds are present in all of the windows. Manual controls can be easily reached.

The view of the windows from the work space is largely unobstructed, although there are low shelves located against the east facing window. The office has two recessed troffer light fixtures with two 32-W lamps each and a single recessed troffer light fixture with two 17-Watt lamps. A plan drawing of the monitored space can be found in Appendix B.

The lighting controls in the private office are manual-on primary via a wall switch and then dimming to available daylight.

The site monitoring period consisted of 31 weekdays.

The lighting system was programmed in such a way that supported review of light settings by fixture and energy data download from the LMCS for the monitored period. The energy savings presented in Table 14 are calculated on the basis of daylight dimming savings alone (assuming a high-end tuning level of 50%) and for lighting energy savings from both tuning and daylight dimming together. The energy savings figures quoted are for a one month period from 13 September to 12 October. These figures are factored up to a 12 month period to estimate annual energy savings.

Table 14: Cottage Way Federal Building dimming energy savings

Control Strategy	Measured Energy Savings (kWh)	Estimated Annual Energy Savings (kWh)	Dimming Energy Reduction (%)
Daylight dimming	15	180	38.8%
Tuning and daylight dimming	19.7	236	33.5%

Table 15: Cottage Way EUI savings

Control Strategy	Baseline EUI (kWh/ ft^2/yr.)	Dimming EUI (kWh/ ft^2/yr.)	EUI Reduction (kWh/ ft^2/yr.)
Daylight dimming	2.03	0.96	1.07
Tuning and daylight dimming	2.36	0.96	1.4

4. CLERK OF THE COURT OFFICES, 1ST FLOOR, HAMMOND COURTHOUSE

The assessed site is a south facing location on the ground floor of the Hammond Courthouse, consisting of two private offices, one conference room and an open office area containing two cubicles. One of the private offices is located on a corner and also has a single east facing window. The view from the windows is largely unobstructed as the building is located on a small hill. Small saplings are located outside several windows; at present, these are not sufficiently large to block light, but this will change over time.

The punched windows hold slightly tinted double glazing and have an internal window-to-wall ratio of around 0.3. Roller shades are present in all of the windows and are accessible by occupants in all locations.

The view in the private offices and conference rooms is unobstructed. In the cubicles, only the view through the nearest window can be seen; other windows are obscured by high cubicle partitions.

One private office has six recessed troffer fixtures, each containing two lamps. The other private office has four troffer fixtures, each containing two lamps. Both the conference room and the open office area have four troffer fixtures, containing two lamps each. A plan drawing of the monitored space can be found in Appendix B.

The lighting controls in the private offices and conference room are manual-on and then dimming to daylight. In the open office area, lights are activated by occupancy and dim to daylight.

The site monitoring period consisted of 110 weekdays.

The energy savings presented in Table 16 show energy savings arising from the individual work spaces. Energy savings are calculated on the basis of daylight dimming savings alone (assuming a high-end tuning level of 70-80% depending on the space) and for lighting energy savings from both tuning and daylight dimming together. The energy savings figures quoted are for a two month period from 2 July to 30 November. The annual energy results are estimated by factoring five months of data to represent one year.

Table 16: Hammond Courthouse dimming energy savings

Control Strategy	Measured Energy Savings (kWh)	Estimated Annual Energy Savings (kWh)	Dimming Energy Reduction (%)
Daylight dimming	96.7	232.1	10.7%
Tuning and daylight dimming	232.9	558	18.8%

Table 17: Hammond Courthouse EUI savings

Control Strategy	Baseline EUI (kWh/ ft^2/yr.)	Dimming EUI (kWh/ ft^2/yr.)	EUI Reduction (kWh/ ft^2/yr.)
Daylight dimming	1.15	0.86	0.29
Tuning and daylight dimming	1.54	0.86	0.69

5. GSA PROPERTY MANAGEMENT, 2ND FLOOR, DIRKSEN FEDERAL BUILDING

The assessed site is in a west facing perimeter location in the Dirksen Federal Building, consisting of a single small private office, three open office cubicles and a reception area. The view from the windows is obstructed to the west by high buildings. The angle to the top of the highest obstruction is around 30 degrees (also known as the vertical angle of sky).

The curtain wall windows consist of untreated single glazing, and an internal window-to-wall ratio of around 0.85. Venetian blinds are present in all windows. In the reception area and the private office, manual controls are easy to reach. In the open office cubicles, the controls are not as accessible due to the presence of a partition between the work area and the space adjacent to the windows. Occupants have to walk around the end cubicle to access the controls; the structural pillars complicate this access further.

The window view outside is largely unobstructed in the private office and the reception area. The cubicle partitions obscure the lower portion of the window, which reduces access to natural light.

The single private office has four ceiling-mounted troffers with one lamp each. The open office cubicles have 12 ceiling-mounted troffer fixtures, with one lamp each. The reception area has six ceiling-mounted troffer fixtures with one lamp each. The monitored space is a portion of the area served by a single lighting circuit, and the energy savings quoted are from the larger area. A plan drawing of the monitored space can be found in Appendix B.

The lighting controls for the whole area are occupancy-based primary control and then dimming to daylight.

The site monitoring period consisted of 118 weekdays.

Energy savings presented in Table 18 are calculated on the basis of daylight dimming savings alone (assuming a high-end tuning level of 70-80% depending on the space) and for lighting energy savings from both tuning and daylight dimming together. The energy savings figures quoted are for a five month period from 2 July to 30 November. The annual energy results are estimated by factoring five months of data to represent one year.

Table 18: Dirksen Federal Building energy savings

Control Strategy	Measured Energy Savings (kWh)	Estimated Annual Energy Savings (kWh)	Dimming Energy Reduction (%)
Daylight dimming	596	1431	26%

Table 19: Dirksen EUI savings

Control Strategy	Baseline EUI (kWh/ ft^2/yr.)	Dimming EUI (kWh/ ft^2/yr.)	EUI Reduction (kWh/ ft^2/yr.)
Daylight dimming	5.88	4.32	1.56

D PHOTOMETRIC ANALYSIS

In order to determine whether the IDS supplied the recommended light levels, light sensors were installed at or near the workplane. The installed sensors were mounted so as to record horizontal and vertical illuminance, and where possible, were mounted atop the workplace computer monitor. In four rooms, across two sites, sensors were also mounted on table and desk tops; this was to provide a) greater detail as to workplace light levels and b) as a useful back-up. This was only possible at certain locations as it was necessary not to distract or irritate occupants of the monitored workspaces.

It is assumed here that appropriate minimum light levels for office spaces are 30 footcandles at the workplane, per IESNA recommendations and referred to in the 2010 P100 Design Document. This section presents the results of light measurements at each site and reflects an average light reading recorded at five minute intervals throughout the monitoring period. The period for which light measurements were recorded varied by site – it is worth noting that as data was not collected for a full annual cycle, maximum sun angle range and range of weather conditions corresponding to the seasons, there is a degree of uncertainty over the representative nature of the measured light levels. It is also worth noting that the standards assumed here are not uniformly useful for different people, a fact supported by the occupant survey results.

1. PEACE CORPS, 6TH FLOOR, RONALD DELLUMS FEDERAL BUILDING

Figure 10 shows light levels measured at the window (in the vertical plane) and light levels measured at the camera location, which was installed approximately 10 feet from the window. The data indicates that the average day was bright and clear, and that light levels passing through the window were generally high. The data from the window mounted light meter also indicates the time at which solar radiation is directly incident on the west façade of the building in the early to mid-afternoon (depending on the time of year). It is from this time onwards that there is the greatest potential to take advantage of bright conditions, but also the greatest potential issue with glare. Light levels recorded at the camera, indicates that light penetration is degraded significantly.

Figure 10: Ronald Dellums Federal Building, 6th Floor measured average ambient daylight levels (vertical illuminance) recorded at window-mounted light meter and a camera tripod-mounted light meter positioned approximately 10 feet from the window. The data comprises light levels measured for weekdays over a period of approximately four months.

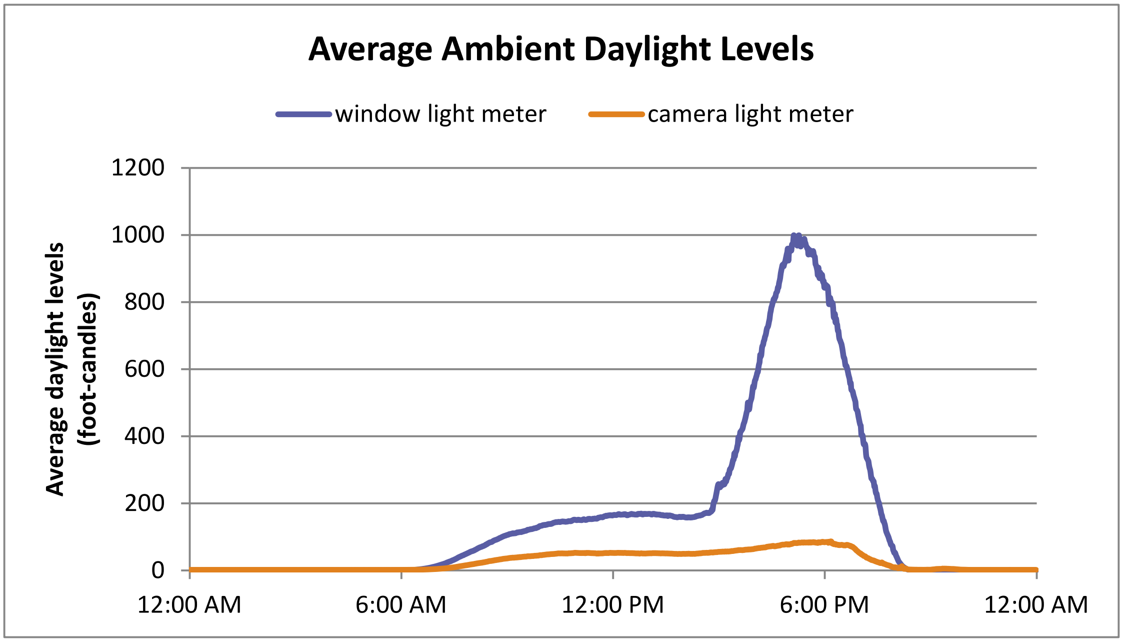


Figure 11 highlights light levels and lighting power use in the measured area for a period including week days and weekend days. The data indicates that light levels in the open office are similar on weekend days to those on weekdays. There is no electric lighting operation during the weekend periods and interior light levels remain high, suggesting that interior light levels can be relatively independent of electric lighting during bright periods, which were the norm during the monitoring period – this is particularly true of afternoon periods when there is direct sunlight on the adjacent windows. The conclusion is that electric lighting operates when often it is not required, and when it is on, its impact is negligible in terms of providing additional illumination. Figure 12 shows data from the same period for the private office. Similar to situation in the open office, the data shows that interior light levels are relatively independent of the operation of electric lighting, suggesting the electric lighting is overused.

Figure 11: Ronald Dellums Federal Building, 6th Floor, open office, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting – the monitored period is Friday 21 September to Monday 25 September.

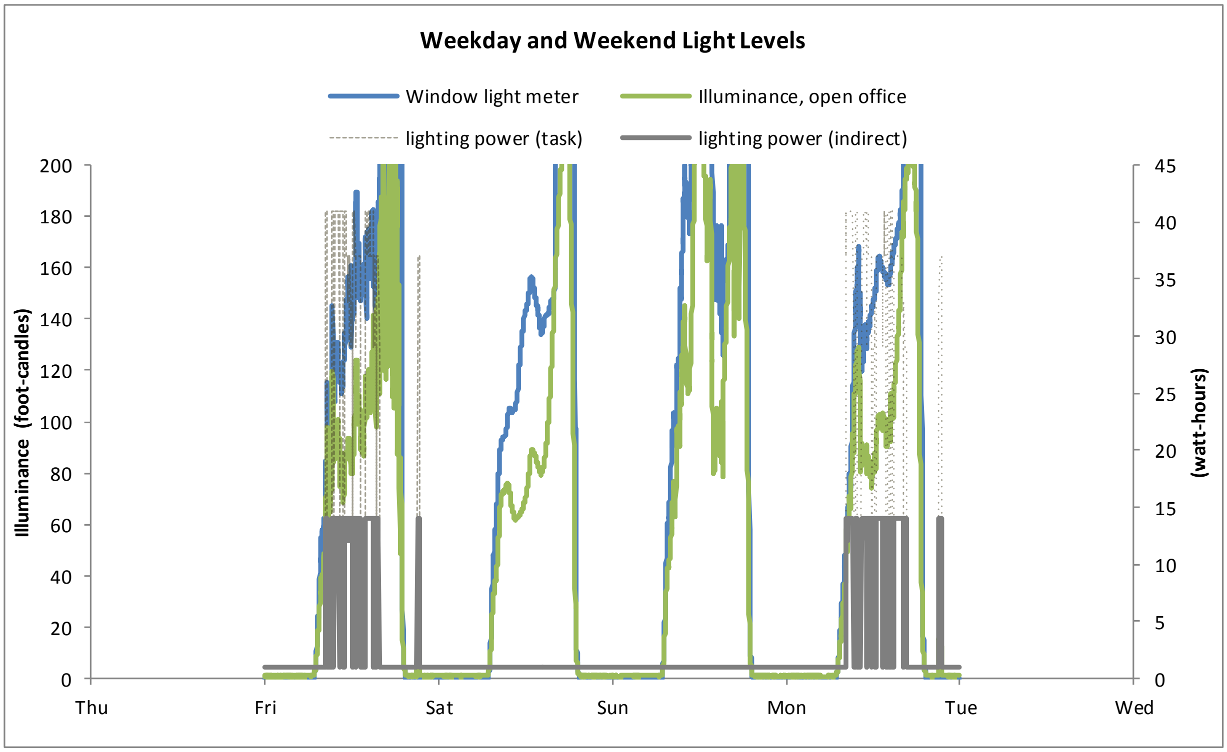


Figure 12: Ronald Dellums Federal Building, 6th Floor, private office, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting – the monitored period is Friday 21 September to Monday 25 September.

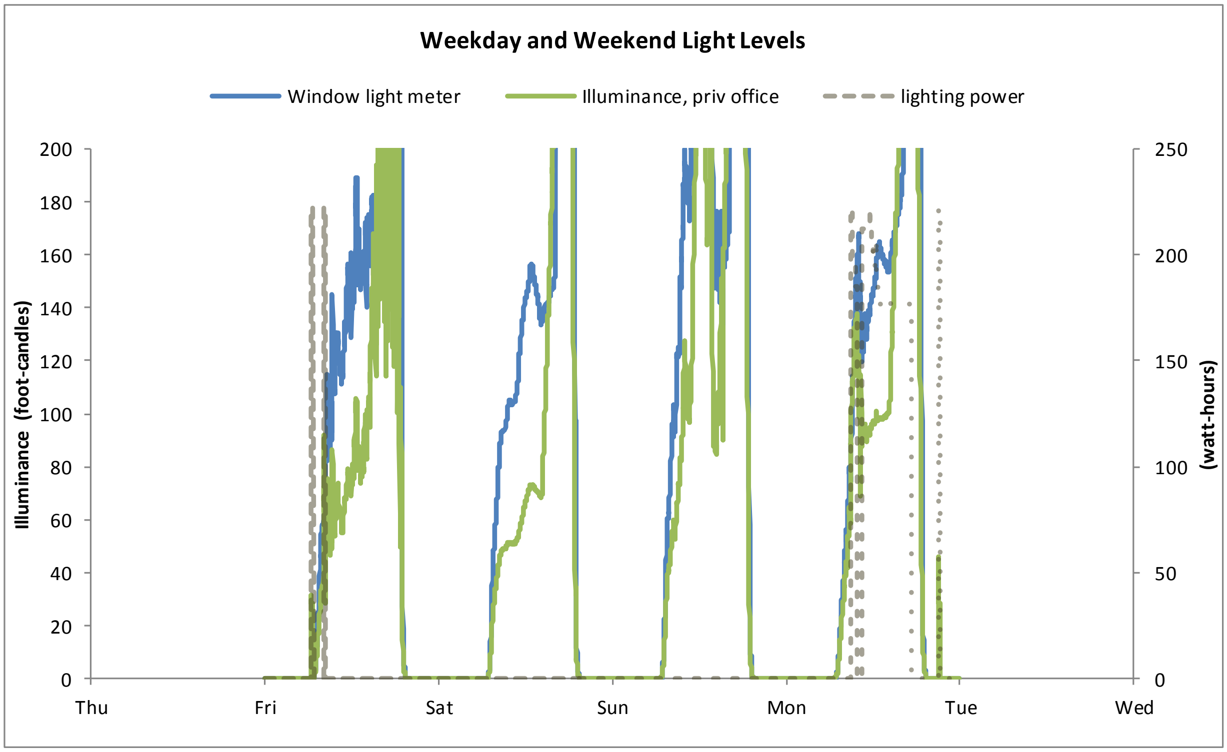
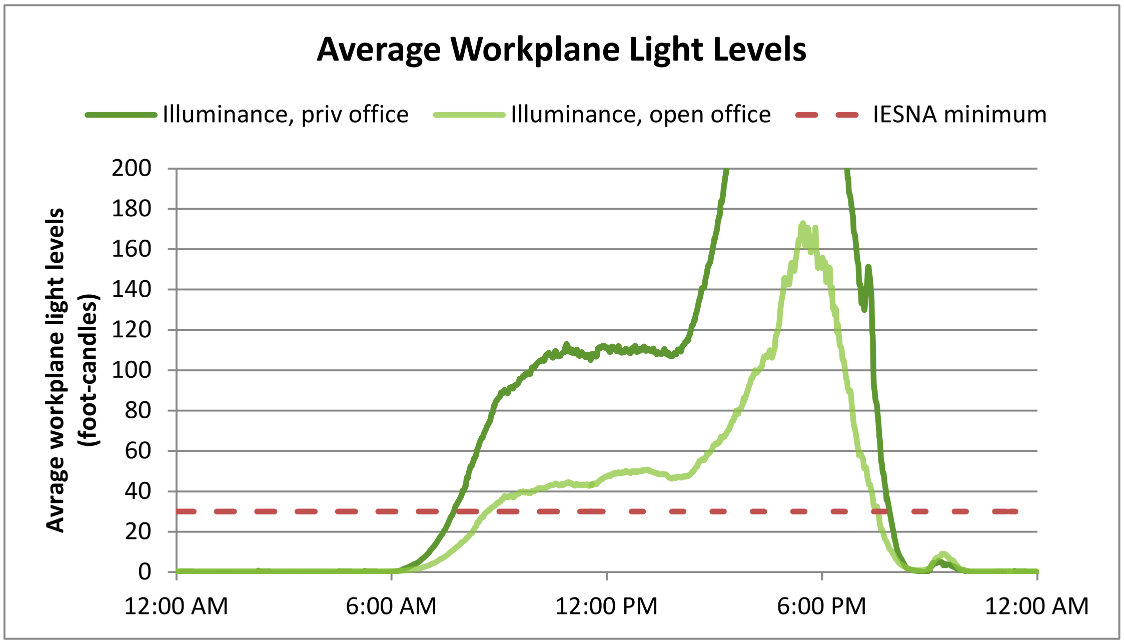


Figure 13 highlights average light levels adjacent to the workplane. The data suggests that the IDS system generally provided higher light levels than recommended by the IESNA. During the monitoring period, average light levels in the private office exceeded the minimum recommendations from approximately 7:30AM until approximately 6:00PM, far exceeding them with values greater than 100 footcandles) between 11:00AM and 6:00PM. For the open office cubicles, light levels exceeded 30 footcandles from approximately 8:30AM until 8:00PM, and far exceeded them between approximately 4:30PM and 6:30PM. The average vertical illuminance data recorded during the monitoring period (not plotted on axes) suggests that disability glare is not an issue at any of the monitored work spaces.

Figure 13: Ronald Dellums Federal Building, 6th Floor, measured average horizontal light levels (illuminance) recorded in the private office and open office cubicles throughout the monitoring period. The data comprises light levels measured for weekdays over a period of approximately four months.



Maximum lamp output was tuned to 46% of rated power output in the private office and 56% of rated power input in the open office space, and would operate as soon as the office or cubicles were occupied. Due to the prevailing bright, clear weather conditions during the monitoring period, the data shows that light levels are relatively independent of the operation of electric lights. The data also shows that the lights operated somewhat independently of daylight conditions. The results indicate that light levels required to complete work tasks are normally achieved or exceeded (for the most part, quite significantly).

2. BANKRUPTCY COURT, 9TH FLOOR, ROYBAL FEDERAL BUILDING

Figure 14 shows light levels measured at the window in the vertical plane. The data indicates that the average day was bright, and that light levels passing through the window were generally high. The data from the window mounted photometer also indicates the time at which direct solar radiation is no longer incident on the east façade of the building in the early afternoon (depending on the time of year) as the sun passes across the sky. The period in the morning offers the greatest opportunity to take advantage of direct sunlight, but conditions in the afternoon are also conducive to natural lighting and due to the absence of direct sunlight, the impact of glare is significantly reduced. It was not possible to install a camera mounted light meter in an appropriate position at this site, due to the disruption it would have created for occupants.

Figure 14: Roybal Federal Building, 9th Floor measured average ambient daylight levels (vertical illuminance) recorded at window-mounted light meter. The data comprises light levels measured for weekdays over a period of approximately six weeks.

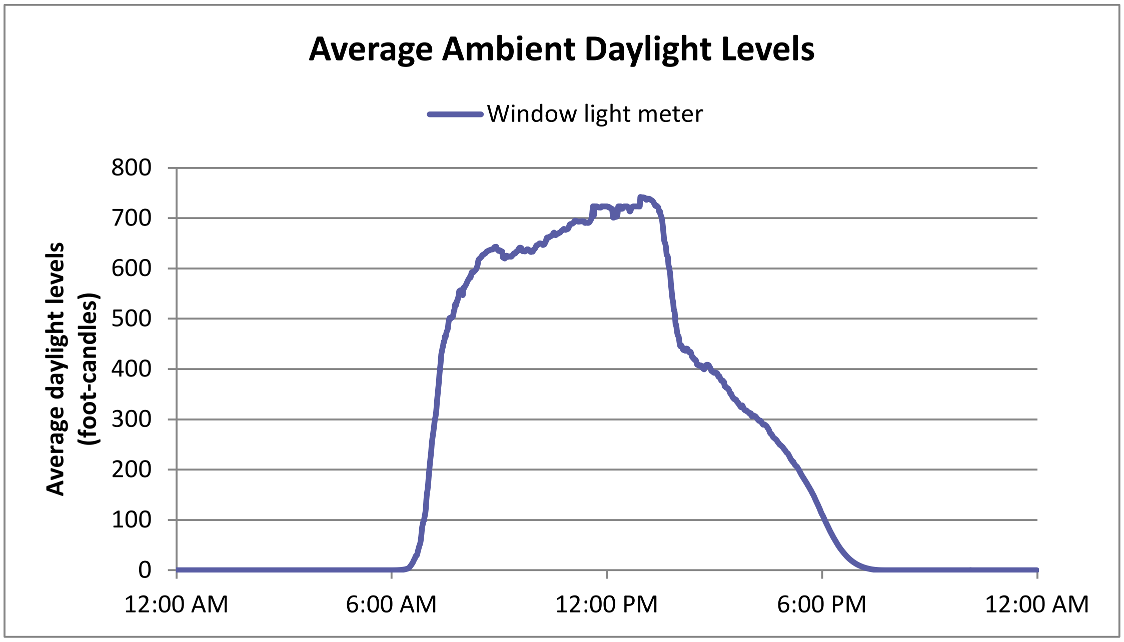


Figure 15 highlights light levels and lighting power use in the measured area for a period including week days and weekend days. The data indicates that for a short period in the morning, light levels are influenced significantly by ambient light levels but become dependent on operation of electric lighting in mid to late morning and for the remainder of the day. A review of the photographic images taken during the monitoring period indicate the primary cause of this - the majority of blinds remained lowered and closed regardless of time of day.

Figure 15: Roybal Federal Building, 9th Floor, open office area, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting. The monitored period is Friday 21 September to Monday 25 September.

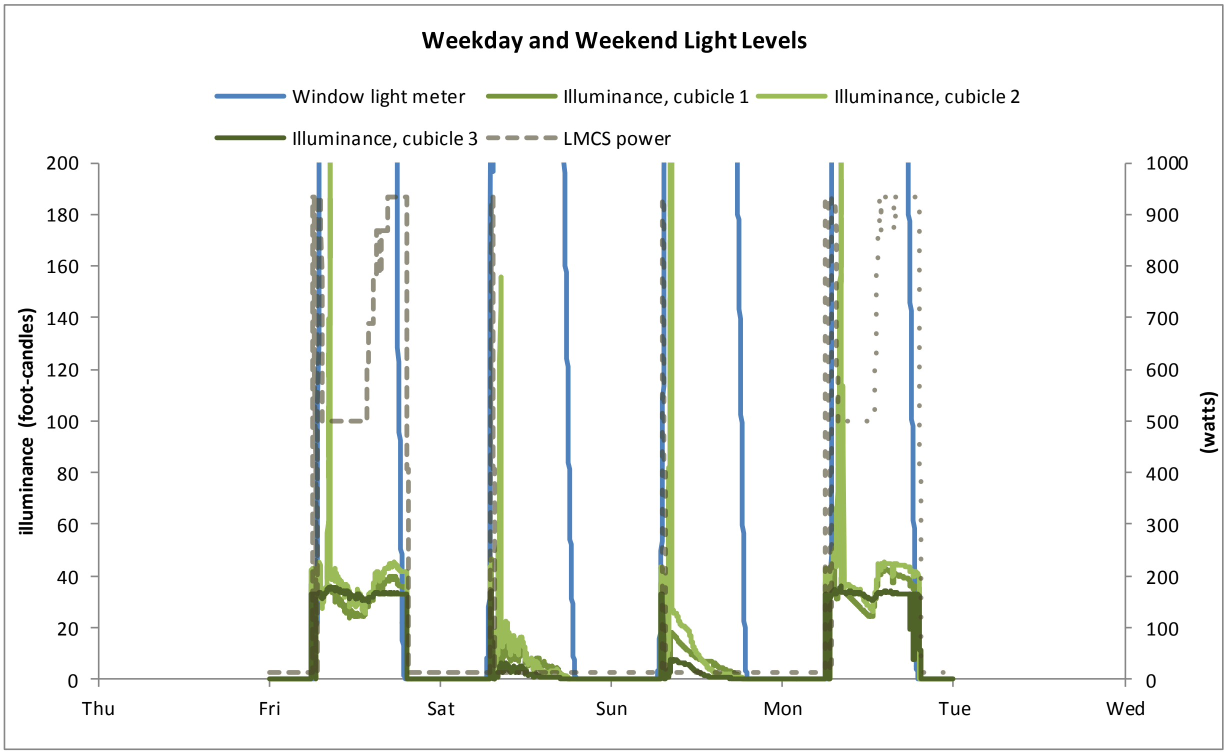
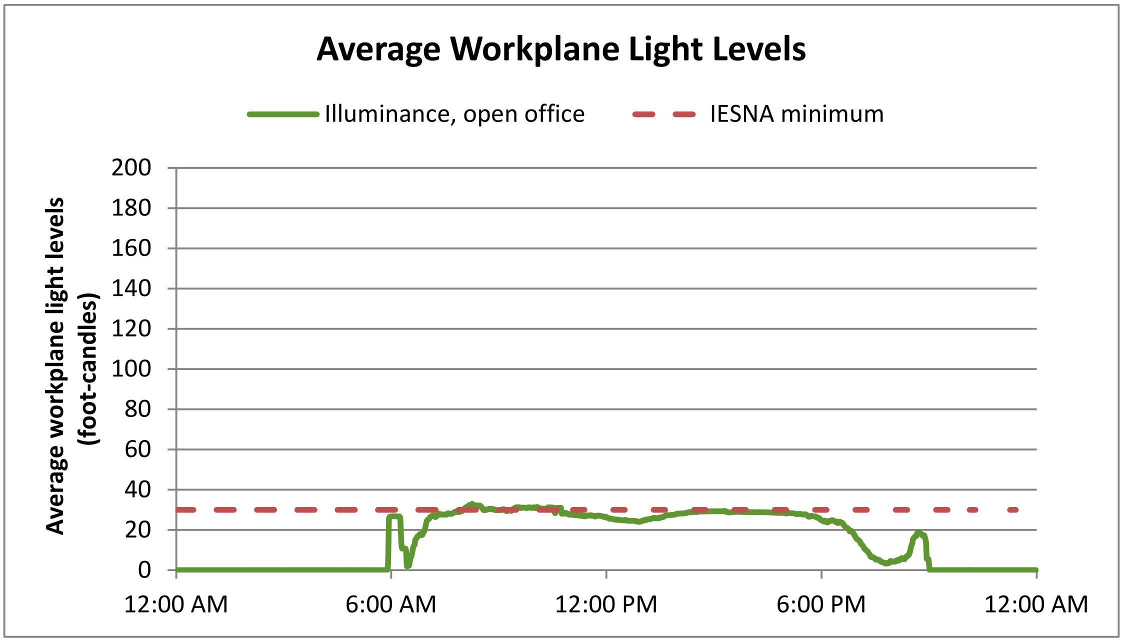


Figure 16 highlights average light levels adjacent to the work plane. The data indicates that the IDS system generally provided light approximately at the levels recommended by the IESNA. Maximum lamp output was tuned to 86% of rated power input, and would operate as soon as the zone was occupied. During the monitoring period, average light levels in the private office exceeded the recommended minimum from approximately 7:30AM until approximately 5:00PM. The average vertical illuminance data recorded during the monitoring period (not plotted on axes) suggests that disability glare is not an issue.

Figure 16: Roybal Federal Building, 9th Floor, measured average horizontal light levels (illuminance) recorded in the open office cubicles throughout the monitoring period. The data comprises light levels measured for weekdays over a period of approximately six weeks.



Maximum lamp output was tuned to 80% of rated output, and would operate as soon as the zone was occupied. Although the prevailing weather conditions were bright and clear during the monitoring period, the data shows that light levels are relatively independent of daylight levels and more dependent on the operation of electric lighting. This suggests that daylight is not being utilized as well as it could be.

3. GSA DIRECTORATE, 1ST FLOOR, COTTAGE WAY FEDERAL BUILDING

Figure 17 shows light levels measured at the window in the vertical plane and light levels measured at the camera location, which was installed at a distance of around 10 feet from the west-facing window. The data indicates shows that the average day was bright and clear, and that light levels passing through the window were generally high. Light levels recorded by the window-mounted light meter also indicates the time at which solar radiation is directly incident on the west façade of the building from early afternoon (depending on the time of year). It does not show the effects of direct sunlight on the south façade as there was no light meter installed there. Photographs show that for the majority of days where daylight levels were high in the afternoon, they were also high in the morning. The data also shows that despite bright conditions outside, the natural light levels detected at the camera location are relatively low.

Figure 17: Cottage Federal Building, 1st Floor measured average ambient daylight levels (vertical illuminance) recorded at window-mounted light meter. The data comprises light levels measured for weekdays over a period of approximately six weeks.

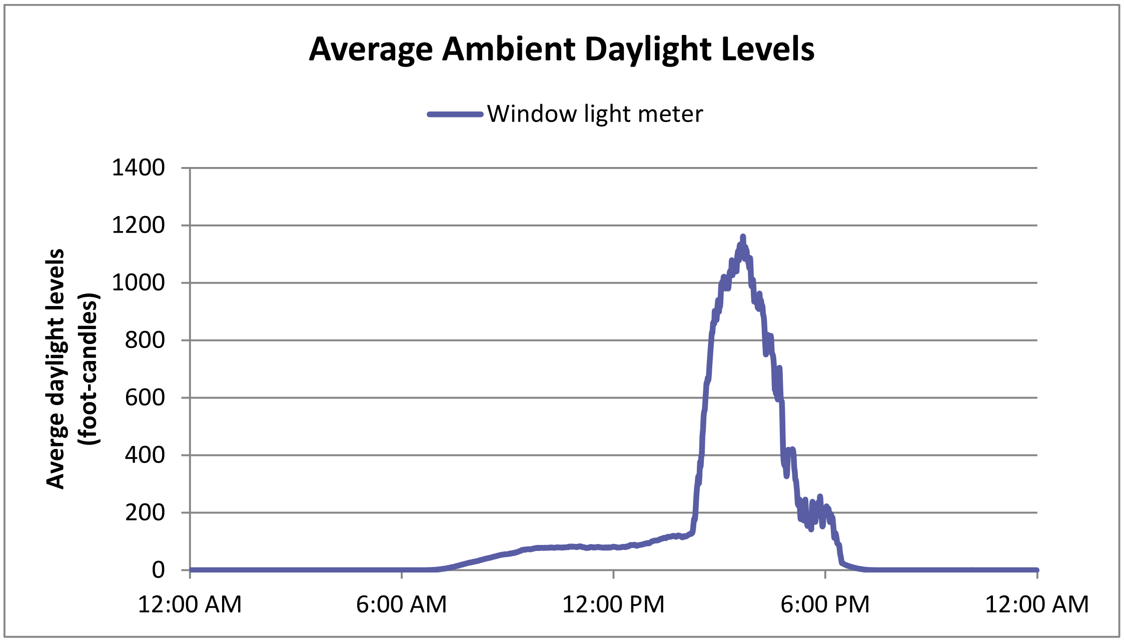


Figure 18 highlights light levels and lighting power use in the measured area for a period including week days and weekend days. The data indicates shows that weekend light levels, when electric lighting is not operational, are significantly lower than those on weekdays. The conclusion is that despite prevailing bright conditions, light levels on the space are dependent on electric lighting to meet recommended minimum light levels. A review of the photographic images taken during the monitoring period indicate the primary cause of this - the majority of blinds remained drawn and partly closed regardless of the time of day.

Figure 18: Cottage Way Federal Building, 1st Floor, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting. The monitored period is Friday 21 September to Monday 25 September.

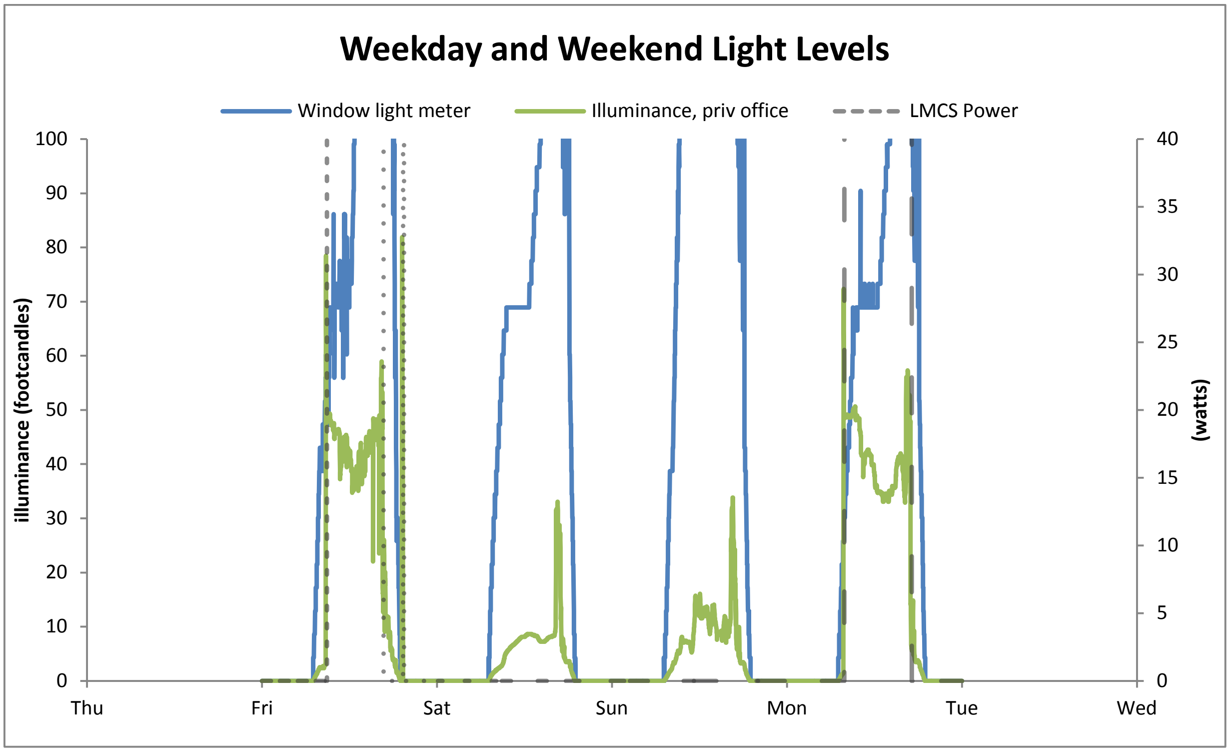
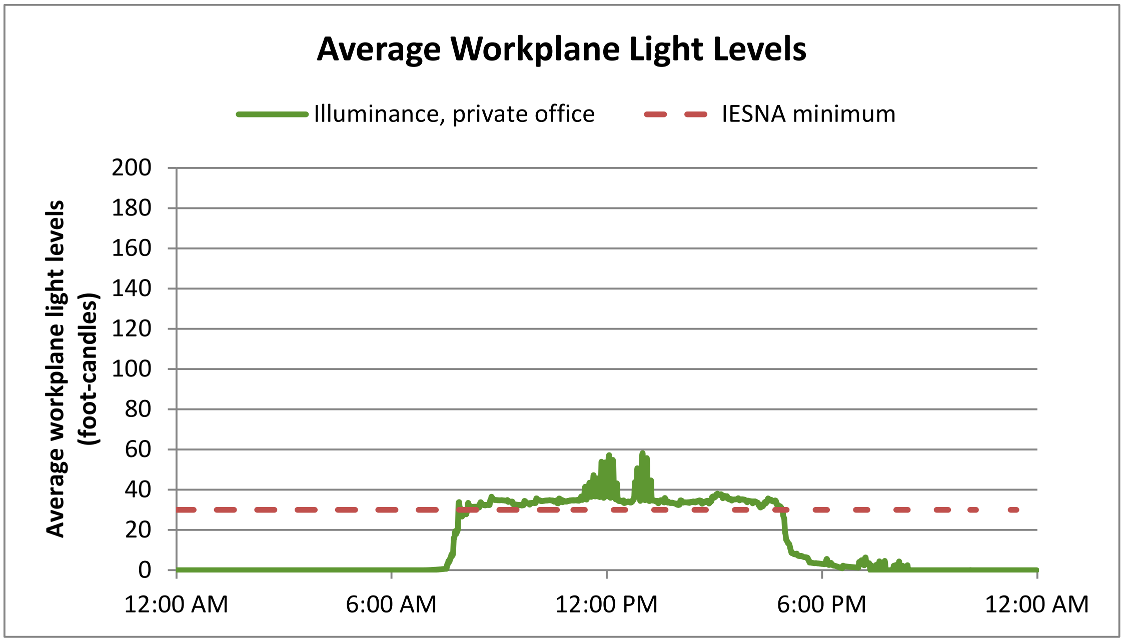


Figure 19 highlights average light levels adjacent to the work plane. The data indicates that the IDS system generally provided light levels at those recommended by the IESNA. Maximum lamp output was tuned to 86% of rated power input, and lamps would operate as soon as the office was occupied. During the monitoring period, average light levels in the private office exceeded recommended minimum from approximately 7:30AM until approximately 5:00PM. The average vertical illuminance data recorded during the monitoring period (not plotted on axes) suggests that disability glare is not a constraint on comfortably completing work tasks.

Figure 19: Cottage Way Federal Building, 1st Floor, measured average horizontal light levels (illuminance) recorded in the private office throughout the monitoring period. The data comprises light levels measured for weekdays over a period of approximately six weeks.



4. CLERK OF THE COURT, 1ST FLOOR, HAMMOND COURTHOUSE

Figure 20 shows light levels measured at the window in the vertical plane. The data indicates that the average day during the monitoring period was bright and clear, and that light levels passing through the window were generally very high. Light levels recorded by the window-mounted photometer also indicates that light availability on the south facing part of the building increases steadily until peak sun height in the middle of that day and that the rate of light level decrease is similar to the morning rate of increase. It was not possible to install a camera tripod mounted light meter in this location.

Figure 20: Hammond Courthouse, 1st Floor measured average ambient daylight levels (vertical illuminance) recorded at window-mounted light meter. The data comprises light levels measured for weekdays over a period of approximately five months.

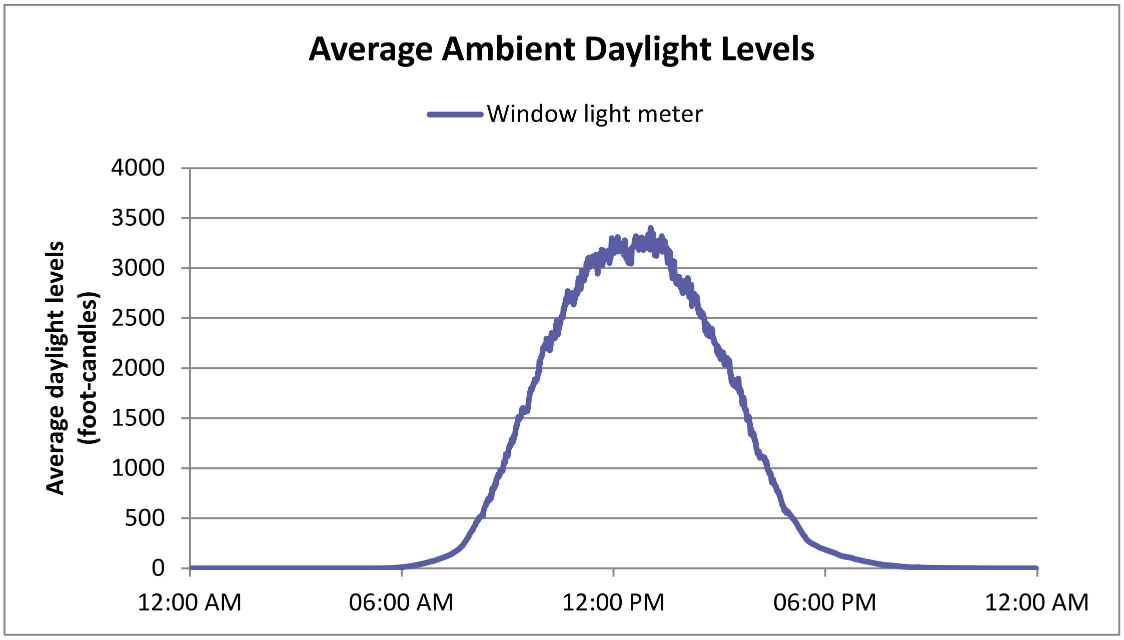


Figure 21 highlights light levels and lighting power use in the measured area for a period including week days and weekend days. The data indicates that weekend light levels, when electric lights are not operating, are lower than those on weekdays. The conclusion is that despite prevailing bright conditions, light levels on the space are dependent to a degree on electric lighting to meet recommended minimum light levels. This is particularly true of the cubicle 1 space.

Figure 21: Hammond Courthouse, 1st Floor, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting. The monitored period is Friday 21 September to Monday 25 September.

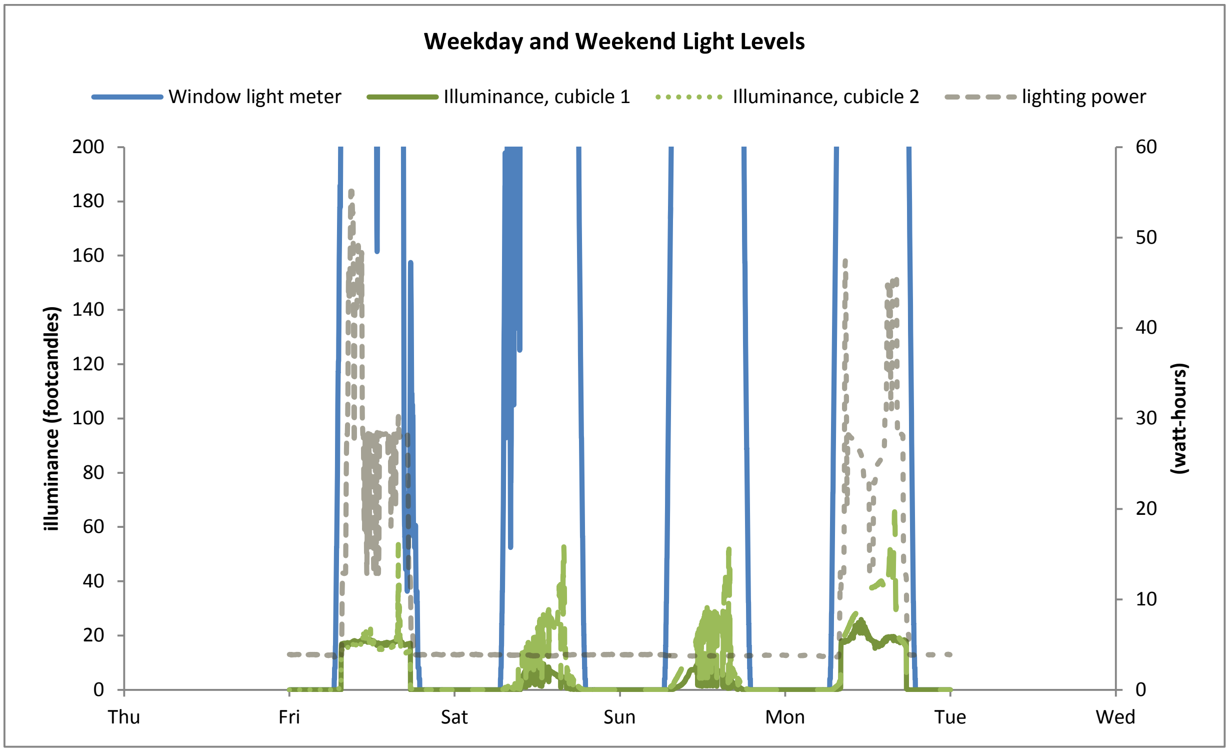
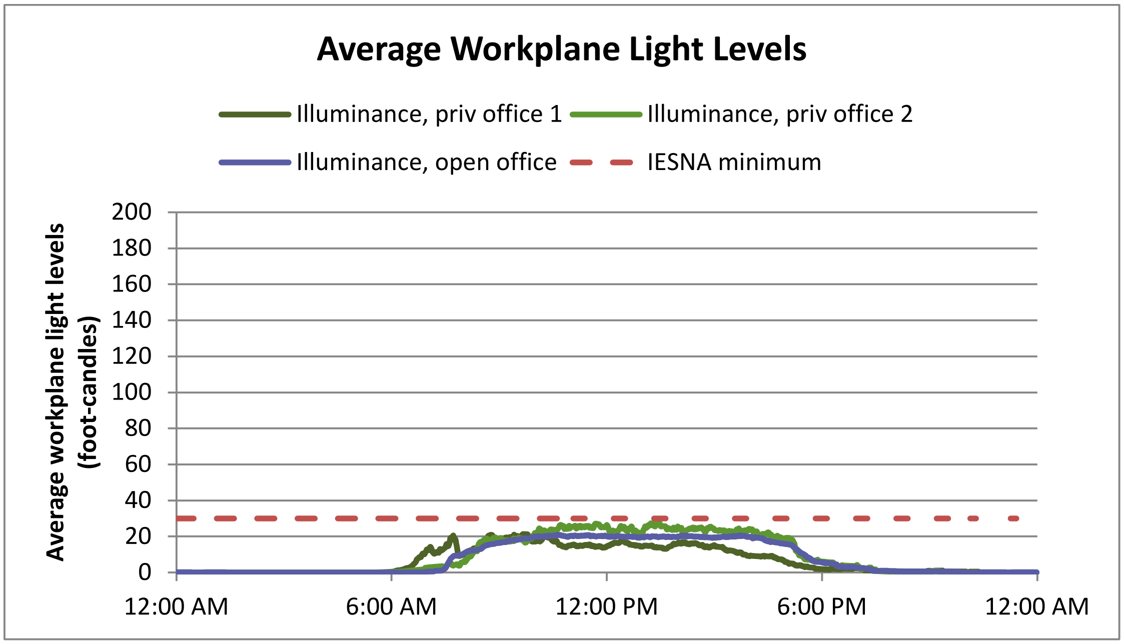


Figure 22 shows that the IDS system generally does not provide light to the permanent work locations (the two private offices and open office area) at or above the minimum levels recommended by the IESNA. Maximum lamp output was tuned down to 80% of rated power input in the open office area and 70% in all other spaces, and so there is capacity to draw on if brighter lighting is requested or required. The occupancy-based control in all areas meant that lamps would operate as soon as the office was occupied. During the monitoring period, average desktop light levels in the corner private office were typically between 10 and 20 footcandles during the day. Power metering data suggests that this is often due to the office being vacant and so therefore the lights were off. In the second private office, light levels during occupancy were between 30 and 40 footcandles at the desktop, and between 20 and 25 footcandles at the computer work location. In the open office areas, light levels remained at a fairly constant 20 footcandles. In all of these locations, the default position for the shades was closed. The average vertical illuminance data recorded during the monitoring period (not plotted on axes) suggests that disability glare is not an issue at any of the work locations.

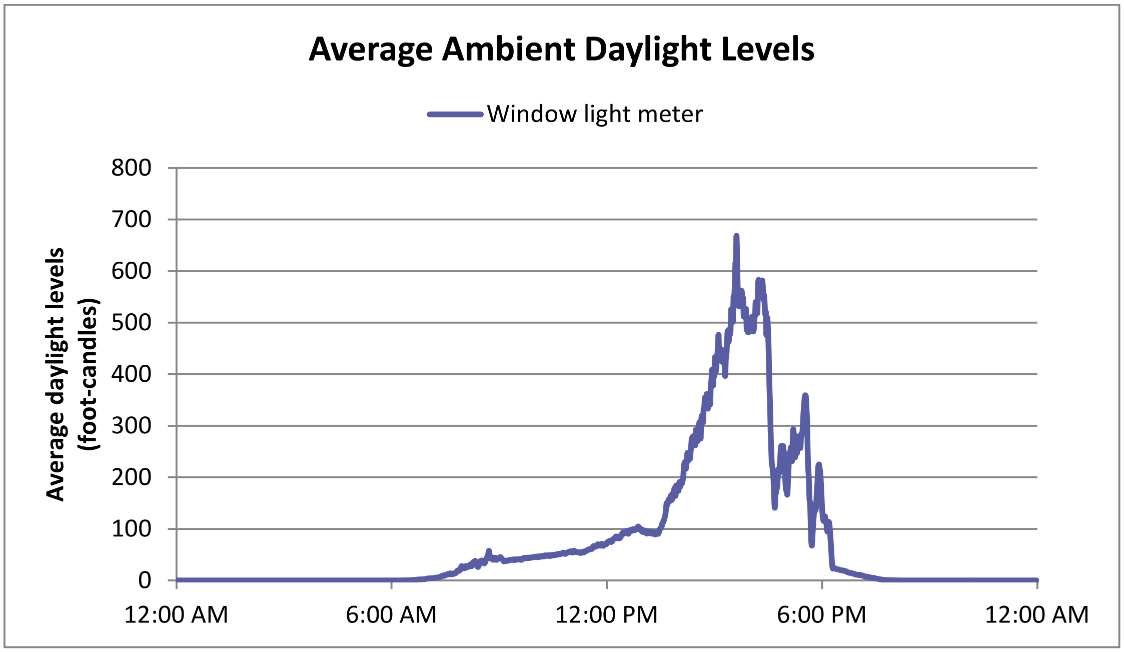
Figure 22: Hammond Courthouse, 1st Floor, measured average horizontal light levels (illuminance) recorded in the private office throughout the monitoring period. The data comprises light levels measured for weekdays over a period of approximately five months.



GSA PROPERTY MANAGEMENT, 2ND FLOOR, DIRKSEN FEDERAL BUILDING

Figure 23 shows light levels measured at the window in the vertical plane. The data indicates that the average day was brighter in the afternoon; light levels passing through the window began to increase quickly after 1-1:30PM. In the morning, natural light levels were much lower. This pattern is due primarily to site orientation to the west and the fact that the building is located in a densely built urban environment containing many high buildings; these building prevent a significant proportion of natural light from reaching the site. Natural light levels peak between 3:30PM and 4:15PM, with an intervening decrease. The cause for this is unclear but may be due to an obstruction by an adjacent building located to the west of the site, that shades the monitored window in the afternoon.

Figure 23: Dirksen Federal Building, 2nd floor, measured average ambient daylight levels (vertical illuminance) recorded at window-mounted light meter. The data comprises light levels measured for weekdays over a period of approximately three months.



A comparison of weekday data to weekend day data, presented in Figure 24 shows that weekend light levels, when electric lights are not operating, are lower than those on weekdays. The conclusion is that even when there are bright external conditions, light levels on the space are dependent largely on electric lighting to meet recommended minimum light levels.

Figure 24: Dirksen Federal Building, 2nd Floor, example measured ambient light levels for weekdays and weekends, indicating dependence of lighting levels on operation of electric lighting. The monitored period is Friday 12 October to Monday 16 October.

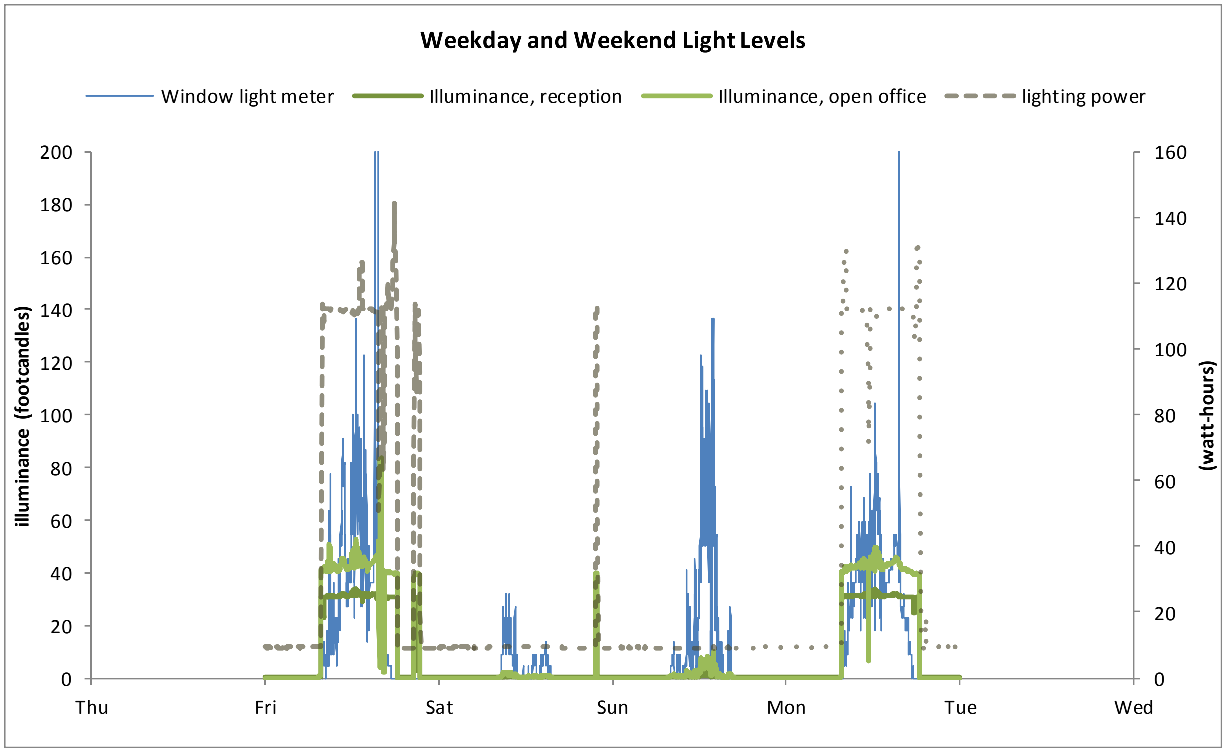
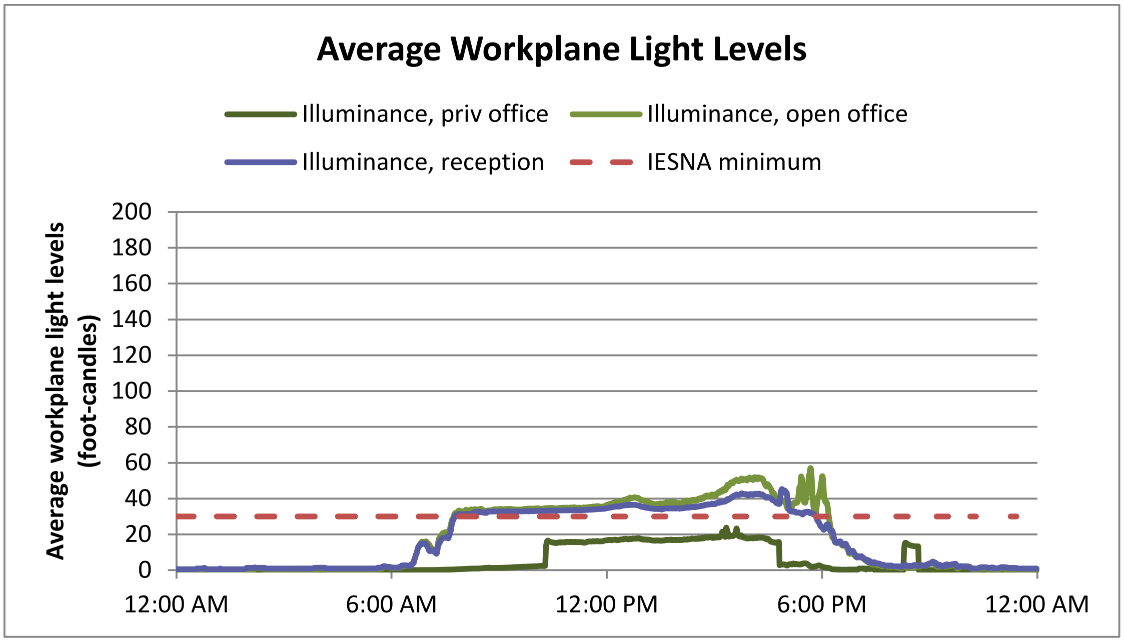


Figure 25 shows that the IDS system generally provides light to two of the permanent work locations (the reception and open office area) at the target levels recommended by the IESNA or marginally higher. Light levels in the private office are typically lower at between 15-20 footcandles. Note that lamp output was not tuned at this location – lighting would operate at 100% of rated power input when not dimming to daylight. Lights would operate as soon as the first person entered the office. The average vertical illuminance data recorded during the monitoring period (not plotted on axes) suggests that disability glare is not an issue.

Figure 25: Dirksen Federal Building, 2nd floor, measured average horizontal light levels (illuminance) recorded in the private office throughout the monitoring period. The data comprises light levels measured for weekdays over a period of approximately three months.



E COST EFFECTIVENESS

Cost-effectiveness analysis is conducted for any potential investment decision. For energy efficiency measures, its purpose is to determine whether the value of future energy savings is sufficient to justify the investment associated with installing and operating it.

In terms of inputs to the analysis, as far as possible, costs have been broken down to the individual equipment item type level and also the labor cost associated with installation and commissioning of each item type. Where detailed information was not available, reference labor costs have been used in their place.

Based on project quotes from implemented GSA projects, the total ballast cost at the time of installation was confirmed at $40 each. This cost can be considered high now, and will reduce further in the future as the market grows. With respect to total ballast costs at each site, this depended on the number and type of light fixtures installed. Recessed fixtures were controlled by a single DALI ballast. Pendant fixtures were controlled by two DALI ballasts – one ballast controlling the downlight component (2 lamps) and one controlling the uplight component (1 lamp). In the analysis, an incremental ballast cost of $25 is used, and represents the difference between a non-dimming ballast (which would be used for sites with time-scheduling and occupancy-based control only) and a dimming ballast (necessary for high-end tuning and daylight dimming).

The assessment metrics utilized in this study are simple payback, savings investment ratio (SIR) and life-cycle costs, assuming a system lifetime of 15 years.

Table 20 contains the key economic inputs broken down into equipment and labor cost and other items.

Table 20: Summary of cost inputs

Item Type	Item	Cost Basis	Region 9 - California Sites	Region 5 – Illinois / Indiana Sites
Equipment	Photosensor	$/item	46	46
	Wiring / cabling	$/length foot	0.75	0.5
	Ballasts[12]	$/item	25	25
	Software[13]	$/sqft	0.1	0.1
Labor	Installation (general - ballasts)[14]	$/sqft	0.3	0.3
	Photosensor install and calibration	$/item	50	80
	Programming*	$/sqft	0.3	0.3
	O&M (daylighting)	$/sqft	0.02	0.02
	O&M (tuning and daylighting)	$/sqft	0.05	0.05
Other	Electricity rate[15]	$/kWh	0.12-0.13	0.077-0.1
	Discount rate	%	3.9	
	Equipment lifetime	years	15	

*Programming costs aligned with overall installation cost, considered to be a conservative (high) estimate

[12] Incremental cost between non-dimming ballast ($25 per item) and electronic dimming ballast ($50 per item) – cost of electronic dimming ballast suggested by N Ingersoll as reasonable existing market price.

[13] Based on a Lumenergi software cost for one of the CA sites

[14] Consistent with assumptions used in ALS Study for minimum installation labor cost. Labor costs used here also include for other line item costs so overall labor installation costs are higher (by a factor of ~ 2.3) than this minimum.

[15] Site dependent

Table 21 presents initial costs for each of the study sites using the cost inputs presented above. There is a significant range in equipment costs, which mainly reflects the variation in lighting design across sites.

Table 21: Summary of Initial costs

Site	Daylight Dimming Initial costs ($/ft^2)		Set point Tuning and Daylight Dimming Initial costs ($/ft^2)	
	Equipment	Labor	Equipment	Labor
Ron Dellums	0.33	0.28	1.08	0.88
Roybal	0.26	0.27	0.89	0.88
Cottage Way	0.3	0.4	0.85	0.98
Hammond	0.21	0.2	0.74	0.89
Dirksen	0.43	0.3	1.92	0.94

Table 22 and Table 23 contain the details of the energy savings and energy cost savings observed at each site for daylight dimming and for set point tuning and daylight dimming respectively. The data indicates a significant range in energy saving performance. Factoring in the range of utility rates, which are significantly higher in California than they are in the Midwest, accentuates the range of energy cost savings.

Table 22: Summary of annual incremental operating savings for daylight dimming

Site	Tuned EUI (kWh/ft^2/yr.)	Daylight Dimming EUI (kWh/ ft^2/yr.)	EUI Savings (kWh/ ft^2/yr.)	Annual Operating Savings ($/ft^2/yr.)
Ron Dellums	1.25	0.99	0.26	0.03
Roybal	4.17	3.15	1.02	0.12
Cottage Way	2.03	0.96	1.07	0.14
Hammond	1.15	0.86	0.29	0.02
Dirksen	5.88	4.32	1.56	0.1

Table 23: Summary of annual operating savings from tuning and daylight dimming

Site	Operating Lighting EUI (kWh/ ft^2/yr.)	Tuning and Daylight Dimming EUI (kWh/ ft^2/yr.)	EUI Savings (kWh/ ft^2/yr.)	Annual Operating Savings ($/ft^2/yr.)
Ron Dellums	2.37	0.99	1.38	0.18
Roybal	4.84	3.15	1.69	0.2
Cottage Way	2.36	0.96	1.4	0.18
Hammond	1.54	0.86	0.69	0.07
Dirksen	5.88	4.32	1.56	0.12

*Dirksen Building lighting system is not tuned

Table 24 presents results of the economic analysis in terms of project payback period. Table 25 presents the results of economic analysis in terms of savings investment ratio.

Table 24: Payback period analysis results

Site	Payback Period in years (daylight dimming only)	Payback Period in years (tuning and daylight dimming)
Ron Dellums	>15	10.9
Roybal	4.3	8.7
Cottage Way	4.9	10
Hammond	14	>15
Dirksen	6.3	>15

Table 25: Savings Investment Ratio (SIR) analysis results

Site	Savings Investment Ratio (daylight dimming only)	Savings Investment Ratio (tuning and daylight dimming)
Ron Dellums	0.63	1.03
Roybal	2.61	1.29
Cottage Way	2.3	1.12

Site	Savings Investment Ratio (daylight dimming only)	Savings Investment Ratio (tuning and daylight dimming)
Hammond	0.8	0.47
Dirksen	1.79	0.47

1. SENSITIVITY ANALYSIS

The results of sensitivity analysis for set point tuning and daylight dimming are presented below. This process was not completed for the daylight dimming only scenario as the installed costs for that option are incremental and therefore the results are more difficult to interpret.

Figure 26 indicates the initial costs cost-effectiveness break-even point for set point tuning and daylight dimming at each of the five installations, indicated by the point at which the project SIR curve intersects with the dashed red line. One leading industry vendor has indicated that installed costs for advanced control systems may range from $0.5-$4 per square foot of floor area. Within this cost range all five study sites can be cost-effective, although the range of cost points at which this is achieves varies significantly between the sites, from $0.65 per square foot to $2.28 per square foot.

Figure 26: Impact of installed cost on cost-effectiveness

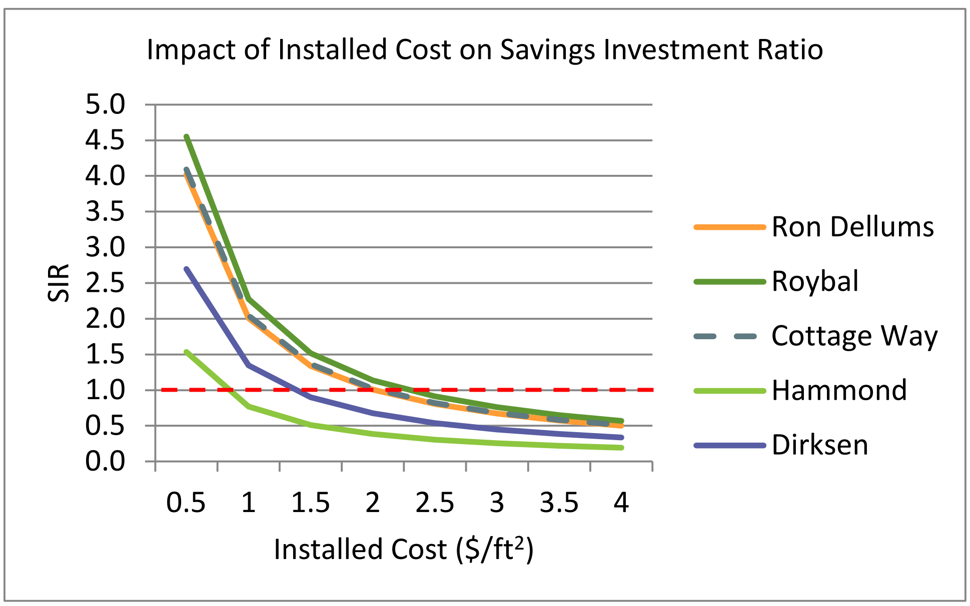


Figure 27 indicates the utility rate cost-effectiveness break-even point for set point tuning and daylight dimming at each of the five installations, indicated by the point at which the project SIR curve intersects with the dashed red line. The range of utility rates points at which this is achieves varies significantly between the sites, from approximately $0.1 per kilowatt-hour to $0.2 per kilowatt-hour.

Figure 27: Impact of utility rate on cost-effectiveness

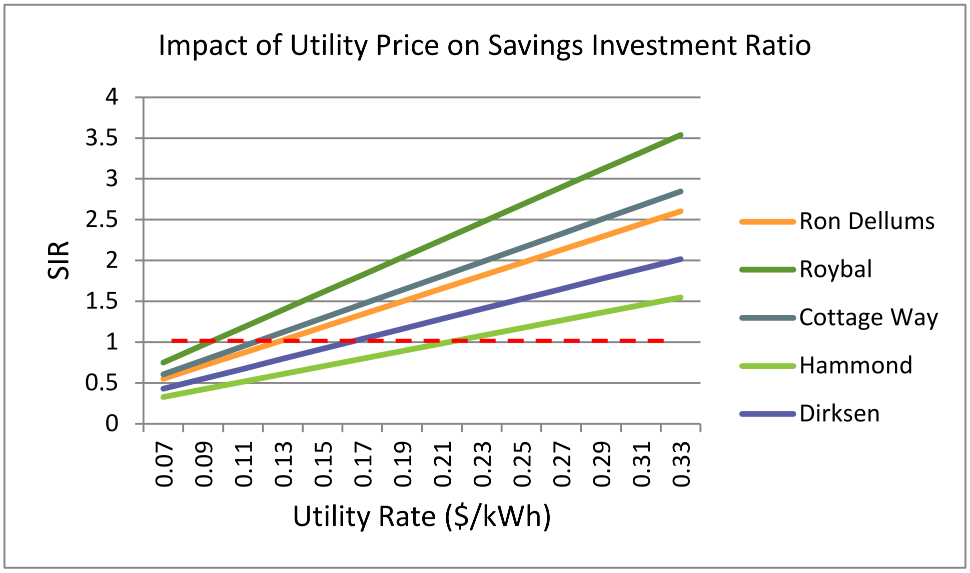
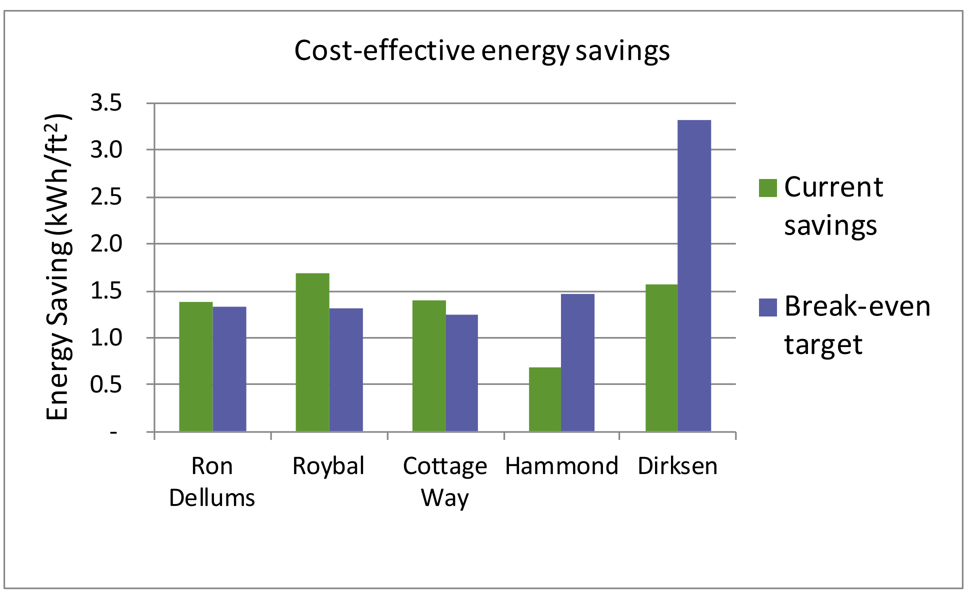


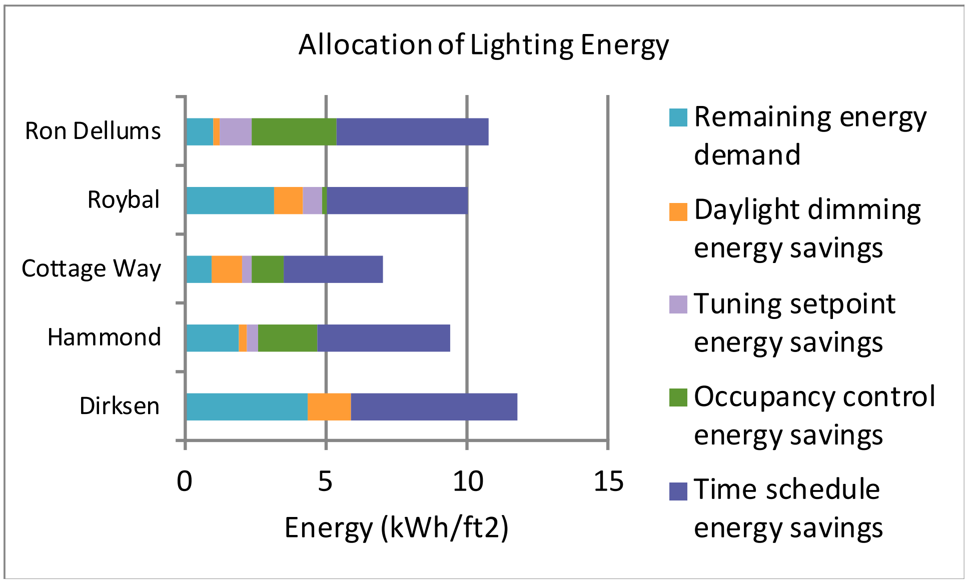
Figure 28 shows how each study site is performing in terms of current energy savings versus those required to achieve break-even. These results reflect the utility prices currently in effect at each site. It is clear that the California-based sites are all exceeding the required energy saving performance, whilst the two Midwest sites are not achieving break-even levels.

Figure 28: Comparison of actual energy savings and those required to achieve cost-effectiveness (SIR > 1)



To improve the cost effectiveness of these existing systems requires either an increase in local utility rates; a variable that cannot be controlled, or increase IDS energy savings. As Figure 29 indicates, there are two options to generate greater energy savings from IDS - either through better use of natural light (i.e. by operating the blinds more often (this applies to all sites to some extent, or by making other interior design changes that increase daylight effectiveness in the space) or by ensuring that offices with IDS are occupied for a greater proportion of annual working hours (at Ron Dellums, Cottage Way and Hammond).

Figure 29: Lighting energy savings and end use



The data in Figure 29 also indicates that the two sites with deeper day lit zones (at least two work locations or cubicles in depth) have higher lighting energy use intensities. This is due to desks further from the window requiring greater illumination from the electric lights as the efficacy of natural light is reduced further from the window wall. At the Dirksen site, another contributory factor is likely to be that part of the measured daylit zone is adjacent to north facing windows, which face a tall building, further limiting the impact of daylight. Energy savings from IDS on the north facing day lit zone are likely to be significantly lower than those for the west facing zone, and will reduce energy savings per square foot for the overall area.

2. RONALD DELLUMS FEDERAL BUILDING

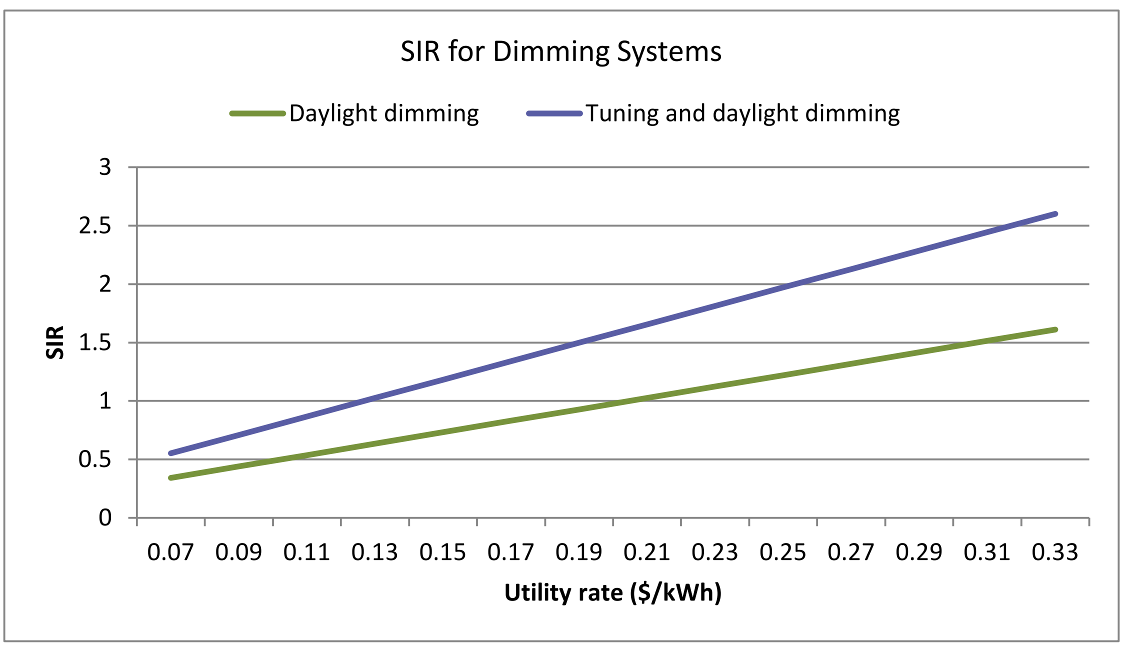
Table 26: Ronald Dellums dimming project costs, operating savings and simple payback

	Equipment Cost ($/ft^2)	Labor Cost ($/ft^2)	Total Cost ($/ft^2)	Annual Operating Saving ($/ft^2)	Simple Payback Period (years)
Daylight dimming costs	0.33	0.28	0.61	0.03	17.6
Tuning and dimming costs	1.08	0.88	1.96	0.18	10.9

The Ronald Dellums IDS was estimated to have a payback period of 17.6 years for the 'incremental daylight dimming" and 10.9 years for the 'tuning and daylight dimming'. The calculated EUI resulted in energy savings of 0.26 kWh/ft^2/year for incremental daylight dimming and 1.38 kWh/ft^2/year for tuning and daylight dimming. The annual operating savings for incremental daylight dimming is $0.03/ft^2/year and for tuning and daylight dimming is $0.18/ft^2/year.

The SIR was 0.63 for daylight dimming only and 1.03 for tuning and daylight dimming. For the SIR of daylight dimming to achieve a rating of 1, the local electricity price would need to be approximately $0.21 / kWh.

Figure 30: Ronald Dellums dimming systems - variation in SIR value with local electricity prices



The lifecycle costs for daylight dimming are estimated at $2.27 per square foot and for set point tuning and daylighting dimming are estimated at $3.96 per square foot.

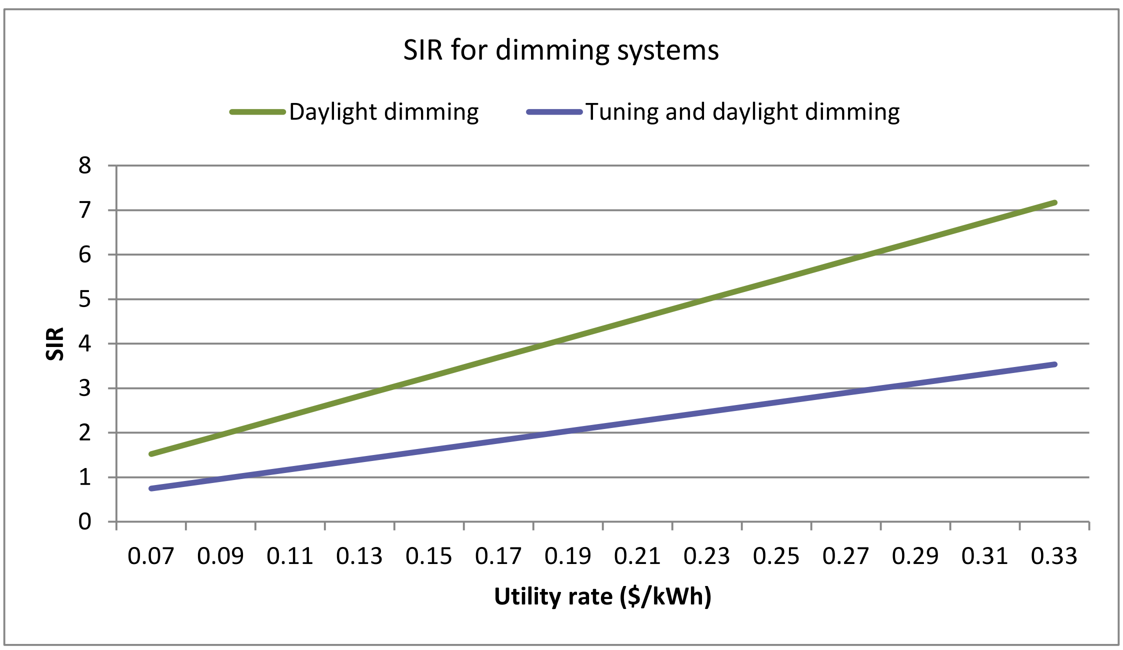
Table 27: Roybal dimming project costs, operating savings and simple payback

	Equipment Cost ($/ft^2)	Labor Cost ($/ft^2)	Total Cost ($/ft^2)	Annual Operating Saving ($/ft^2)	Simple Payback Period (years)
Daylight dimming costs	0.26	0.27	0.53	0.12	4.3
Tuning and dimming costs	0.89	0.88	1.77	0.2	8.7

The Roybal IDS was estimated to have a payback period of 4.3 years for the 'incremental daylight dimming' and 8.7 years for the 'tuning and daylight dimming'. The calculated EUI resulted in energy savings of 1.02 kWh/ft^2/year for incremental daylight dimming and 1.69 kWh/ft^2/year. The annual operating savings for incremental daylight dimming is $0.12/ft^2/year and for tuning and daylight dimming is $0.2/ft^2/year.

The SIR was 2.61 for daylight dimming only and 1.29 for tuning and daylight dimming.

Figure 31: Roybal dimming systems - variation in SIR value with local electricity prices



The life cycle costs for daylight dimming are estimated at $4.98 per square foot and for set point tuning and daylight dimming are estimated at $6.56 per square foot.

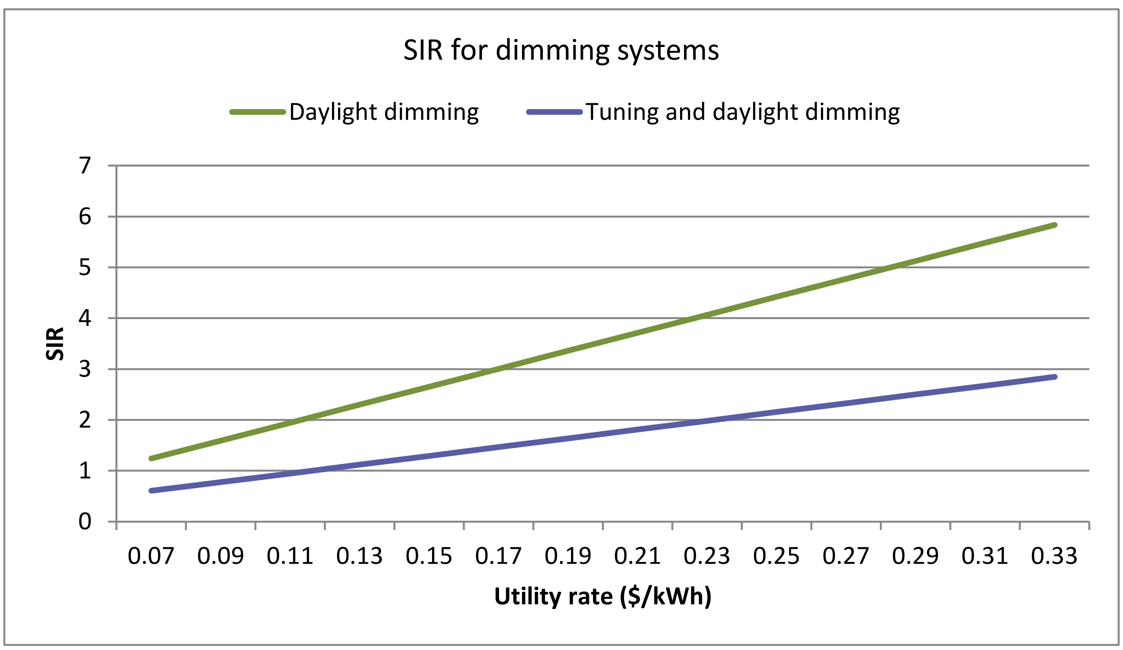
Table 28: Cottage Way dimming project costs, operating savings and simple payback

	Equipment Cost ($/ft²)	Labor Cost ($/ft²)	Total Cost ($/ft²)	Annual Operating Saving ($/ft²)	Simple Payback Period (years)
Daylight dimming costs	0.3	0.4	0.7	0.14	4.9
Tuning and dimming costs	0.85	0.98	1.83	0.18	9.9

The Cottage Way IDS was determined to have a payback period of 4.9 years for the ‘incremental daylight dimming” and 9.1 years for the ‘tuning and daylight dimming’. The calculated EUI resulted in energy savings of 1.07 kWh/ft^2/year for incremental daylight dimming and 1.4 kWh/ft^2/year. The annual operating savings for incremental daylight dimming is $0.14/ft^2/year and for tuning and daylight dimming is $0.18/ft^2/year.

The SIR was 2.3 for daylight dimming only and 1.22 for tuning and daylight dimming.

Figure 32: Cottage Way dimming systems - variation in SIR value with local electricity prices



The life cycle costs for daylight dimming are estimated at $2.30 per square foot and for set point tuning and daylight dimming are estimated at $3.78 per square foot.

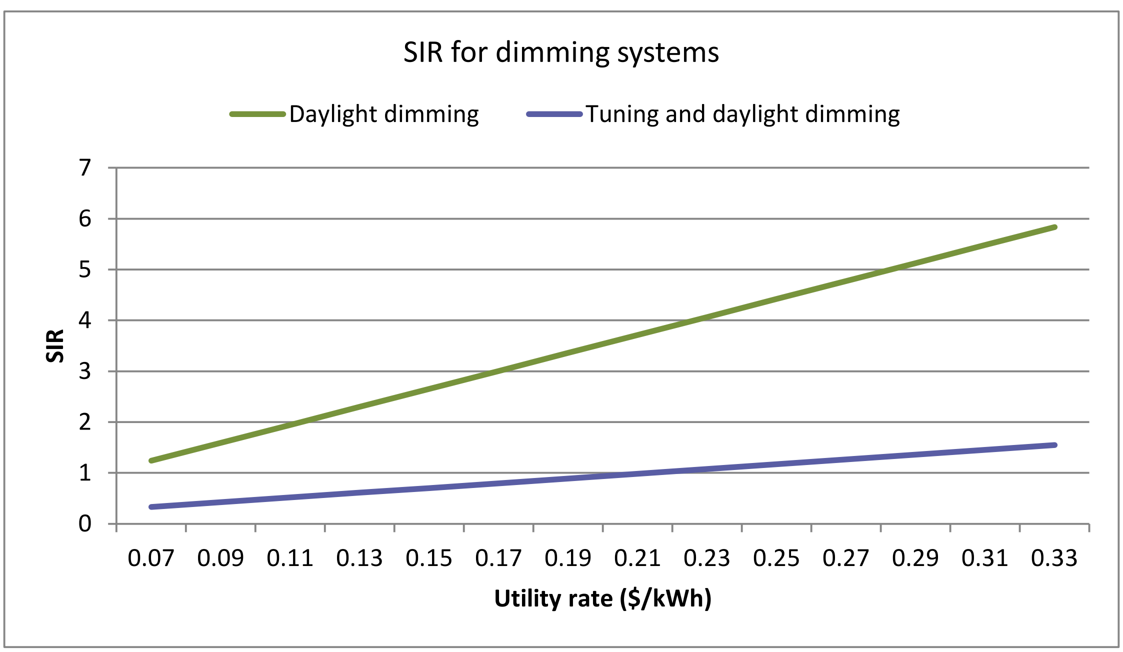
Table 29: Hammond dimming project costs, operating savings and simple payback

	Equipment Cost ($/ft²)	Labor Cost ($/ft²)	Total Cost ($/ft²)	Annual Operating Saving ($/ft²)	Simple Payback Period (years)
Daylighting dimming costs	0.21	0.2	0.41	0.03	14
Tuning and dimming costs	0.75	0.91	1.66	0.07	>15

The Hammond Courthouse IDS was estimated to have a payback period of 14 years for the 'incremental daylight dimming" and over 15 years for the 'tuning and daylight dimming' scenarios. The calculated EUI resulted in energy savings of 0.29 kWh/ft^2/year for incremental daylight dimming and 0.7 kWh/ft^2/year. The annual operating savings for incremental daylight dimming is \$0.2/ft^2/year and for tuning and daylight dimming is \$0.07/ft^2/year.

The SIR was 0.8 for daylight dimming only and 0.47 for tuning and daylight dimming. For the SIR of daylight dimming to achieve a rating of 1, the local electricity price would need to be approximately $0.13 / kWh, and for tuning and daylight dimming it would need to be $0.22 / kWh.

Figure 33: Hammond dimming systems - variation in SIR value with local electricity prices



The life cycle costs for daylight dimming are estimated at $1.58 per square foot and for set point tuning and daylight dimming are estimated at $3.16 per square foot.

6. DIRKSEN FEDERAL BUILDING

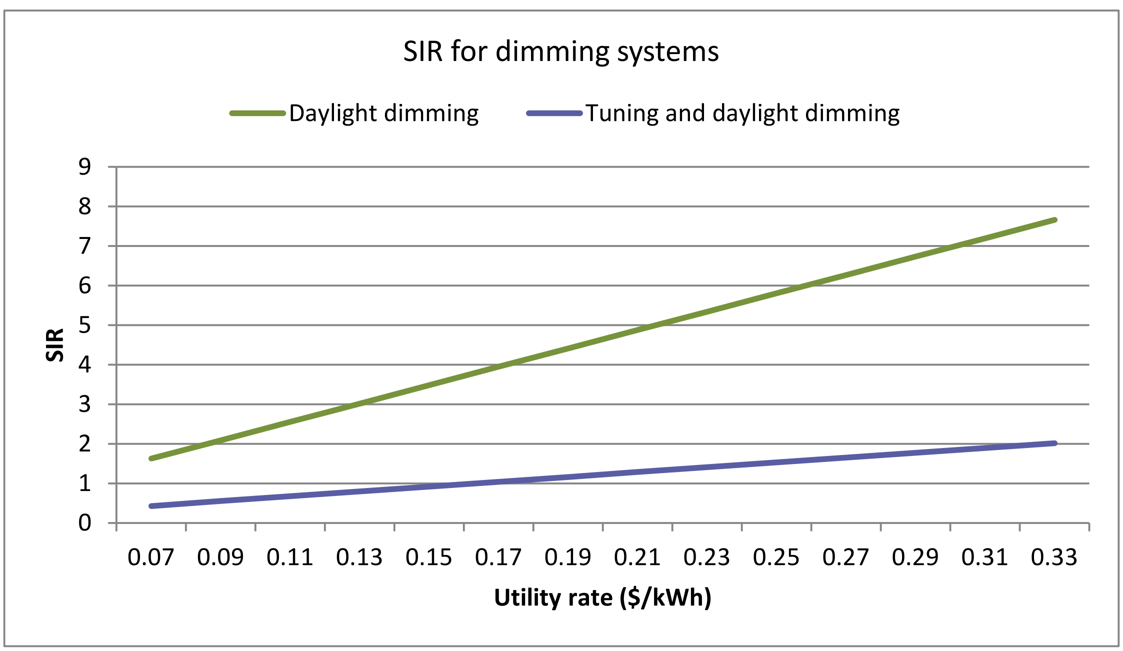
Table 30: Dirksen dimming project costs, operating savings and simple payback

	Equipment Cost ($/sqft)	Labor Cost ($/sqft)	Total Cost ($/sqft)	Annual Operating Saving ($/sqft)	Simple Payback Period (years)
Daylighting dimming costs	0.43	0.3	0.73	0.12	6.3
Tuning and dimming costs	1.92	0.94	2.86	0.12	>15

The Dirksen IDS was estimated to have a payback period of 6.3 years for the 'incremental daylight dimming" and over 15 years for the "tuning and daylight dimming". The calculated EUI resulted in energy savings of 1.56 kWh/ft^2/year for daylight dimming (there is no high-end tuning of lamps at Dirksen). The annual operating savings for daylight dimming and for set point tuning with daylight dimming is $0.12/ft^2/year.

The SIR was 1.79 for daylight dimming only and 0.47 for tuning and daylight dimming. For the SIR of tuning and daylight dimming to achieve a rating of 1, the local electricity price would need to be approximately $0.17 / kWh.

Figure 34: Dirksen dimming systems - variation in SIR value with local electricity prices



The life cycle costs for daylight dimming are estimated at $4.70 per square foot and for set point tuning and daylight dimming are estimated at $7.15 per square foot.

F OCCUPANT SATISFACTION SURVEYS

To understand occupant perceptions of IDS, an electronic survey was distributed to building occupants, with the aim of understanding the degree to which people felt that elements of integrated daylighting systems created or detracted from a comfortable working environment.

The survey was typically distributed via an on-site contact and was voluntary, with the responses kept anonymous. Where there were responses that indicated the individual did not have access to daylight, these were excluded, as they are not relevant to this study.

To encourage participation and completion of the survey, none of the questions were compulsory: no one from any of the four sites that took part in the survey answered all of the questions. The results illustrate how people felt about specific elements of the IDS system and how their perceptions of IDS compared to other key aspects of lighting and personal visual comfort.

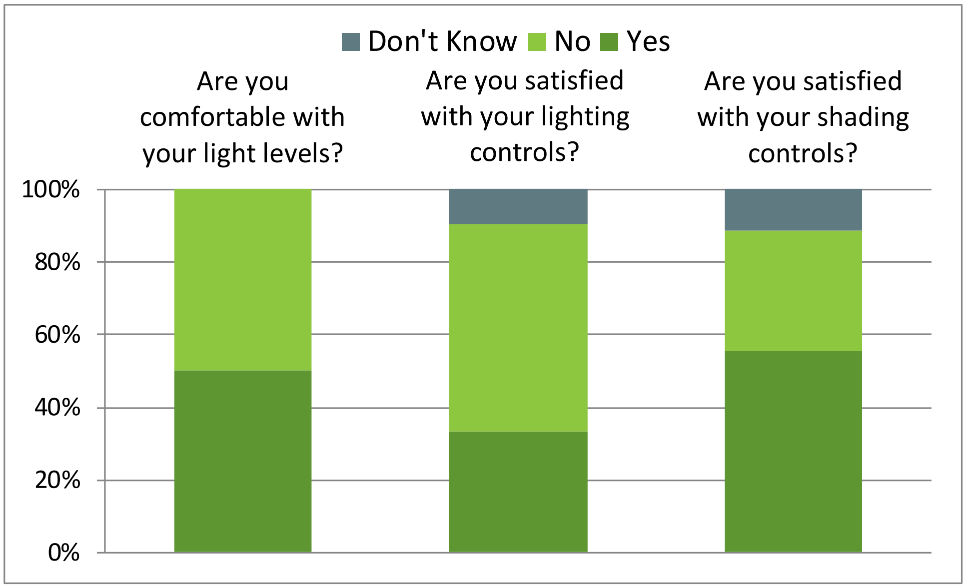
The survey focused on understanding the perspective of each respondent towards their personal working environment, and how the various characteristics within it contributed towards satisfaction or dissatisfaction. The objective was to determine to what degree IDS systems are instrumental in creating a satisfactory working environment in terms of lighting conditions. The survey results also aimed to reveal any other important factors in determining satisfaction associated with work area lighting. The method of analysis was a cross-tabulation of responses, where factors related to and common with satisfaction and dissatisfaction were determined. From this cross-tabulation, some conclusions could be drawn.

From the survey responses, it was possible to identify the key lighting issues for each site, whether these were IDS related or not. The results lead to some key conclusions about where effort should be focused in the future when it comes to implementation of IDS specifically, and new lighting systems generally.

1. RONALD DELLUMS FEDERAL BUILDING

The occupant survey was distributed by the Building Manager to occupants in perimeter areas of the building, working for three different agencies. In total, 56 people responded to the occupant survey at this location, 44 of which worked in day lit spaces. The results for this site represent a statistically significant sample and may therefore be regarded as being representative of the population of occupants working within daylighting zones of the building.

Figure 35: Occupant satisfaction with work space lighting levels



Asked about satisfaction with their workspace light levels, 50% of respondents (21 people) stated that they were; 50% were dissatisfied.

When asked if they were satisfied with the lighting controls provided, 33% of respondents (14 people) stated that they were. 57% (24 people) were dissatisfied and 10% (4 people) were unsure.

56% of respondents (20 people) stated that they were satisfied with their blinds and shading controls. 12 respondents (33%) were dissatisfied, with 4 people (11%) unsure.

Figure 36: Factors commons with satisfaction with lighting

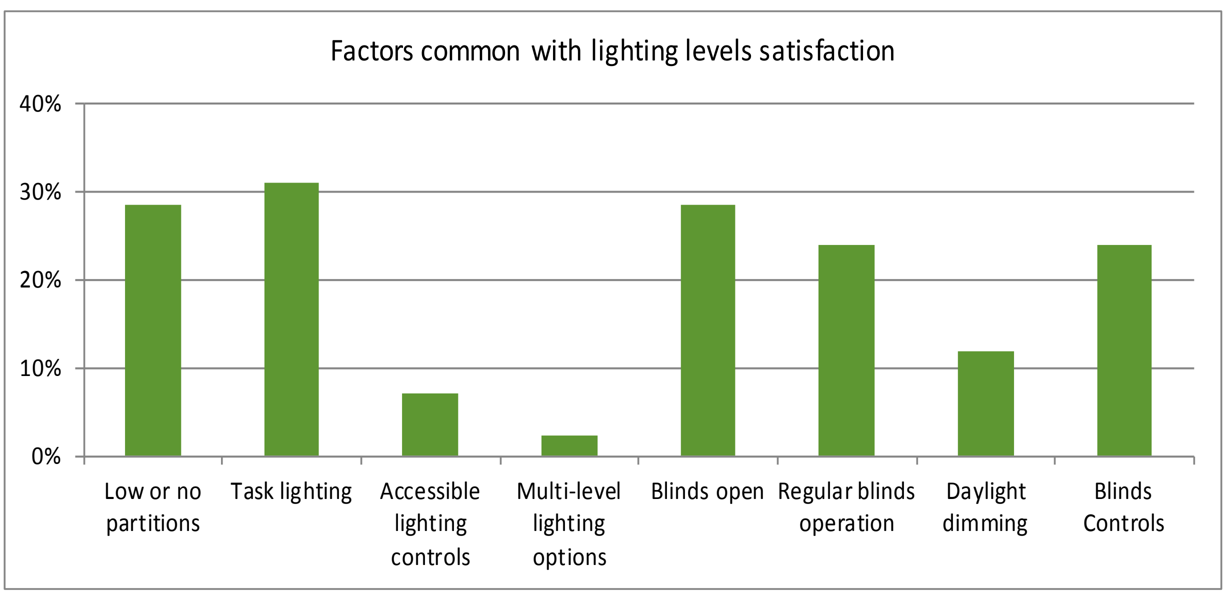


Figure 36 presents the results of how occupant satisfaction with lighting levels – which was low at this site – coincides with responses about other aspects of the lighting system and working environment. Of the factors common for those occupants that stated that they were satisfied with their lighting levels, provision of task lighting was the highest in occurrence (31%, 13 respondents) - occupants were afforded a degree of control over light levels experienced at their desks and were able to tailor light levels to their personal requirements. Other common factors to satisfaction included the presence of low partitions, and local blinds in a default open position, (both 29%, 12 respondents), control of natural light through operation of local blinds, and satisfaction with blinds and blind controls (24%, 10 respondents), daylight dimming (12%, 5 respondents), and accessible lighting controls and multi-level light level options (both <10% of respondents).

Figure 37: Factors common with dissatisfaction with lighting

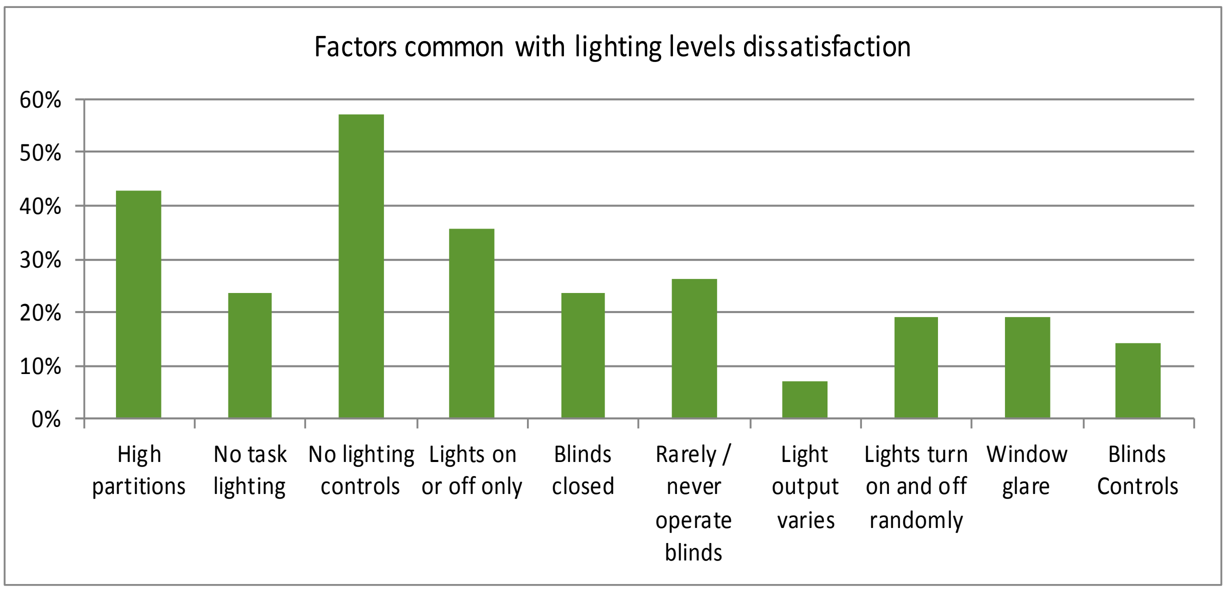


Figure 37 shows how dissatisfaction with lighting levels coincides with responses about other aspects of the lighting system and working environment. The factor most common with occupants' dissatisfaction with their light levels was the absence of lighting controls (57%, 24 responses). To relate this to the free comments section of the survey, when asked what they would like to improve about their lighting environment, was that light levels are often not sufficient for the tasks being performed. Other site specific characteristics that were common to dissatisfaction were to be high partitions (43%, 18 respondents), lights only being able to switch on and off (36%, 15 respondents), an absence of task lighting (24%, 10 respondents), the apparently random operation of electric lighting and window glare (19%, 8 respondents), dissatisfaction with blinds and blind controls (14%, 6 respondents) and not operating window blinds (26%, 11 respondents).

Of the factors common for those occupants that stated that they were dissatisfied with their lighting levels, daylight dimming (electric lighting levels changing noticeably throughout the day and light levels noticeably affected by operation of blinds) is the lowest ranked factor common with dissatisfaction (7%, 3 respondents) identified in the survey. The data suggests that for over 90% of respondents, IDS is not perceived as a problem in terms of its overall impact on visual comfort.

Figure 38: Factors commons with satisfaction with lighting controls

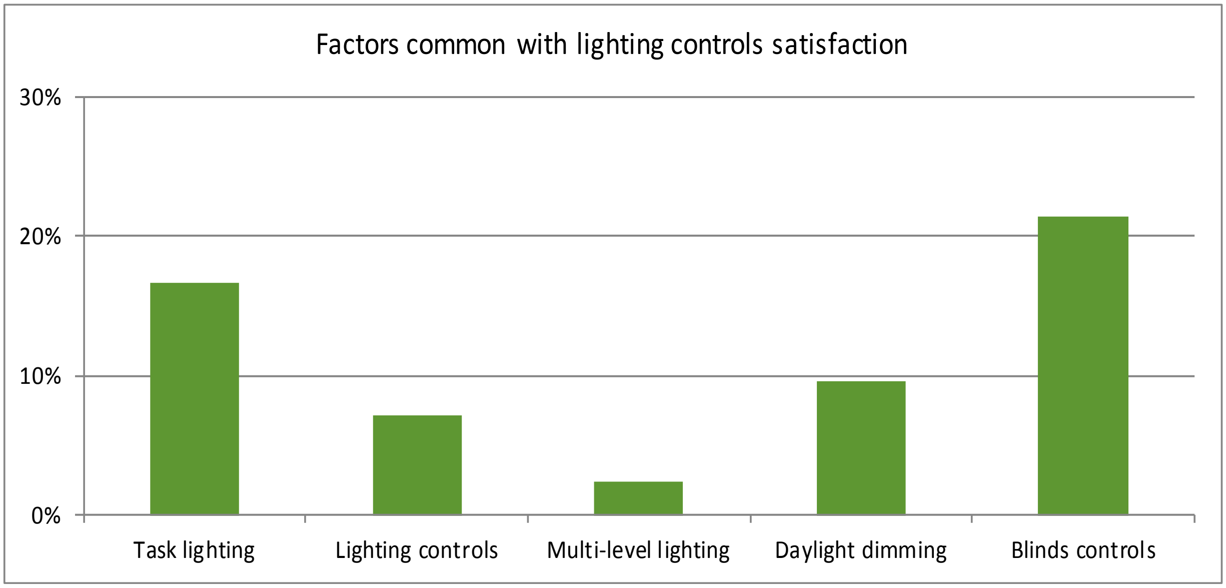


Figure 38 presents the results of how satisfaction with lighting controls – which was relatively low at this site - coincides with responses about other aspects of the local lighting environment. Satisfaction with blinds controls was the common factor most frequently observed in the responses (21%, 9 respondents), with providing task lighting (17%, 7 respondents), dimming of electric lighting to available natural light (10%, 4 respondents) and provision of lighting controls (7%, 3 respondents) and multi-level lighting options (1 respondent) also identified.

Figure 39: Factors commons with dissatisfaction with lighting controls

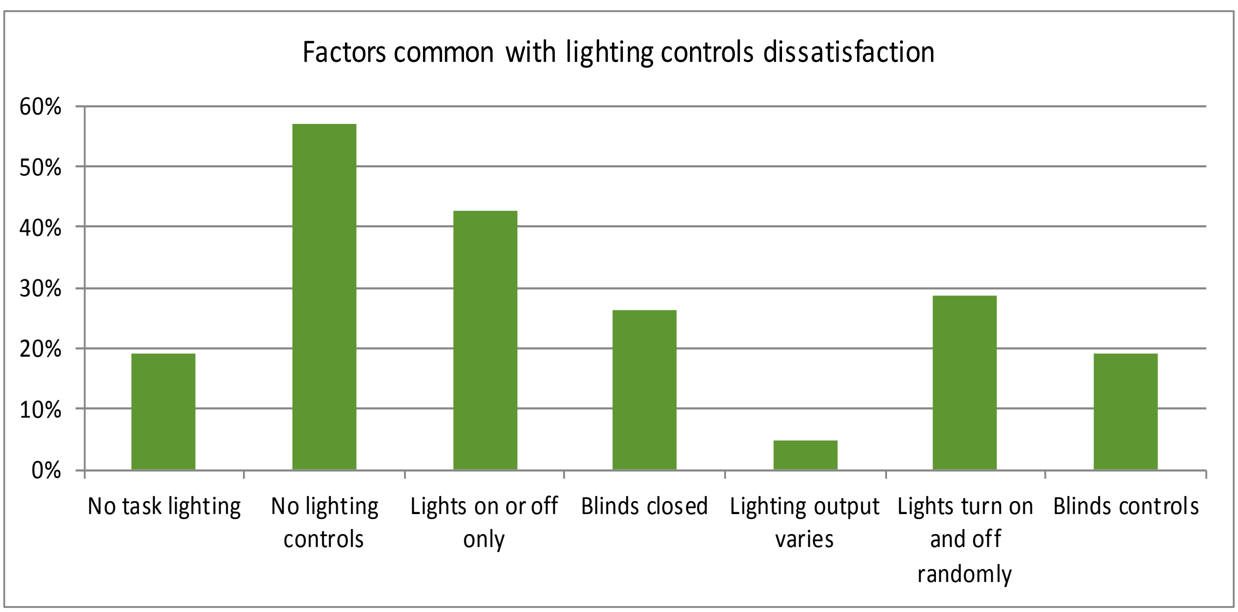


Figure 39 presents results of how dissatisfaction with lighting controls coincides with other aspects of the lighting environment. The most frequently observed common factor was the absence of personal lighting controls, with 57% (24 respondents) identifying it as a problem. Having lights only turn on and off was also identified as a significant common issue, with approximately 43% of respondents (18 people) identifying it. The remaining significant common factors in order of frequency of occurrence were lights turning on and off randomly (29%, 12 respondents), blinds remaining closed (26%, 11 respondents) and an absence of task lighting and dissatisfaction with blinds and blind controls (both 19%, 8 people). 2 respondents had negative views on the variation of output from electric lighting over the course of the day.

Occupant Survey Results and Conclusions – Ron Dellums

Cross referencing the results on satisfaction and dissatisfaction allows some conclusions to be drawn. The first is that providing personal lighting controls is perceived as important. Results of the surveys suggest that it is significantly more important to occupants not satisfied with their personal light levels – the logic being that occupants are more likely to notice the absence of controls when they are not satisfied with their light levels and not able to adjust light settings to their liking. This same pattern is repeated on the issue of satisfaction (or not) with lighting controls. Provision of task lighting is important at this site – it provides the means to change personal light levels and a means to control local electric lighting. This is highlighted by the results for those respondents that did not have task lighting – out of 17 respondents that did not have it, 10 were dissatisfied with their light levels, and also by the free responses of occupants when asked about light levels, stating that lighting conditions were often too dim. Of the same 17 respondents, 9 were dissatisfied with their lighting controls. Provision of good blinds and blind controls is a common factor with a satisfactory lighting environment while those dissatisfied noted in the free responses that the equipment and controls currently installed were ineffective in blocking direct sunlight and preventing window glare.

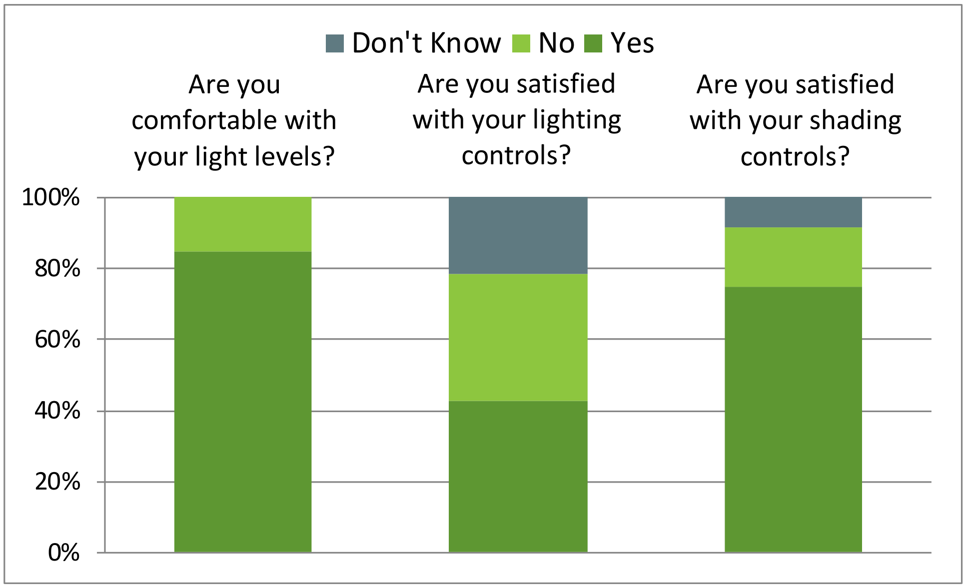
Making respondents aware of ‘Low, Medium or High’ light settings may resolve some of the light level and lighting control issues - over one third of respondents were not aware of this choice – this would require a separate investigation as the survey does not pinpoint what existing lighting settings are, and as responses are anonymous and non-location-specific, it is not possible to draw further conclusion. The current mechanism for requesting a change in light level settings, where the occupant has to dial a hotline number, is not considered satisfactory – occupants must wait up to 24 hours for the lighting level changes to be implemented.

Dynamic dimming to available daylight was not considered either as a significant positive common factor with lighting levels or lighting controls satisfaction or significant negative common factor, which suggests that when it is experienced, it is regarded as a relatively benign influence on lighting.

2. ROYBAL FEDERAL BUILDING

The occupant survey was distributed by the Building Manager to occupants in perimeter areas of the building, working for three different agencies. In total, 34 people responded to the survey at this location, 28 of which worked in day lit spaces. The responses from those that characterize their workspace as not having access to daylight are not included in the results presented. No one responded to all of the questions. The responses from this site are not sufficient to represent a statistically significant sample and are therefore not regarded as being representative of the population of occupants working within daylighting zones of the building.

Figure 40: Occupant satisfaction with work space lighting levels



When asked about their whether they were satisfied with their workspace light levels, 84% of respondents (22 people) stated that they were satisfied. The remaining 16% of respondents (4 people) were not satisfied with their lighting levels.

43% of respondents (12 people) stated that they were satisfied with their lighting controls. 36% of respondents (10 people) said that they were dissatisfied with their lighting controls, while the remainder, over 21% of respondents (6 people), were unsure.

When asked about whether they were satisfied with the controls provided for blinds and shades, 75% of people (18) stated that they were satisfied. 17% (4 people) were not satisfied and 8% (2 people) were not sure.

Figure 41: Factors commons with satisfaction with lighting

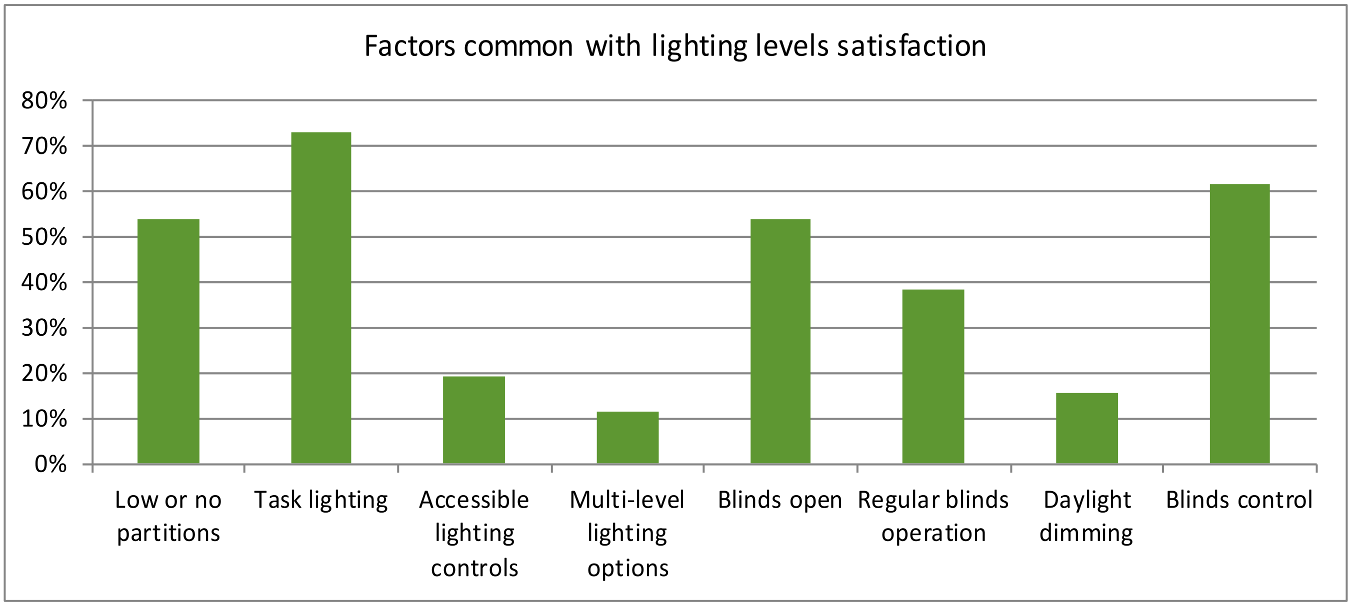


Figure 41 presents the results of how occupant satisfaction with lighting levels – which was high at this site – coincides with responses about other aspects of the lighting system and working environment. Of the factors common for those occupants that stated that they were satisfied with their lighting levels, provision of task lighting is the most important (73%, 19 respondents) – the majority of occupants were afforded a deal of control over light levels experienced at their desks and were able to tailor light levels to their personal requirements. Providing access to natural light was also a frequently observed common factor – satisfaction with blinds and blinds control, (62%, 16 respondents) low partitions (54%, 14 respondents) and open local blinds (54%) were identified. Of the remaining commons factors operation of local blinds was also identified as important by 38% of respondents (10 people), accessible lighting controls (19%, 5 respondents) and daylight dimming (15%, 4 respondents). Multi-level light level options were identified as a factor common to satisfaction for approximately 12% of respondents (3 people).

Figure 42: Factors common with lighting levels dissatisfaction

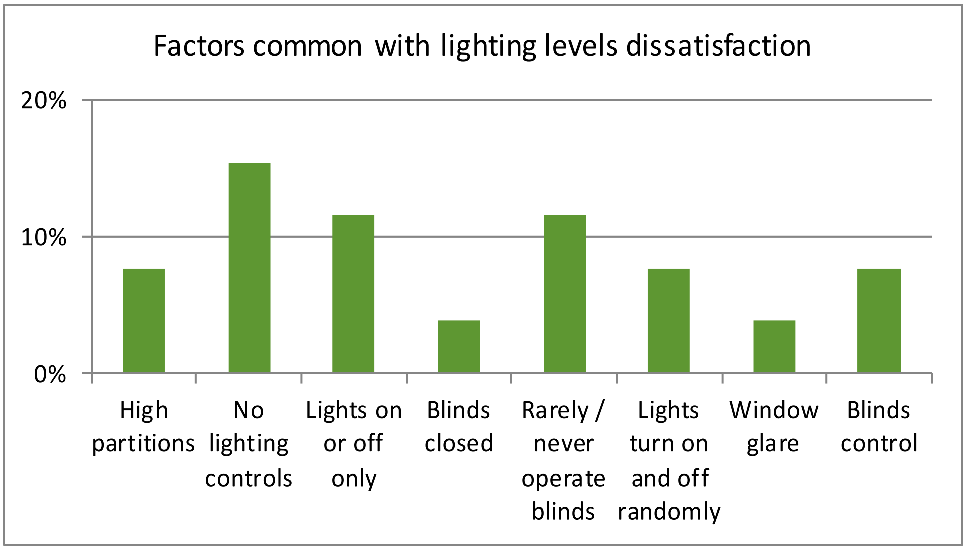


Figure 42 shows how dissatisfaction with lighting levels – which was low at this site – correlates to responses about other aspects of the lighting system and working environment. The factor most common with dissatisfaction with light levels was no access to lighting controls (15%, 4 respondents) – all of those dissatisfied with light levels wanted lighting controls. Other site specific characteristics that were common to dissatisfaction were infrequent operation of blinds (12%, 3 respondents) the apparently random operation of electric lighting (8%, 2 respondents), high partitions (8%, 2 respondents), dissatisfaction with blinds and blind controls (both 8%, 2 respondents), closed blinds default position and window glare (both 4%, 1 respondent). In terms of occupant behavior, the lack of window blinds operation is the most significant common factor. When asked about what they would like to improve about their lighting environment, the main issue identified by dissatisfied respondents was that light levels were not sufficient for the tasks being performed.

Of the factors common for those occupants that stated that they were dissatisfied with their lighting levels, negative perceptions of daylight dimming (categorized as electric lighting levels changing noticeably throughout the day and light levels noticeably affected by operation of blinds) is the second lowest factor associated with dissatisfaction, suggesting that for over 95% of respondents, IDS is not perceived as a problem in terms of its overall impact on visual comfort.

Figure 43: Factors commons with satisfaction with lighting controls

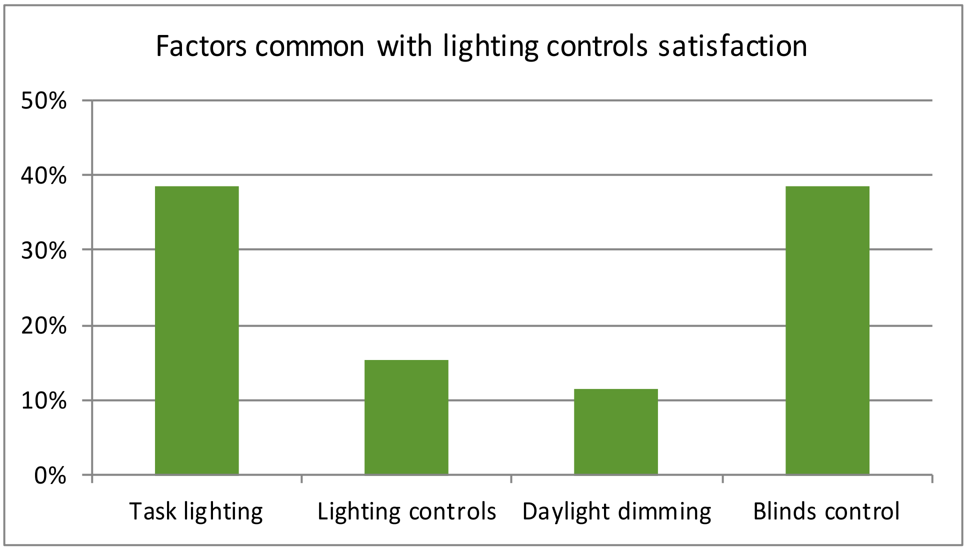


Figure 43 presents the results of how satisfaction with lighting controls – which was relatively low at this site - coincides with responses about other aspects of the local lighting environment. Providing task lighting and satisfaction with blinds and blind controls were the factors most commonly associated with this (both 38%, 10 respondents), with provision of lighting controls (15%, 4 respondents) and dimming of electric lighting to available natural light (12%, 3 respondents) also identified.

Figure 44: Factors common with dissatisfaction with lighting controls

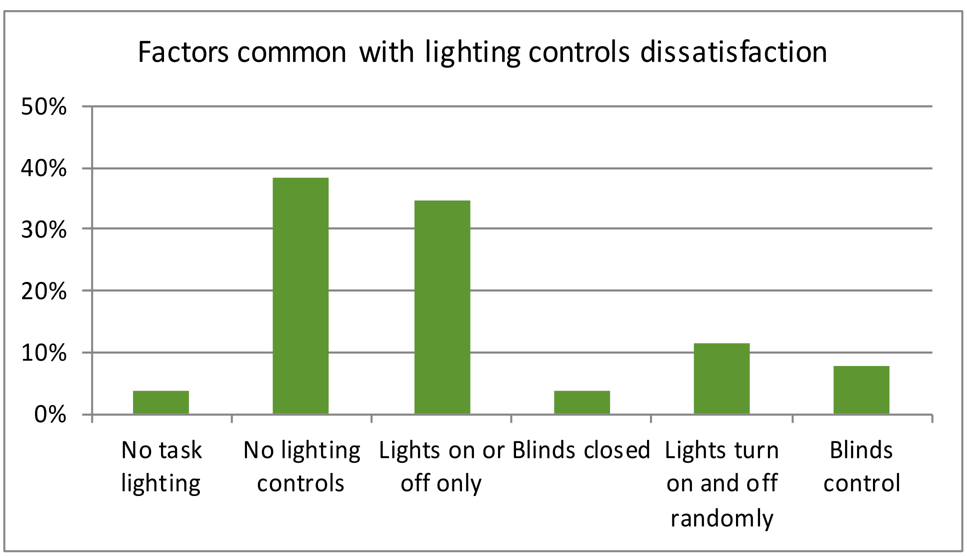


Figure 44 presents results of how dissatisfaction with lighting controls coincides with other aspects of the lighting environment. By far the most frequently occurring common factor is the absence of personal lighting controls, (38%, 10 respondents). The perception of lights only being able to turn on and off rather than having various available light output setting was also identified as a significant common issue, with approximately 35% of respondents (9 people) identifying it. The other common factors in order of importance were lights turning on and off randomly (12%, 3 respondents), dissatisfaction with blinds and blind controls (8%, 2 respondents) blinds remaining closed (4%, 1 respondent) and an absence of task lighting (4%, 1 person).

Occupant Survey Results and Conclusions – Roybal

Cross referencing the results on satisfaction and dissatisfaction, the first conclusion is that providing lighting controls is perceived as being important to those occupants not satisfied with their personal light levels. Occupants are more likely to be sensitive to the absence of controls when they are not satisfied with their light levels and not able to adjust light settings to their liking. This same conclusions can be drawn from satisfaction (or not) with lighting controls. Provision of task lighting is important at this site – it is identified as a significant common factor with satisfaction with light levels and lighting controls. Blinds and blinds controls were often a common factor with a satisfactory lighting environment, and a minor common factor with dissatisfaction.

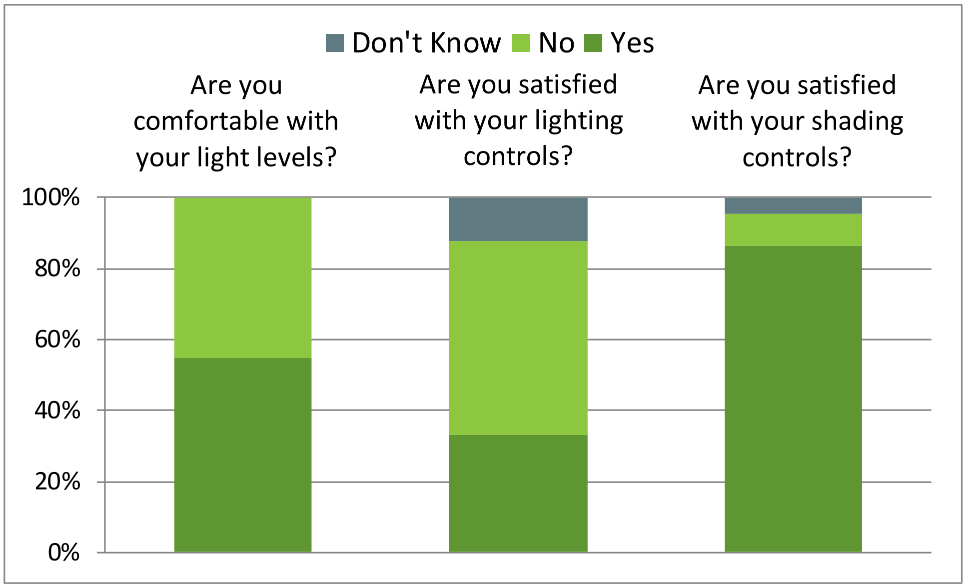
Making respondents aware of available 'Low, Medium or High' light settings – if these are available - might resolve the remaining light level issues and change perception of some of those dissatisfied with lighting control - approximately one third of respondents were not aware of this choice. The current route to requesting a change in light level settings was not clear.

Dynamic dimming to available daylight was not considered either as a significant positive common factor with lighting levels or lighting controls satisfaction or significant negative common factor, which suggests that when it is experienced, it is regarded as a relatively benign influence on the lighting environment.

3. COTTAGE WAY FEDERAL BUILDING

In total, 42 people responded to the survey at this location, 24 of which worked in day lit spaces. We are discounting responses from those that characterize their workspace as not having access to daylight. No one responded to all of the questions. The responses from this site are not sufficient to represent a statistically significant sample and are therefore not regarded as being representative of the population of occupants working within daylighting zones of the building.

Figure 45: Occupant satisfaction with work space lighting levels



When asked about whether they were satisfied with their personal lighting levels, 55% of respondents (12 people) said that they were satisfied. 45% of respondents (10 people) stated that they were dissatisfied.

One-third of respondents (8 people) said they were satisfied with the lighting controls provided. 54% of respondents (13 people) are dissatisfied with this, and three people (13% of respondents) said that they were unsure.

86% of respondents (19 people) said they were satisfied with their personal shading controls. Two respondents (9%) were dissatisfied, and the remaining person was unsure.

Figure 46: Factors common with satisfaction with lighting

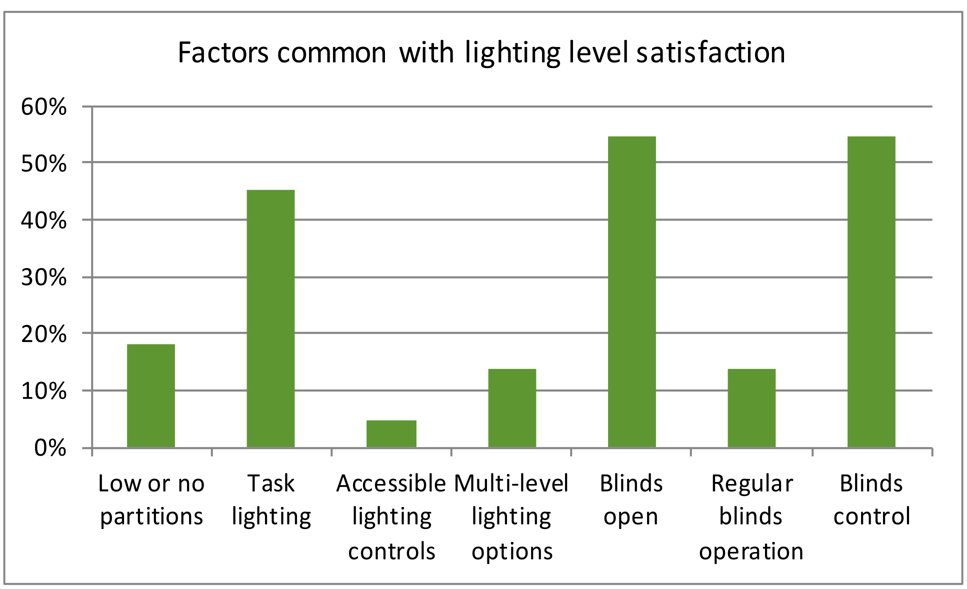


Figure 46 presents the results of how occupant satisfaction with lighting levels – which was relatively low at this site – coincides with responses about other aspects of the lighting system and working environment. Of the factors common for those occupants that stated that they were satisfied with their lighting levels, having the blinds open by default and being satisfied with the installed blinds and the means to control them were the most frequently observed common factor with satisfaction for 55% of respondents (12 people). Other common factors included provision of task lighting (45%, 10 respondents), low partitions (18%, 4 respondents), multi-level lighting options (14%, 3 respondents), regular blinds operation (14%) and accessible lighting controls (5%, 1 person).

Figure 47: Factors commons with dissatisfaction with lighting

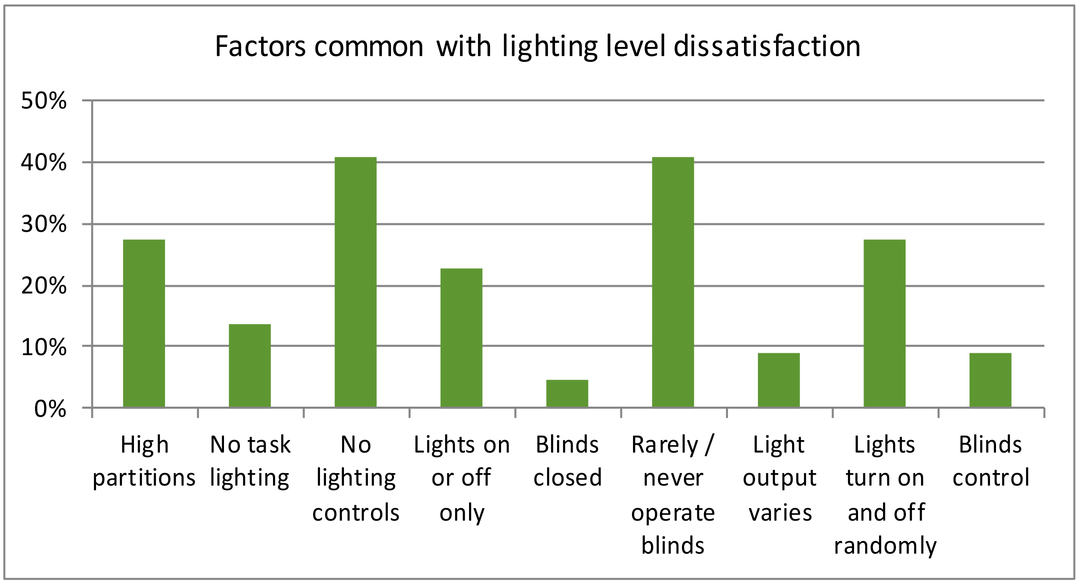


Figure 47 shows how dissatisfaction with lighting levels – which was relatively high at this site – correlates to responses about other aspects of the lighting system and working environment. The factor most common with dissatisfaction with their light levels was no access to lighting controls and not operating window blinds (both 41%, 9 respondents). Other site specific characteristics that influence the negative perceptions of occupants appear to be the apparently random operation of electric lighting (27%, 6 respondents), high partitions (27%, 6 respondents) and an absence of task lighting (14%, 3 respondents). Dissatisfaction with blinds and blind controls and variation in light output over the course of the day (both 9%, 2 respondents) and closed blinds default position (5%, 1 respondent) were minor common factors. When asked about what they would like to improve about their lighting environment, the main issue identified by respondents was that light levels were not sufficient for the tasks being performed.

Of the factors common for those occupants that stated that they were dissatisfied with their lighting levels, daylight dimming (electric lighting levels changing noticeably throughout the day and light levels noticeably affected by operation of blinds) is the second lowest ranked common factor. The data suggests that for over 90% of respondents, IDS is not perceived as a problem in terms of its overall impact on visual comfort.

Figure 48: Factors common with satisfaction with lighting controls

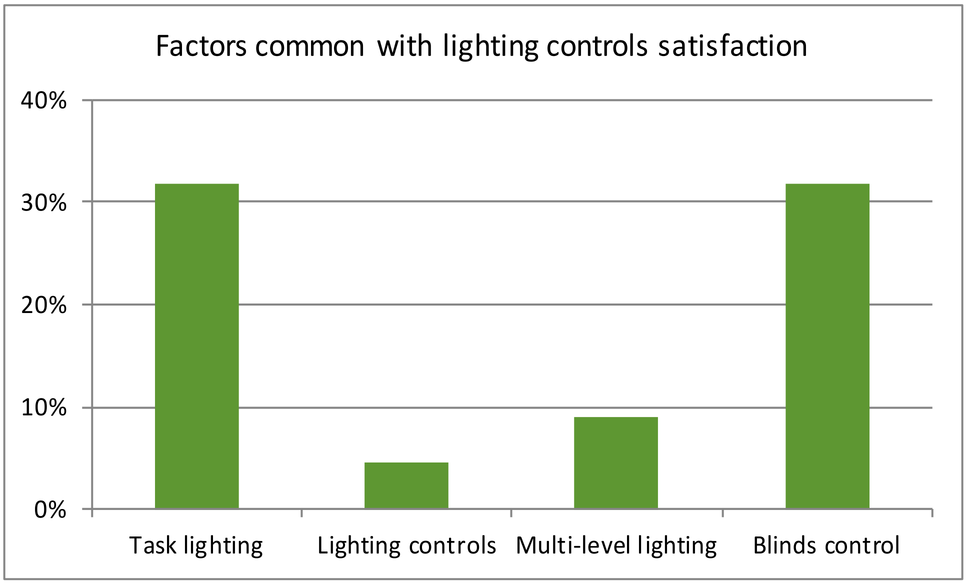


Figure 48 presents the results of how satisfaction with lighting controls – which was relatively low at this site – coincides with responses about other aspects of the local lighting environment. Providing task lighting and satisfactory blinds and blind controls were the factors most commonly associated with satisfaction (both 32%, 7 respondents), with options for multi-level lighting (9%, 2 people) and provision of lighting controls (5%, 1 respondent) also identified.

Figure 49: Factors commons with dissatisfaction with lighting controls

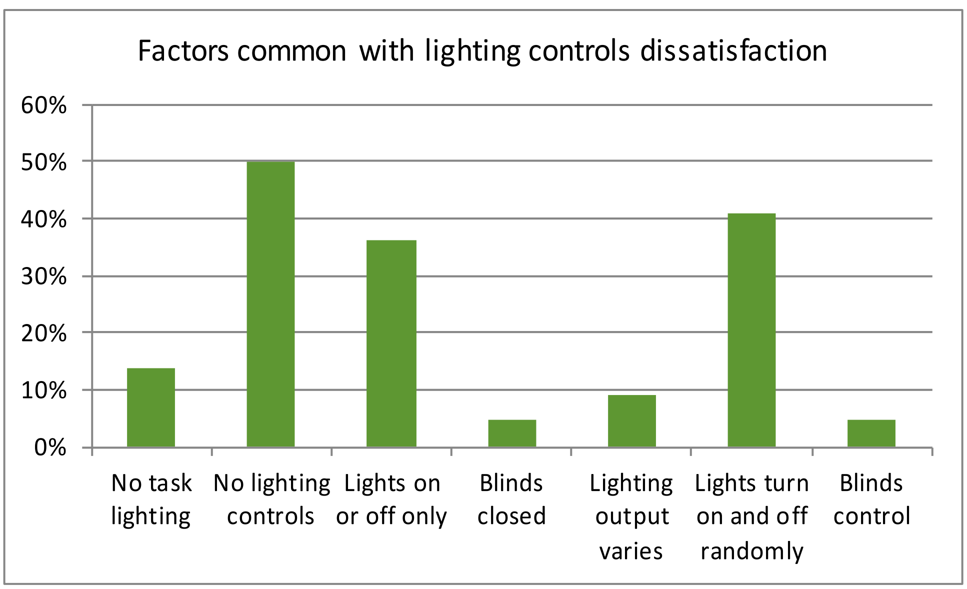


Figure 49 presents results of how dissatisfaction with lighting controls coincides with other aspects of the lighting environment. The most frequently occurring common factor is the absence of personal lighting controls, with 50% (11 respondents) identifying it as a problem. The perception of random operation of electric lighting (41%, 9 respondents) and lights only being able to turn on and off rather than having various available light output setting (36%, 8 respondents) were also identified as significant common issues with dissatisfaction. The remaining common factors in order of importance were an absence of task lighting (14%, 3 respondents), a variation in lighting output over the course of the day (9%, 2 respondents) and both blinds remaining closed, and dissatisfaction with blinds and blinds controls (both 5%, 1 person).

Occupant Survey Results and Conclusions – Cottage Way

Cross referencing the results on satisfaction and dissatisfaction, the first conclusion is that providing lighting controls is perceived as being important to those occupants not satisfied with their personal light levels. Occupants are more likely to be sensitive to the absence of controls when they are not satisfied with their light levels and not able to adjust light settings to their liking. This same conclusions can be drawn from satisfaction (or not) with lighting controls. Another conclusion is that occupants might benefits from operating their blinds more regularly. Provision of task lighting appears to be less of a factor in dissatisfaction although it is identified as a significant common factor with satisfaction with light levels and lighting controls. Providing adequate blinds and blind controls was often common in creating a satisfactory lighting environment.

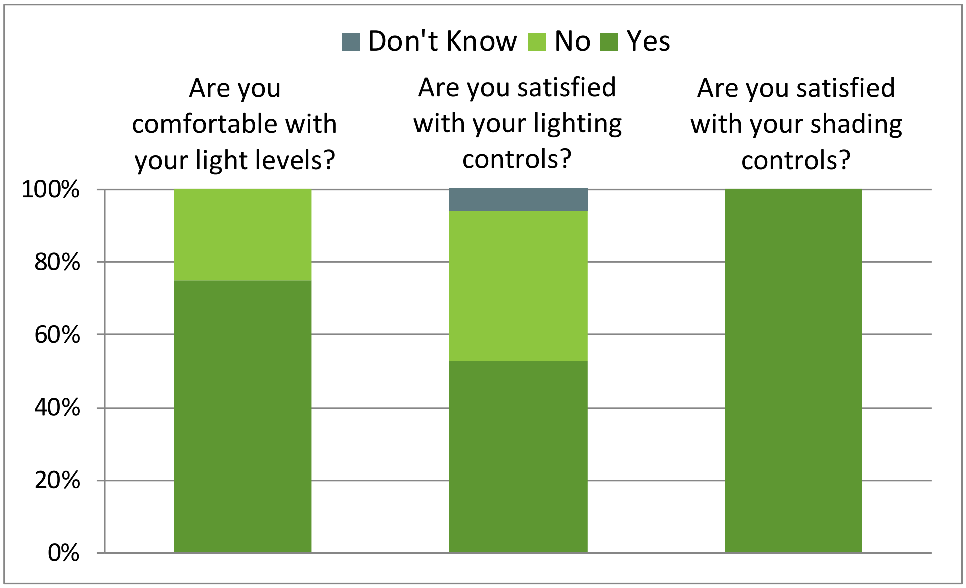
Making respondents aware of available 'Low, Medium or High' light settings may resolve some of the light level and lighting control issues - almost one quarter of respondents who were dissatisfied with light levels and over one third who were dissatisfied with their lighting controls were not aware of this choice. The route to requesting specific light level settings was not clear.

Dynamic dimming to available daylight was identified as a common factor with dissatisfaction with lighting levels and lighting controls, although the incidence of this was very low (9%, 2 people for both). This suggests that it is rarely perceptible, and by the majority it is regarded as a benign influence on the lighting environment.

4. HAMMOND COURTHOUSE

In total 18 people responded to the survey, all of whom work in day lit office spaces. No one responded to all of the questions. The responses from this site are not sufficient to represent a statistically significant sample and are therefore not regarded as being representative of the population of occupants working within daylighting zones of the building.

Figure 50: Occupant satisfaction with work space lighting levels



Three-quarters of respondents (12 people) expressed satisfaction with their workstation light levels, and 25% (4 people) were unsatisfied.

When asked whether they were satisfied with their lighting controls, over 53% of respondents (9 people) said they were satisfied, with 41% (7 people) not satisfied. One respondent was unsure.

All occupants that had blinds were satisfied with the personal controls for their interior blinds.

Figure 51: Factors common with satisfaction with lighting

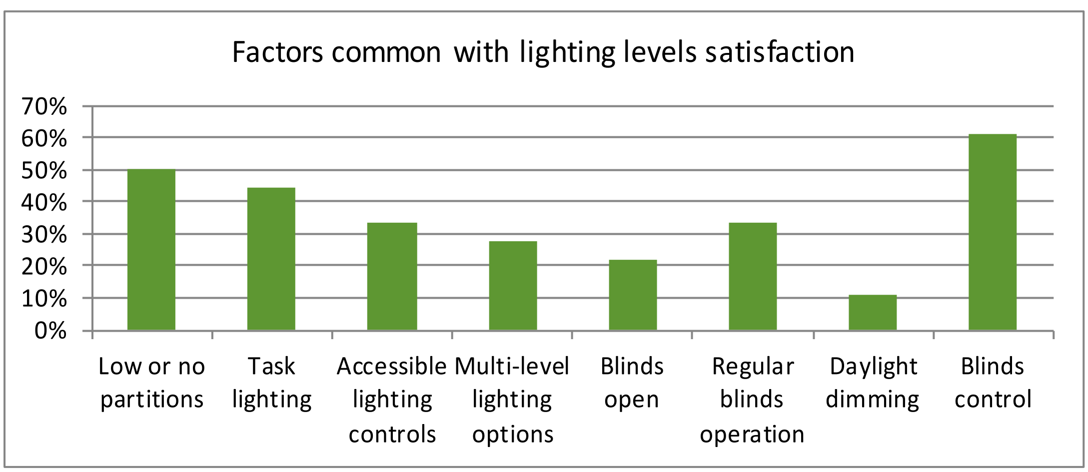


Figure 51 presents the results of how occupant satisfaction with lighting levels – which was relatively high at this site – coincides with responses about other aspects of the lighting system and working environment. Of the factors common for those occupants that stated that they were satisfied with their lighting levels, being satisfied with blinds and blind controls is the most frequently occurring (61%, 11 respondents). Other common factors include having low or no partitions (50%, 9 respondents), provision of task lighting (44%, 8 respondents), accessible lighting controls (33%, 6 respondents), regular operation of blinds (33% of respondents), availability of lighting output according to personal preference (28%, 5 respondents), blinds open by default (22%, 4 respondents) and daylight dimming (11%, 2 respondents.

Figure 52: Factors commons with dissatisfaction with lighting

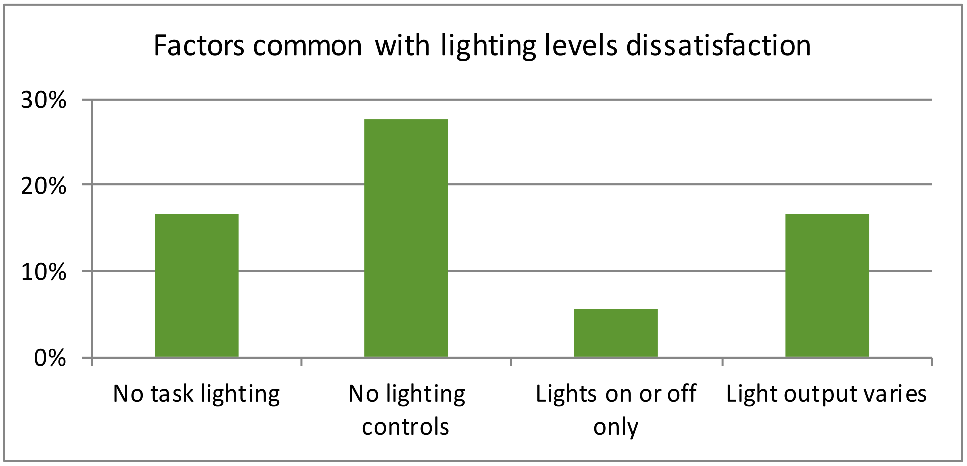


Figure 52 shows how dissatisfaction with lighting levels – which was relatively low at this site – correlates to responses about other aspects of the lighting system and working environment. The factor most common with dissatisfaction was an absence of personal lighting controls, identified by 28% of respondents (5 people) as an issue. The other characteristics in common with dissatisfaction were an absence of task lighting (17%, 3 respondents), a variation in light output over the course of the day (17% of respondents) and the option of only having lights on or off (6%, 1 person). Daylight dimming (electric lighting levels changing noticeably throughout the day and light levels noticeably affected by operation of blinds) is a common factor perceived as a problem by a minority - for over 80% of respondents, IDS is not perceived as a problem in terms of its overall impact on visual comfort.

Figure 53: Factors common with lighting controls satisfaction

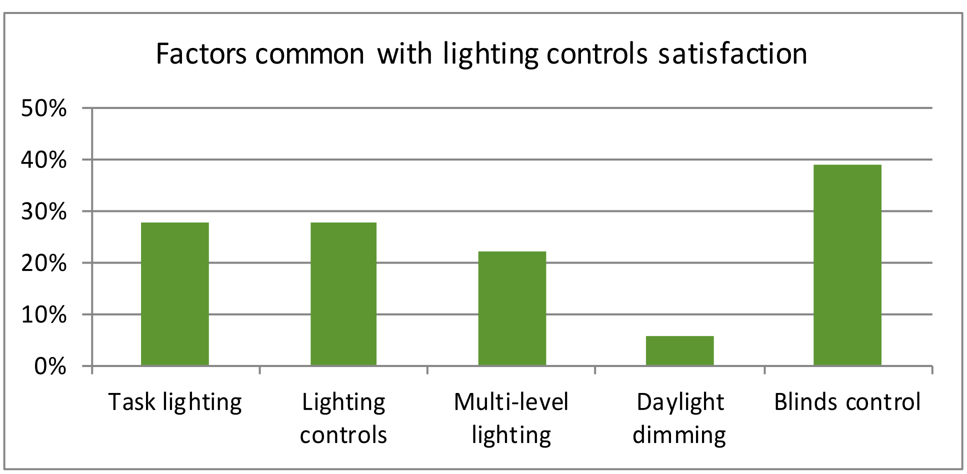


Figure 53 presents the results of how satisfaction with lighting controls – which was relatively low at this site – coincides with responses about other aspects of the local lighting environment. Providing satisfactory blinds and blind controls was the factor most commonly associated with satisfaction. Task lighting (28%, 5 respondents) and lighting controls (28% of respondents), options for multi-level lighting (22%, 4 people) and blinds open by default (22% of respondents) and daylight dimming (6%, 1 respondent) were also identified as common factors with satisfaction.

Figure 54: Factors common with lighting controls dissatisfaction

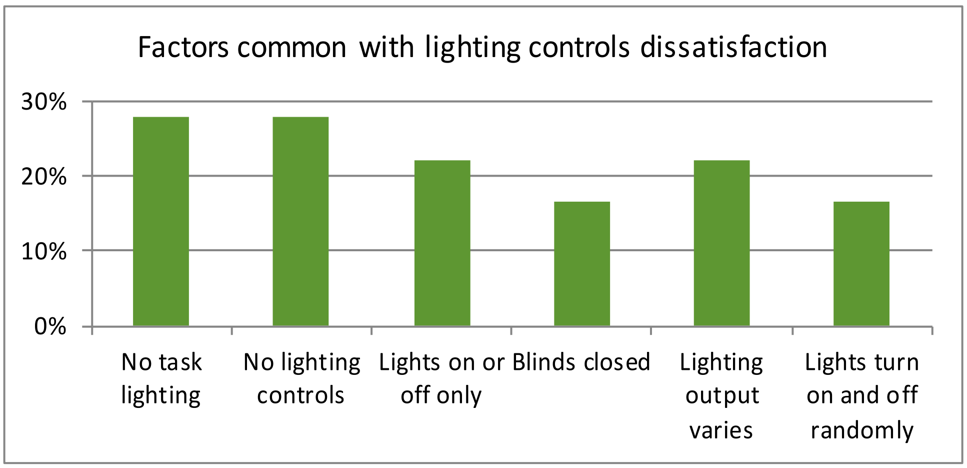


Figure 54 presents results of how dissatisfaction with lighting controls coincides with other aspects of the lighting environment. The most important are the absence task lighting and of personal lighting controls, (both 28%, 5 respondents). The perception of lights only being able to turn on and off rather than having various available light output setting and of light output varying over the course of the day (both 22%%, 4 respondents) and blinds closed by default and apparent random operation of electric lighting 9both 17%, 3 respondents) were also identified as common factors.

Occupant Survey Results and Conclusions – Hammond Courthouse

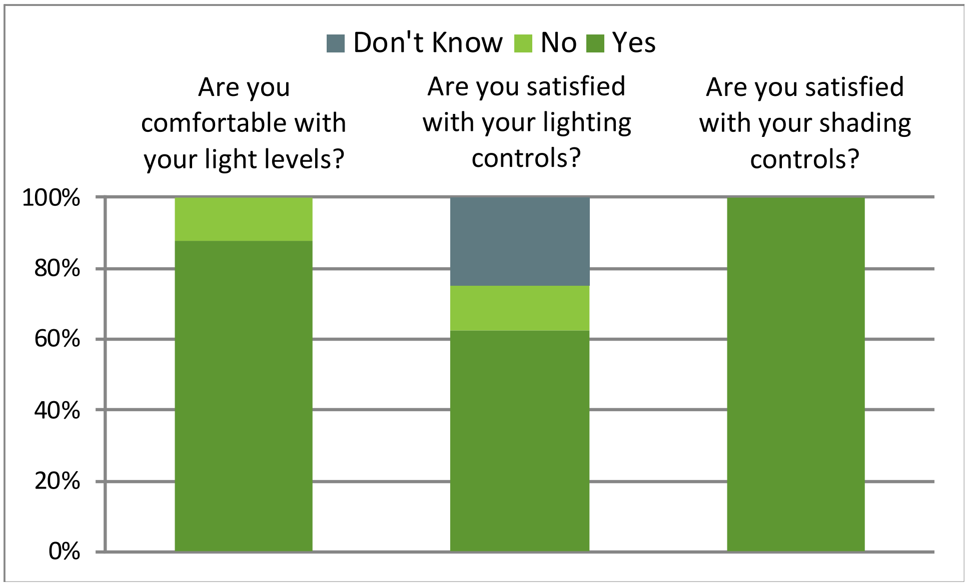
Cross referencing the results on satisfaction and dissatisfaction, the first conclusion is that providing lighting controls is perceived as being important to occupants both satisfied and dissatisfied with their personal light levels. This same conclusions can be drawn from satisfaction (or not) with lighting controls. Provision of task lighting was less of a common factor in dissatisfaction with lighting levels that with lighting controls, and was a significant common factor with satisfaction with light levels and lighting controls. Satisfaction with blinds and blind controls appears to be a factor associated with comfortable lighting, but dissatisfaction does not identify blind controls as a negative common factor.

Dynamic dimming to available daylight was identified as a common factor with dissatisfaction with lighting levels (17%, 2 respondents) and lighting controls (22%, 3 respondents), although the incidence of this was very low (17%, 2 people for both). This suggests that it is rarely perceptible, and by the majority it is regarded as a benign influence on the lighting environment.

5. DIRKSEN FEDERAL BUILDING

In total 8 people responded to the survey, all of whom work in day lit office spaces. No one responded to all of the questions. This is a small sample and cannot therefore be regarded as statistically significant or representative of the population of people that occupy day lit parts of the building. A sample of this size means that drawing meaningful conclusions from the results is not possible.

Figure 55: Occupant satisfaction with work space lighting levels



88% of respondents (7 people) expressed satisfaction with their workstation light levels, and 12% (1 person) were unsatisfied.

When asked whether they were satisfied with their lighting controls, 63% of respondents (5 people) said they were satisfied, with 12% (1 person) not satisfied. Two respondents were unsure.

All occupants that had blinds were satisfied with the personal controls for their interior blinds.

Figure 56: Factors common with satisfaction with lighting

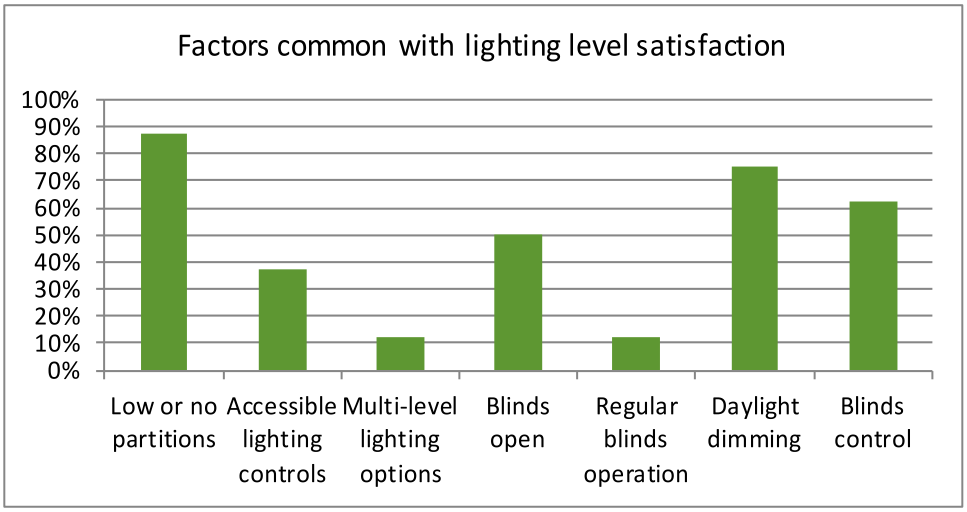


Figure 56 presents the results of how occupant satisfaction with lighting levels – which was relatively high at this site – coincides with responses about other aspects of the lighting system and working environment. Of the factors common for those occupants that stated that they were satisfied with their lighting levels, having low or no partitions is the most frequently observed (88%, 7 respondents). In decreasing order of frequency of occurrence, dimming to daylight conditions (75%, 6 respondents), meeting the needs of occupants through provision of satisfactory blinds and blind controls (63%, 5 respondents), blinds open by default (50%, 4 respondents) accessible lighting controls (38%, 3 respondents), and regular operation of blinds and multi-level lighting options (both 13%, 1 respondent) were all identified as factors common with lighting level satisfaction.

Figure 57: Factors commons with dissatisfaction with lighting

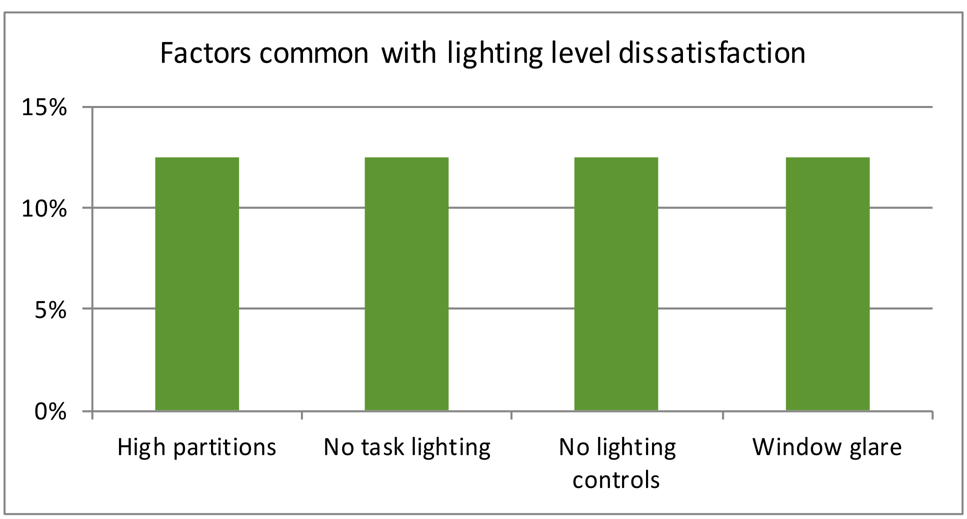


Figure 57 shows how dissatisfaction with lighting levels – which was low at this site – correlates to responses about other aspects of the lighting system and working environment. Of the factors common for the respondent that stated that they were dissatisfied with their lighting levels, daylight dimming (gradual dimming to daylight, electric lighting levels changing noticeably throughout the day and light levels noticeably affected by operation of blinds) is not one. The data suggests that IDS is not perceived as a problem in terms of its overall impact on visual comfort.

Figure 58: Factors common with satisfaction with lighting controls

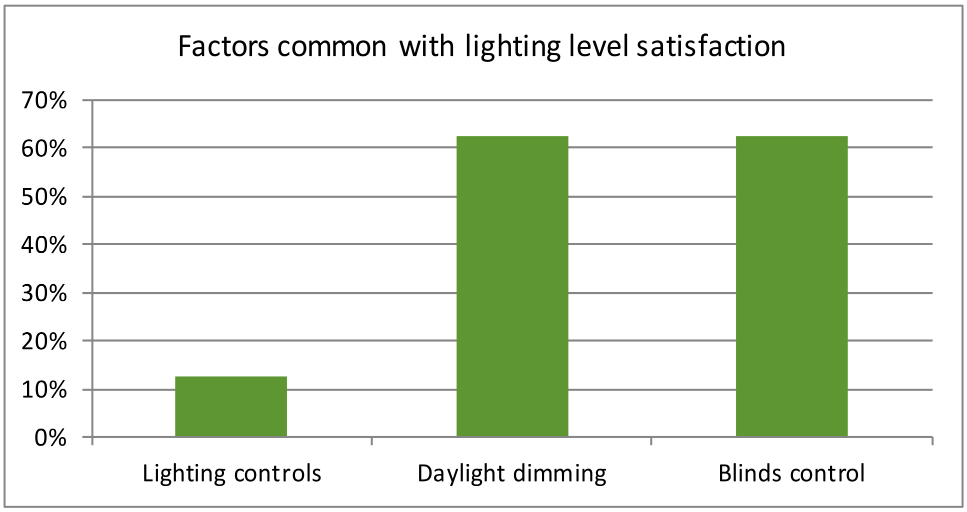


Figure 58 presents the results of how satisfaction with lighting controls – which was relatively high at this site – coincides with responses about other aspects of the local lighting environment. Daylight dimming and satisfactory blinds and blind control were the factors most common with satisfaction (both 63%, 5 respondents), with provision of lighting controls (13%, 1 respondent) also a common factor identified.

The only factor common to dissatisfaction with lighting controls was the absence of task lighting (1 respondent).

Occupant Survey Results and Conclusions – Dirksen Federal Building

No conclusions were drawn from the results at this site due to the small sample size.

V. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITIES

The results and conclusions presented below represent results from two levels of investigation, the first of which was a photometric characterization of 13 GSA sites, and the second of which involved more in depth, long-term monitoring of five of the 13 sites.

The aim of this study was to characterize the performance of IDS within GSA buildings and focused on four key objectives:

- Understanding GSA's approach to implementation of IDS, including approach to retrofit interior design and workplace configuration.
- From the five sites at which detailed assessment was conducted, quantifying light conditions, energy savings and occupant satisfaction associated with the daylight dimming elements of the lighting system and understanding their interdependencies.
- Evaluating the costs and paybacks associated with the daylight dimming element of the lighting system at the five sites participating in the long-term monitoring.
- Analyzing the results across sites to provide recommendations for future deployment of IDS technology across the GSA portfolio.

PHOTOMETRIC CHARACTERIZATION

Utilizing both natural and artificial light together, spot measurements indicated that the IDS at the 13 sites supported light levels to meet the illuminance requirements outlined in GSA's P100 document: 30 foot-candles at the work plane for the office work areas and 10 foot-candles in non-work areas. No incidences of disability glare[16] were measured at any of the sites. Provision of task lighting was mixed – they were present at three of the 10 office sites, all in private office spaces.

Of the 13 sites visited for single-day site assessments, eight sites (offices) were capable of meeting necessary light levels with natural light alone during bright conditions. Of these eight sites, six were observed to support light levels at work locations above the recommended P100 lighting levels with daylight alone, although switching lights off required manual operation of wall switches at all but one site; lights were typically programmed to dim to minimum but not switch off. Two of the eight sites were observed to be capable of utilizing natural light sufficiently to not require any electric lighting during bright conditions. Lighting control systems at these two sites were not programmed to enable lights to switch off automatically, and had no operable switches to manually switch lights off. An assessment of electric lighting output identified three sites that were significantly over lit[17] – with the window shades closed; light levels were 67, 80, and 113 foot-candles respectively at these sites.

[16] Assumed here to be values higher than 185 foot-candles (2000 lux) in the vertical plane.

[17] Assumed here to be 60 foot-candles, double the IESNA recommendation of 30 foot-candles.

The interior design of occupied spaces (*i.e.* systems and furnishings that impact the utilization of natural light) varied across sites. The default window blinds/shades position was partly or fully closed at nine of the 10 office sites. At three sites, the closed blinds resulted in the need for electric lighting where natural light alone would have been sufficient to meet P100 recommended light levels. At two of the 10 sites, electric lighting alone was unable to achieve the P100 recommended light levels.

A wide range of furniture types were present in terms of specification and color. For instance, in open office areas, cubicle partitions were installed both perpendicular and parallel to the window, were generally greater than 3 feet in height, and were medium-to-dark in color. This impacted the penetration and distribution of natural light, as the partitions channel (perpendicular) and block (parallel) light from the windows and the darker partition surfaces absorb natural light rather than reflecting it.

Of the five sites participating in the long-term monitoring portion of the study, data from 4 of them confirmed that over the course of the monitoring period, total light levels measured at the work plane achieved or exceeded the IESNA recommended level, although in some cases electric light was the predominant source and in others it was electric light, depending in design details.

Data collected for work plane light levels and cross-referenced with external light levels, photographs of blinds position and lighting energy data showed that four sites were not making best use of available natural light and were consequently over-reliant on electric lighting.

ENERGY SAVINGS AND COST-EFFECTIVENESS

Energy savings and cost-effectiveness were assessed for five of the 13 sites, in which long term energy monitoring equipment was installed. The IDS at all five study sites realized energy savings from a combination of daylight dimming and set point tuning. The installed lighting power density (LPD) varied by +/- 20% from the average across the sites, but was not the determining factor in energy savings. Average annual energy savings for IDS across the five sites was 1.35 kilowatt-hours per square foot, which at U.S. average electricity prices amounts to $0.135 per square foot in savings.

At three sites, the energy savings emphasis was on daylight dimming, attributable to less aggressive set point tuning and relatively well calibrated system operation. Set point tuning contributed greater energy savings than daylight dimming at the other two sites, demonstrating an aggressive approach to set point tuning and targeting a low operating LPD.

Daylight dimming energy savings resulted in an average payback period of 10 years. There was a broad spread in payback across study sites, ranging from 4.5 years to 16.5 years. For set point tuning and daylight dimming, average payback was 15 years, ranging from approximately 9 years to 24 years.

The assessment of cost-effectiveness was undertaken using the savings investment ratio (SIR) metric, from which a value equal to or greater than 1 indicates cost-effectiveness. Assessment of cost-effectiveness for daylight dimming indicated an average SIR value of 1.63. For set point tuning and daylight dimming together, the average SIR value was 0.88.

Initial costs (equipment, installation and commissioning) varied significantly across study sites and were a key factor in determining payback and cost effectiveness at all sites. One leading industry vendor has suggested that the current total installed cost of their advanced lighting control systems (for systems that support set point tuning and daylight dimming) range from $0.50-$4.00 per square foot of floor space.[18] At the low end of this cost range (less than $0.77 per square foot), all the assessed sites would be cost effective (have an SIR > 1), whilst at the high end (greater than $2.28 per square foot) none of them would be. For the assessed sites currently operating cost-effectively, IDS becomes cost-effective with maximum installed cost of approximately $2 per square foot. For daylight dimming, sites that are currently operating cost effectively become so at an installed cost of approximately $1.40 per square foot.

Utility rates proved to be another critical element in determining cost-effective operation. Utility rates for sites participating in the long-term monitoring study range from $0.08 - $0.13 per kilowatt-hour. At the time of writing, the average US electricity price for commercial customers was approximately $0.10 per kilowatt-hour. Assuming this rate applied to all sites and initial costs associated with daylight dimming alone, three out of five sites would be judged to be cost effective; assuming full installation costs (for set point tuning and daylight dimming), only one of the five monitored sites would be judged to be cost-effective.

OCCUPANT SATISFACTION

Occupant satisfaction was assessed at the five sites participating in the long-term assessment. Results of the 22 question survey indicate that satisfaction with lighting and visual comfort of work spaces varies significantly, with a range of perceptions within individual sites and with differing degrees of overall occupant satisfaction across sites. The results suggest that the level of satisfaction relates to the presence of absence of available personal lighting controls, an inconsistent approach to occupant engagement by management and issues of incomplete commissioning of the control system. The surveys also report that more could be done to improve overall visual comfort levels. In examining the negative perceptions of the lighting systems overall, performance of the IDS aspects (*e.g.* active dimming and impact of window blinds/shades operation) were among the least important elements contributing to dissatisfaction. Occupants were generally satisfied with their light levels at all sites. Where they were not satisfied, feedback was consistent in terms of three primary reasons: 1) with lighting being too dim, 2) absence of task lighting and 3) a perceived lack of influence over light level settings for ceiling-mounted fixtures. Occupants' feedback on the availability of lighting controls indicated similar sentiments. While the majority expressed satisfaction, over 45% (55 respondents) stated that the current arrangements did not meet their needs. These results may reflect a mixture of two different concerns: in some cases the lack of availability of suitable control options, and in others a lack of proper communication to occupants of what those options are and how to use them.

B. LESSONS LEARNED AND RECOMMENDATIONS

Daylighting, or "integrated daylighting systems" as discussed here, has been specified and implement for many years as a design and energy saving strategy, although often with mixed success and outcomes. A small number of buildings are described in magazines and conferences with limited performance data suggesting that the energy savings potentials are real. But the very slow progress nationally toward producing larger and more reliable energy savings as part of visually comfortable work environments motivated GSA to examine some recently renovated buildings where the lighting and daylighting retrofits

[18] Monitoring lighting energy savings from dimmable lighting controls in the New York Times Headquarters Building, (2013)

were undertaken as part of a broader renovation and efficiency program, without an explicit focus on deploying IDS.. This study reveals a range of lessons learned from this implementation of IDS, which will help inform future efforts to enhance GSA workspace and meeting agency energy savings goals. These include:

- Results from the interviews with project managers and facilities managers indicate that when commissioning was completed by a third-party commissioning agent of record there was a high level of satisfaction. Satisfaction was assessed in terms of completing key activities with little to no rework, and providing a full and transparent documentary record (*e.g.* a commissioning report, system operating manuals and a list of settings and protocols). When other project stakeholder groups completed commissioning tasks, the satisfaction rate was lower, due mainly to insufficient documentation provided at handover. This absence of documentation could compromise operations and maintenance tasks in terms of maintaining system operation and persistence of energy savings.
- According to facilities staff at the 13 sites, building occupants were generally unaware of the lighting options available to them in terms of setting their local electric light levels. Only occupants of private offices were provided with manual controls for switching or adjusting their overhead lighting.
- At present the approach to system operation and maintenance is reported to be varied; some sites rely on system warranties to complete maintenance tasks, others have resident trained operations and maintenance teams or to monitor and troubleshoot system issues.
- Greater focus on the end-user experience of lighting system operation is needed. To achieve high levels of occupant satisfaction with IDS and lighting systems generally, it is important that occupants a) understand how best to utilize their lighting system and b) have their needs met. As a matter of course, occupants should be engaged and educated about newly-installed lighting systems. Providing lighting controls is one of the best routes to meeting occupant lighting requirements, and may lead to greater energy savings.
- Commissioning IDS is a complex process. As such, a thorough, well-documented commissioning process is essential to providing a control system that matches owner intent, operates effectively, and can be maintained over time. This should include training for operators and occupants in order to ensure effective use of the system and an understanding of its benefits. To help achieve this, it is recommended to engage a third party commissioning agent as an observer early in the project development process. This will support a robust critical assessment of the implementation process and is more likely to identify performance issues early. Employing a third party for this task is also more likely to prevent inclusion of product specific language and jargon that can make commissioning handover documents difficult to interpret and understand.
- Stipulate that all lighting management control systems installed in GSA buildings should be usable by the building operator. The lighting control system user interface should be simple and clear for use of operations and maintenance staff – stipulations on how this is achieved at the interface could refer to the use of floor plan-based graphics and clearly documented lighting system layouts. The control system should produce real time continuous reports of energy consumption by zone so that

the facilities management team can track results on a continuous basis – reporting should again be at the user interface level, as well as having functionality to produce text-based reporting.

- Identify the preferred approach to operations and maintenance (*e.g.* trained in-house resources, subcontracts, or contracts with the product vendor). Current arrangements vary by site, with each of the above options having benefits and drawbacks. However, the most effective way to leverage the benefits of each option is to adopt it to the exclusion of the others. In doing so GSA would increase the cost-effectiveness of procurement (in the instances of subcontracts or vendor contracting), increase the value-added from resources provided for training and career progression in facilities and operations (where utilizing trained GSA personnel or subcontractors), contributing to a sharpened focus and increased capacity within GSA to continuously improve in this area.

C. BARRIERS AND ENABLERS TO ADOPTION

Daylight was the “original” source of daytime illumination in government buildings preceding the introduction of electric lamps. IDS have been actively discussed and promoted since the energy crises of the 1970’s, through its adoption with appropriate lighting control systems is not common. The main barriers to implementation of IDS are:

- The low market penetration of integrated lighting control systems, the difficulty in obtaining reliable installation and systems commissioning, and the perception of high lighting control costs.

- Costs are much higher than they could be because 1) high cost of fluorescent dimming ballast associated with being a low volume, custom product, and 2) elevated installation costs due to the lack of contractor experience.

- U.S. market penetration of advanced lighting control systems is very low. After decades simple occupancy and scheduling controls are becoming more common, driven in part by building codes and standards. Until relatively recently, for the majority of buildings only the advent of the need for lighting system replacement triggered installation of advanced lighting controls.

- The absence of an economic value that can be reasonably and consistently applied to the non-energy benefits of daylight. Some research suggests there are both physical health benefits as well as psychological and productivity benefits associated with natural light, but the literature is not definitive in this regard. There is little direct causal information that directly links specific design decisions to measurable outcomes. Given that occupant salaries far exceed energy costs in the vast majority of commercial buildings, this could provide an added economic rationale for promoting more extensive use of daylighting.

Enablers to adoption include:

- Greater familiarity with the installation process as IDS become more widespread will help reduce installation and commissioning costs.

- Improvements to control systems technology include better sensors, wireless controls, auto-commissioning etc. are also being developed to allow for greater flexibility, easier installation and lower cost.

- Continuing field studies verifying energy savings and unbiased predictive tools to estimate savings can help address performance uncertainty.

Manufacturers must also make a concerted effort to improve real-world performance and diagnostics if IDS is to become widespread. This includes improving commissioning through simplifying the necessary processes, making systems easy to operate, providing accurate energy use estimates, and giving operators sufficient instruction and support. Better training and education of the design community, the contractors and building operators are all needed to enhance the market viability and greater adoption of IDS.

D. MARKET POTENTIAL WITHIN THE GSA PORTFOLIO

Based on the sheer size of the GSA building portfolio, there exists a huge opportunity for potential energy savings through IDS.

The focus should be:

- **Perimeter areas of buildings.** Access to natural light is a prerequisite to implementation of an IDS control strategy, and perimeter areas of the building are the most appropriate zones for this. The assumed perimeter depth should be no more than two times the maximum window height.

- **Zones / offices with high occupancy / hours of light operation.** To unlock energy savings from IDS, there must be a demand for light. Zones or offices with low occupancy or little need for light, e.g. storage, reduce the cost-effectiveness of the daylighting strategy as no daylighting energy savings occur during periods of low or zero demand since we assume a simple occupancy switch is used.

- **Locations with unobstructed sky views.** Daylight access is typically good to excellent for buildings in low density neighborhoods or surrounded by low rise structures. In urban areas with high building density or tall buildings, access to natural light may be compromised by the shading from other built structures. Ideally, day lit areas should be able to see some sky from an observer’s location, although this may not be possible in some spaces. IDS should be prioritized on upper floors of buildings in dense urban environments and for façade orientations that have a clear sky view. Sometimes light colored surfaces of adjacent buildings can actually enhance daylight utilization.

- **Locations with limited seasonal daylight variation**. The specific design response needs to be tailored to the characteristic of the location in terms of cloud cover and sun. In virtually all designs proper sun control is a requirement; although sunlight brings high illumination levels, it also brings undesirable contrast and glare, so that effective shading is a necessity.

- **Orientation-driven solutions.** Focus on all building facades but tune solutions to orientations. Perimeter areas that can receive direct sunlight will have more daylight available but require the judicious use of window blinds or shades to moderate glare and cooling. Shading must be retracted when the sun is gone or on overcast days, with smart occupant engagement or with the use of automated shading. North facing orientations or other orientations with external shading obstructions may have lower daylight levels but are not as dependent on the proper use of window shading.

- **Adequate Daylight Aperture (area x transmittance)**. Window size and visible light transmittance are important factors in the success of an IDS control strategy as they determine how much natural light can be used effectively. Ideal window size is a function of the overall energy balance of the buildings (*i.e.* the need to optimize the performance of multiple building systems), but buildings with medium size windows (*i.e.* with a Window-to-Wall Ratio (WWR) of approximately 0.5) with a visible transmittance of approximately 60% will provide the best support for use of daylight. Windows that utilize absorbing glass or reflective glass, or those with WWR less than 0.2 will usually not provide sufficient daylight. Design teams have tools to optimize window size and properties for different cities, sites and orientations.

E. CONCLUSIONS

As GSA strives to reduce and to comply with mandated targets in energy use intensity, greenhouse gas (GHG) emissions (develop net-zero energy building designs), the demand to find innovative technologies that can deliver significant whole-building energy savings will grow. This study has demonstrated that overall, integrated daylighting systems have proven the technical ability to achieve significant lighting energy savings while providing comfortable light levels and occupant satisfaction.

The results suggest that if the criteria for deployment were strictly geared towards achieving energy and GHG reductions, irrespective of payback, IDS could be applied effectively in most buildings in every GSA zone and region. However, this study has also showed that while lighting energy savings of approximately 28% over baseline conditions can be achieved for different office space types, these savings may not always be achieved cost effectively, even with relatively high utility tariffs of over $0.12 kWh. With nominal payback periods of less than ten years as a criterion, two studied spaces proved to be cost effective: one open office space and one private office. In these locations, IDS delivered 34% and 40% lighting energy savings and payback periods of approximately 8.5 years and 10 years, respectively. Other systems had either higher costs or lower savings and did not meet the 10 year target.

The IDS studied here were deployed in a range of space types, including non-work areas, controlled by a lighting management system manages and responds to photosensor input, and also utilized other non-daylight related advanced control strategies such as time scheduling and occupancy sensing. For deployment across GSA offices and other space use types, Integrated Daylighting Systems are best implemented at the zone level (e.g. open work areas containing multiple occupants with similar daylighting access), as this reduces unit equipment and installation costs and as a result of operating at the zone level, reduces the impact of occupancy / vacancy on the cost-effectiveness of system operation. The requirements of intelligent IDS should always be a design consideration when light fixtures, lighting controls, glazing and shading, and ceiling grids are being renovated or refurbished.

With careful planning, design, and implementation, Integrated Daylighting Systems may offer a cost-effective opportunity to reduce lighting energy in GSA buildings. As noted in the analysis, this is dependent on the design of the existing lighting and control systems, occupancy of the space, local electric rates and other factors. A significant proportion of energy savings at 4 of the 5 monitored sites came from setpoint tuning, where the existing lighting system design allowed for significantly higher light levels at the workplane than those stipulated in P100 – reducing light output with dimming control was part of meeting the required light levels, and also delivered energy savings versus maximum rated output. Where setpoint tuning is not necessary to achieve desired work plane illuminances, (such as the system at the Dirksen site), these savings will not occur and so IDS systems in these settings are less likely to be cost-effective. It is therefore recommended that a policy of targeted deployment be adopted for potential retrofit projects, where existing lighting power density and energy use intensity are relatively high – a rule of thumb for site where IDS should be considered is an installed LPD of higher than 1.1 Watts per square foot and a lighting EUI of approximately 3.3 kilowatt-hour per square foot or higher, although the analysis of site results indicates significant variation on this (one site is estimated to be cost effective at a pre-retrofit EUI of 2.67 kilowatt-hours per square foot). For whole-building modernization and new construction projects, the costs associated with implementing IDS would be lower due to the incremental cost increase of including IDS in an advanced, integrated lighting control system. Furthermore, as the market for advanced controls matures, it is anticipated that the cost of materials and labor will reduce. Consequently, IDS should be considered for implementation in all future new GSA buildings.

The high granularity of control inherent in the newer advanced lighting controls system provides additional opportunities for energy savings beyond those studied here. Data from occupancy sensors, particularly when associated with a workstation-specific lighting layout, could inform other systems (*e.g.* HVAC, ventilation to direct less air to unoccupied spaces). Since lighting accounts for 26% of electricity use in commercial buildings, control systems could also be programmed to coordinate with building level EMS and be involved in demand response events and other electric load management strategies in response to time of use electricity rates.

VI. Appendices

A. RESEARCH DETAILS - SINGLE-DAY SITE ASSESSMENTS

SITE SUMMARY

Table 31 contains details of the 13 assessed sites.

Table 31: Single-day site visit locations

Site	Site Reference	Location	Approximate floor area (ft^2)	Description of monitored work spaces
Philip Burton FB, GSA Office, 2nd floor, North façade	PB2N	San Francisco, CA	130	Private office
Robert Matsui CH, IT Offices, 5th floor, North facades	RM5N	Sacramento, CA	230	Private office
Cottage Way FB, GSA Directors Office, West building, 1st floor, East facade	CW1E	Sacramento, CA	140	Private office
Ronald Dellums FB, Peace Corps, N tower, 6th floor, West facade	RD6W	Oakland, CA	230	Private office
Roybal FB and CH, Bankruptcy Court, 9th floor, West facade	R9W	Los Angeles, CA	250	Private office
Lloyd George FB, North and East facades	LG4NE, LG4E, LG1E	Las Vegas, NV	1040 (1 x 560, 1 x 130, 1x 350)	Private offices
Metcalf FB, 1st floor, North and West facades	MN1NW	Chicago, IL	2,300	Lobby and Reception
JCK FB, 36th Floor, North Facade	JK36N	Chicago, IL	480	Open office plan
The Loop Post Office, 1ST floor, East and South facades	LPO1E	Chicago, IL	2,000	Post office area
Dirksen FB and CH, GSA Office, 2nd floor, West façade	ED2W	Chicago, IL	720	Open office plan and private office

Site	Site Reference	Location	Approximate floor area (ft^2)	Description of monitored work spaces
Hammond CH, 1st floor, East and South facades	HC1SE	Hammond, IN	320	Private office
Dept. of Commerce, 4th floor, East and South facades	DC4SE	Washington DC	530	Private office
Dept. of the Interior, basement level	DIB	Washington DC	3,600	Cafeteria

INVENTORY OF SITE MEASUREMENT EQUIPMENT

Table 32 contains details of the equipment utilized during the single-day site visits. All of this equipment was portable: in the case of the light meter, it was used to record light levels at various specific locations within each measured space. The camera was set-up in a single location to record data and information for the duration of the site visit, then disassembled and removed.

Table 32: Data Collection Equipment

Measurement Type	Measuring Instrumentation	Range of Measurement	Measurement Type or Frequency
Light levels – illuminance	Konica Minolta T10	0 – 100 Klux	1 measurements per location for each lighting condition
Glare	Canon A570IS camera and Opteka Fisheye lens	Visible and infrared frequency radiation	7 bracketed photos every 5 minutes
Space characterization	Canon A570IS camera and Opteka Fisheye lens	n/a	Record of physical characteristics of the space

KEY METRICS

A PHOTOMETRIC AND PHYSICAL SPACE CHARACTERIZATION

The site visit objective was to characterize the space, recording the prevailing daylighting scenario and measuring light levels under different lighting conditions (i.e., by varying the position of shades or turning off electric lights). The general approach adopted was to capture all relevant information to understand the characteristics of the day lit space as could be interrogated meaningfully. The following data and information was collected:

- Building characteristics, such as vintage, floor plate and orientation
- Envelope characteristics, such as exterior shading or architectural features and glazing
- Office / space measurements, features and furniture
- Lighting level and glare data. Glare is separated into discomfort glare (which results in difficulty in seeing a task or a reaction to look away from the light source) and disability glare (which inhibits the view of objects or tasks).
- Perspectives of the site Lighting Project Manager (or equivalent person made available during the site visit)

Observations on the type, specification and location of furniture relative to light fixtures and windows were recorded, as were dimensions of the study area.

The number of workspaces measured at each site varied from a minimum of one to a maximum of four. The types of workspaces monitored also varied: open plan office areas, private offices, and lobby areas were visited, although the vast majority was office spaces.

Light levels were measured at the workplane and at regular distances from the window to characterize light distribution. Light level readings were recorded under different lighting scenarios (for example, daylight, electric lights off, blinds open) and indicate the circumstances under which light levels requirements were being met. The value of such spot measurements is limited in that the results reflect the weather at that time (i.e., taking readings on a cloudy day means that the influence of daylight will be reduced) but the process and methodology have value as conclusions can still be drawn from the measurements. The range of possible lighting conditions varied according the means of light control in the assessed sites.

Light level data was collected using handheld photometers, measuring illuminance in the horizontal and vertical planes. Natural light levels were recorded by mounting a light-sensitive diode to the window; this equipment measured and logged daylight levels for the duration of each site visit.

To determine brightness and glare from daylight and electric light, a tripod-mounted high dynamic range (HDR) camera was set up to take pictures of the space, and positioned so the windows were in view. These photographs were processed to reveal the brightness and glare resulting from the natural light penetrating the space. Photographs were also taken to record details of the study area for reference, such as light fixture design and location of furniture.

Information and data relating to the installed building systems and surrounding environment were measured to understand how the effective use of daylight was controlled, directed, inhibited and prevented. For the building itself, overall measured area, window height and area, presence of blinds or shades, arrangement of office furniture and orientation of workers to the window wall were among the important observations gathered. For the lighting system, type and location of fixtures relative to the workspace, the photo sensors' location and distance from the window and the presence of task lights was recorded.

The main drawback of the single day visit is that the results are subject to the weather, which is inherently unpredictable. Ideally, visits would take place on a bright, clear day, as the results would provide a better indication as to the effectiveness of the IDS and other non-lighting elements that support it.

B TECHNICAL DESCRIPTION AND PROJECT IMPLEMENTATION

In order to understand the scope and development path of the project the Facilities Manager, Lighting Project Manager or equivalent was interviewed. The 'interview' took the form of a structured discussion during which the nominated individual was asked questions relating to the technical and process aspects of project implementation, such as:

- Specifications of the new installed hardware and infrastructure
- Justification for the project
- Performance since completion
- Project development process
    - How many organizations involved and who did what
    - Commissioning – what was the process and what were / will be the outputs
    - Staff training for operation of system (O&M and user groups)
    - Provisions made for maintenance
- Lessons Learned on the project

All of this information together provides an insight into how well daylight was being utilized, and whether the site as currently configured and used can realize the maximum value from an IDS.

SITE 1 - PHILIP BURTON FEDERAL BUILDING, SAN FRANCISCO

Figure 59: Golden Gate Federal Building, San Francisco Civic Center

Source: LBNL

A GENERAL BUILDING DESCRIPTION

The Phillip Burton Federal Building in San Francisco, California, (Fig. 1) is a 1960's construction with a deep rectangular floor plate. The building has 21 main floors with a total floor area of around 1.1 million square feet. The building fabric consists of a reinforced concrete structure with a curtain wall envelope. The work areas of the building consist largely of open offices and private offices, and are typically occupied between 7am and 7pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The project was selected to proceed as a lighting retrofit under the American Recovery and Reinvestment Act (ARRA) and was selected to proceed as part of the lighting specification drafted by GSA. The project had no specified energy savings targets, and it is understood that no detailed analysis was completed to estimate savings, although full building audit was conducted by the one of the project vendors as a project precursor.

The daylighting retrofits consisted of installation of photosensors and manually operated venetian blinds. The same specification was adopted throughout the building perimeter area and had been fully implemented.

C LIGHTING PROJECT MANAGER INTERVIEW

As part of the project design process an energy audit was conducted, and this led to a concept design, in which energy modeling and rough energy calculations were completed, focusing on certain technologies, interior lighting being one. The output from this work was a relatively detailed energy audit, which formed the basis of a proposal. Three companies were involved in implementation of the project: the first completed the lighting design, the second completed the installation and a third completed the controls programming and commissioning. According to the building manager, the project had progressed smoothly through to completion, although the deep building profile and high partitions in open office areas limited the potential impact of IDS.

For lighting 3200K color-temperature T8 lamps were replaced with 4100K color-temperature T8s. Areas with appropriate lighting were excluded from the retrofit. Ballasts have been installed to operate each two lamp fixtures. Lamps have manual controls with automatic off. Light levels at the work plane were set at 50 foot-candles, and light output has been observed to change noticeably in response to available natural light levels. The electric lights shut down altogether in response to daylight. The lighting controls are manual-on, auto-off, and then dim according to daylight levels. No task lights are provided to occupants. Manually operated blinds are present throughout the majority of the building; their operation varies by location / window orientation.

Installation: Issues with the system include that lighting equipment was originally showing a standby power of 7 watts, which is very high. Other challenges include the large footprint in the building core and the high partitions between cubicles. Security in the building was an issue with regards to obtaining clearance for outside contractors.

Commissioning: A commissioning log remains on-site which contains details of control settings.

Training: On-going training with O&M staff is provided by the contractors. A log report will be submitted to the property managers upon completion of training.

Maintenance: The status of each fixture can be monitored which includes energy use, which enables ongoing automatic Fault Detection and Diagnostics (FDD) and therefore supports maintenance. The lighting vendor provide maintenance support as and when required as part of the system warranty.

Occupant Satisfaction: There have not been any complaints about operation of the lighting system.

D DESCRIPTIONS OF THE PROJECT AREA

The assessed site is a private office located on the 9th Floor.

The office has north facing windows with a WWR around 0.6. The strip windows are untreated single glazing strip windows with a base height of 2.8 feet from the floor and a maximum height of 9 feet. Manually operated venetian blinds were installed. The window view is relatively unobstructed: the nearest building at eye height is several hundred meters away. The office contains a single wraparound desk with two main work locations – one for paper tasks and one for use of the computer.

The lighting fixtures consist of 4 recessed 2x4 troffers, each containing 2 32W T8 lamps, which are oriented with their long axis perpendicular to the window. These can be switched on and off with a manually operated wall switch. There was an under-cabinet light integrated into the office furniture but this was not functioning at the time of the visit. Task lights are not provided to occupants.

The main office furniture was a wraparound desk which was medium brown in color and there were two office chairs that were both black. There is a large overhead cabinet above the desk and bookshelves adjacent to the desk against the wall. The ceilings and interior walls were mainly white in color; one wall was light blue . The carpet was dark gray in color. The interior windows that formed the back wall adjacent to the corridor had venetian blinds installed.

Figure 60: 450 Golden Gate office floor plan

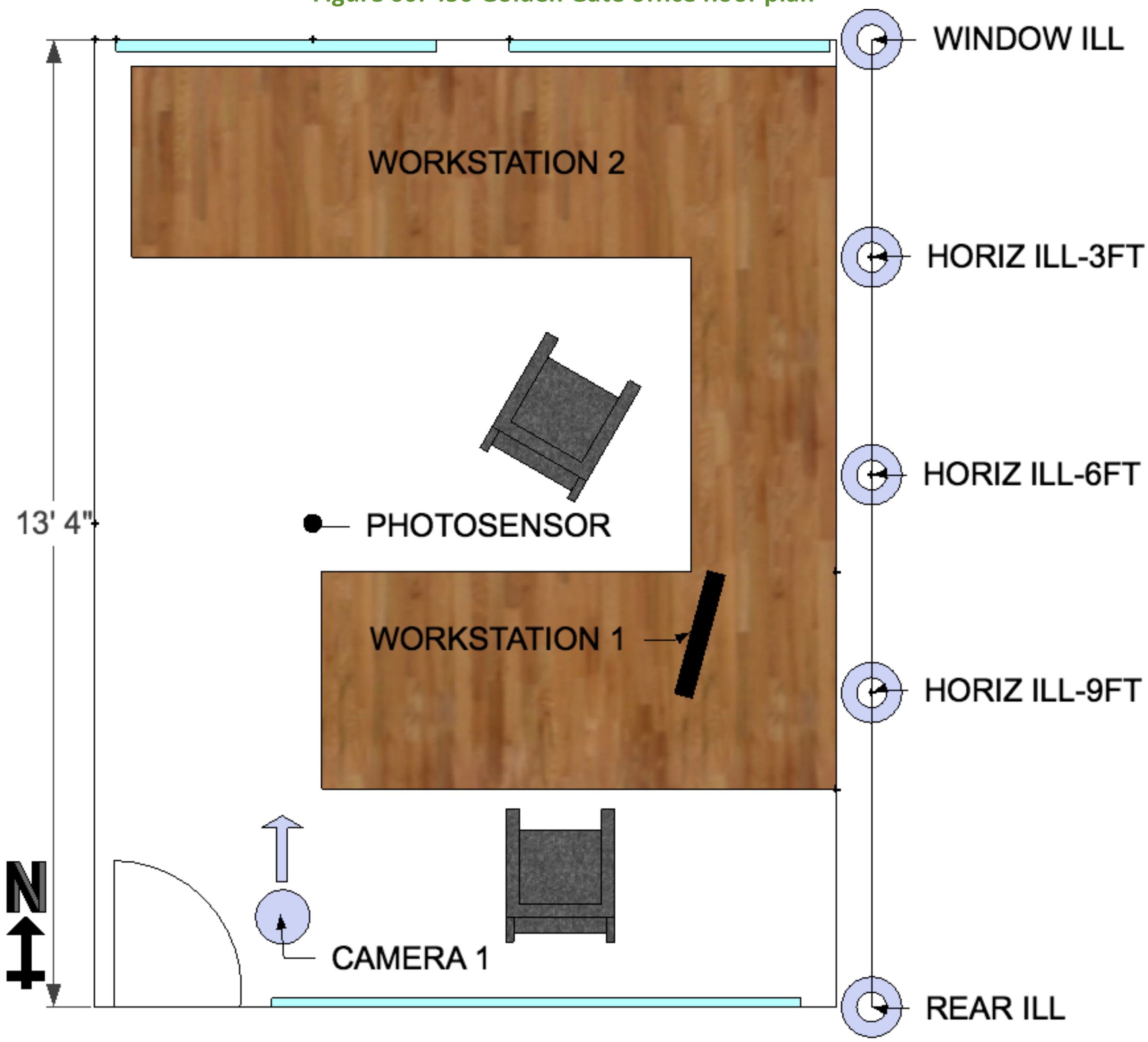


Table 33: Philip Burton Federal Building light measurements

	Daylight Only	Daylight and Blinds at 45 degrees*	Electric Lighting with Blinds Closed
Window – Horiz. Ill	228	40.7	47.5
3 ft. – Horiz. Ill	110	30.7	38.1
6 ft. – Horiz. Ill	80.8	25.2	36.9
9 ft. – Horiz. Ill	44.6	14.3	28

	Daylight Only	Daylight and Blinds at 45 degrees*	Electric Lighting with Blinds Closed
Rear Wall – Horiz. Ill	22.7	7.5	11.6
Rear Wall – Vert. Ill	64.7	17.9	15.5
Workstation 1			
Horiz. Ill	46.9	19.2	12.6
Vert. Ill	105	24.9	21.1
Vert. lum (gray card)	64	13.1	10.3
Workstation 2			
Horiz. Ill	50.1	19.4	14.0
Vert. Ill	68	20.9	16.3
Vert. lum (gray card)	43.7	16	12.8

* Prior to readings were taken, one of the light fixtures switched off in response to daylight

E OBSERVATIONS

The site visit was conducted in a sunny day in April at around lunchtime. When we entered the office, the blinds were closed with the slats at 45 degrees. The lighting appeared to be operating as intended, dimming according to daylight. The venetian blinds installed in the corridor window were closed.

1. DAYLIGHT ONLY

The horizontal illuminance at the window was 225 fc. Inside the space the horizontal illuminance range from 110 fc to 22.7 fc at the rear wall. The rear vertical illuminance was 64.7 fc. Workstation horizontal illuminance were 46.9 fc and 50.1 fc. Vertical illuminance were 105 fc and 68 fc.

2. DAYLIGHT, BLINDS DOWN, AND OVERHEAD LIGHTS

The horizontal illuminance at the window was 47.5 fc. Inside the space the horizontal illuminance range from 38.1 fc to 11.6 fc at the rear wall. The rear vertical illuminance was 17.9 fc. Workstation horizontal illuminance were 19.2 fc and 19.4 fc. Vertical illuminance were 24.9 fc and 20.9 fc.

3. DAYLIGHT AND BLINDS DOWN

The horizontal illuminance at the window was 41.7 fc. Inside the space the horizontal illuminance range from 30.7 fc to 7.5 fc at the rear wall. The rear vertical illuminance was 15.5 fc. Workstation horizontal illuminance were 12.6 fc and 14 fc. Vertical illuminance were 21.1 fc and 16.3 fc.

F **BRIGHTNESS**

As it was a bright sunny day, it was possibly to draw some conclusions about how to make appropriate use of daylight.

Light levels measured at each of the workstations without electric light and with the blinds in their default position were well below the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100. Opening the blinds significantly increased the illumination, and achieved the recommended light level range without operation of electric lights.

The light levels achieved with electric lights was difficult to assess as the fixture above the desk repeatedly switched off automatically, supposedly in response to bright natural light – it is possible to say that light levels under these conditions were very dim – significantly lower than recommended levels.

The results suggest that on bright days there is no need for operation of electric lighting – natural light is well capable of meeting the required conditions. During overcast or gloomy conditions, this is unlikely.

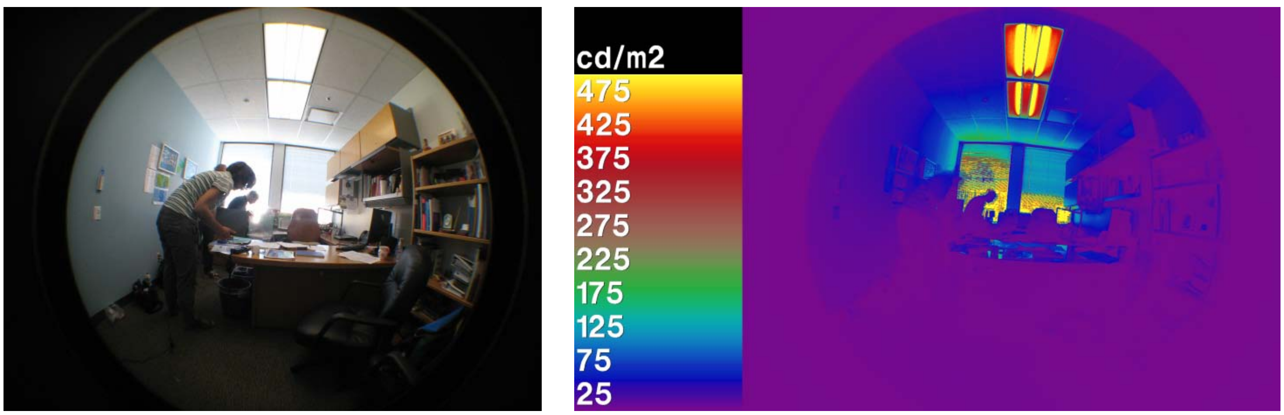


Figure 61: Wide-angle and false color images with electric lighting

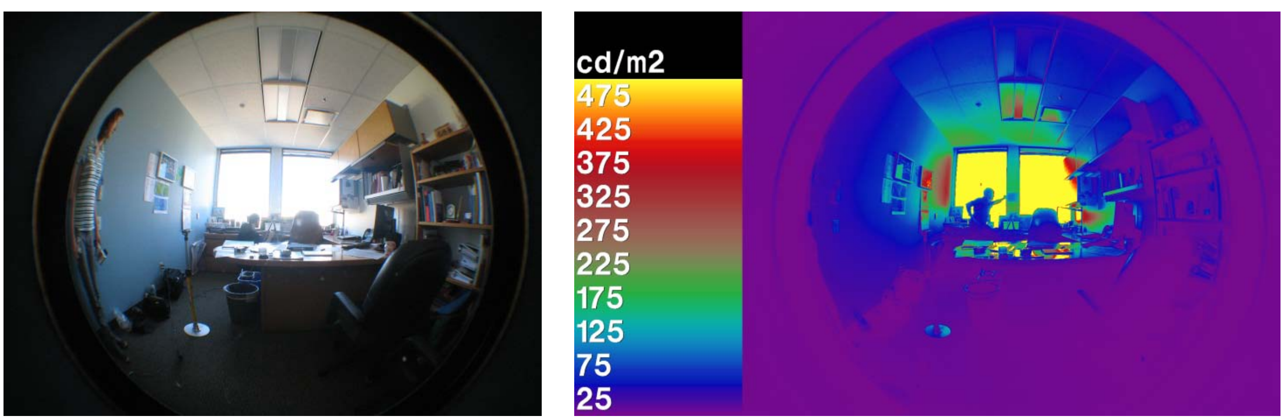


Figure 62: Wide-angle and false color images with daylight only

G GLARE

The façade orientation means that direct sunlight will never be a problem at this site. The large visible sky area means that discomfort glare may sometimes be present, but the chosen work locations mean that the impact of this is likely to be negligible – there were no bright reflections from the computer monitor and the work location for paper-based tasks did not have the window in the field of view. Disabling glare is very unlikely to occur – only solar reflections from neighboring buildings could possibly create this condition.

SITE 2 - ROBERT MATSUI COURTHOUSE, SACRAMENTO

Figure 63: Robert Matsui Federal Courthouse, Sacramento, CA

A GENERAL BUILDING DESCRIPTION

The Robert Matsui Federal Courthouse in Sacramento, California (Figure 63) was completed and occupied in 1999. The property consists of two rectangular buildings. The smaller building has four floors, while the larger building has 15 floors. The total area is 650,000 square feet. The building envelope consists mainly of concrete with punched windows and has a large curtain wall on the south-west façade, which extends nearly the full height of the building. Most of the working areas in the building are private offices occupied between 7 am to 6 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to maximize energy savings and reduce the buildings carbon footprint. The project did not have a specified energy target. An energy audit by a consultant estimated the value of overall energy savings from the retrofit, of which the lighting project was only part.

The daylighting project consists of installation of sensors and manually operated blinds. Other lighting retrofits included in the project were lamp and fixture replacements. The project was complete at the time of the site visit.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines and part of the selected control system including an IDS option. Three companies were involved in the project: one was responsible for the lighting design, a second completed the installation, and a third manufactured the ballasts, controllers and LMCS software and was the commissioning agent for the project.

The lighting specification changed as part of the retrofit: 17W T8 lamps replaced their old lamps. Target light levels were 50 foot-candles at the work plane according to GSA design guidance. The building manager did not notice light levels changing during the day and do not shut off with response to daylight but are designed to dim to a 10% light output (which equates to between 25-35% power input). Some lamps flicker at dimming at less than 20%, so the lights were typically dimmed to within the 50%-30% light output range depending on daylight levels. Lighting controls were occupancy-based, although manual switches were still present; the electric lights dims to available daylight. Occupants could request their own light settings and provide feedback about their lighting but this would have to go through the building management, which adds another step to the process. Occupants can request their preferred light settings for individual fixtures. Occupants could also control daylight in their offices by adjusting their manually-operated blinds.

Installation: The controls were not performing as expected because of the lighting design – the method of assigning of ballasts to fixtures was not consistent. For instance, in some places the light color turns pink because of the ballast control of three lamps. It was also suggested that lamps installed could dim to around 20% of output – lower than that and lamp flicker would commence, creating a distracting light condition and shortening lamp life.

Commissioning: Commissioning was completed as of the interview date, but the project manager was unsure if there was a physical report. Closeout documents with equipment settings were left with the O&M building staff.

Training: Training of tenants commenced after system commissioning. Tenants decided whether to provide training: some tenants believed that offering the lighting control options covered within the training caused more issues than it resolved.

Maintenance: The system is under a 5-year warranty which includes twice yearly check-up. It was unknown how the system maintenance will be managed and documented.

Occupant Satisfaction: A common complaint from occupants was that the lights were too bright, since changing from 3,500 K to 4,000 K lamps – it appears that engagement with tenants and occupants prior to lap replacement was fairly limited

D DESCRIPTION OF PROJECT AREA

The project site for the one-day site visit was a northeast-facing private office with WWR 0.60-0.70. The curtain wall windows had untreated single-glazing with a base height of 2 feet from the floor with a height of 7.7 feet and a width of 3.4 feet. Manually operated blinds were installed in all of the windows. The occupant of the space closes the blinds fully when there is glare. The view from the window was unobstructed. The office area was around 16 feet by 14 feet with a ceiling height of 8.75 feet.

The lighting fixtures were recessed troffers, installed with the long axis perpendicular to the window. The lamps were 32W T8's. There was no workstation or task lights present. Manually light switches were present and could be used to override the occupancy-based controls.

The ceiling and interior walls are white, the floor carpet is medium gray. The furniture consists of an L-shaped desk of medium wood and a computer chair.

Figure 64: Robert Matsui office floor plan

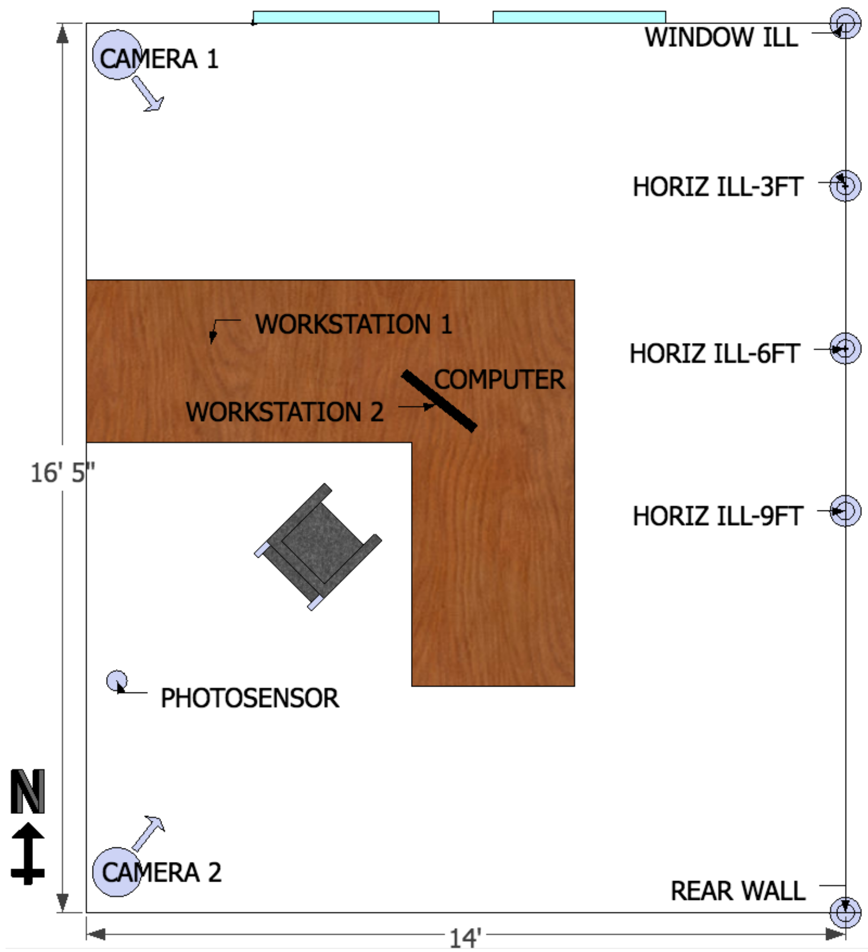


Table 34: Robert Matsui Courthouse light measurements

	Daylight and Blinds half-closed	Daylight and Overhead Lights	Daylight Only
Window – Horiz. Ill	36.2	56.0	36.1
3 ft. – Horiz. Ill	26.7	60.3	40.2
6 ft. – Horiz. Ill	19.3	53.8	29.7
9 ft. – Horiz. Ill	11.5	45.9	18.4
Rear Wall – Horiz. Ill	11.6	33.9	17.0
Rear Wall – Vert. Ill	20.8	30.9	28.3
Workstation 1			

	Daylight and Blinds half-closed	Daylight and Overhead Lights	Daylight Only
Horiz. Ill	15.9	38.8	24.4
Vert. Ill	5.45	19.7	9.25
Vert. lum (gray card)	28.24	21.37	24.61
Workstation 2			
Horiz. Ill	11.9	42.2	17.8
Vert. Ill	14.3	28.7	20.3
Vert. lum (gray card)	10.93	5.817	7.675

E OBSERVATIONS

The site visit was conducted on a sunny day in May around mid-afternoon (PDT).

The electric lights were switched on upon arrival. The blinds were closed and halfway down the windows. The lights appeared to be operating as designed, dimming to daylight levels. One site was assessed in the location with two workstations identified.

1. DAYLIGHT AND BLINDS HALF-CLOSED

The horizontal illuminance at the window was 36.2 fc. Inside the space the horizontal illuminance range from 26.7 fc to 11.6 fc at the rear wall. The rear wall vertical illuminance is 20.8 fc. The workstation 6 feet from the window had a horizontal illuminance were 15.9 fc and vertical illuminance of 5.45 fc. The computer workstation has a horizontal illuminance of 11.9 fc and vertical illuminance of 14.3 fc.

2. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal illuminance at the window was 56 fc. Inside the space the horizontal illuminance range from 60.3 fc to 33.9 fc at the rear wall. The rear wall vertical illuminance is 30.9 fc. The workstation 6 feet from the window had a horizontal illuminance were 38.8 fc and vertical illuminance of 19.7 fc. The computer workstation has a horizontal illuminance of 42.2 fc and vertical illuminance of 28.7 fc.

3. DAYLIGHT ONLY

The horizontal illuminance at the window was 36.2 fc. Inside the space the horizontal illuminance range from 40.2 fc to 17 fc at the rear wall. The rear wall vertical illuminance is 28.3 fc. The workstation 6 feet from the window had a horizontal illuminance were 24.4 fc and vertical illuminance of 9.25 fc. The computer workstation has a horizontal illuminance of 17.8 fc and vertical illuminance of 20.3 fc.

F BRIGHTNESS

The natural light conditions at the time of the site survey made assessment of daylight use possible.

Light levels measured at the workstations without the electric lights were below the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100. Operation of the electric lights was necessary to achieve the recommended light levels. Workstation 1 had lower daylight incidence compared to workstation 2. This is mainly because of the structural column that decreases available window area. Reduced daylight incidence at the workstations could be attributed to the desk location. The daylight incidence 3 feet in front of the desk was within the comfortable visual range. Moving the desk closer to the window might increase the daylight incident on the workspace. Another option is moving the desk towards the center of the room.

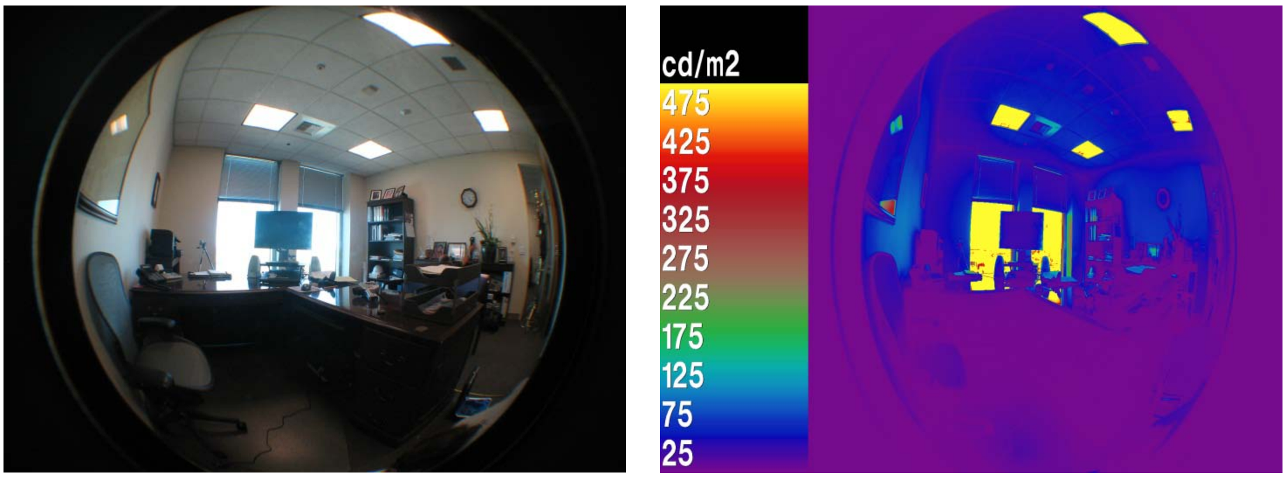


Figure 65: Wide-angle and false color images with electric lighting

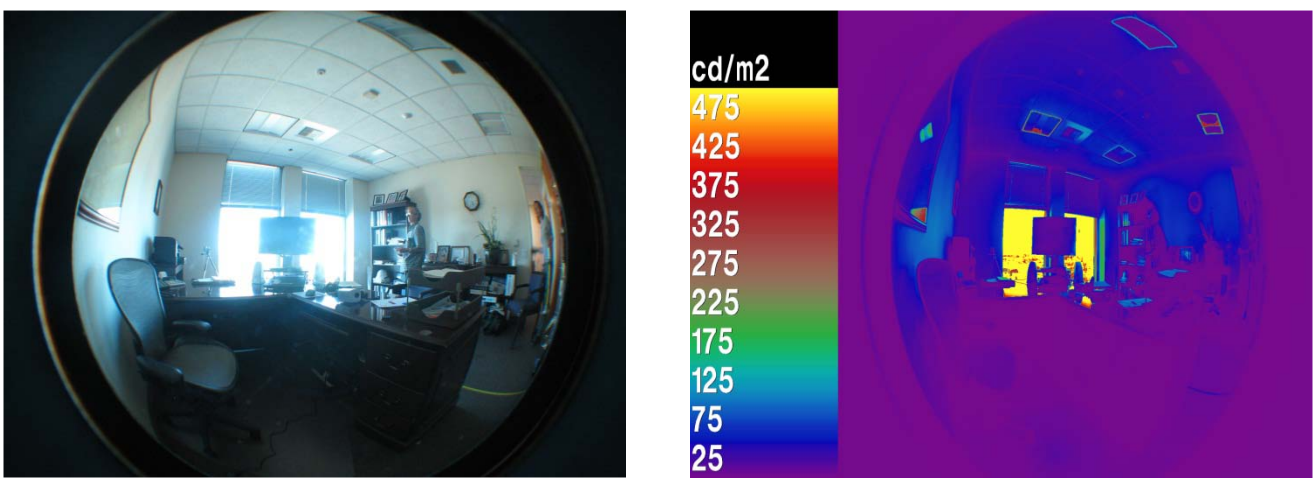


Figure 66: Wide-angle and false color images for private office

G GLARE

The façade orientation results in an absence of direct sunlight, and there is no potential for solar reflection – consequently disabling glare is very unlikely to occur. There is substantial glare coming from the windows. The electric lights had minimal contribution to glare in the workspace. The computer location and orientation is not ideal in terms of visual comfort because of the glare from both the windows and the table top. The choice in location for paper-based tasks was possibly influenced by the window glare.

SITE 3 - COTTAGE WAY FEDERAL BUILDING, SACRAMENTO

Figure 67: Cottage Way Federal Building in Sacramento, CA

A GENERAL BUILDING DESCRIPTION

The Federal Building at Cottage Way, Sacramento, California (Figure 67) is a late 1960's construction. The building consists of two separate square blocks, one small and one large, with two floors in each. The total floor area is 323,000 square feet. The building envelope is a reinforced concrete lattice with curtain wall windows. The open offices and private offices working areas are occupied by several state departments and federal department, usually between 7am to 6pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to achieve significant energy savings and control of individual lighting fixtures and to provide comfortable lighting conditions for building occupants. The project had no specific energy saving targets - no specific analysis was completed to assess savings.

The daylighting project was part of an overall upgrade of building systems and controls whose overall objective is to reduce energy load. The daylighting retrofits consisted of replacement of old lighting fixtures, and photosensors. The project was completed in August 2012.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines, and the fact that prior to the upgrade, the building had relatively high energy use. Two companies were involved in implementation of the project, the first did the design and the second did the installation and the system commissioning. According to the building manager, implementation of the project was challenging in several ways: the project schedule proved to be demanding and transition from the old lighting system to the new one was not seamless. Consequently, there were a significant number of complaints early on, and some additional fixture had to be added to the original design. In addition there were performance issues with the control system software and light flicker. Occupancy timeout period had to be increased from 20 minutes to 45 minutes to improve satisfaction with the system, although this might improve cost-effectiveness of the IDS elements.

The lighting specification changed as part of the retrofit: T12 lamps were replaced by 32W T8 lamps. Target light levels initially set at 50 fc at the work plane. Electric light levels do not change noticeably during the day and do not shut off with response to daylight but dim to about 10% light output (which equates to between 25-35% power input), although the building manager reports that interior light levels do not change noticeably throughout the day. Most of the lighting has occupancy-based control, although there are also manual switches still present: both auto and manual activated lighting dims to available daylight. There is under-cabinet task lighting in some office spaces. Vertical blinds were installed in all of the perimeter offices, the default positions of which depend on the office window orientation, but tend to be partly open. The 4 foot overhangs provide shading from direct sunlight from mid-morning to mid-afternoon.

Installation: DALI light fixtures were installed in order to allow control of individual lighting fixtures and tuning of maximum light levels. Additional lights, not in the design plan, were installed. Some newly installed fixtures and switches had to be replaced. There were technical significant issues during project implementation.

Commissioning: System operating manuals have been left with building O&M staff.

Training: Face-to-face training and demonstration of the system was conducted for the O&M staff.

Maintenance: Daily O&M will be handled by in-house mechanics. Deeper maintenance will be contracted to an external company (which was not selected at the time of the site visit).

Occupant Satisfaction: Tenants were satisfied with the change despite initial resistance. A satisfaction survey will be conducted after two years to assess the project effectiveness.

D DESCRIPTION OF PROJECT AREA

The project site for the one-day site visit is a south-facing private office located on the first floor measuring around 10 feet by 14 feet with a ceiling height of 10 ft. There are several shading elements outside of the office: a one-story structure on the east and a four-foot overhang. There was reflected sunlight from the windshields of the cars parked in the adjacent car park. There is some shading provided by nearby trees.

The floor-to-ceiling windows have an interior height of 9 feet high, and are tinted single glazing. The resulting Window-to-Wall ratio is around 0.80 once the structural pillars are factored in. The existing manual shading is gray vertical blinds which are typically closed.

The light fixtures are recessed 2x4 troffers holding two lamps each, with the long axis of the fixture perpendicular to the window wall. There is under-cabinet task lighting at one of the work areas. Manually operated wall switches turn on the lights.

Two workstations were identified, the first is near the door parallel to the window and the second is where the computer monitors are located. The energy efficiency measures related to daylighting include a replacement of the whole lighting fixture and installation of photosensors.

The ceiling and interior walls are white, the floor carpet is dark blue. The furniture consists of an L-shaped desk of light gray color, a computer chair, a dark-colored file cabinet, and a light-colored circular table across the door.

Figure 68: Cottage Way office floor plan

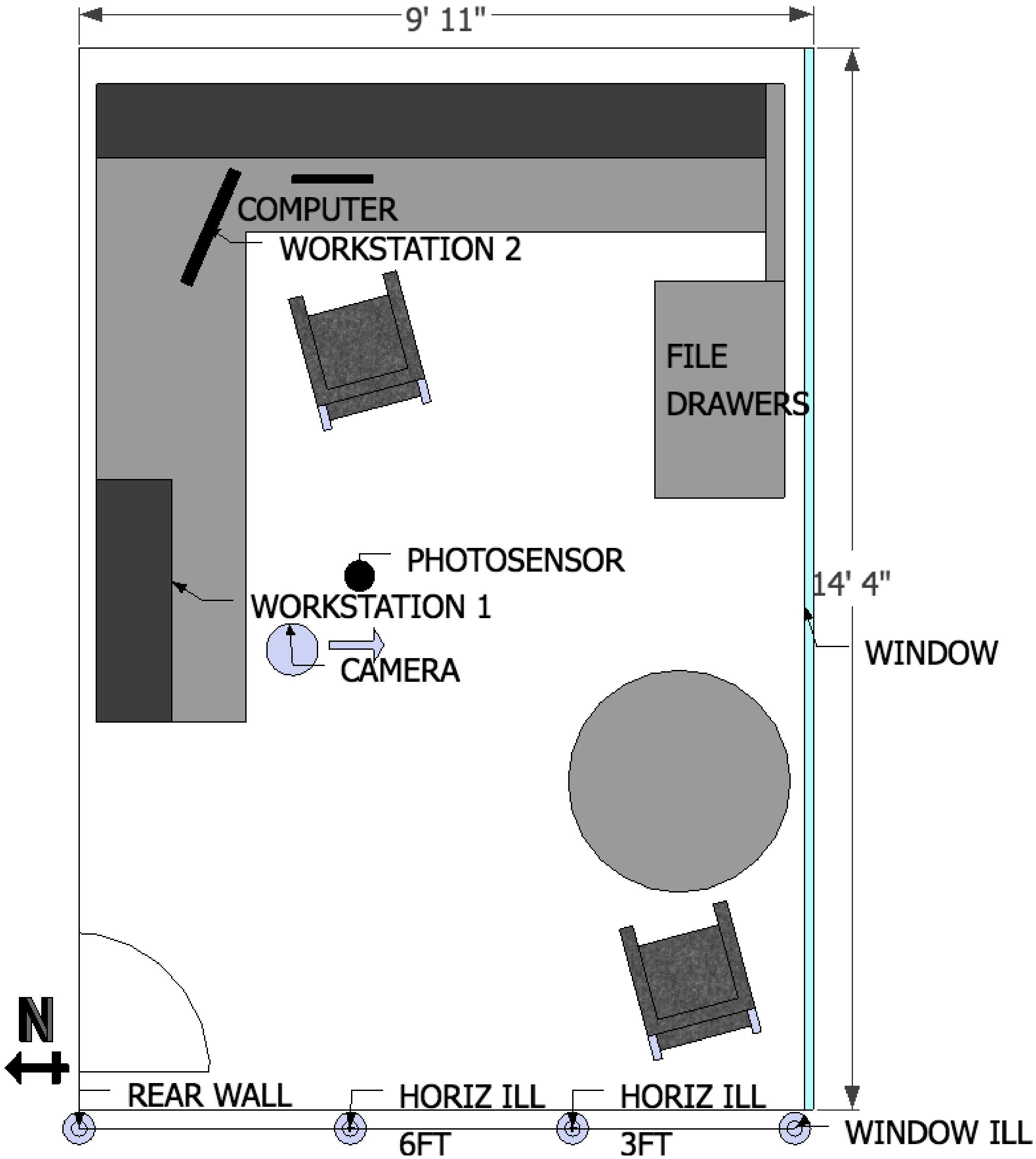


Table 35: Cottage Way Federal Building lighting measurements

	Daylight Only	Daylight and Electric Lights	Daylight, Electric Lighting and Task Lights
Window – Horiz. Ill	168	328	289

	Daylight Only	Daylight and Electric Lights	Daylight, Electric Lighting and Task Lights
3 ft. – Horiz. Ill	67	392	316
6 ft. – Horiz. Ill	50	441	354
Rear Wall (9ft) – Horiz. Ill	62	248	193
Rear Wall – Vert. Ill	102	222	219
Workstation 1			
Horiz. Ill	33	259	669
Vert. Ill	62	129	831
Vert. lum (gray card)	3.98	7.05	49.1
Workstation 2			
Horiz. Ill	24.3	217	218
Vert. Ill	35	179	195
Vert. lum (gray card)	1.5	7.9	9

1. OBSERVATIONS

The site visit was during a sunny day on August from noon to 2 pm.

The lights and task lights were switched on upon arrival. The blinds were all closed except for one which was kept open with a binder clip. There was no mechanism to move the blinds aside. Office furniture consisted of an L-desk with overhead shelves, a small circular conference table, office chairs, and a dark gray file drawer next to the window.

2. DAYLIGHT ONLY

The horizontal window illuminance was 168 fc. The horizontal illuminance in the space was between 50 and 67 fc, at the rear wall. The vertical illuminance at the rear wall is 102 fc. The workstation near the door had a horizontal illuminance of 33 fc and vertical illuminance of 62 fc. The computer workstation has a horizontal illuminance of 24.3 fc and vertical illuminance 35 fc.

3. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal illuminance at the space was highest at the middle of the space where the lights were located. The horizontal illuminance at the window was 328 fc while in the middle of the space horizontal illuminance was 392 and 441 fc. The rear wall horizontal illuminance is 248 fc and horizontal illuminance is 222 fc. Workstation horizontal illuminance were 217 fc and 259 fc. Vertical illuminance for the workstations were 179 fc and 129 fc.

4. DAYLIGHT, OVERHEAD LIGHTS, AND TASKLIGHTS

Workstation 1, where the task lights were located had a horizontal illuminance of 669 fc and vertical illuminance of 831 fc. The illuminance at the other workstation increased only slightly; horizontal illuminance was at 218 fc and vertical illuminance at 195 fc.

E BRIGHTNESS

Prevailing natural light conditions at the time of the site survey are useful in supporting analysis of daylight use.

Light levels measured without electric lighting were above the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100. For workstation 2, electric lighting is required to bring light levels above the minimum recommendation – this is possibly due to the location of the large filing cabinet between workstation 2 and the window.. Operation of electric lights made light levels very high at both work station locations – over 200 foot-candles at both locations.

Figure 69: Wide-angle and false color images with electric lighting

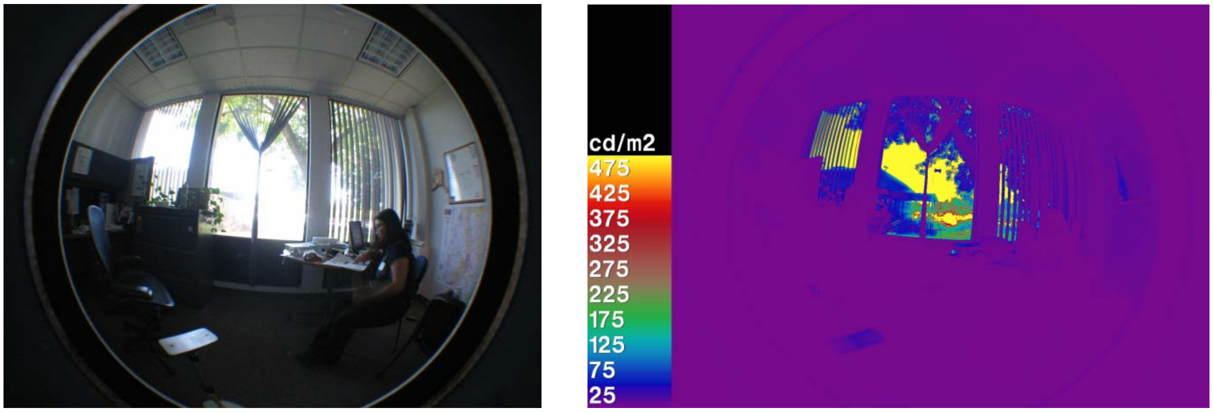


Figure 70: Wide-angle and false color images for private office

F GLARE

The façade orientation means that this space has good access to daylight, although the architectural overhang is likely to exclude direct sunlight other than possibly during winter months – this reduces the possibility for disabling glare to occur. The adjacent trees also provide good shading. The choice of working locations likely minimizes the impact of discomfort glare on working conditions – the computer monitor is at right angles to the window and the work area for paper tasks faces away from the window.

SITE 4 - RONALD DELLUMS FEDERAL BUILDING, OAKLAND

Figure 71: Ronald V. Dellums Federal Building at Oakland City Center

A GENERAL BUILDING DESCRIPTION

The Ronald Dellums Federal building (Figure 71) in Oakland, California is a 2000's construction. The building has moderately deep square floor plate. The building consists of two towers, with 18 main floors, connected by a ground level atrium and bridge and an overall floor area of approximately 700,000 square feet. The building envelope is a concrete structure with strip windows. The normal occupied hours are between 6 am to 6 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The daylighting project was part of an integrated overhaul of the building's lighting control system – this building was the first of several sites in California to install these systems. The lighting project objective was to reduce lighting energy by 15-20%. Prior to implementation, energy savings from the new lighting system was estimated by an independent contractor/consultant, and reviewed by GSA engineers. This was done as a requirement by the local utility company in order to incentivize the retrofit. The energy savings estimate has not been confirmed.

The project consisted of installation of an integrated, advanced lighting control system.. This included lamp and fixture replacements and installation of occupancy sensors, photosensors and electronic dimming ballasts. The project was completed as of July 2011.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines, which included the installation of a DALI-based lighting control system. Three companies were involved in the project; one company did the lighting design, while the other two did the installation and control programming. The company responsible for programming the lighting controls was also the commissioning agent. The project manager indicated some challenges involving the equipment and calibration during project implementation. For instance, there was noise from integral sensors for the workstations and higher-than-expected standby power from the ballasts. With regards to calibration, the challenge was accommodating the variety of furniture and finishes in daylit spaces.

The lighting specification changed as the 32W T8 lamps were changed from 3,500K color temperature to a cooler 4,100K color temperature. According to the Project Manager ,target light levels were 50 foot-candles at the work plane, to reflect current GSA design guidance. The electric light levels were observed to change during the day. The lights were not programmed toswitch off completely off in response to daylight. DALI ballasts were observed to flicker at low levels – consequently the current minimum was set at 15% lighting output and a maximum of 50%. The lighting controls were automatic occupancy–based control, though manual controls were still installed in some areas. Perimeter lighting dims to daylight levels once switched on. Tasklights were not provided to the occupants. The space had existing manually-operated vertical blinds, which were observed to be typically in the closed position.

Installation: Replacement ballasts were required for the workstation specific lighting in the open office areas: these were installed to reduce initial standby power from 7 Watts to less than 1Watt. The project manager had assessed the density of photosensors during the project development process - the final design had one photosensor for every 2 – 4 workstations, located at a distance 10 to 15 feet from the window. Calibrating sensors for different areas was also a particular challenge due to the range of furniture and finishes in daylit spaces.

Commissioning: Close-out documents were submitted at the end of commissioning, including a spreadsheet with reference settings: this is to allow future assessment and documentation for maintenance, commissioning and re-commissioning. According to the project manager, the submitted documents were cumbersome and have rarely been used – only when absolutely necessary. The performance monitoring software was robust and exhaustive in terms of data acquisition. Reports could be generated at the granular level, but the energy data is calculated rather than measured and so for accurate results, requires adjustment for power factor.

Training: Training of operations and maintenance staff was done face-to-face with reference literature and presentation materials.

Maintenance: Maintenance of the lighting system was under an overall building maintenance contract. These contractors did not have prior experience with the lighting system, but had sufficient training. A contractor will be involved for deeper maintenance of the lighting system.

Occupant satisfaction: Occupants were satisfied with their lighting. Occupants can request light output be adjusted up or down, and individuals can set their own light levels.

D DESCRIPTION OF PROJECT AREA

The project area was a private office located on the 6th floor. The project area measures 18 feet by 12 feet with a full ceiling height of 10 feet and a dropped ceiling height of 9 feet. The windows were west-facing with an interior WWR of 0.75-0.80. The single-glazed, untreated window panels were installed on thick mullions, extending 4 inches inside the room and 6 inches outside. The window height is 10 feet with a base height of 1 foot measured from the ground. The existing interior shading was gray vertical blinds. There was no installed external shading. The view from the window was unobstructed.

The lighting fixtures were six troffer light fixtures oriented parallel to the window. Each fixture had two 32W T8 lamps. Under-cabinet lights at one of the workdesks provided additional task-specific lighting. Manual wall switches were installed on the interior office wall.

The ceiling and interior walls are white, the floor carpet is dark blue. The furniture consists of two L-shaped desks of light gray color and a computer chair.

Figure 72: Ronald Dellums floor plan

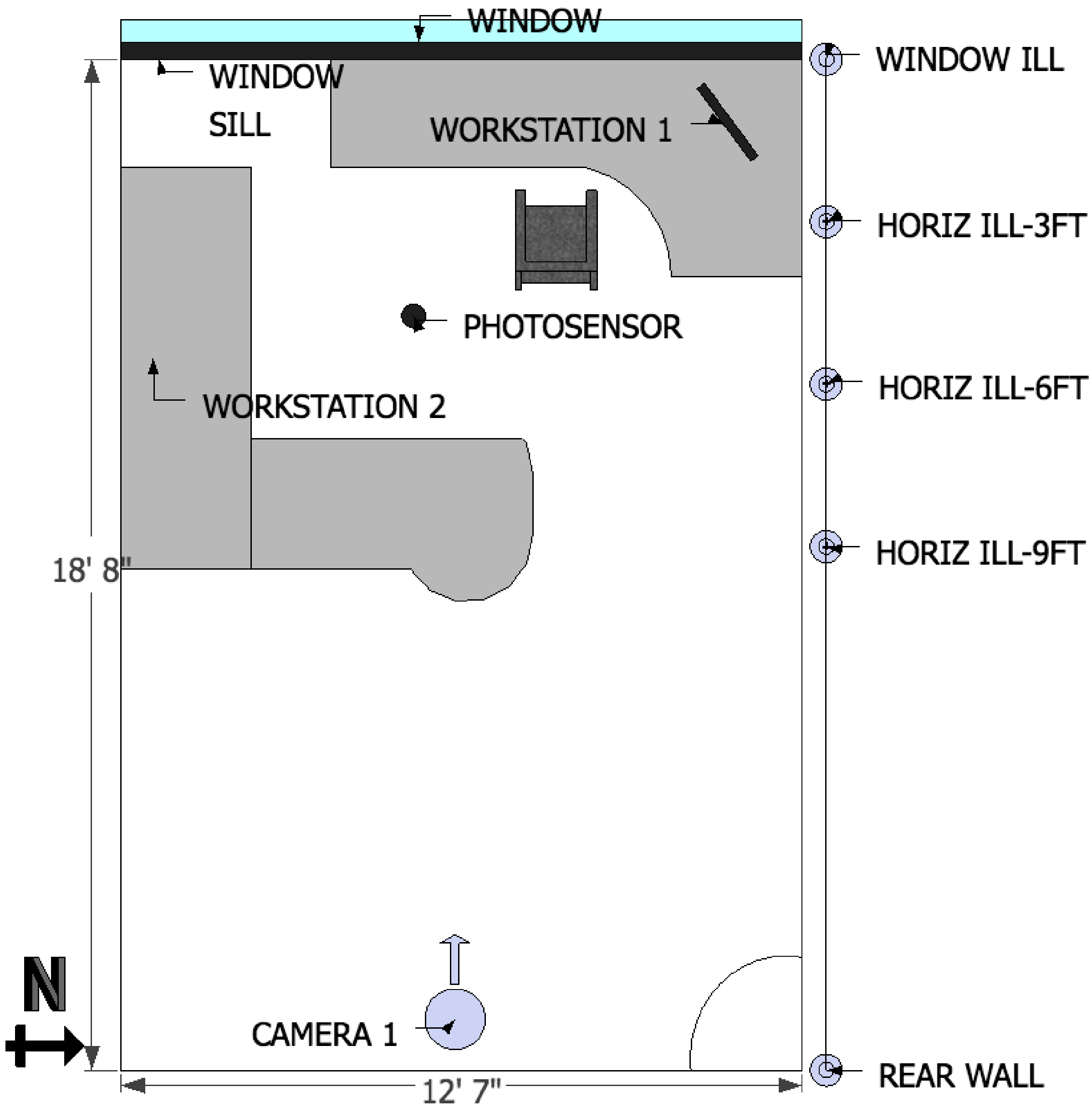


Table 36: Ronald Dellums Federal Building lighting measurements

	Daylight and Blinds Closed	Daylight, Overhead Lights, and Blinds Closed	Daylight and Overhead Lights	Daylight, Blinds Closed, and Overhead & Task Lights
Window – Horiz. Ill	77.7	103.4	190.5	
3 ft. – Horiz. Ill	62.2	94.8	142.4	
6 ft. – Horiz. Ill	52.3	92.0	100.7	
9 ft. – Horiz. Ill	27.3	71.0	72.7	
Rear Wall – Horiz. Ill	17.1	55.6	49.5	
Rear Wall – Vert. Ill	23.7	40.1	73.8	
Workstation 1				
Horiz. Ill	36.2	69.4	96.2	
Vert. Ill	37.9	52.5	127.0	
Vert. lum (gray card)	24.6	31.7	71.5	
Workstation 2				
Horiz. Ill	32.1	64.1	56.5	149.1
Vert. Ill	43.8	49.2	61.0	136.7
Vert. lum (gray card)	32.1	64.1	56.5	149.1

E OBSERVATIONS

The site visit was conducted in mid-afternoon (PDT) in May on a sunny day. The office was unoccupied during the visit. The existing lighting conditions were a combination of electric lights and daylight with the vertical blinds deployed. . The lighting appeared to operating as designed, dimming according to daylight levels. The site assessment was conducted at one work location.

1. DAYLIGHT AND BLINDS CLOSED

The horizontal window illuminance was 77.7 fc. Horizontal illuminance in the space was between 27.3 fc at 9 ft from the window and 17.1 fc at the rear wall. Vertical illuminance at the rear wall was 23.7 fc. The workstation parallel to the window had a horizontal illuminance of 36.2 fc and vertical illuminance of 37.9 fc. The workstation 6 feet from the window had horizontal illuminance of 32.1 fc and vertical illuminance of 43.8 fc.

2. DAYLIGHT, OVERHEAD LIGHTS, AND BLINDS CLOSED

The horizontal window illuminance was 103.4 fc. Horizontal illuminance in the space was between 94.8 fc at 3 ft from the window and 55.6 fc at the rear wall. Vertical illuminance at the rear wall was 40.1 fc. The workstation parallel to the window had a horizontal illuminance of 69.4 fc and vertical illuminance of 52.5 fc. The workstation 6 feet from the window had horizontal illuminance of 64.1 fc and vertical illuminance of 49.2 fc.

3. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal window illuminance was 190.5 fc. Horizontal illuminance in the space was between 142.4fc at 3 ft from the window and 49.5 fc at the rear wall. Vertical illuminance at the rear wall was 73.8 fc. The workstation parallel to the window had a horizontal illuminance of 96.2 fc and vertical illuminance of 127.0 fc. The workstation 6 feet from the window had horizontal illuminance of 56.5 fc and vertical illuminance of 61.0 fc.

4. DAYLIGHT, BLINDS CLOSED, AND OVERHEAD & TASK LIGHTS

The workstation 6 feet from the window had horizontal illuminance of 149.1 fc and vertical illuminance of 136.7 fc.

F BRIGHTNESS

Light levels measured for daylight only conditions at the site were above the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100 – indicating that that visual comfort levels can be achieved without the use of electric lights. When the electric lights were activated, light levels became significantly higher. Brightness can be regulated somewhat by operation of the blinds, but as the sun comes into the western sky, natural light levels will become very high.

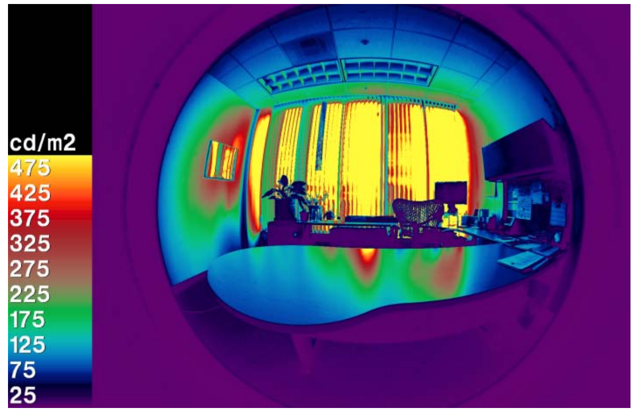


Figure 73: Wide-angle and false color images for private office

G GLARE

The façade orientation means that bright daylight and direct sunlight will be present in this space in the afternoon, which is when these images were taken – with the blinds open, there is the possibility for disabling glare. Due to the position of the computer work location relative to the window wall, the occupant could be significantly impacted by discomfort glare as a window view is likely to be in the peripheral vision range.

SITE 5 - ROYBAL FEDERAL BUILDING, LOS ANGELES

Figure 74. Roybal Federal Building

A GENERAL BUILDING DESCRIPTION

The Roybal Federal Building (Fig. 1) in Los Angeles, California, was completed in the 1990's with a ten-sided floorplate. The building has 22 main floors with a total floor area of 1.1 million square feet. The building is on a northeast-southwest axis; the façade of the assessed site is oriented to the southeast. The building envelope consists of a granite-covered, concrete and steel structure. The building contains open and private offices and courtrooms and is typically occupied between 7am and 5pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The project goal was increasing overall energy savings by selecting for the most cost-effective solution - energy savings were evaluated on a floor-by-floor basis, using inputs from the National Institute for Science and Technology (NIST) model for occupancy. Control strategies implemented were occupancy-based control, high-end tuning and daylight dimming, and high efficiency T8 lamps were installed in new fixtures, which were a like for like replacement for the originals. The project was completed in February 2012 with a pending maintenance issue with regards to some occupancy sensors.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of the additional jobs it created, the fact that it could be implemented quickly and that it was a clear opportunity for realizing energy savings. Three companies were involved in implementation of the project: the first completed the lighting design and installed the fixtures, the second installed and commissioned the integrated control system and a third commissioned the fixture controls.

The project consists of an advanced, integrated lighting strategy. The objectives were confirmed using NIST energy model that uses occupancy profiles as a model input. The project was completed in February 2012, with follow-up maintenance pending for incorrectly wired occupancy sensors.

Primary controls are occupancy-based control then dimming according to available daylight. Manual control of lighting is not available to occupants; they can request adjustment of their personal workstation light levels. Occupants have access to manually controlled venetian blinds which allows adjustment of the amount of daylight; default blind position is closed for most of the workstations – this reflects the axis of the building: many occupants are likely to experience direct sun in the morning or afternoon.

The challenges associated with project commissioning was working in a federally secure building with stringent security requirements, getting contractors on-board and finally, verification of the correct system installation. The installed system was also implemented for the first time at this site. The system is under a seven-year warranty with the contractors; which includes maintenance and training of in-house staff.

The main lessons learned were that it is worthwhile investing in a reliable spine the lighting system. Ensuring occupancy sensors were wired / connected according to standards would have reduced volume of initial complaints.

Installation: Included installation of 2x4 and 2x2 troffer fixtures, and pendant fixtures with dedicated integrated sensors. Building lighting changes include replacing old T8 lamps and standard fixtures with new lamps. New pendants were installed in some floors. Light levels were dictated by tenant agreements but are typically 50 foot-candles at desks. The new fixtures were installed in identical locations to those that were removed. The lights do not shut down in response to daylight levels. Light levels have been observed to change in response to daylight on the west side of the building. Task lights are included in the office furniture in some agencies, and some Agencies offer desktop task lights to their staff.

Commissioning: Commissioning certificates only have been retained.

Training: Operations and Maintenance and Energy Management staff have been instructed how to use the controls system software. They have also been provided with documentation that supports maintenance and system recommissioning.

Maintenance: There is a seven year warranty on system operation, which includes access to staff from the commissioning agent and the control system vendor to undertake troubleshooting tasks. They will also be required to complete periodic ‘deep’ system maintenance.

Occupant Satisfaction: Seminars and pamphlets were made available to tenants outlining how the daylighting element of the system worked. However, dimming of lights in the late afternoon was a common cause of complaints – despite the information made available, many occupants were aware that this would happen and assumed system defects. Flickering lamps were also a problem, caused by dimming lamps to their minimum limit. Most of these complaints were addressed and occupancy sensors are being rewired. Occupant feedback to GSA showed that 98% of the tenants were comfortable with the changes once implemented.

D DESCRIPTION OF PROJECT AREA

The site is a private office at the 9th floor on the north side of the building. The ceiling is 9 feet high and the daylight depth is 15 feet. Two workstations were identified within the assessed area, one in front of the computer monitors and on the side desk. Some of the workstation furniture includes integrated task lighting.

The sill height at the base of the strip windows is 2 feet 7 inches with a maximum window height of 9 feet. The Window-to-Wall Ratio is approximately 0.6-0.7. The building is one of the taller structures in the local area, hence there is minimal obstruction to daylight though there is a possibility for externally reflected daylight, mainly from windows of other tall buildings. Manual venetian blinds were installed at the 9th floor, though other floors have roller film shades (such as the 10th floor). The blinds are deployed by default due to the normally high natural light levels.

The lighting consists of two 2x4 recessed troffers with diffusers, each holding 2 T8 lamps: these are activately on the basis of occupancy only as there is no wall switch present. The office furniture houses integrated task lighting which was being utilized at the time of the site assessment.

The private office contains a large wraparound desk which has a light-colored top and several cabinets and shelving units that are dark grey in color. The interior walls are white though the wall space is mostly obscured by the office furniture. The desk and shelves / cabinets are dark colored, while the 3-foot benches are brightly colored. The carpet is a medium-grey color.

E OBSERVATIONS

The site visit was conducted on a cloudy morning in May. The electric lights were on and the blinds were lowered and closed, except for one that was partly lowered. The office space was uncluttered with minimal obstructions to daylight. The electric lights were not operated during the measurement; this is not possible as there are no manual switches.

1. DAYLIGHT, OVERHEAD LIGHTS, BLINDS CLOSED

The horizontal illuminance at the window was 449.7 fc. Inside the space the horizontal illuminance ranged from 51.7 fc to 24.2 fc at the rear wall. Workstation horizontal illuminance were 30.5 fc at workstation 1 and 64.5 fc at workstation 2. Vertical illuminance were 20.1 fc at workstation 1 and 22.5 fc at workstation 2.

2. DAYLIGHT, OVERHEAD LIGHTS, AND BLINDS DEPLOYED, SLATS AT 0 DEGREES

The horizontal illuminance at the window was 467.3 fc. Inside the space the horizontal illuminance ranged from 104.1 fc to 47.7 fc at the rear wall. Workstation horizontal illuminance were 56.8 fc at workstation 1 and 89 fc at workstation 2. Vertical illuminance were 84.5 fc at workstation 1 and 41.3 fc at workstation 2.

3. DAYLIGHT, OVERHEAD LIGHTS, AND BLINDS OPEN

The horizontal illuminance at the window was 471.9 fc. Inside the space the horizontal illuminance range from 296.4 fc to 54.2 fc at the rear wall. Horizontal illuminance were 56.8 fc at workstation 1 and 89.0 fc at workstation 2. Vertical illuminance were 84.5 fc at workstation 1 and 41.3 fc at workstation 2.

4. DAYLIGHT, OVERHEAD LIGHTS, BLINDS OPEN, AND WORKSTATION 1 TASKLIGHT

Workstation 1 had a horizontal illuminance of 40.4 fc and vertical illuminance of 32.1 fc.

Figure 75. Roybal office floor Plan

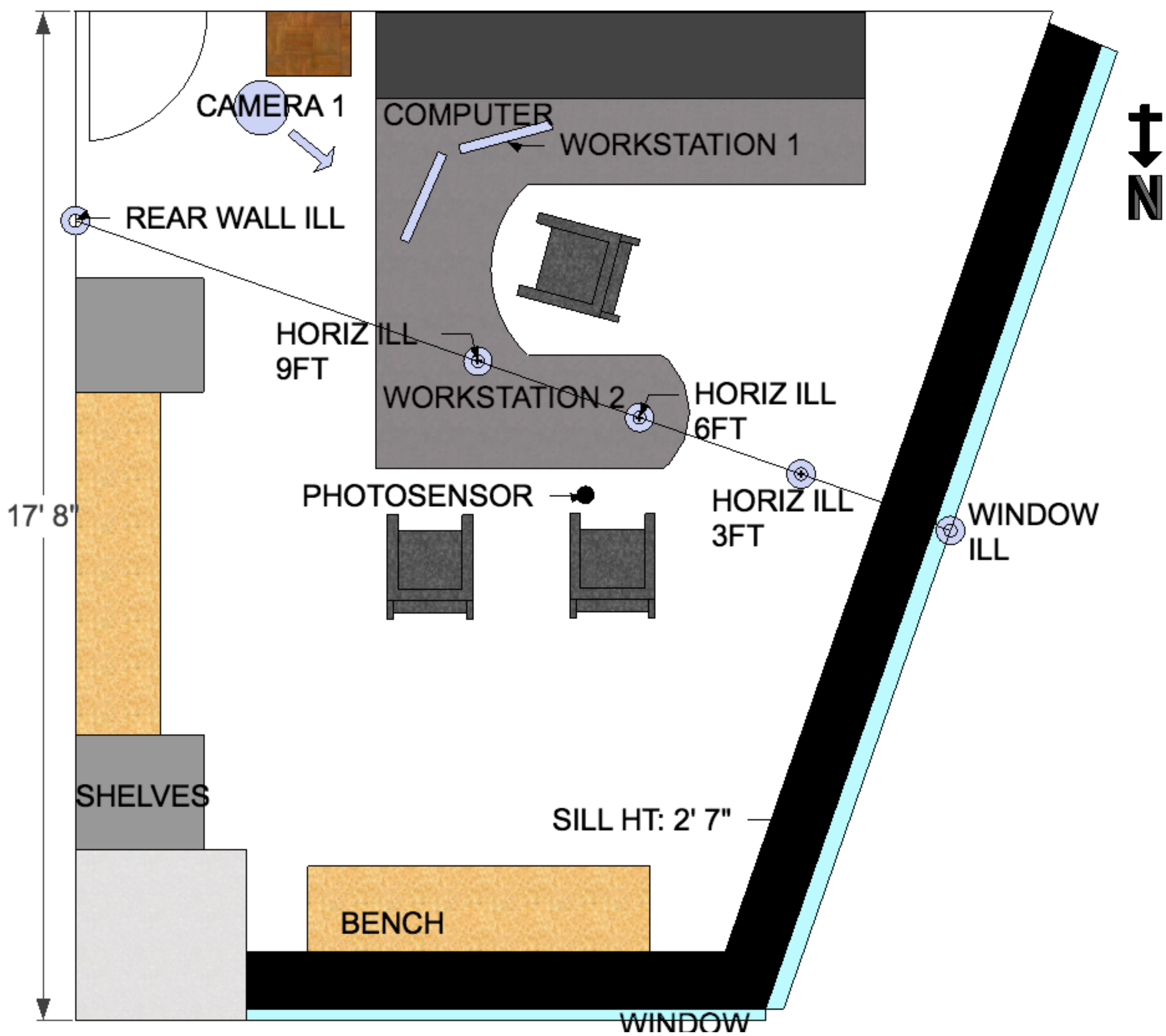


Table 37: Roybal Federal Building lighting measurements

	Daylight, Overhead Lights and Blinds Closed	Daylight, Overhead Lights, and Blinds at (00)	Daylight, Overhead Lights, and Blinds Open	Daylight, Overhead Lights, Blinds Closed, and Tasklight

	Daylight, Overhead Lights and Blinds Closed	Daylight, Overhead Lights, and Blinds at (00)	Daylight, Overhead Lights, and Blinds Open	Daylight, Overhead Lights, Blinds Closed, and Tasklight
Window – Horiz. Ill	449.7	467.3	471.9	
3 ft. – Horiz. Ill	45.8	97.7	296.4	
6 ft. – Horiz. Ill	49.1	104.1	178.6	
9 ft. – Horiz. Ill	51.7	93.0	107.8	
Rear Wall – Horiz. Ill	24.2	47.7	54.2	
Workstation 1				
Horiz. Ill	30.5	56.8	76.6	40.4
Vert. Ill	20.1	84.5	121.3	32.1
Vert. lum (gray card)	14.77	54.45	83.9	25.84
Workstation 2				
Horiz. Ill	64.5	89.0	196.1	
Vert. Ill	22.5	41.3	132.5	
Vert. lum (gray card)	13.29	28.42	72.75	

F BRIGHTNESS

Light levels measured at each work location were above minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100, when the blinds were down.

When the blinds slats were open or when the blinds were raised altogether, it was very bright – under either condition light levels were significantly above the P100 / IESNA recommended range.

It was not possible to measure light levels in the absence of electric lighting or the impact of electric lights when natural light was made available through the lifting of blinds as there was no accessible means to switch it off. However, by comparing light levels with the blinds down and the blinds raised it is reasonable to conclude that despite it being a cloudy day, daylight alone would be sufficient to meet the P100 / IESNA recommendations for visual comfort.

Figure 76: Camera 1 with blinds deployed

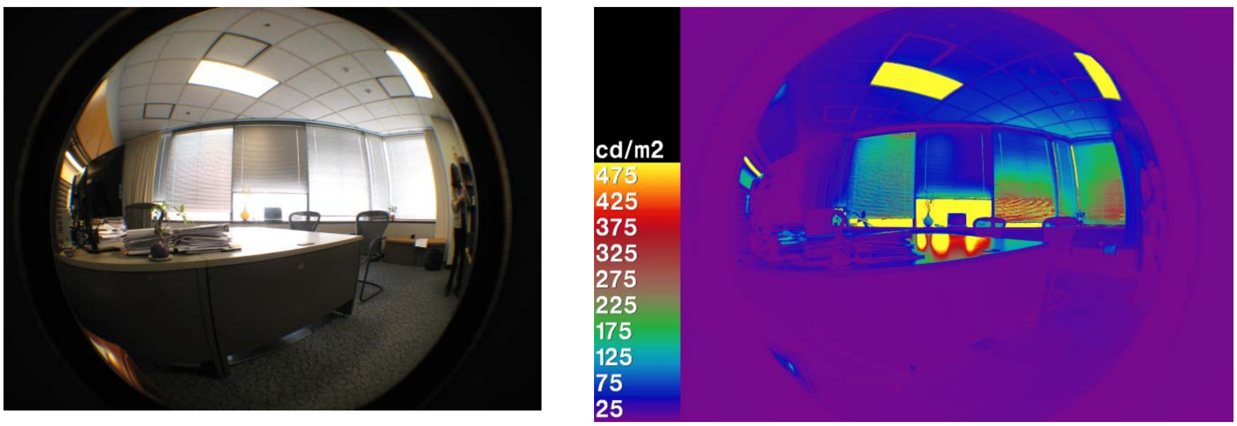
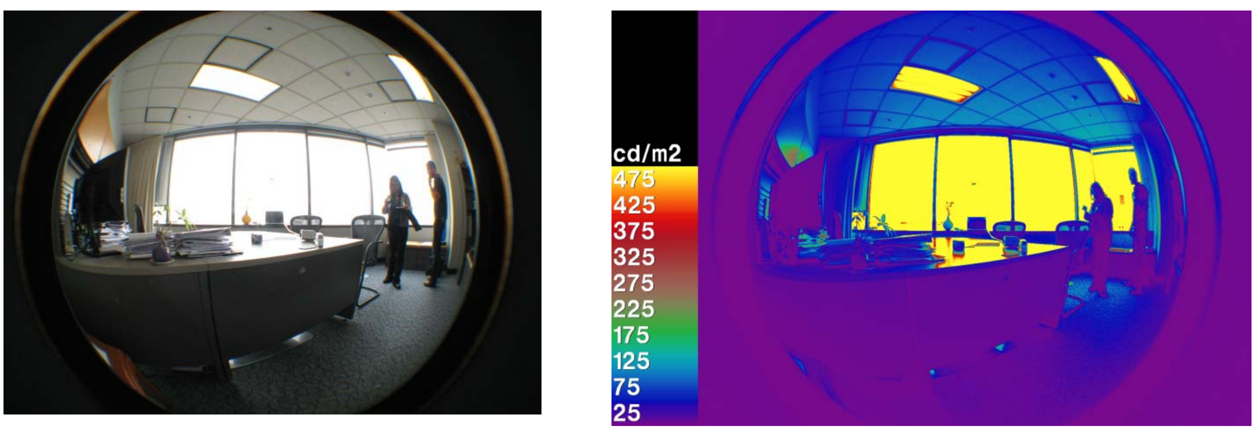


Figure 77: Camera 1 with blinds open



G GLARE

The façade orientation means that daylight and direct sunlight may be present in this space in the morning – it is possible that disabling glare could occur during a bright clear day. Comparison of the photographs illustrate how effective the blinds are at cutting down on glare, although neither of the work locations in this office should be affected as they do not face the window. There is the potential for discomfort glare to impact the occupant at work location 1 as with the blinds up, uncomfortable reflections may occur in the computer monitors.

SITE 6 - LLOYD GEORGE FEDERAL BUILDING, LAS VEGAS

Figure 78: Lloyd George Courthouse in downtown Las Vegas

Source: US Marshals Office

A GENERAL BUILDING DESCRIPTION

The Lloyd George Courthouse was built in 2000 in downtown Las Vegas. The building has 8 main floors. The building has two distinct sections - the northern section is rectangular in shape, with a large cutaway, which is covered by a vast canopy, the southern section has a square plan. The building envelope is a concrete structure with a rectangular floor plate. The north and west facades under the canopy consist largely of glass curtainwall. The other facades are of heavier concrete and steel mass, with smaller strip windows that are shaded by horizontal overhangs. The building working area consists of open cubicles, private offices and courtrooms and operates during conventional daytime office hours, usually occupied between 8:30 am to 5 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to improve light quality and reduce energy consumption associated with lighting. The lighting system vendor provided an estimate of energy savings in advance of implementation, although indications are that energy savings relating specifically to IDS were not quoted separately, rather that savings arising from operation of the integrated elements of the lighting system – occupancy-based control, high-end tuning and daylight dimming – would realize the estimated savings.

The new lighting controls allowed operations / maintenance staff to tune lighting according to the tenants requirements or those of individuals. It also supports earlier and easier diagnosis of failed fixtures, ballasts, or sensors.

The daylighting retrofit included changing out the entire lighting system: lamps, ballasts, fixtures; and changing from manually switches to automated occupancy sensors.

C LIGHTING PROJECT MANAGER INTERVIEW

The retrofit project was selected on the basis of meeting ARRA guidelines, due primarily to the previous lighting system, which was almost exclusively manually controlled, approaching the end of its useful life. The system upgrade included a removal and replacement of manual switches with automated sensors. Two companies were involved in the implementation of the project: the first completed the lighting design and the second did the installation and commissioning. Energy savings were projected by the vendors during the design phase. The project was finished in May 2012.

New lighting fixtures, lamps and ballasts were installed in all work areas except the courtrooms, with three lamp fixtures being replaced with two lamp alternatives. High-power T8 lamps were replaced with lower output equivalents. Lighting was initially set to achieve 50 foot-candles at the work plane, and although occupants notice electric light dimming in response to daylight, overall light levels remain fairly stable regardless of outside conditions. Task lighting was provided to occupants through undercabinet units integrated within the office furniture. Occupants were permitted to use their own task lighting if so desired. Overhead lighting was occupancy-activated primary control and then dim according to daylight levels. Private offices retained manual controls to override the occupancy sensors or for switching task lights on and off. Overhead lights do not shut off entirely, but dim to a set minimum of around 10% light output during intense daylight. No new shading systems were installed.

Installation: The project started in August 2010 with retrofits for the first two floors. The third and fourth floors were not started until a year later because of lack of funds and were finished in May 2012. Project timeline was drawn-out because of underfunding. Two project managers have worked on this project, one oversaw the first half of the project, another the second half.

One agency retained their canned lights at their open offices instead of upgrading to pendant lights. Local GSA decided to prioritize tenant relationship and did not install the pendant lights.

Fourth floor east-wing occupants noticed their lights dimming to daylight hence requested their electric light levels always remain at an output level equivalent to 50 foot-candles at the work plane. Tenants who were not used to cooler light color temperatures requested to have their lights dimmed from the prescribed 50 fc.

Commissioning: A full set of close-out documents were part of the GSA contract with the commissioning agent.

Training: Training of O&M staff was provided by the installation contractors. Occupants were informed of the change during installation.

Maintenance: Daily maintenance will be provided by the internal staff with work orders to adjust light levels forwarded to the local GSA office. The lighting control program made resetting light levels and diagnosing problems simpler for the O&M staff. Deeper maintenance and activities that should result in persistent energy savings will be contracted to external companies.

Occupant Satisfaction: Some tenants who resisted the change were informed that their rent would increase if they insisted on retaining the original lighting systems. Despite this initial resistance the general feedback from tenants was positive.

D GENERAL DESCRIPTION OF PROJECT AREAS

Three project sites were selected for the building. Two were located on the 4th floor used by visiting judges and attorneys and the third is a private office on the first floor. On average the rooms were occupied two to three weeks per month.

The strip windows in all three site locations were double-glazed and untreated, with the base 3 ft from the floor with a maximum height of 6 ft: the Window-to-Wall Ratio was around 0.3. There are no outside obstructions to the view as by-and-large all nearby building have a single floor. Manually-operated vertical blinds were installed on all windows. Manual light switches were still present in the offices - these override the occupancy sensors. The ceiling and interior walls were white, the floor carpet was medium-dark grey. Task lights are not provided to occupants.

E SITE 1 - JUDGES OFFICE

The measured area consisted of a private office located on the fourth floor on the north-east corner of the building, measuring 25 feet by 28 feet. Windows were located on the north and east side of the office, each under exterior metal overhanging shades.

There were nine lighting fixtures in the office, which were recessed troffer fixtures, laid out on a 3-by-3 grid. The light fixture directly above the main work area also serves as the emergency light, and consequently always remains on.

The furniture was mostly dark-colored hardwood book shelves, side table, a desk and a conference table. The office chairs were dark-colored and so was the couch near the south window. The office has two work locations, one at the main desk facing the north window and one at the computer station, facing the east window.

Figure 79: Visiting Judge Office floor plan

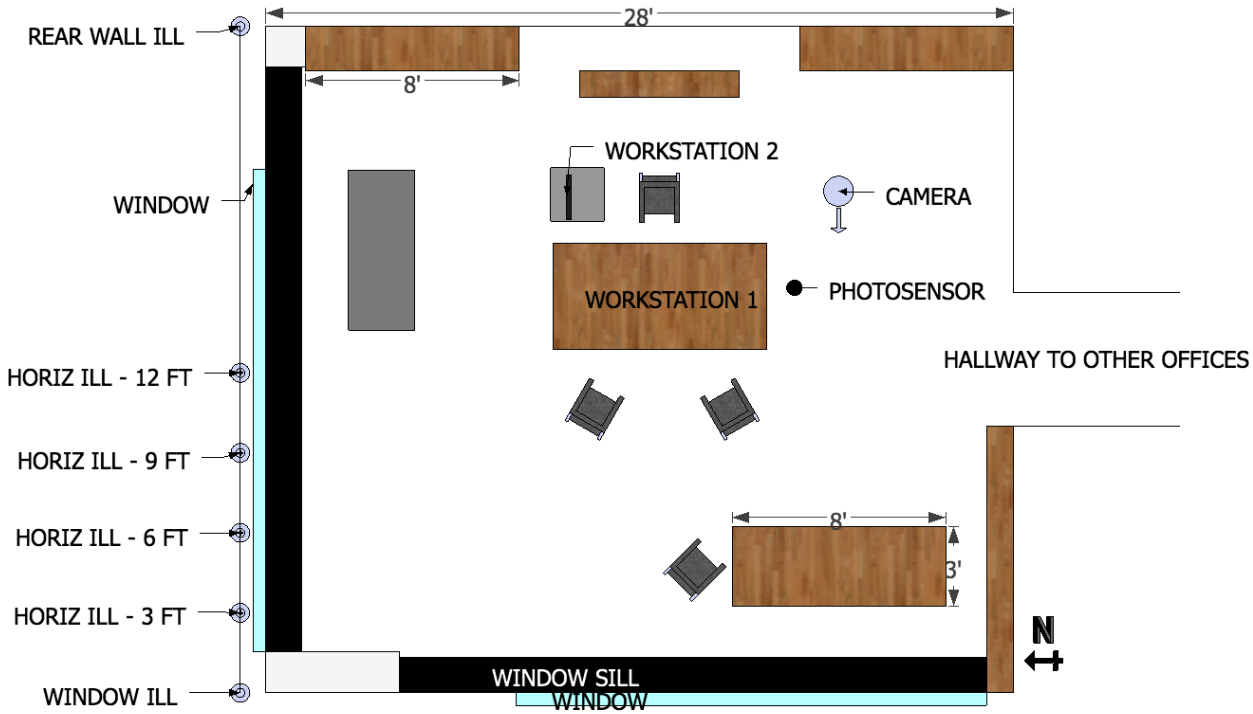


Table 38: Lloyd George Federal Building lighting measurements – Visiting Judges Office

	Daylight Only	Daylight and Blinds Closed	Daylight, Blinds Closed, and Overhead Lights
Window – Horiz. Ill	3372	3410	3400
3 ft. – Horiz. Ill	3131	148	539
6 ft. – Horiz. Ill	131	84	266
9 ft. – Horiz. Ill	98	71	105
12 ft. – Horiz. Ill	82	61	90
Rear Wall – Horiz. Ill	53	39	55
Rear Wall – Vert. Ill	95	65	72
Workstation 1			
Horiz. Ill	60	40	59
Vert. Ill	132	68	80

	Daylight Only	Daylight and Blinds Closed	Daylight, Blinds Closed, and Overhead Lights
Vert. lum (gray card)	25.64	16.15	20.33
Workstation 2			
Horiz. Ill	51	36	49
Vert. Ill	30	14	21
Vert. lum (gray card)	17.58	10.40	13.95

1. OBSERVATIONS

The site visit was conducted on a sunny morning in August. The office was unoccupied. Occupancy sensors at the judge's office triggered the lights upon arrival. Blinds were closed on the North window but were open at the East window. Controls for the blinds were easy to access and operate.

The view from the window was unobstructed though the north façade is below a metal overhang.

2. DAYLIGHT ONLY

The horizontal illuminance at the window was 3372 fc. Inside the space the horizontal illuminance ranged from 3131 fc 3 feet from the window to 53 fc at the rear wall. The rear wall vertical illuminance was 95 fc. Workstation horizontal illuminance were 60 fc and 51 fc for workstation areas 1 and 2 respectively. Vertical illuminance at the workstation was 32 fc and 30 fc.

3. DAYLIGHT, OVERHEAD LIGHTS, BLINDS CLOSED

The horizontal illuminance at the window was 3400 fc. Inside the space the horizontal illuminance range from 539 fc 3 feet from the window to 55 fc at the rear wall. The rear wall vertical illuminance was 72 fc. Workstation horizontal illuminance were 59 fc and 49 fc for workstations 1 and 2 respectively. Vertical illuminance were 80 fc and 21 fc.

4. DAYLIGHT AND BLINDS CLOSED

The horizontal illuminance at the window was 3410 fc. Inside the space the horizontal illuminance ranged from 148 fc 3 feet from the window to 39 fc at the rear wall. The rear wall vertical illuminance was 65 fc. Workstation horizontal illuminance were 40 fc and 36 fc for workstations 1 and 2 respectively. Vertical illuminance were 68 fc and 14 fc.

F SITE 2 – ATTORNEY'S OFFICE

The attorney's office measured 10.5 ft x 12.5 ft with an east-facing window. One work location was identified within the office, which was in front of the computer monitor.

There was one recessed lighting fixture in the space located above the desk. The interior shading was medium-gray vertical blinds.

The private office had one desk and an office chair, both dark in color.

Figure 80 Visiting Attorney Office floor plan

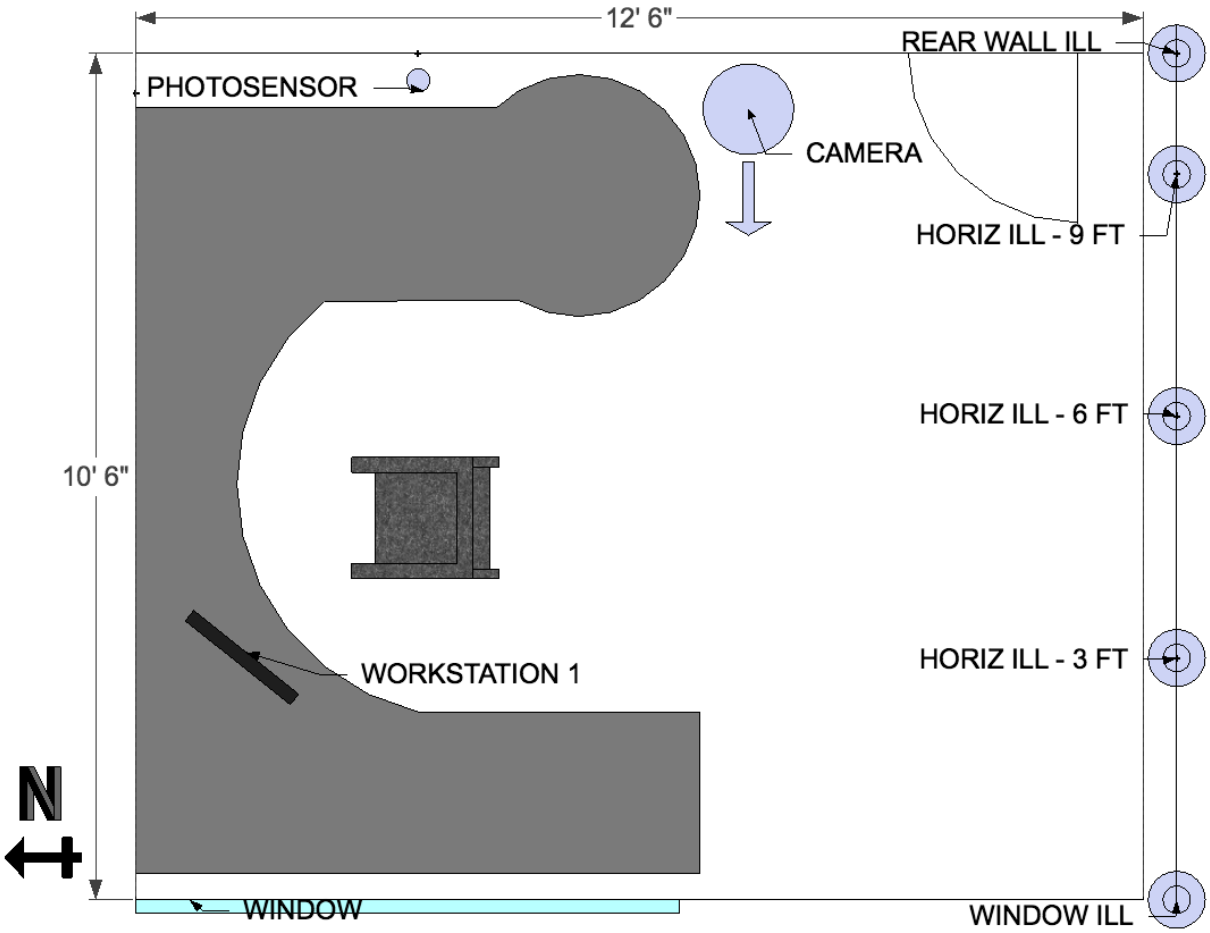


Table 39: Lloyd George Federal Building lighting measurements – Visiting Attorney's Office

	Daylight Only	Daylight and Blinds Closed	Daylight, Blinds Closed, and Overhead Lights
Window – Horiz. Ill	3390	3428	3418
3 ft. – Horiz. Ill	179	130	138
6 ft. – Horiz. Ill	104	85	86
9 ft. – Horiz. Ill	72	58	67
Rear Wall – Horiz. Ill	73	66	71
Rear Wall – Vert. Ill	120	106	111
Workstation 1			

	Daylight Only	Daylight and Blinds Closed	Daylight, Blinds Closed, and Overhead Lights
Horiz. Ill	90	79	80
Vert. Ill	169	140	142
Vert. lum (gray card)	99.74	82.07	83.53

1. OBSERVATIONS

The lights were triggered by the occupancy sensors upon arrival. The vertical blinds were open and collected to one side of the window. Controls for the blinds were easy to access and operate.

2. DAYLIGHT ONLY

The horizontal illuminance at the window was 3390 fc. Inside the space the horizontal illuminance range from 179 fc at 3 feet from the window to 72 fc, 9 feet from the window. The rear wall horizontal illuminance was 73 fc; vertical illuminance was 120 fc. Workstation horizontal illuminance was 90 fc and vertical illuminance was 169 fc.

3. DAYLIGHT, OVERHEAD LIGHTS, BLINDS CLOSED

The horizontal illuminance at the window was 3418 fc. Inside the space the horizontal illuminance range from 138 fc at 3 feet from the window to 67 fc, 9 feet from the window. The rear wall horizontal illuminance was 71 fc; vertical illuminance was 111 fc. Workstation horizontal illuminance was 80 fc and vertical illuminance was 142 fc.

4. DAYLIGHT AND BLINDS CLOSED

The horizontal illuminance at the window was 3428 fc. Inside the space the horizontal illuminance range from 130 fc at 3 feet from the window to 67 fc, 9 ft from the window. The rear wall horizonal illuminance was 66 fc; vertical illuminance was 106 fc. Workstation horizontal illuminance was 79 fc and vertical illuminance was 140 fc.

G SITE 3 – FIRST FLOOR PRIVATE OFFICE

The window was located on the South side of the office.

There were four recessed troffer lighting fixtures located above the main desk controlled by an occupancy sensor. Three canned lights located at the rear wall act as ambient lighting for the office and were controlled by a manual switch. Two canned lights above the side table function as task lights and were controlled by a manual switch. The recessed lighting fixture closest to the rear wall next to the window was the emergency light, which always remains on.

The private office on the first floor has hardwood desk, bookshelves, and a worktable and dark-colored office chairs. Two work areas were identified, the first is in front of the computer and the second is at the worktable near the window.

Figure 81: First floor private office floor plan

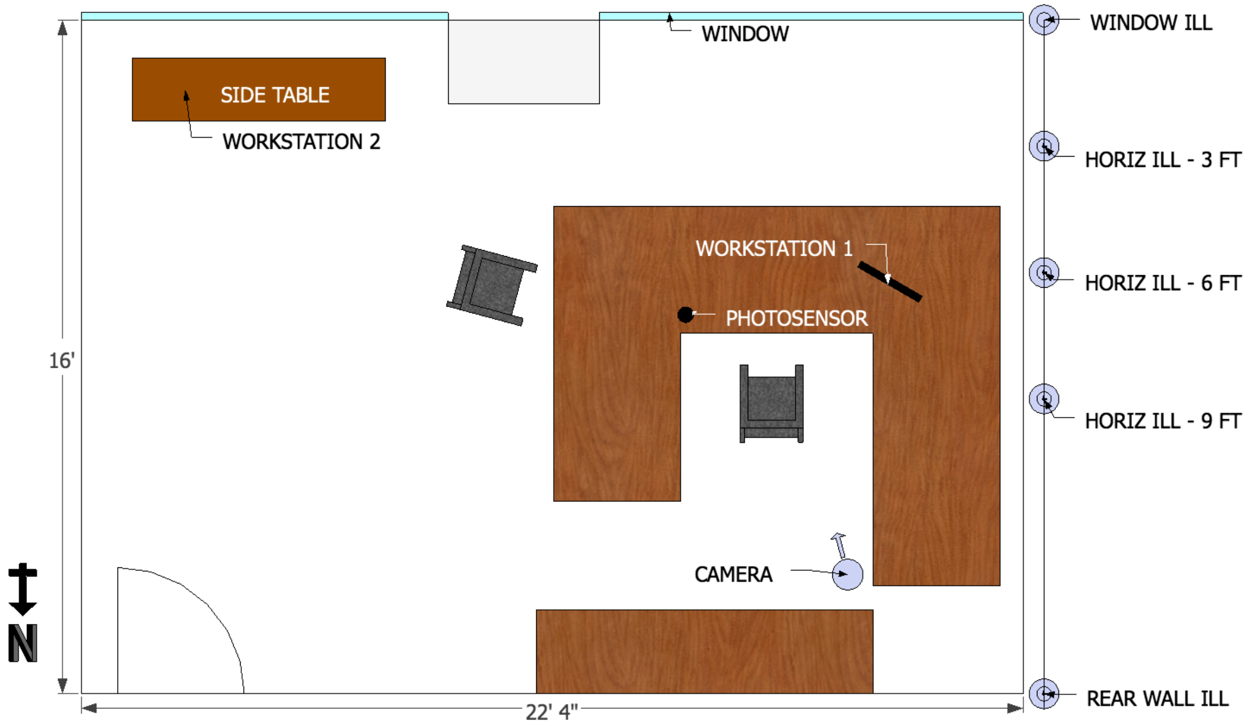


Table 40: Lloyd George Federal Building lighting measurements - First floor private office

	Daylight and Overhead Lights	Daylight, Overhead Lights, and Blinds Closed
Window – Horiz. Ill	2954	2889
3 ft. – Horiz. Ill	202	46
6 ft. – Horiz. Ill	109	32
9 ft. – Horiz. Ill	66	22
Rear Wall – Horiz. Ill	37	10
Rear Wall – Vert. Ill	59	13
Workstation 1		
Horiz. Ill	69	21
Vert. Ill	21	8
Vert. lum (gray card)	12.48	4.37

	Daylight and Overhead Lights	Daylight, Overhead Lights, and Blinds Closed	
Workstation 2			
			with Tasklights
Horiz. Ill	198	11	53
Vert. Ill	429	21	34
Vert. lum (gray card)	32.48	3.26	13.02

1. OBSERVATIONS

The site visit was conducted on a sunny mid-morning in August. The office was occupied upon arrival. The recessed lights and canned lights at the rear wall were switched on and the blinds were closed during the visit. The lights were controlled purely by occupancy sensor with no manual controls except for the task lights. The task lights for the side table were turned off. Controls for the blinds were easy to access and operate.

2. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal illuminance at the window was 2954 fc. Inside the space the horizontal illuminance range from 202 fc 3 feet from the window to 37 fc at the rear wall. The rear wall vertical illuminance was 59 fc. Workstation horizontal illuminance were 198 fc and 69 fc for workstation 1 and 2 respectively. Vertical illuminance were 429 fc and 21 fc.

3. DAYLIGHT, OVERHEAD LIGHTS, AND BLINDS CLOSED

The horizontal illuminance at the window was 2889 fc. Inside the space the horizontal illuminance range from 46 fc 3 feet from the window to 10 fc at the rear wall. The rear wall vertical illuminance was 13 fc. Workstation horizontal illuminance were 21 fc and 11 fc. Vertical illuminance were 8 fc and 21 fc.

4. DAYLIGHT, OVERHEAD LIGHTS, AND TASKLIGHTS

The tasklights were switched on when the occupant needs to work at the side table. The tasklights switch on at 100% and dimmed to daylight levels. The horizontal illuminance was 53 fc and the vertical illuminance 34 fc at the side table.

H BRIGHTNESS

1. JUDGES' OFFICE

Light levels measured for daylight only conditions at the site were well above minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA. The daylight only condition has very similar light levels to having the blinds closed and with overhead lights. This suggests that the fixtures were appropriately dimming to the available daylight. Brightness would have to be regulated through use of the blinds throughout the day.

2. ATTORNEY'S OFFICE

Light levels measured in the space were well above the minimum illuminance levels required to support visual comfort, in the daylight only condition. The overhead lights barely increased light levels in the office which suggests that the lights were dimming appropriately. Even with closed blinds and without electric lights the light levels were meeting guidance on visual comfort lighting levels.

3. FIRST FLOOR PRIVATE OFFICE

The light levels in the office were well above the minimum illuminance levels required to support visual comfort, for the daylight only condition. Closing the blinds, which was the default blinds position, decreased the light levels to below 30 foot-candles. Instead of having the blinds closed the whole day and with overhead lights switched on, the occupant should be able to partially open the blinds and adjust according to daylight availability and glare.

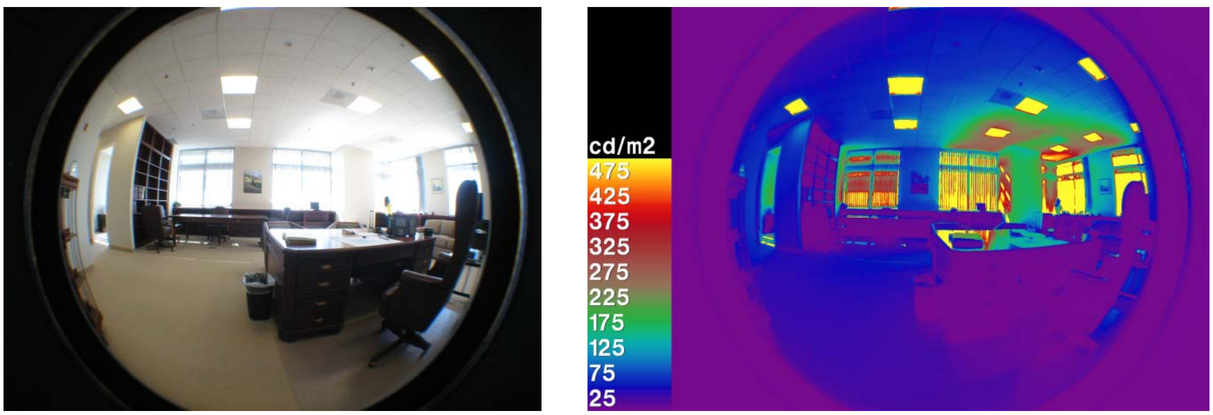


Figure 82: Wide-angle and false color images for Judges Office

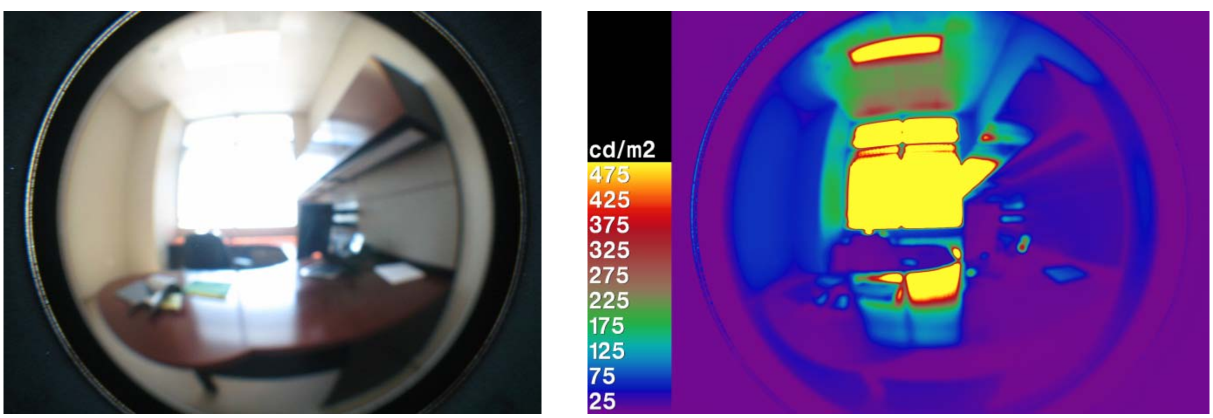


Figure 83: Wide-angle and false color images for Attorneys' office

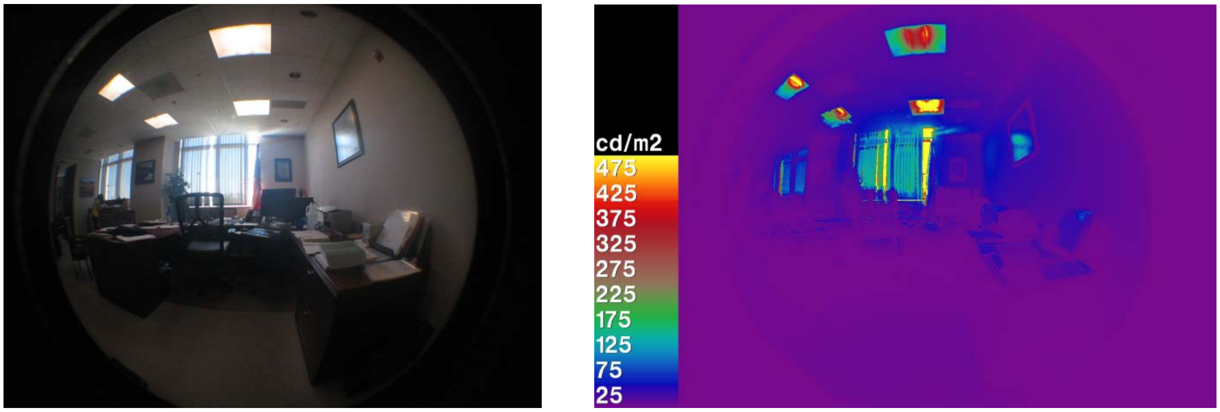


Figure 84: Wide-angle and false color images for Private Office

I GLARE

1. JUDGES' OFFICE

The façade orientation means that this office has good access to natural light and direct sunlight – disabling glare could occur without deployment of blinds. The image shows that bright conditions outside transfer to the inside. The dual aspect windows makes selection of a computer work location problematic as the occupant would always either be facing a window or away from one – in either scenario discomfort glare could be a problem without operation of the blinds.

2. ATTORNEY'S OFFICE

The façade orientation means that this office has good access to natural light and direct sunlight – disabling glare could occur if the blinds were not closed. The large windows and proximity of the work area to them means that glare will often be an issue as the number of annual sun-days in this location is very high. The main work surface is oriented so that the occupant works at computer or paper-based tasks with the window to the one side, which reduces the impact of discomfort glare.

3. FIRST FLOOR PRIVATE OFFICE

The façade orientation means that this office has good access to natural light throughout the day, with peak daylight conditions being from midday to mid-afternoon – disabling glare could be a facor without the closed blinds. The structural pillar between the windows breaks up natural light penetration to the degree that conditions do appear to be too bright in the image. The arrangment and orientation of the office furniture means that the occupant is likely to experince discomfort glare sometimes by virtue of facing the window whilst undertaking work tasks.

SITE 7 - METCALFE FEDERAL BUILDING, CHICAGO

Figure 85. Metcalfe Federal Building

A GENERAL BUILDING DESCRIPTION

The Ralph Metcalfe Federal Building (Figure 88) in Chicago, Illinois was completed in the 1991. The building has a rectangular footprint and comprises almost 1million square feet over 27 floors. The building envelope is a steel frame with single glazing curtain wall. The working area consists of open cubicles and private offices which operate during conventional daytime office hours, usually occupied between 7 am to 6 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to leverage energy savings associated with advanced lighting controls, and also to bring uniformity to light levels in lobby areas of Chicago Federal Buildings – this was identified as an important architectural objective. The project had no specific energy saving targets and it was understood that no specific energy saving analysis had been completed.

The retrofit of the assessed location comprised installation of photosensors. This specification is only installed in the lobby area – it was not known if daylighting design would be implemented elsewhere in the building. The project was already complete at the time of the site visit.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected to go forward on the basis of meeting ARRA guidelines, including installation of a IDS component. Four companies were involved in the implementation of the project: the first completed the design, the second - the prime contractor – subbed the lighting controls installation to the third company, and the fourth completed the system commissioning. According to the building manager, progress had been interrupted by activities that happened out of sequence with others and also due to an incomplete design process.

The lighting specification included replacement of 175 metal halide lamps installed in recessed can fixtures, each of which is controlled by a dedicated ballast. Target light levels were 50 foot-candles within workspaces generally, although within lobby areas this was not the case. The daylight dimming takes place in the first three rows of fixtures adjacent to the windows. Electric light levels do not change noticeably during the day and do not shut off completely in response to bright conditions.

Lighting controls are time-clock activated primary control and then dimming to available daylight. No manual lighting controls are available to occupants. No energy savings measurements associated with the daylight controls had been undertaken since project completion.

Installation: There were several challenges that had to be dealt with during implementation. The main one related to system wiring, which contributed to excessive bulb failures early on and non-functioning emergency lights. This cascades down to the design process, which was perceived as being somewhat hurried due to the funding timeline and a truncated project planning process. The building manager suggested that project should have been implemented through the existing O&M teams, so they could supervise the design and implementation and also would know how to operate it at completion.

Commissioning: There was a close-out failure, meaning that critical activities were not completed and the documents that would enable proper recommissioning have not been provided. This also makes measurement and verification and fault detection challenging. The GSA project manager is not always on-site until project completion which further hampers effective handover of the building.

Training: The planning included provision of training to O&M staff in all of the buildings having similar new installations. This had not happened at the time of the site visit.

Maintenance: At the time of the site visit, no resources had been allocated to ensure persistence of system operation. It was not anticipated that system maintenance would be provided beyond ensuring functional system operation.

Occupant Satisfaction: There have not been any complaints with regards to system operation.

D DESCRIPTION OF PROJECT AREA

The assessed site was the ground floor lobby.

The lobby has north and west-facing windows that extend from floor to ceiling, which is around 25 feet in height. The windows are untreated single-glazing. There were no architectural shading devices or blinds present. The view from the windows is obstructed due to the high built density of downtown Chicago – the angle of view for the sky is around 85 degrees. The measured area consists of the entire daylit zone, which at two times the window height, extends into the building to 50 feet. This space is largely open, with a security gate located in the center and a circular security monitoring booth with a diameter of approximately 10 feet adjacent to it – the booth has several work surfaces and multiple screens showing security camera footage.

The ceiling installed lighting fixtures are recessed cans, holding a single lamp each. These are installed at eight foot on center in the ceiling tiles throughout and extend to the rear wall of the lobby space. The lamps are 175W metal halide bulbs.

The interior space has light and medium-colored granite tile floors and a white ceiling, with the structural columns and walls clad in dark granite tiles. The security booth is aluminum clad with a dark granite top surface and dark granite work surfaces.

Figure 86: Metcalf entrance lobby floor plan

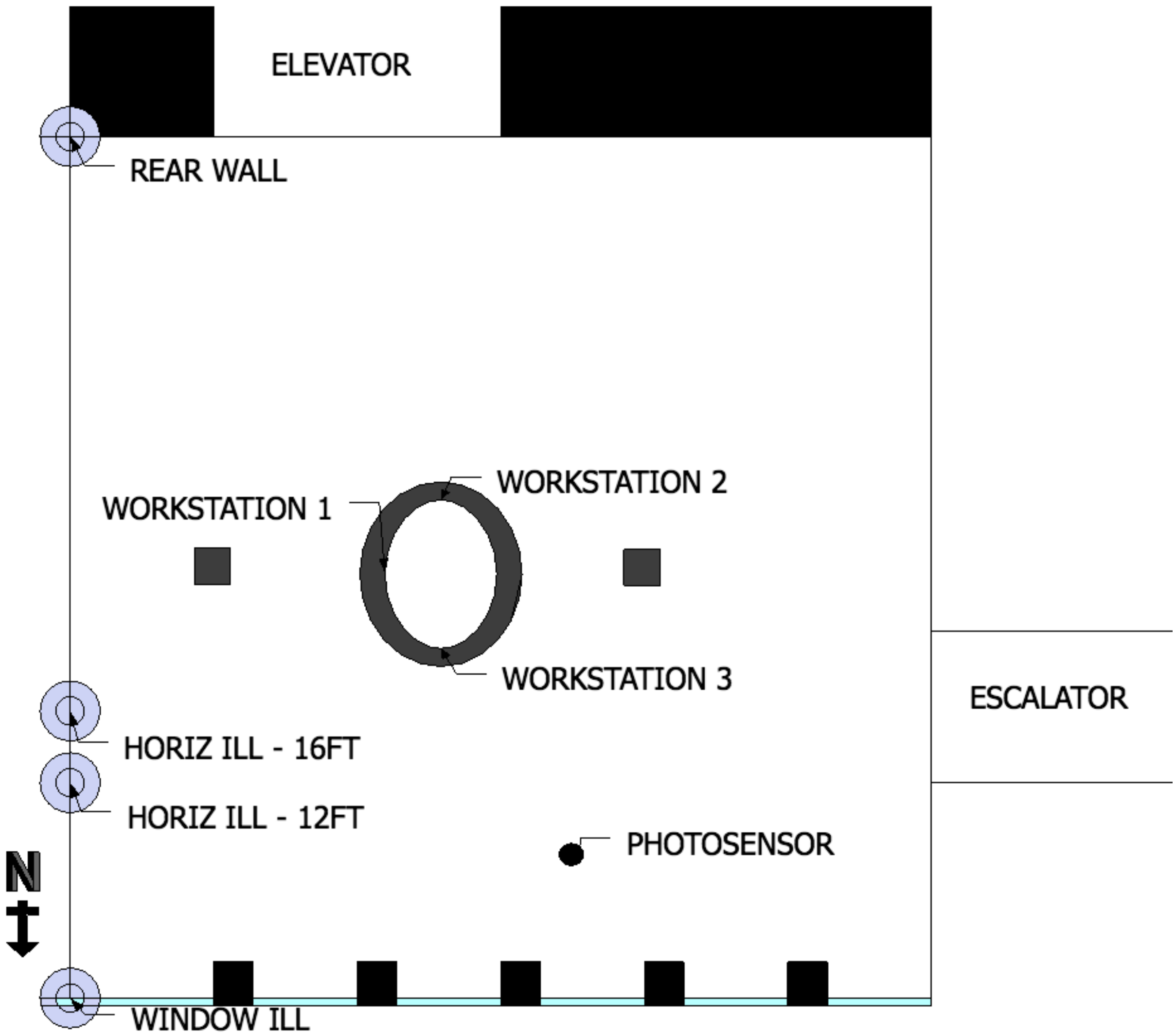


Table 41: Metcalf Federal Building lighting measurements

	Daylight Only	Daylight and Overhead Lights
Window – Horiz. Ill	224	191
12 ft. – Horiz. Ill	33.6	41.6
16 ft. – Horiz. Ill	12.8	18.7
Rear Wall – Horiz. Ill	2.78	26.9

	Daylight Only	Daylight and Overhead Lights
Rear Wall – Vert. Ill	6.38	13.5
Workstation 1 – North		
Horiz. Ill	8.9	24.2
Vert. Ill	10.1	17.1
Vert. lum (gray card)	3.61	7.9
Workstation 2 – East		
Horiz. Ill	9.47	24.3
Vert. Ill	12.4	18.4
Vert. lum (gray card)	6.95	9.64
Workstation 3 – West		
Horiz. Ill	5.72	19.7
Vert. Ill	2.92	9.8
Vert. lum (gray card)	1.88	6.84

E OBSERVATIONS

The site visit was conducted on a bright, partly-cloudy morning in May. On arrival the electric lighting was on and the perimeter lamps appeared to be dimmed. The site assessment was conducted at 3 locations within the security booth.

1. DAYLIGHT ONLY

The horizontal illuminance measured at the window was 224 fc. Horizontal illuminance in the space was between 33.6 fc at 12 ft from the window and 2.78 fc at the rear wall. Vertical illuminance at the rear wall was 6.38 fc. The workstation horizontal illuminance were between 9.5 fc and 6 fc. The vertical illuminance were between 12 fc and 3 fc.

2. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal window illuminance measured at the window was 191 fc. Horizontal illuminance in the space was between 41.6 fc at 12 ft from the window and 26.9 fc at the rear wall. Vertical illuminance at the rear wall was 13.5 fc. The workstation horizontal illuminance were between 24 fc and 20 fc. The vertical illuminance were between 18 fc and 10 fc.

F **BRIGHTNESS**

Prevailing natural light conditions at the time of the survey supported the assessment of use of natural light. Light levels measured at each of the work locations in the absence of electric light were well below the acceptable visual comfort range. When the lights were switched on, light levels increased significantly to levels acceptable for transitional lobby spaces.

Figure 87: Wide-angle and false color images for open office

G **GLARE**

As the measured work spaces were only occasionally occupied, no glare assessment was completed at this site.

SITE 8 - J.C. KLUCZYNSKI FEDERAL BUILDING, CHICAGO

Figure 88: John C. Kluczynski Federal Building, Chicago

A GENERAL BUILDING DESCRIPTION

The John Kluczynski Building (Figure 88) in Chicago, Illinois was completed in the 1970's. The building has a rectangular footprint and comprises around 1.2 million square feet over 43 floors. The building envelope is a steel frame with single glazing curtain wall. The working area consists of open cubicles and private offices which operate during conventional daytime office hours, usually occupied between 7 am to 6 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to leverage occupancy-based energy savings, high-end tuning and daylight dimming to save energy. The project had no specified targets for energy savings, and it is understood that no detailed analysis was completed to quantify potential savings.

The retrofits for the assessed site include installation of occupancy-based lighting control and daylight dimming and also incorporated the use of manually operated blinds. The same specification was planned for the majority of the 37th floor perimeter areas. Originally the project scope also included retrofit of the 35th and 36th floors but that portion of the retrofit did not proceed. The project was due to be completed in the Fall of 2012.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines, including the installation of a DALI-based system. Three companies were involved in implementation of the project: the first completed the lighting design, the second completed the installation and a third completed the controls programming. As the project was not yet complete, the commissioning agent was unknown to the building manager at the time of the site visit. According to the building manager, the project had progressed smoothly once scope had been agreed – as mentioned, proposals for the 35th and 36th floors were with withdrawn and value engineering meant led to removal of DALI fixtures from the design for the building core areas. At the time of the site visit, the project was estimated as being 98% complete.

The lighting specification changed as 32W T8 lamps were replaced with 28W T5 lamps. Target light levels are 50 foot-candles at the work plane according to GSA design guidance. Electric light levels do not change noticeably during the day and do not shut off with response to daylight but dim to about 10% light output (which equates to between 25-35% power input). The lighting controls are occupant activated primary control then dim to daylight levels. No manual lighting controls are available to occupants, although they can control their use of daylight through by using the manually-operated blinds. Tasklights were not provided to occupants. The default position for blinds is typically lowered and closed. As the project was not yet fully installed, no energy savings measurements have been taken. It was not clear whether this exercise would be completed post-commissioning.

Installation: DALI light fixtures were removed from lighting design for the core of the building due to value engineering decisions. Only the 37th floor has the new lighting system which is unique to the installed lighting systems in other parts of the building. A single O&M contract covers maintenance of the lighting systems in the whole building. Consequently the O&M contract for the new system is relatively inefficient and expensive, as staff has to learn the new operating systems and practices associated with the new system. Working with multiple lighting systems within a single location increases time commitments to individual projects and the cost associated with it. Ideally there would be a single lighting system for the whole building and a single O&M contract for that system or separate O&M contacts let for each of the multiple systems within the building.

Commissioning: Close-out documents for the project will be made available after the scheduled staff training.

Training: Face-to-face training of property management and building engineers has been scheduled for June. It was not clear whether the same training was going to be provided to office workers.

Maintenance: Trained staff members will be responsible for daily operation and maintenance of the system. No contracts are anticipated for maintenance on the system for the purposes of ensuring the persistence of energy saving performance.

Occupant Satisfaction: At the time of the site visit, occupants were satisfied with system operation and the property manager suggested operation was asexpected.

D DESCRIPTION OF PROJECT AREA

The assessed site was the GSA office located on the 37th floor.

The office has north-facing windows with a WWR around 0.85-0.90. The curtain wall windows house untreated single-glazing with a base height of 3 inches. from the floor and a maximum height of 8.75 feet. A perimeter reheat duct 1.5 feet deep by 1.5 feet high is located adjacent to the curtain wall and runs the length of the floor perimeter. Manually operated blinds were installed in all of the windows. The view from the window is unobstructed. The measured area consisted of two four cubicle cells with a walkways for access to other part of the office space between them. It is representative of the retrofit design throughout the floor, with identical lighting, office furniture and layout. Each cubicle measures 8.25 feet by 8.25 feet in area with partitions - these are 3.6 feet in height next to the window and 4.3 feet in height elsewhere. Floor standing filing cabinets around 4.3 feet in height are located between the first row of cells (next to the window) and the second.

The lighting fixtures are 1x4 recessed troffers holding two lamps each, oriented perpendicular to the northern window. The lamps are 28-watt T5's that provide direct lighting to the workstations. Tasklights and workspecific lights were not made available to employees. There were no manual switches for the lights.

The ceiling and interior walls are white, although many of the subdividing walls are glass partitions allowing daylight penetration into corridor spaces. The floor carpet is medium grey in color . The office furniture consists of pale desk tops and filing cabinets, and the partitions are black.

Figure 89: Kluczynski Federal Building open office floor plan

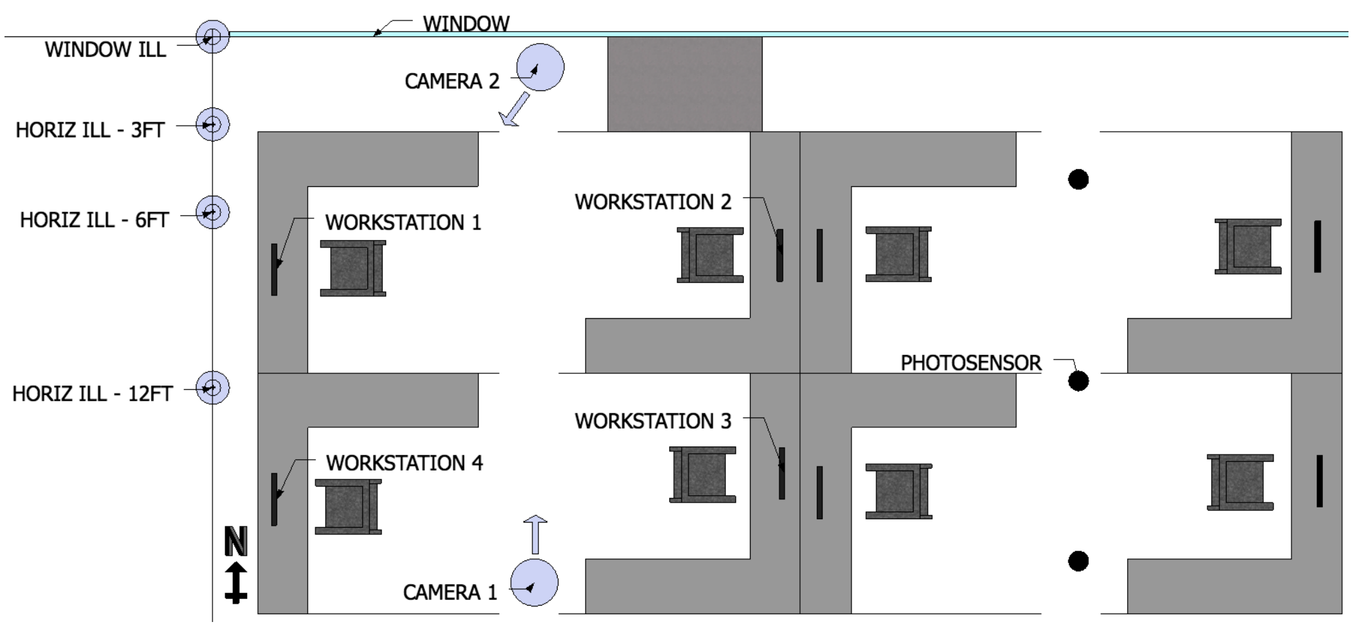


Table 42: John Kluczynski Federal Building lighting measurements

	Daylight Only	Daylight and Blinds Closed	Electric Lighting with Blinds Closed
Window – Horiz. Ill	155	171	149
3 ft. – Horiz. Ill	55.2	25.6	58.8

	Daylight Only	Daylight and Blinds Closed	Electric Lighting with Blinds Closed
6 ft. – Horiz. Ill	12.8	10.8	50.3
12 ft. – Horiz. Ill	12.8	10.8	50.3
Rear Wall – Horiz. Ill	2.57	2.84	50.3
Rear Wall – Vert. Ill	6.74	10.4	18.4
Workstation 1			
Horiz. Ill	17	8.5	43.6
Vert. Ill	30.4	10.2	26.5
Vert. lum (gray card)	16.15	9.85	16.44
Workstation 2			
Horiz. Ill	6.05	4.5	41.6
Vert. Ill	11.6	5.07	18.2
Vert. lum (gray card)	2.08	1.9	11.64
Workstation 3			
Horiz. Ill	2.82	2.47	54.3
Vert. Ill	11.8	9.9	25.2
Vert. lum (gray card)	3.49	2.94	15.14
Workstation 4			
Horiz. Ill	2.4	2.53	55.9
Vert. Ill	10.2	10.1	25.6
Vert. lum (gray card)	3.04	2.9	16.46

E OBSERVATIONS

The site visit was conducted on a cloudy, fairly gloomy afternoon in May. On arrival, the electric lighting was on, lamps were dimmed and blinds were fully deployed, with slats at around zero degrees. The lighting appeared to operating as designed, dimming according to daylight levels. The site assessment was conducted at 4 work locations, each of which had a different orientation relative to the windows.

1. DAYLIGHT ONLY

The horizontal window illuminance is 155 fc. Horizontal illuminance in the space is between 55 fc at 3 ft from the window and 2.57 fc at the rear wall. Vertical illuminance at the rear wall is 6.7 fc. Workstation horizontal illuminance varies between 17 fc 6 ft from the window to 2.4 fc 15 feet from the window. The vertical illuminance is between 30 6 ft from the window fc to 10 fc 15 feet from the window.

2. DAYLIGHT AND BLINDS CLOSED

The horizontal window illuminance is 171 fc. Inside the space the horizontal illuminance is between 25.6 fc 3 ft from the window to 2.8 fc at the rear wall. The vertical illuminance at the rear wall is 10.3 fc. The workstation horizontal illuminance is between 8.5 fc 6 ft from the window to 2.47 fc 15 feet from the window. The vertical illuminance is between 10 fc 6 ft from the window to 5 fc 15 ft from the window.

3. DAYLIGHT, BLINDS CLOSED, AND OVERHEAD LIGHTS

The horizontal window illuminance is 149 fc. Inside the space the horizontal illuminance is between 64 fc 6 ft from the window to 50 fc at the rear wall. The vertical illuminance at the rear wall is 18 fc. Workstation horizontal illuminance is between 55 fc 15 ft from the window to 41 fc 6 ft from the window. Vertical illuminance is between 26.5 fc 15 ft from the window to 18 fc 6 ft from the window.

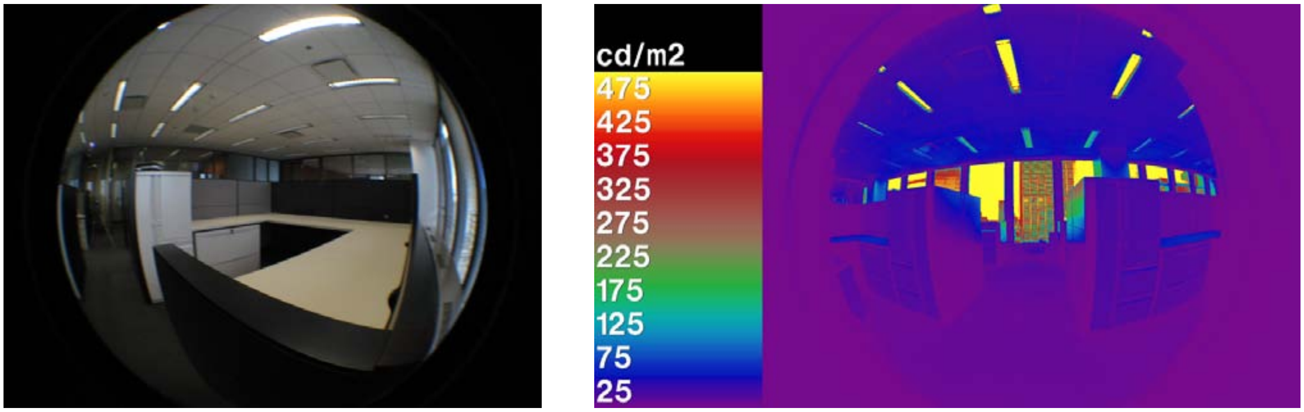
F BRIGHTNESS

Prevailing natural light conditions at the time of the site survey make assessment of daylight use challenging.

Light levels measured at each of the workstations without electric light and with the blinds closed were below the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100. Opening the blinds increases the illumination somewhat but not enough to be in the visual comfort range without electric lighting.

The reduction of daylight incidence at the second row of workstations can be partly attributed to the partitions and filing cabinets present – this can be seen in the comparison of illuminance measurements taken at the workspace, and measurements taken at interval distances in the walkways. For the first row of individual workstations, one workstation shows a reduction incident daylight mainly due to the structural column limiting the accessible window area. Operation of the electric lights increased the light levels to a comfortable level of 41 foot-candles. Reducing partition height or removing the partitions entirely would increase the daylight incident in the workspaces. The partitions also restrict access to the shading controls which discourages regular operation and means the blinds may often remain closed the whole day instead of adjusted to allow use of natural light.

Figure 90: Wide-angle and false color images for open office



G GLARE

The façade orientation means that direct sunlight will not be an issue for this site – disabling glare could occur, but only as a result of solar reflection from nearby buildings. The prevailing low natural light levels during the site visit limited the potential for discomfort glare, but there is sufficient visible sky area to lead to bright sky conditions being an issue for workers who choose to face the window (none in the study area, but occupants in other areas of the same office had chosen to face the window). The choice of location for the computer monitors at two workstations means that occupants of those spaces may experience some discomfort glare from the reflection of natural light in the monitor, which may be of some discomfort.

SITE 9 - THE CHICAGO LOOP POST OFFICE, CHICAGO

Figure 91: The Chicago Loop Post Office, Chicago city center

A GENERAL BUILDING DESCRIPTION

The Chicago Loop Post Office is Chicago, Illinois, was built in 1975. The building has a square footprint and comprises around 40,000 square feet on a single floor. The building envelope is a steel frame with very large glazings in a steel frame. The occupied area consists of 8 table surfaces where customers review and complete their transaction paperwork and a manned service desk where transactions are completed with post office staff. The post office is open between 7 am and 5 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to reduce lighting electricity consumption by 30% - this was specifically related to the performance of IDS, and as a test facility for other similar installations in Chicago. A series of studies were completed by an architecture and engineering consultancy looking at how advanced technologies could be leveraged into the Chicago Federal Center, of which The Loop Post Office is a part. Advanced daylight dimming was one of the technologies specified in that study. The concept design developed by the architectural engineers was further developed into a detailed design by a lighting consultants in conjunction with the winning bidder (participation of the lighting consultant in design development was a contract condition).

The retrofit included replacement of 429 fixtures and lamps and installation of photosensors and manually operated venetian blinds, which are installed for approximately the top three-quarters of the windws. The project was completed in March 2012.

C LIGHTING PROJECT MANAGER INTERVIEW- DIGEST

The project was selected on the basis of providing proof of concept for IDS and also the payback indicated by the initial analysis was acceptable. Four companies were involved in the implementation of the project: the first did the design, the second did the installation with input from a lighting design consultancy (on the development of the final lighting design and specification) and the third company, the controls vendor, commissioned their own controls system. There was no wider commissioning process as such. The project manager stated that the main challenge was the fact that it was a design and build project but was developed by several companies: this resulted in multiple design philosophies throughout the design development process and continuity / handover issues between the project participants.

The lighting specification changed from single metal halide lamps in each fixture to 3 36W CFLs. The can fixtures were also replaced. Two ballasts control each fixture: one controls the center lamp, another the two outside lamps, with the center lamp programmed to switch off before the outside lamps dim for daylight. Electric light levels do not change noticeably throughout the day and do not switch off in response to daylight but dim to around 10% light output. The primary lighting controls are time scheduled based on observed occupancy patterns, with the core and counter area tuned to specific light output levels and the perimeter dimming to available daylight. No manual controls are available to occupants although it is a simple process for the lighting manager to control light output via desktop computer software. The default position for the blinds is lowered and closed due to direct and reflected sunlight on bright clear days through the east and west facades.

Since installation it has become clear that there are detailed nuances associated with IDS in locations such as this one – the success of the daylighting system depends on elements outside the building almost as much as those inside – adjacent reflective surfaces have a significant impact on how the IDS is utilized at this site. The installed blinds also act as fins in reflecting light internally, which can be beneficial, but can have negative impacts as well.

Installation: Once the final design was agreed, the installation went ahead fairly smoothly.

Commissioning: A commissioning report was produced – whether a resource will ever be made available to read and interpret it is a different matter. Fortunately the lighting control system interface is easy to access and use.

Training: Face-to-face training with O&M staff is ongoing, and staff will be given the opportunity to feedback on how the system works for them. There have been some complaints about the system with people observing that the perimeter lights are dimmer than those in the core – this highlights a lack of understanding of the system operation and therefore a shortcoming in communications to staff on this issue.

Maintenance: On-site maintenance resources will be provided for the lighting system but it is unlikely the anyone will be contracted to ensure persistence of system operation.

Occupant Satisfaction: Occupants are largely satisfied with their work environment, beyond not understanding the mode of system operation in the perimeter zone. However, they work under the core zone lighting and are consequently less affected by it.

D DESCRIPTION OF PROJECT AREA

The assessed site was the east facing side of the Post Office.

This location has east facing windows with a WWR around 0.95. The large windows are of untreated glass with a base height of around 3 inches and up to full ceiling height of around 25 feet. Manually operated blinds are installed in the top half of the windows, although these can only be operated via use of a ladder as the control wires are out of reach otherwise. The window view is obstructed by tall buildings adjacent and nearby the site. The measured area consists of the counter area and three table top areas where customers complete and check their paperwork prior to completing their transaction at the counter. Each tabletop location is approximately 6 feet from the window at a height of 3.5 feet.

The ceiling installed lighting fixture are recessed cans containing 3 CFLs. There are no manual switches for these lights.

The ceiling is white and the floor tiles are white granite. The furniture consists of dark table tops and a dark colored service counter top. The building core area has a separating wall which is dark brown in color.

Figure 92: floor plan and illumination data

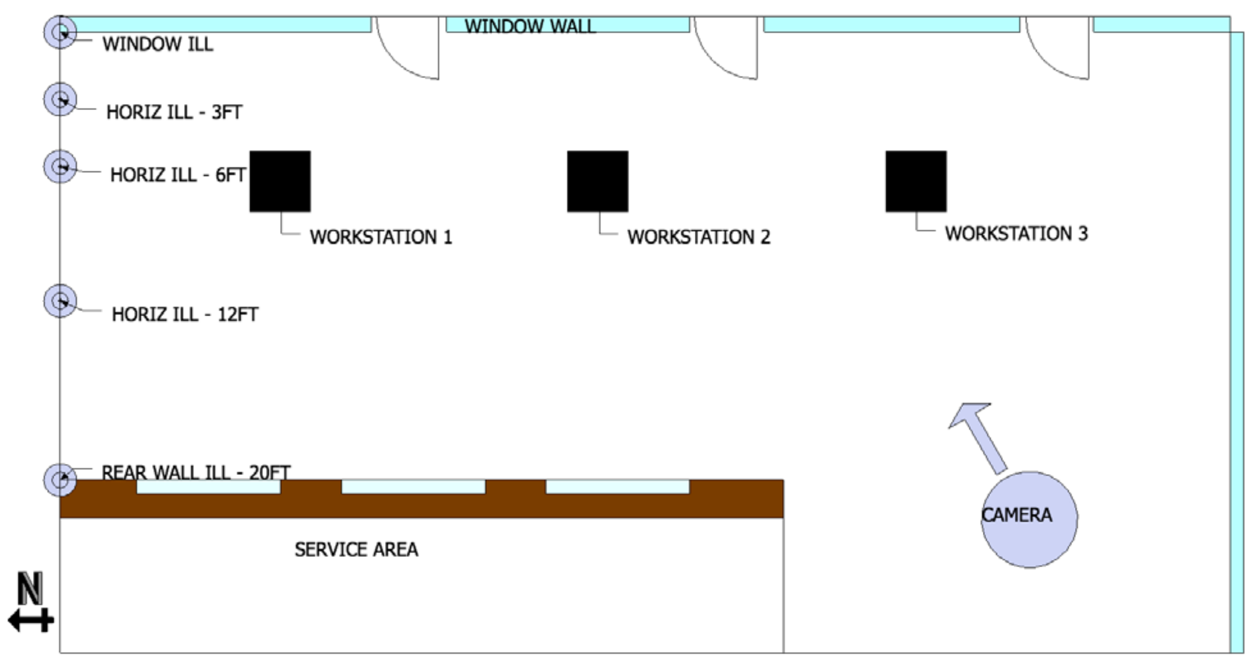


Table 43: The Loop Post Office light measurements

	Daylight Only	Daylight and Overhead Lights
Window – Horiz. Ill	165	198
3 ft. – Horiz. Ill	36.2	130.5
6 ft. – Horiz. Ill	24	20
12 ft. – Horiz. Ill	23.7	21.3

	Daylight Only	Daylight and Overhead Lights
Rear Wall – Horiz. Ill	25.5	24.7
Workstation 1		
Horiz. Ill	16.0	15.9
Workstation 2		
Horiz. Ill	19.5	17.9
Workstation 3		
Horiz. Ill	23.5	20.6

E OBSERVATIONS

The site visit was conducted on a bright, partly cloudy afternoon in May. On arrival the electric lighting was operating, and the perimeter lamps ere dimmed compared to those in the core areas. The blinds were fully deployed and closed. The site assessment was conducted at 3 locations along the perimeter.

F BRIGHTNESS

The prevailing natural light conditions at the time of the site survey support assessment of daylight use.

Light levels at each of the table-top locations achieved the levels that are recommended for areas that are utilized for intermittent administration (IESNA). These light levels would have been increased if the blinds were open.

The reduction of light levels in under the daylight plus electric light condition can be put down to a change in outside conditions – clouds present during the site visit had obscured the sun at that point in time. Adjustment of the venetian blinds would have increased light levels generally in the perimeter area, but the blinds primary purpose is to prevent glare from reflections from the opposite buildings glazing affecting occupants of the core areas, principally the permanent workers.

Figure 93: Wide-angle and brightness images for the post office

G GLARE

As the measured work spaces were only occasionally occupied, no glare assessment was completed at this site.

SITE 10 - DIRKSEN FEDERAL BUILDING AND COURTHOUSE, CHICAGO

Figure 94: Dirksen Federal Building, Chicago city center

A GENERAL BUILDING DESCRIPTION

The Dirksen Building (Fig. 1) in Chicago, Illinois, is a 1960's construction with a rectangular floor plate. The building has 30 main floors with a total floor area of 1.4 million square feet. The building fabric consists of a light mass steel column superstructure, with an assembly of curtain wall panels. The building is composed of open offices and private offices and courtrooms, typically occupied between 9:00AM and 6:00PM.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

This project is reported as being the largest installation of a single integrated lighting control system in a GSA building and therefore provides the opportunity to test large-scale impacts of the control and lighting system. No explicit energy targets were established prior to implementation. The lighting project incorporates occupancy-based zonal control and daylight dimming. The lighting control system was reported to be optimized in design to reduce energy consumption associated with electric lighting.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected to go forward as the largest installation of a lighting control system in a GSA building and a test case for future installations. This provided a good opportunity to test the large-scale impacts of the control system. Three companies were involved in project implementation: the first completed the lighting design, the second completed the installation and the third undertook the commissioning. Another is responsible for system operation.

Daylighting is provided for the perimeter of the building up to a depth of around 15 feet and in the lobby area on the ground floor. The project is expected to reduce energy consumption in the building through optimization of the lighting controls. The optimization method was to lower light levels by 1% per week until a suitable minimum is reached without occupant complaints. Evaluation of the project is done through metering at the building level and calculation of energy savings done by the manufacturers of the control system. The project was due to be completed in October 2012.

Changes in building lighting were minimal throughout the duration of the project retrofit. New 32-Watt T8 lamps replaced old lamps, and though fixtures remained the same, some 2-lamp fixtures were reduced to 1-lamp fixtures, as has happened at this location. Light levels were measured as part of the commissioning process and with lighting controls set to provide desktop illuminance of 50 foot-candles. The system is not designed to shut down in response to daylight because of concerns over the impacts this would have on lamp life.

Primary controls are occupancy-based then dimming to accommodate daylight levels. The dimming controls operate at different ambient light conditions, from sunny to cloudy days. Wall switches allow for manual dimming down to design-minimum illuminance in some locations. Lighting switches-on at 50 foot-candles with a manual switch off. Blinds are provided on every window for manual control of lighting, and are kept up for most workstations; the blinds are lowered for the period leading up to sunset to exclude the direct sunlight. There are reportedly issues of heat gain on the upper floors.

Installation: The electric work has caused some wiring issue that affected the lights and building electrics.

Commissioning: Commissioning reports are being passed over as installation is completed, floor by floor.

Training: All operators and building staff representatives were due to receive face-to-face training on operation and use of the system at the Lutron offices. Training hours are also being provided by Lutron as part of the contract to help operators and user groups.

Maintenance: At the present there is no cleaning protocol for lamps or sensors. The manufacturer of the control system handles maintenance for the system temporarily; there are suggestions that the future arrangement will involve contracting a single organization to operate and maintain the system throughout its lifetime. The organization currently responsible for operation and maintenance of the system may leave the site in October 2013, a year after project completion. Monitoring for the space includes reports run through software, alerts when lamps are out or when devices are not reporting.

Occupant Satisfaction: User complaints about the system were mainly related to understanding how to use the system, such as how to turn on the lights, which led to negative feedback initially. Despite complaints, occupants are said to be comfortable with the system.

D DESCRIPTION OF PROJECT AREA

The project site is located on the 2nd floor measuring 40 feet wide by 18 feet deep with a ceiling height of 9 feet. The site consists of an open office area with three workstations and a private office. The building façade for the assessed site is oriented west with a north facing window in the private office, which is located on the corner of the building. Energy efficiency measures relevant to daylight lighting include a reduction in lamps per fixture, moving from two to one, manually controlled blinds and wall control switches to support active dimming.

The single-glazed, untreated window panels were installed from floor to ceiling with a max height of 8 feet, 9 inches. The resulting Window-to-Wall ratio is between 0.85-0.90. Manual blinds were installed at every window, with their default position dependent on the workstation. The view from the window is obstructed by surrounding buildings with an approximate vertical angle of sky at 30 degrees on the west façade and 85+ degrees on the north side. Whether there is reflected daylight that can cause glare and affect comfort light levels is unconfirmed; occupants present during the survey suggested it wasn't generally an issue due to the westerly façade orientation.

The ceiling and interior walls are white, the floor carpet is medium dark grey. Furniture items in the open workstations are mainly desks, which are medium brown in color, and black chairs. The private office contains three black desks and a brown shelving unit. Partitions in the open office area are 3 feet 7 inches high and have a light brown color. Interior glazing is installed in the dividing walls between the open office and the private office.

The installed lighting consists of 12 ceiling-mounted troffer light fixtures in the open office and 3 in the private office, which provide direct lighting. Each of the fixtures contains a single T8 lamp oriented perpendicular to the west-facing window. Primary lighting control is by zonal occupancy sensor, and is dimmed to daylight levels once occupied. Light switch controls were present to support switching lamps on and off by occupants – this switch controls luminaires in the whole zone. It was not confirmed whether lights were switched off on bright days. Individual task/workstation lighting was not provided.

Of the three work locations, workstation 1 is a flexible workspace and was vacant and without a computer during the survey. For the purposes of the site assessment, it was assumed that the computer would be located in the middle of the work surface facing the window. The computer monitors at workstations 2 and 3 are almost perpendicular to the west-facing window wall. The computer monitor in the private office is oriented perpendicular to the west-facing window wall.

The work surface / desk tops in the open office space are a red-brown color, while in the private office the desktops are black. The walls and ceiling were white, although much of the wall is occupied by cabinets and shelves. In the open office, the partitions were a light brown color and the carpet was also light grey.

Figure 95: Dirksen Federal Building open office floor plan

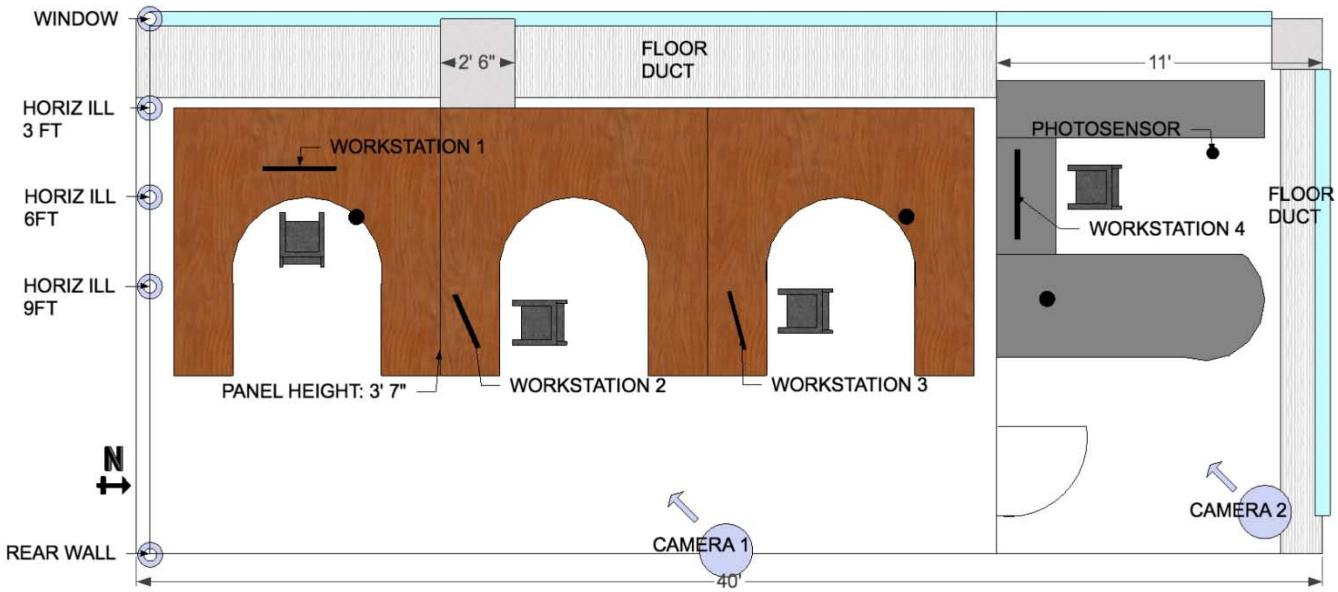


Table 44: Dirksen Federal Building lighting measurements

	Daylight and Blinds Open	Daylight, Blinds Closed, and Overhead Lights
Window – Horiz. Ill	86	122
3 ft. – Horiz. Ill	51.3	71.7
6 ft. – Horiz. Ill	18.7	48.1
9 ft. – Horiz. Ill	2.57	39.2
Rear Wall – Horiz. Ill	1.49	16.8
Rear Wall – Vert. Ill	2.3	11.1
Workstation 1		
Horiz. Ill	25.1	43.3
Vert. Ill	2.53	14.7
Vert. lum (gray card)	1.27	8.3
Workstation 2		
Horiz. Ill	10.5	41.5
Vert. Ill	7.35	19.2

	Daylight and Blinds Open	Daylight, Blinds Closed, and Overhead Lights
Vert. lum (gray card)	4.66	12.66
Workstation 3		
Horiz. Ill	24.3	43.3
Vert. Ill	4.57	18.6
Vert. lum (gray card)	6.63	15.1
Workstation 4		
Horiz. Ill	8.68	27.2
Vert. Ill	7.86	16.1
Vert. lum (gray card)	5.48	10.57

Figure 96: Dirksen Federal Building Lighting Measurements

E OBSERVATIONS

The site visit was conducted on a cloudy afternoon in early May. On arrival, the electric lighting was on, lamps were on and dimmed and blinds were open. The lighting appeared to operating as designed, dimming according to daylight levels.

Due to difficulty accessing the blinds controls and disruption that this would have caused workers, the effects of lowering the blinds on internal light levels was not investigated.

There was an indication of difference in thermal comfort conditions by location; one open office workstation has a small fan off to the side, while a heater was located below the desk at the private office.

1. DAYLIGHT ONLY

For daylight only lighting condition (lights off), horizontal illuminance readings ranged from 86 foot-candles (fc) at the window to 1.49 fc at the back wall, at around 18 feet from the window. At the open office workstation locations, the horizontal illuminances were between 25 and 10.5 fc, with vertical illuminance was between 7.4 to 2.5 fc. The private office has lower light levels compared to the three open workstations despite the fact that it has two large windows. Horizontal illuminance was 8.7 fc, vertical illuminance was 7.9 fc.

2. DAYLIGHT AND OVERHEAD LIGHTS

With the electric lights on, the illuminance ranged from 122 fc at the window to 16.6 fc at the wall. At the open office workstations, the horizontal illuminances were between 43 and 41 fc. The vertical illuminances were between 19 fc and 14.7 fc. The private office has much lower light levels: horizontal illuminance of the workstations was 27 fc and vertical illuminance was 16 fc.

F BRIGHTNESS

Light levels measured at the site for the daylight only lighting condition, both at the open offices and the private office, were significantly below the minimum illuminance levels required to support visual comfort – defined as 30 foot-candles by IESNA, and the GSA P100. It is likely that this was due largely to the local weather at the time of survey. Workers required operation of the electric lights in order to achieve a comfortable level around 40 footcandles. The private office has very low light levels even with the electric lights turned on, although this may be at the request of the occupant.

The relatively low daylight incidence at the workstations can be partly attributed to the partitions installed parallel to the windows, and that form a barrier between them and the work locations. These block a significant amount of the available daylight, and offset the benefits of the high window-to-wall ratio. This impact could be reduced if partitions were removed. Normally moving desks closer to the façade would also be an option, but the presence of perimeter reheat ducts prevents this. The partitions restrict access to the blind controls – this is likely to discourage appropriate / frequent use. The piles of paper and folders on desk surfaces are also obstructions to light at working level.

Figure 97: Wide-angle and false color images for open office

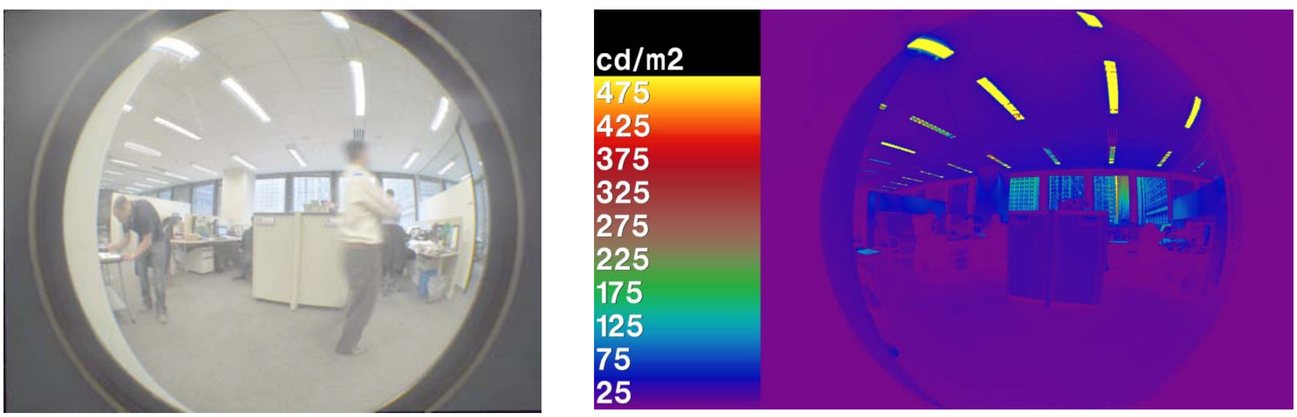
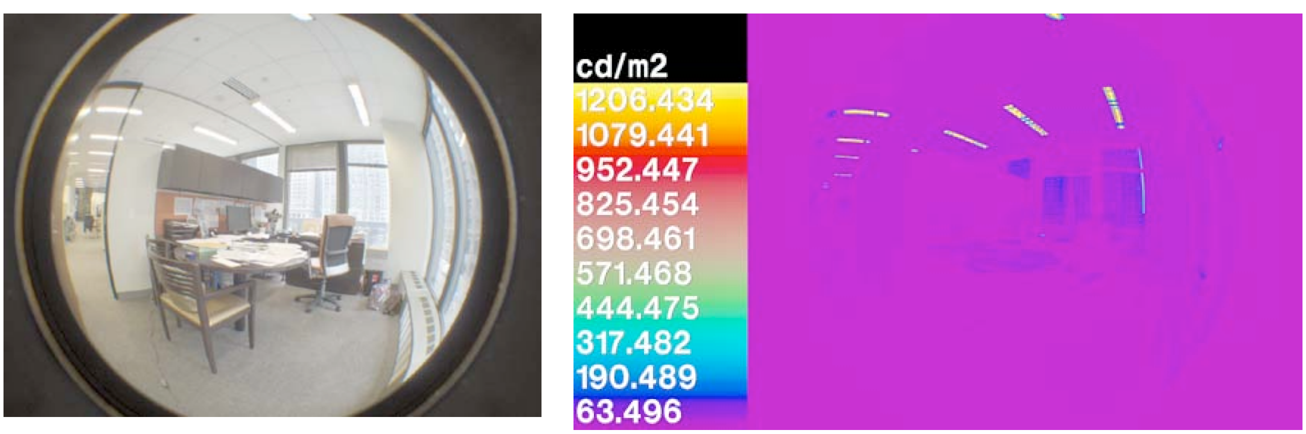


Figure 98: Wide-angle and false color images for private office



GLARE

The false-color images indicate minimal glare from the windows and workstation surfaces in the open office area (Fig. 3) and there is minimal glare and low light levels in the private office (Fig. 4) – this is due mainly to the gloomy prevailing conditions experienced during the site visit. In brighter ambient conditions, there is the possibility for discomfort glare in the afternoon, when direct sun is incident on the façade. Due to the surrounding high buildings, it is unlikely that disabling glare would occur in this location, other than in the winter, when the low afternoon sun could have an impact. In such cases, the frequent use of the blinds and access to the blind controls would be important.

SITE 11 - HAMMOND COURTHOUSE, HAMMOND

Figure 99: Hammond Courthouse

A GENERAL BUILDING DESCRIPTION

The Hammond Courthouse (Figure 99) in Indiana was built in 2002. The building has a square footprint and has a total floor area of 269,000 square feet over 3 main floors. The building envelope is a concrete and steel superstructure clad in limestone and glass. The working area consists of open office cubicles, private offices and courthouse spaces and is usually occupied between 7 am to 5 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project objectives were to leverage IDS and to save lighting system energy. There were no explicit energy savings targets: only that lighting energy should be reduced as far as possible, with a report completed by technical consultants identifying the opportunities for daylighting.

The daylighting retrofit consists of photosensors and manually operated blinds (which predated the lighting system retrofit). The integrated lighting system was installed for the southern part of the building – it is anticipated that a similar system will be implemented in the northern section once funding is available.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was chosen to go forward to take advantage of the building structure with the glass walls, also maximize energy savings. The main infrastructure of the lighting system was already installed, so it was a case of building on this. Two companies were involved in project implementation: the first completed the design, and the second completed the installation with assistance from the system vendors and the commissioning was completed by the installers and by GSA themselves. A separate operation and maintenance contract will be let. It was noted that the GSA Contracts Officer for this project had been an invaluable resource, holding project delivery team to the stated requirements.

According to the property manager, there were challenges during every step of the project development process. The main issues related to coordinating with the various tenants, monitoring the system, identifying operation in variance with intent and troubleshooting and also compensating for lack of flexibility by ensuring regular and frequent communications with tenants and occupants.

The lighting specifications remained the same, with initial target light levels set at 50 foot-candles at the work plane, with high-end tuning taking place over time. Electric light levels change noticeably during the day but overall light levels do not change and are controlled to a minimum output level in bright conditions – lights do not switch off in response to bright daylight. Some manual controls are available in private office spaces, although the majority of lighting is under occupancy-based control. Task lights are also provided to occupants when requested. All windows in the day lit zone have roller shades installed, the majority of which are manually operated, but some of which are electric. The default position for blinds is closed. No energy saving measurements specific to daylighting have been taken since the system was installed.

Installation: The project consists of photosensors based on the daylight availability. Auto controls to daylight levels were installed. A time clock enables lights, occupancy sensors activate lights and light levels are controlled by daylight. Occupants can manually switch on the lights, but occupancy sensors have the light levels at minimum. Manual and electric blinds already exist in the building but are always closed.

Light levels stayed the same, but lamps dim to daylight. Lamps switch to lowest limit, but do not turn off. Eco ballasts were installed, one per lamp. The light levels are set at 50 fc with ongoing modification. If there are issues with workstation light levels, occupants can contact the property management. Task lights are provided to occupants.

Commissioning: Commissioning reports were passed to GSA on completion as directed by the Contract Officer.

Training: Staff members were given face-to-face training and shadowed the design team. The O&M contractor will be encouraged to take a class about lighting control system. Deeper maintenance of the system was not part of the current O&M contract.

Maintenance: There is currently an on-site team who take care of the operation and maintenance of the system, but this situation is likely to change in the near future when a new contact is let – this will include requirements to undertake deeper maintenance of the lighting systems.

Occupant Satisfaction: Overall, tenants are comfortable with their new lighting system.

D DESCRIPTION OF PROJECT AREA

The assessed site was the Clerk of the Court private office.

This private, ground floor office has one east facing and two south facing punched windows at a height of 3 feet rising to a height of 7.75 feet, with a WWR of around 0.3. The windows are double glazed with a slight tint. Manually operated roller shades are installed in each of the windows. The view from the window is unobstructed. This office is broadly representative of the numerous other private offices in the building.

The lighting consists of 6 recessed 2x2 troffers holding two T32 lamps each. All 6 fixtures are controlled by a single photosensor, which is positioned to allow monitoring of light from east and south windows. Task lighting is present, although the occupant stated that it had not been used since their taking occupancy.

The ceiling and interior walls are white. The floor carpet is medium grey in color. The office furniture is predominantly of heavy, dark wood – the desk, sideboard and cabinets – with wooden upholstered chairs.

Figure 100: Courthouse private office floor plan

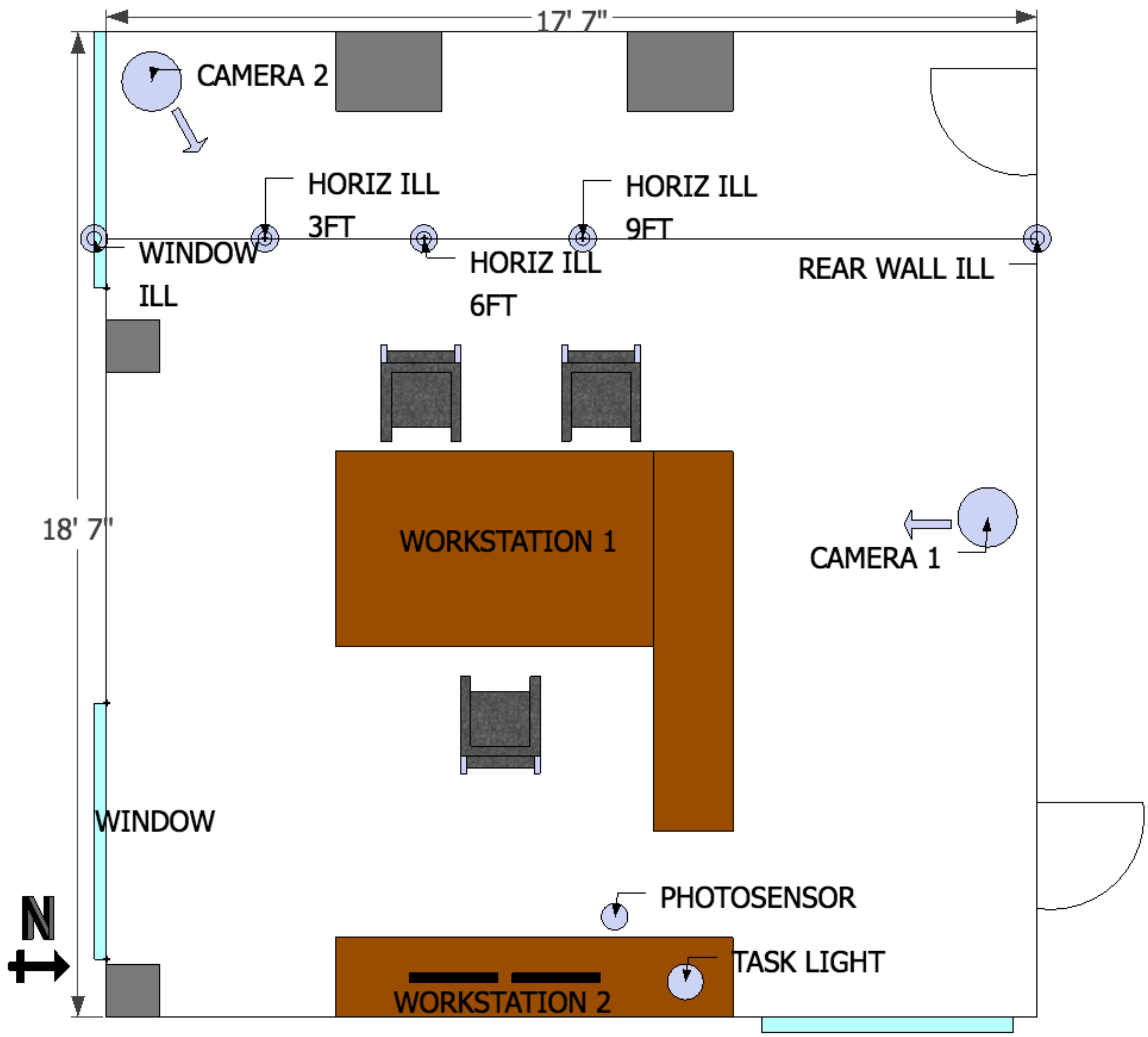


Figure 101: Hammond Courthouse lighting measurements

	Daylight Only	Daylight, Blinds Closed, and Overhead Lights	Daylight and Blinds
Window – Horiz. Ill	696	63.8	212
3 ft. – Horiz. Ill	315	57.9	58.5
6 ft. – Horiz. Ill	138	52.0	20.9
9 ft. – Horiz. Ill	67.2	48.4	6.89
Rear Wall – Horiz. Ill	93.5	38.1	11.1
Rear Wall – Vert. Ill	116	34.0	16.6
Workstation 1			
Horiz. Ill	116	54.3	17.5
Vert. Ill	54.2	16.9	6.31
Vert. lum (gray card)	21.12	10.83	3.41
Workstation 2			
Horiz. Ill	94.6	42.3	9.38
Vert. Ill	70.8	22.4	9.5
Vert. lum (gray card)	45.60	13.02	3.76

E OBSERVATIONS

The site visit was conducted in the morning during a partly cloudy day in May. The lights were on and the blinds were deployed. Two main work areas were identified, the first is the desk in the middle of the room used for paperwork and the second is the computer workstation behind the main desk.

F DAYLIGHT

The horizontal illuminance at the window was 696 fc. Inside the space the horizontal illuminance is between 315 fc to 93.5 fc at the rear wall. The rear vertical illuminance was 116 fc. Workstation horizontal illuminance were 116 fc at workstation 1 and 94.6 fc at workstation 2. Vertical illuminance were 54.2 fc at workstation 1 and 70.8 fc at workstation 2.

G DAYLIGHT, OVERHEAD LIGHTS, BLINDS CLOSED

The horizontal illuminance at the window was 63.8 fc. Inside the space the horizontal illuminance is between 57.9 fc to 38.1 fc at the rear wall. The rear vertical illuminance was 34 fc. Workstation horizontal illuminance were 54.3 fc at workstation 1 and 42.3 fc at workstation 2. Vertical illuminance were 16.9 fc at workstation 1 and 22.4 fc at workstation 2.

H DAYLIGHT AND BLINDS CLOSED

The horizontal illuminance at the window was 212 fc. Inside the space the horizontal illuminance is between 58.5 fc to 6.89 fc, 9 feet from the window. The rear wall horizontal illuminance was 11.1 fc; vertical illuminance was 16.6 fc. Workstation horizontal illuminance was 17.5 fc at workstation 1 and 9.38 fc at workstation 2. Vertical illuminance were 6.31 fc at workstation 1 and 9.5 fc at workstation 2.

I BRIGHTNESS

With the roller shades open, the natural light only condition created very bright conditions – around double the minimum illuminance levels required to support visual comfort. With the electric lighting and blinds closed, the light levels were in line with the same recommendations. When the blinds are closed, although the roller blinds allow a significant amount of natural light to pass through them, it is not sufficient to support comfortable working lighting.

Figure 102: Wide-angle and false color images with electric lighting and blinds closed

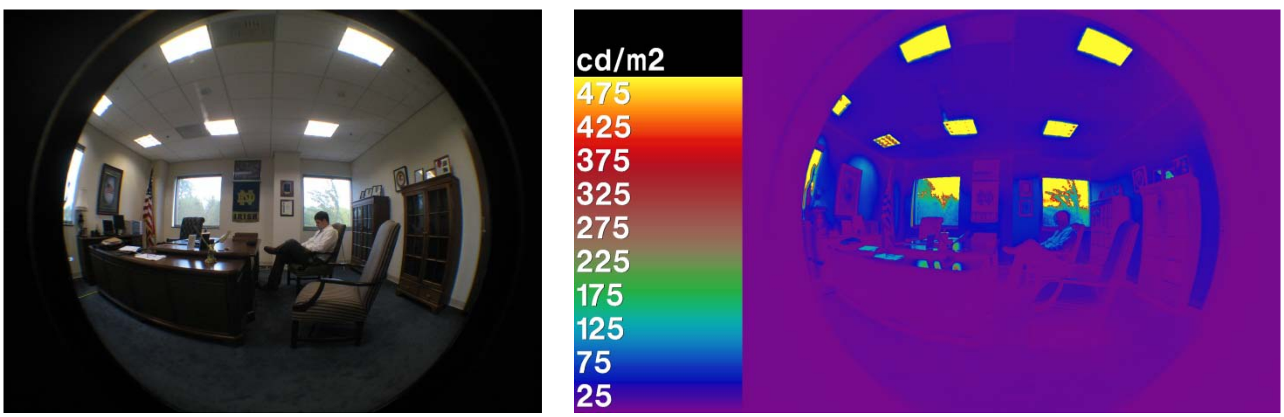
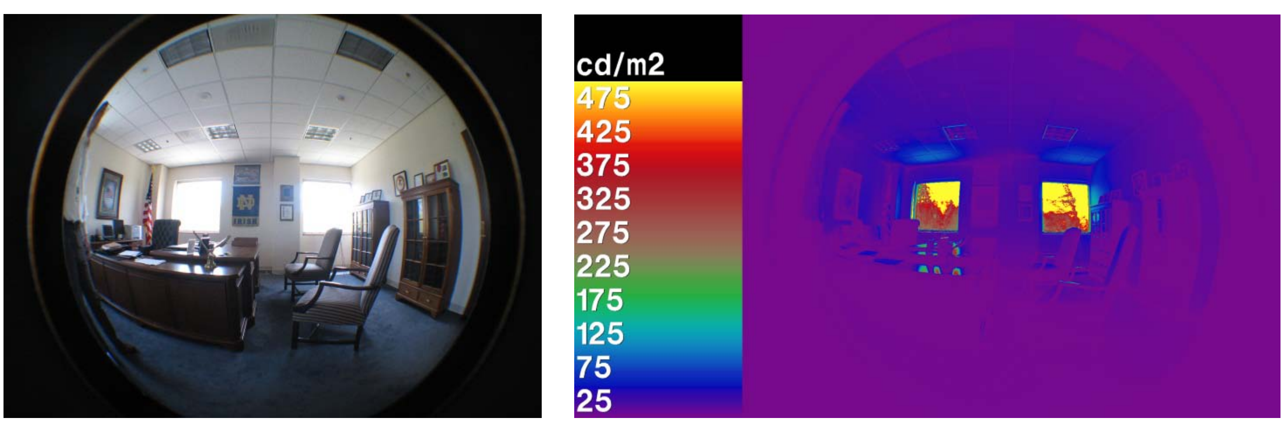


Figure 103: Wide-angle and false color images for daylighting only



J GLARE

The façade orientations mean that direct sunlight is an issue for this site throughout the day and possibly increasingly so in the fall and winter months due to the low sun angle – disabling glare could occur at this site. It is clear to see from the false color images that the glare and brightness for the electric lighting condition and the daylighting condition are similar, although this could be related to the changing natural light conditions during the site visit. The location of the computer monitor and the occupant position at the desk workspace oriented perpendicularly to the window means that the occupant is very unlikely to experience any glare-related discomfort.

SITE 12 – DEPARTMENT OF COMMERCE

Figure 104: US Department of Commerce

Source: glassdoor.com

A GENERAL BUILDING DESCRIPTION

The US Department of Commerce Building (Figure 104) in Washington D.C. was completed in 1931. The building has a rectangular footprint and comprises around 1.2 million square feet over 5 main floors. The building envelope is a steel frame-based structure, clad with limestone. The working areas consist largely of private offices which are operate during conventional daytime hours, usually occupied between 7am and 6pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The building is undergoing a total refurbishment. The project objectives are achievement of the LEED Gold Certification, of which the integrated lighting systems, including IDS, are an important contributor. The project has no specified energy saving targets, and it is understood that no detailed energy analysis was completed to quantify potential lighting energy savings.

The retrofit for the assessed site include installation of occupancy-based lighting control and daylight dimming and also include addition of in-glazing venetian blinds that are installed between the external glass and the secondary blast windows. The same systems are planned for roll-out across the entire building perimeter as the retrofit phases continue (there are 8 phases in total). The project is due for completion in 2021.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines, as part of a whole building system upgrade. Four companies were involved in the projects: the first company did the lighting design, the second installed the fixtures, the third completed the shop design and controls programming, and a fourth responsible for commissioning. The building manager has not received the commissioning report at the time of the interview. According to the building manager, project implementation had its problems related to the age and size of the building, the occupants and the commissioning process. The previous building lighting system was based on manual controls hence the whole system had to be replaced to accommodate the new controls. With regards to the building volume, the retrofits had to be applied in small sections of the building to not disturb a large number of occupants. The occupants and maintenance staff needed time to adjust to the new system.

The lighting specification changed as 32W T8 lamps were replaced with 28W T5 lamps. The target light levels are 40 lumens per square feet, which was based off energy savings and light harvesting. Occupants of the space can specify their desired light levels. Only the light fixtures closest to the window dim to daylight levels. Electric light levels did not change noticeably during the day and did not shut off with response to daylight, the lights dim to a minimum of 25% light output. The lighting controls were occupant activated primary control then dim to daylight levels. Manual lighting controls are available to the occupants. Tasklights were not provided to occupants. Manually operated blinds were installed in between glazings and the default position is open.

Installation: Retrofits had to be done in small sections of the building because of its large volume and the number of occupants. Occupants, in spaces where retrofits were taking place, had to be moved to temporary spaces for more than a year. The building staff was not satisfied with the commissioning process and documentation.

Commissioning: System operating manuals will be left to after commissioning.

Training: Face-to-face training was done with the electrical shop and the office staff. This was mainly an orientation for the staff to be acquainted with the system. The building manager preferred a more detailed training session.

Maintenance: The in-house staff keeps track of failures and issues with sensors while the maintenance is done by an external company. Deeper maintenance of the system would be a project for the in-house staff.

Occupant Satisfaction: Occupants are still getting used to the new system, but are generally satisfied.

D DESCRIPTION OF PROJECT AREA

The project site was a private office at a corner of 4th floor.

The office had two punched windows, one south-facing and one east-facing. The interior WWR was about 0.30. The windows had a base height of 3.2 feet and an area of 6.7 feet by 7.4 feet with 9 inch mullions. The windows were untreated double-glazed with manual shading in between the glazing. The view from the window was unobstructed. The project area had an area of 22.2 feet by 24.8 feet. The main workstation was located on the south-east corner of the room.

The lighting fixtures were recessed troffers with (one or two) lamps each. The fixtures were oriented perpendicular to the southern window. The lamps are 28W T5's. Tasklights and work specific lights were not made available to the employees. There was a manual switch for the lights.

The wall and ceilings were white. The floor carpet was dark green. The office furniture consists of dark wood desks, office chairs, file cabinet, bookshelf, and a flat screen wall-mounted screen.

Figure 105: Department of Commerce private office floor plan

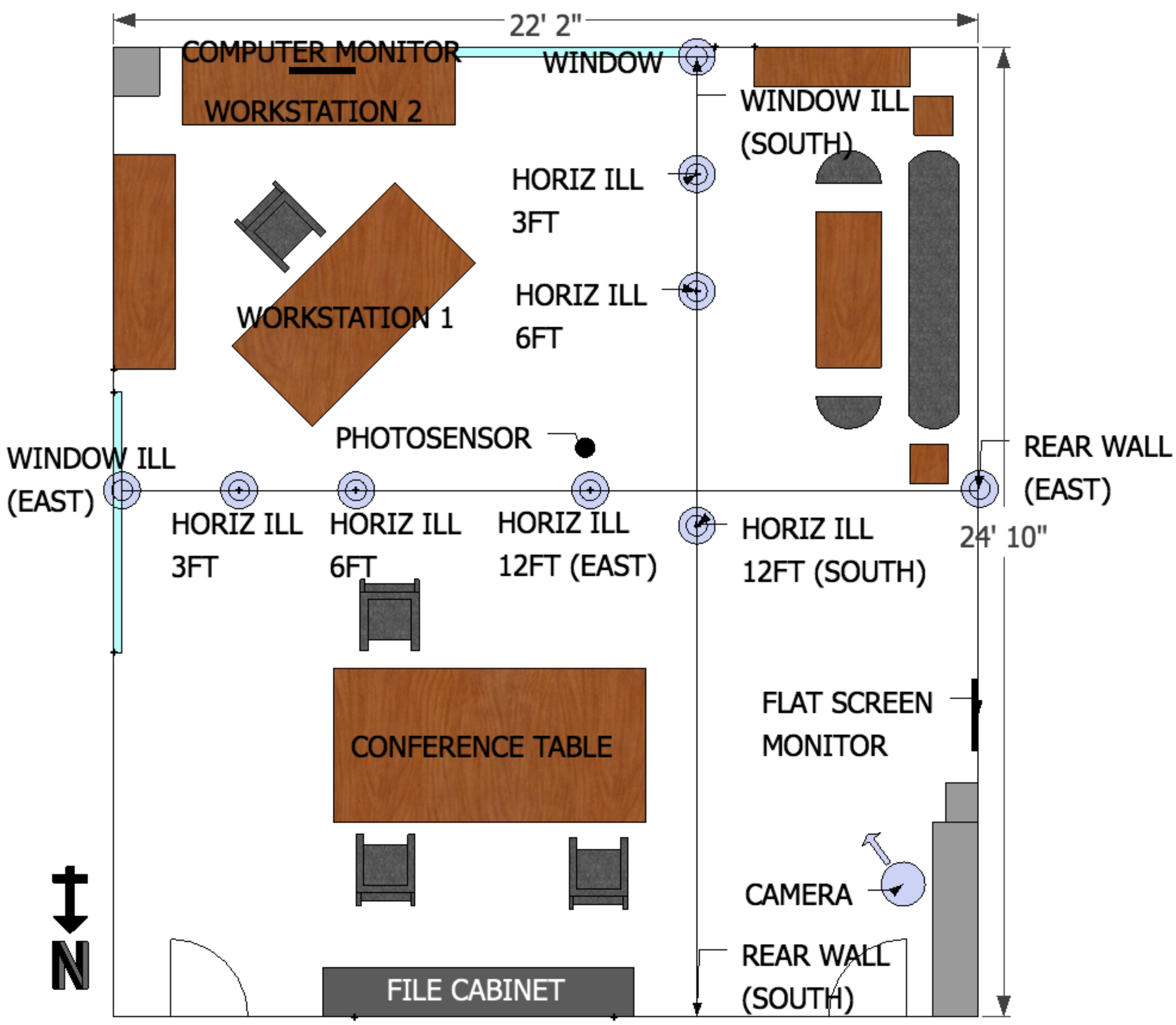


Table 45: Department of Commerce lighting measurements

	Daylight with Blinds Closed	Daylight and Electric Lights, with Blinds Closed	Daylight Only
East Window			
Window – Horiz. Ill	419.9	66.9	743.2
3 ft. – Horiz. Ill	176.1	62.3	196.2
6 ft. – Horiz. Ill	107.7	88.7	134.4
12 ft. – Horiz. Ill	64.5	92.9	113.2
Rear Wall – Horiz. Ill	88.7	68.5	137.2
Rear Wall – Vert. Ill	106.5	47.8	118.0
South Window			
Window – Horiz. Ill	1071.2	101.2	1161.3
3 ft. – Horiz. Ill	239.9	87.7	254.4
6 ft. – Horiz. Ill	141.1	95.9	178.1
12 ft. – Horiz. Ill	72.3	95.5	127.6
Rear Wall – Horiz. Ill	39.3	39.9	57.1
Rear Wall – Vert. Ill	91.7	40.8	96.0
Workstation 1			
Horiz. Ill	101.1	78.7	125.0
Vert. Ill	67.1	32.9	75.1
Vert. lum (gray card)	38.56	28.13	43.73
Workstation 2			
Horiz. Ill	90.2	48.9	100.1
Vert. Ill	73.4	39.0	86.2

	Daylight with Blinds Closed	Daylight and Electric Lights, with Blinds Closed	Daylight Only
Vert. lum (gray card)	39.51	20.16	68.55

E OBSERVATIONS

The site visit was conducted on a sunny morning in January. On arrival, the electric lighting was switched on, lamps were dimmed, and the blinds are down and at 0 degrees. The lighting appeared to be operating as designed, dimming according to daylight levels. The site assessment was conducted at two workstations.

1. DAYLIGHT WITH BLINDS AT 0^O

The east-window horizontal illuminance was 419.9 fc. The horizontal illuminance was between 176.1 fc (3 ft. from the window) and 64.5 fc (12 feet from the window), 88.7 fc at the rear wall. The vertical illuminance at the rear wall is 106.5 fc.

The south-window horizontal illuminance was 1161.3 fc. The horizontal illuminance was between 254.4 fc (3 ft. from the window) and 57.1 fc at the rear wall. The vertical illuminance at the rear wall is 96 fc.

The workstation at the south-east corner had a horizontal illuminance of 101.1 fc and vertical illuminance of 67.1 fc. The computer workstation has a horizontal illuminance of 90.2 fc and vertical illuminance 73.4 fc.

2. DAYLIGHT AND ELECTRIC LIGHTS, WITH BLINDS CLOSED

The east-window horizontal illuminance was 66.9 fc. The horizontal illuminance was between 92.9 fc (12 ft. from the window) and 62.3 fc (3 feet from the window), 68.5 fc at the rear wall. The vertical illuminance at the rear wall is 47.8 fc.

The south-window horizontal illuminance was 101.2 fc. The horizontal illuminance was between 95.9 fc (3 ft. from the window) and 39.9 fc at the rear wall. The vertical illuminance at the rear wall is 40.8 fc.

The workstation at the south-east corner had a horizontal illuminance of 78.7 fc and vertical illuminance of 32.9 fc. The computer workstation has a horizontal illuminance of 48.9 fc and vertical illuminance 39 fc.

3. DAYLIGHT ONLY

The east-window horizontal illuminance was 743.2 fc. The horizontal illuminance was between 196.2 fc (3 ft. from the window) and 113.2 fc (12 feet from the window), 137.2 fc at the rear wall. The vertical illuminance at the rear wall is 118.0 fc.

The south-window horizontal illuminance was 1071.2 fc. The horizontal illuminance was between 239.9 (3 ft. from the window) and 39.3 fc at the rear wall. The vertical illuminance at the rear wall is 91.7 fc.

The workstation at the south-east corner had a horizontal illuminance of 125 fc and vertical illuminance of 75.1 fc. The computer workstation has a horizontal illuminance of 100.1 fc and vertical illuminance 86.2 fc.

F **BRIGHTNESS**

Prevailing natural light conditions at the time of the site survey are useful in supporting analysis of daylight use.

Light levels measured without electric lighting were above the minimum illuminance levels required to support visual comfort. Regardless of the orientation of the blinds there was sufficient illumination in the space to justify not using electric lights.

Figure 106: Wide-angle and false color images with electric lighting

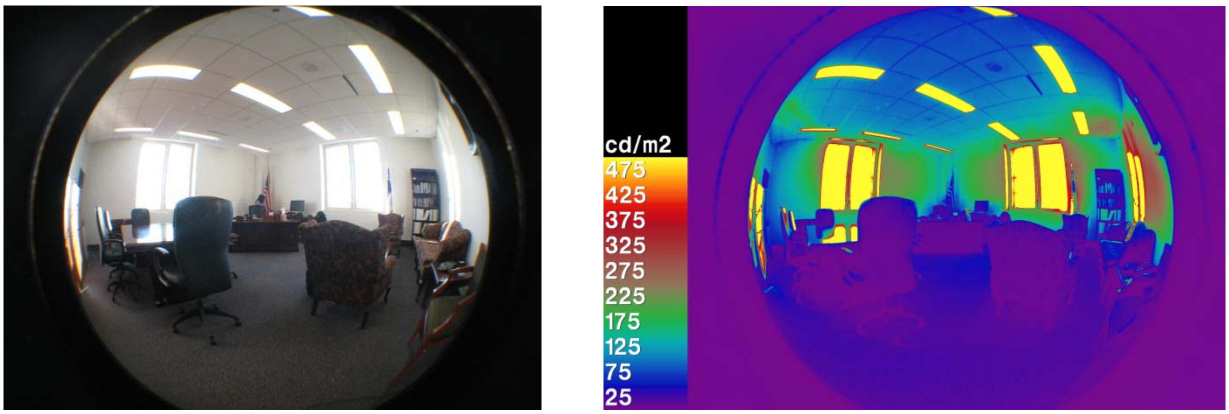
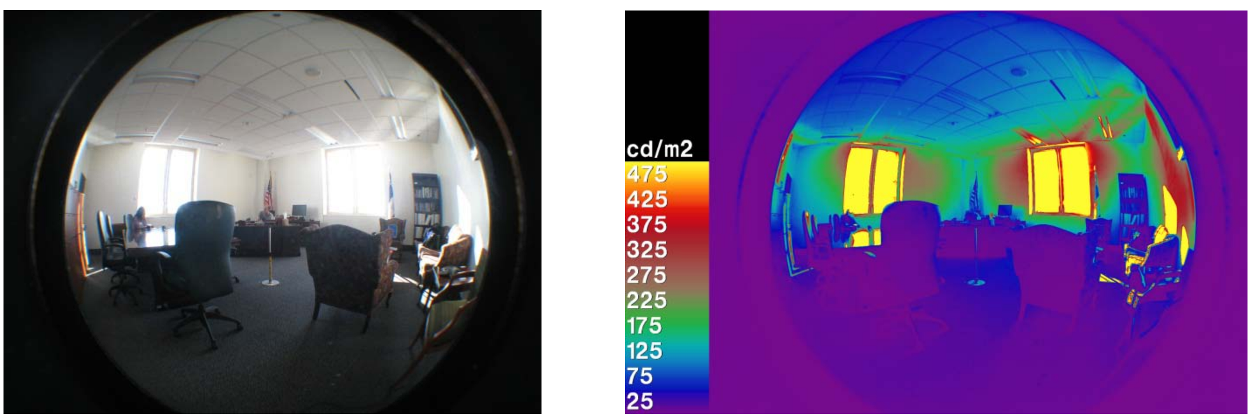


Figure 107: Wide-angle and false color images for private office



G **GLARE**

The façade orientations to the east and south results in a significant amount of direct sunlight throughout the day on clear, bright days, as shown in the false color image – disabling glare could occur. A large building to the east obstructs early morning sun, but from late morning and throughout the day there are no external obstructions to direct sunlight. The workplace locations within the office have been carefully selected to reduce the impact of discomfort glare – the computer work place is astutely positioned to the occupant neither has a window in their field of view, nor sees its reflection in the computer screen – difficult to achieve in an office with windows on two sides. Glare can be reduced or eliminated by closing the blinds.

SITE 13 – DEPARTMENT OF THE INTERIOR

Figure 108: US Department of the Interior

Source: examiner.com

A GENERAL BUILDING DESCRIPTION

The US Department of Interior Building (Figure 108) in Washington D.C. was completed in 1936. The building has a rectangular footprint with an area of 200,000 square feet over 7 stories with a basement. The building envelope is a steel frame-based structure covered in limestone. The daylit area is the eating area of the cafeteria. The building is occupied between 7 am and 6 pm.

B GSA OBJECTIVES OF DAYLIGHTING RETROFIT

The lighting project was part of an overall cafeteria renovation. The objective for the retrofit is to contribute towards achieving LEED Platinum Certification, of which an integrated lighting system with daylight dimming is a part. There were no specified lighting energy saving targets and no detailed lighting energy analysis was completed prior to commencement of the project.

The retrofit for the assessed site included installation of new fluorescent pendant lights, occupancy-based sensors, and daylight harvesting sensors. The project was completed in 2011.

C LIGHTING PROJECT MANAGER INTERVIEW

The project was selected on the basis of meeting ARRA guidelines, as part of a whole building system upgrade. Four companies where involved in the project: one company completed lighting design, two companies completed the installation, and fourth performed the commissioning. GSA has in their possession the commissioning reports and operation manuals. According to the building manager, the main issue during project implementation was the location and performance of the photosensors. The only source for daylight in the space is the skylight. The photosensors were installed oriented towards the open sky instead of being wall or ceiling-mounted and reading light levels that exist from a combination of natural light and electric light. This impacts the performance of the system in that lights often do not switch off as they are expected to (this scenario was proved during the site visit – bright daylight conditions with all the electric lights operating).

The lighting specification involved replacement of old lamps with 28W T5. Target light levels were 30 foot-candles at the work plane according to IESNA design guidance. Electric light levels were observed to change noticeably during the day and are programmed to switch off in response to daylight. The lighting controls were timer-based primary control, which reflected observed building occupancy, then dimming to daylight levels; outside of the operation hours the lighting controls were occupancy-based. No manual lighting controls were available to occupants. To supplement the overhead electric lights, there were halogen lights in the ceiling and wall-mounted ambient lighting on each pillar. The lighting system is monitored by an LMCS system, but the building manager expressed that the software was not user-friendly.

Installation: Additional photosensors were installed for better coverage of a large space – there are three lighting zones. The lighting design had to accommodate use of the space at night within the final design, hence the three different control systems and supplementary lighting types.

Commissioning: Close-out documents were turned in by the commissioning agent.

Training: The building engineering staff was trained in the operation and maintenance of the system, but not GSA staff. There was no mention of training for the occupants.

Maintenance: Trained building staff will be responsible for the daily operation and maintenance of the system and will check in with GSA. Deeper maintenance of the system will be dependent on the building engineers.

Occupant Satisfaction: The occupants were satisfied with their new lighting system.

D DESCRIPTION OF PROJECT AREA

The project site was a cafeteria located in the basement of a 7-storey building.

The only source of daylight is the skylight which covers the entire ceiling of the space with a WWR of around 0.40. The skylight is untreated double-glazing. The ceiling height in the middle of the space is 16 feet and the 13 feet at the lowest point of the ceiling. There is no shading installed. The view of the sky is unobstructed. The project area is 5,000 square feet and has areas for dining (tables and chairs) and relaxation (couches).

The lighting fixtures are pendants containing either one or two lamps each. There are eight rows of 16 fixtures going from north-to-south. The lamps are 28-watt T5's that provide direct lighting to the eating area. There are four 2-lamp halogen directional lights on one-side of 6 ceiling beams and the middle beam has halogen lights on both sides. Wall scones are located on each post providing general supplementary ambient lighting. There were no manual switches for any of the lights.

The ceiling and interior walls are yellow/white. The floor carpet is dark grey in color. The chairs are aluminum and the table-tops are light-colored wood.

Figure 109: Department of the Interior cafeteria floor plan

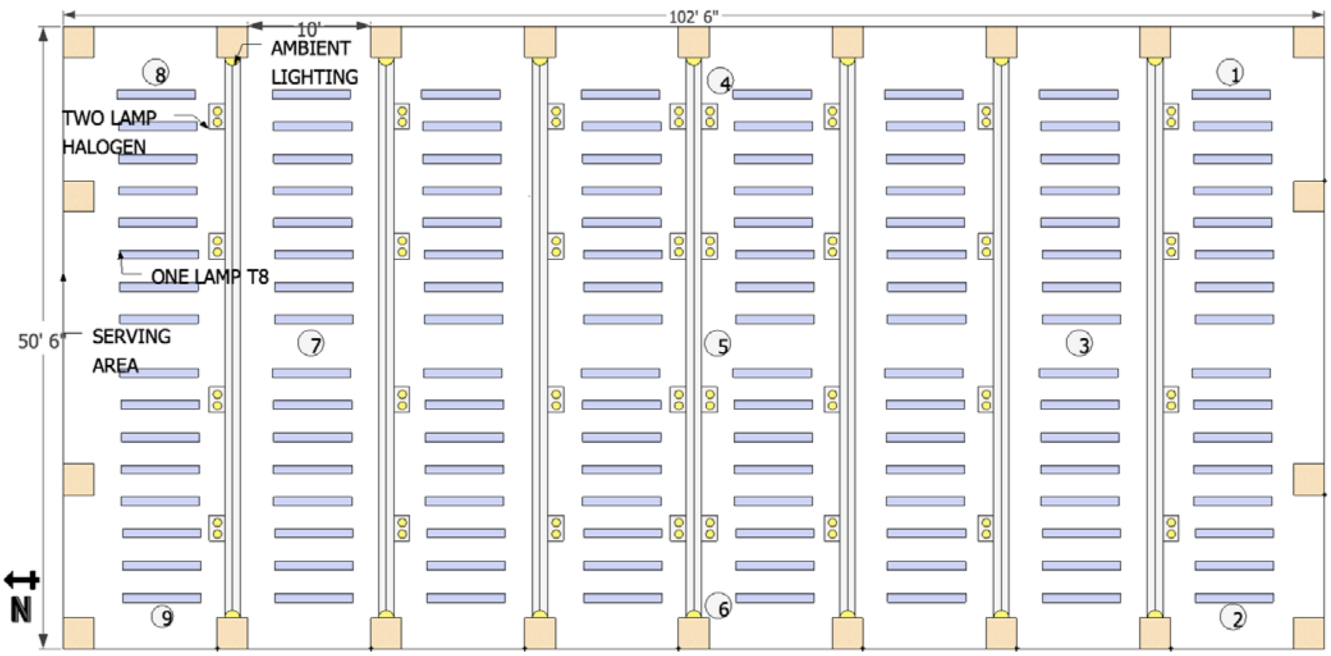


Table 46: Department of Interior cafeteria lighting measurements

Horizontal Illumination	Daylight Only	Daylight and Overhead Lights
1: North-East Corner	6.73	19.16
2: South-East Corner	9.08	23.08
3: Mid-East	8.94	35.12
4: Mid-North	8.96	26.39
5: Center	12.84	42.46
6: Mid-South	12.55	31.31
7: Midwest	12.54	31.03

Horizontal Illumination	Daylight Only	Daylight and Overhead Lights
8: North-West Corner	5.91	13.76
9: South-West Corner	11.79	19.26

E OBSERVATIONS

The site visit was conducted on a sunny afternoon in January. The electric lighting was on upon arrival; some of the fixtures were off. The lighting appeared to operating as designed, dimming according to daylight levels. The site assessment was conducted at 8 locations in the space to provide an idea of light levels in the space.

1. DAYLIGHT ONLY

The horizontal illuminance ranges from 63 foot candles at the north-west corner of the room to 138 foot candles at the center of the room.

2. DAYLIGHT AND OVERHEAD LIGHTS

The horizontal illuminance ranges from 148.1 foot candles at the north-west corner of the room to 457 foot candles at the center of the room.

F BRIGHTNESS

Prevailing natural light conditions at the time of the site survey are useful in supporting analysis of daylight use.

The light levels without the electric lights were above the acceptable minimum recommended by IESNA. Illuminance is higher in the south-west side of the room. The electric lights increase the light levels in the center of the room to acceptable levels. It also evens out the illumination of the space, the middle of the space being the brightest.

Figure 110: Photo of open cafeteria area and of skylight with suspended light fixtures

G GLARE

As this cafeteria is not occupied permanently, no glare analysis has been undertaken.

B. RESULTS - SINGLE-DAY SITE ASSESSMENTS

This part of the study sought to determine how each of the visited sites utilized daylight and to identify the factors that influenced this. This assessment necessitated three types of analysis – physical characterization of the occupied space, measurement of light levels and structured discussions with the building manager, lighting project manager or equivalent.

Figure 111: Study areas and site reference details

Site	Site Reference	Location	Approximate floor area (ft^2)	Description of monitored work spaces
Philip Burton FB, GSA Office, 2nd floor, North façade	PB2N	San Francisco, CA	130	Private office
Robert Matsui CH, IT Offices, 5th floor, North facades	RM5N	Sacramento, CA	230	Private office
Cottage Way FB, GSA Directors Office, West building, 1st floor, East facade	CW1E	Sacramento, CA	140	Private office
Ronald Dellums FB, Peace Corps, N tower, 6th floor, West facade	RD6W	Oakland, CA	230	Private office

Site	Site Reference	Location	Approximate floor area (ft^2)	Description of monitored work spaces
Roybal FB and CH, Bankruptcy Court, 9th floor, West facade	R9W	Los Angeles, CA	250	Private office
Lloyd George FB, North and East facades	LG4NE, LG4E, LG1E	Las Vegas, NV	1040 (1 x 560, 1 x 130, 1x 350)	Private offices
Metcalf FB, 1st floor, North and West facades	MN1NW	Chicago, IL	2,300	Lobby and Reception
JCK FB, 36th Floor, North Facade	JK36N	Chicago, IL	480	Open office plan
The Loop Post Office, 1ST floor, East and South facades	LPO1E	Chicago, IL	2,000	Post office area
Dirksen FB and CH, GSA Office, 2nd floor, West façade	ED2W	Chicago, IL	720	Open office plan and private office
Hammond CH, 1st floor, East and South facades	HC1SE	Hammond, IN	320	Private office
Dept. of Commerce, 4th floor, East and South facades	DC4SE	Washington DC	530	Private office
Dept. if the Interior, basement level	DIB	Washington DC	3,600	Cafeteria

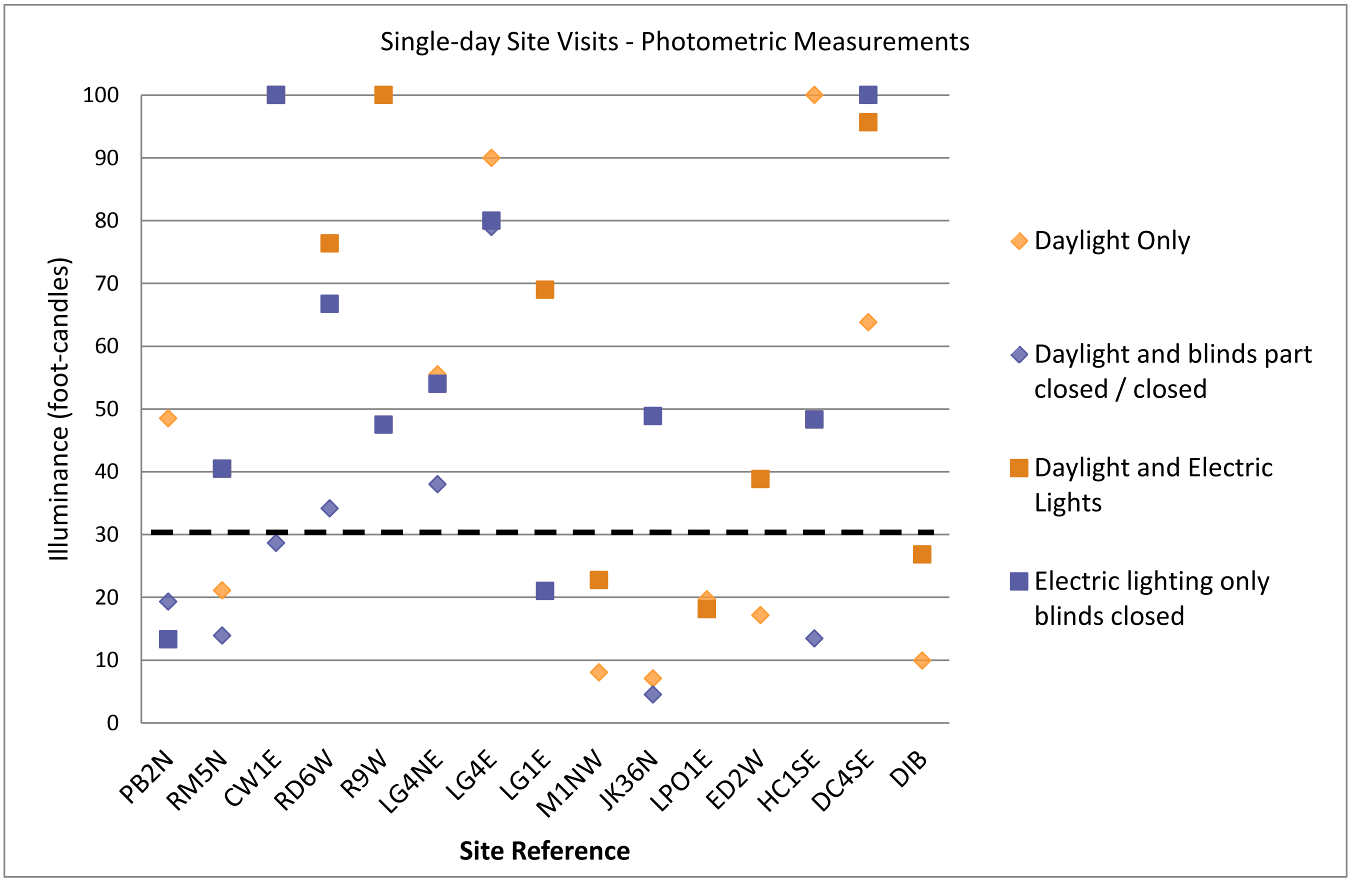
Each visit involved recording measurements and observations over a period of 2-3 hours. Measurements of light levels were taken under various lighting conditions appropriate for the site:

- The default condition, i.e. all lights and blinds at levels they were at on arrival
- Daylight only (electric lights off) where possible
- Electric lighting on
- Blinds in various positions other than the default (where blinds control would cause a distraction or disturbance to occupants)

PHOTOMETRIC ANALYSIS

The data contained in Figure 112 represents the range of horizontal illuminance readings recorded at each of the single day site visit locations under a variety of lighting conditions, such as daylight only, a combination of daylight and electric lighting, or adjusting position of the blinds or shades.

Figure 112: Results of photometric measurements



The results illustrate that the lighting systems installed in all of the working areas (private offices or open office cubicles) could achieve light levels above the IESNA recommended minimum of 30 footcandles at the workplane. The lighting conditions under which these are achieved differ across locations due to the site characteristics and in some cases, to the weather conditions on the day of the visit.

The results also illustrate the variation in light levels achieved by operation of electric lighting alone (i.e. when the blinds are closed). This could be due to many factors, such as sites observing different guidance light levels (i.e. the 2007 version of the P100 as opposed to the 2010 version), systems going out of calibration, due to the lamps or the sensors, or requests for personal preference light levels being implemented.

Under a daylight only scenario, one site was able to both achieve the IESNA recommended minimum and not have uncomfortably high horizontal illuminance values (> 60 footcandles) – electric lighting was important in balancing out overall light conditions in the remainder of locations, its key role being to reduce the perception of glare. While overlighting from electric lights (measured in the horizontal plane) was an issue at three sites, lighting in the vertical plane was sufficient for the environment to not be gloomy.

No incidences of disability glare[19] were measured at any of the sites.

A DAYLIGHT ONLY

Half of the 12 office locations visited (at 9 sites) supported the IESNA recommended minimum lighting levels with daylight only. Two sites (RM5N and CW1E) supported daylight use that was close to achieving the IESNA recommended minimum. The electric lights at one site switched off completely in response to bright daylight. Three sites were visited on days with very overcast and gloomy conditions; it was not possible to come to a similar conclusion at these sites as a result. We were unable to switch off the lights manually at one of the office sites (R9W) and so could not measure daylight only light levels.

In three office locations (at 2 sites), the IESNA recommendations could be met with the blinds drawn and closed. At two of these, the daylight conditions are sufficiently stable throughout the year to suggest that very significant lighting energy savings are possible.

For the remaining three non-office-type locations, according to the guidance for those locations (M1NW – lobby area, LPO1E – Post Office counters, and DIB – basement cafeteria), none of these areas were sufficiently well lit to meet IESNA requirements with daylight alone, although the weather conditions during the visit to the Metcalf building means that the results there are inconclusive.

B DAYLIGHT AND ELECTRIC LIGHTING

All of the office locations visited support the IESNA recommendations when electric lighting supplements the available natural light. Of the non-office locations, two met the IESNA requirements (M1NW and DIB), with one location (LPO1E) being marginally under-lit. [20]

DESIGN

A EXTERNAL

The sites visited were located at a range of latitudes, geographies and urban settings. The sites that best utilized daylight were all east, west or south facing. When located in urban environments, sites with a clear sky view (adjacent roofs at eye level or below) could capitalize on natural light available during bright, clear conditions. When this was not the case, and there were clear obstructions, this limited daylight access. It also presented the problem of window reflections–direct sun reflecting from glass surfaces of other buildings and causing disabling glare for occupants.

B STRUCTURE AND ENVELOPE

The architecture varied in age and type, across sites visited. The main impact of this could be seen in the sizing of windows. As window size determines the amount of natural light that can enter an occupied space, it is the most important factor in determining the success of an IDS system. IDS generally are not

[19] Assumed here to be values higher than 185 foot-candles (2000 lux) in the vertical plane.

[20] P100: Dining area = 10, Table 6.1, Lobby = 10, Table 6.1)

recommended for spaces that have windows occupying less than around 20% of the wall area[21]. All of the sites visited had windows that met this requirement.

Two sites (CW1E and LG4NE) had external shading which consisted of a concrete overhang which limited the impact of direct sunlight in the late morning.

The buildings with heavy structural massing (for better thermal performance) generally had smaller, punched windows (for the same reason), spaced regularly along the envelope perimeter, and a window to wall ratio between 0.3 – 0.5. All of these sites (LG4NE, LG4E, LG1E, HC1SE and DC4SE) were visited during bright clear conditions and all demonstrated good daylight access.

The lighter, predominantly steel buildings typically had strip windows or window curtain-wall, with a window to wall ratio typically between 0.5 – 0.8. All of these sites provide the opportunity for good daylight access, although the measurements taken at three (M1NW, JK36N, ED2W) were in overcast conditions.

Only one site had treated glazing – most sites had either clear single or clear double glazing.

C **INTERNAL**

The decisions taken on how best to install the lights and control systems and how to furnish and arrange equipment in the occupied spaces appeared to have a significant impact on access to natural light.

1. INTERIOR BLINDS AND SHADES

Three different types of interior shades were installed across the sites visited: venetian blinds, vertical blinds or roller shades. The default positions and slat angles of blinds varied according to site: where blinds and shades were lowered and closed, the stated reasons was to counter the effects of direct sun, and in some cases reflected light. Closed blinds were also the default position at two of the three north facing sites.

At the seven locations where blinds or shades typically remain closed,the potential energy benefits associated with IDS will be significantly reduced or nullified entirely as electric lights will operate according to the low natural light levels that result from the blinds position rather than dimming to their full potential for a open or 'slats at zero degrees' position, which allows natural light into the space. However, due to the bright conditions at some sites, such are necessary, at least for a significant portion of the day.

2. PARTITIONS

Cubicle partitions were present in all three open office sites visited. Partitions varied in height from approximately three feet to approximately six feet. Partitions were installed both parallel and at right angles to the window wall. Paritions also were installed between the window and the work areas in the first row of cubicles adjacent to the window.

High partitions (higher than 3 feet 6 inches) parallel to the window wall were observed at one site and high partitions perpendicular to the window wall were observed at all three open office locations.

[21] Rule of thumb

3. FURNITURE TYPE AND COLOR AND DECORATION OF OCCUPIED SPACES

The type and color of furniture varied widely across the assessed sites. In open office locations, desks were generally horseshoe or L-shaped and light in color. In private offices, there was less consistency: modern office furniture was present at five sites and older heavy wooden desks with medium-dark brown finish often were present at four sites. Wall and ceiling colors always were light colored or white and floor carpets were light grey to dark grey in color.

4. FURNITURE ARRANGEMENT

The horseshoe or L-shaped desks installed in the open office sites meant that the occupant could always choose from at least two facing direction – occupants could therefore avoid having a window view within their peripheral vision if they desired. Responses within the occupant surveys suggest that this is not always the case for some of these sites.

However, it is unclear whether guidance was provided with regards to seating position relative to the window or with regards to avoiding eye fatigue while making the most of available natural light. Without this information, some someoccupants may inadvertently select a poorly suited work location.

In private offices, where there were modern L-shaped office desks, the occupant was often able to choose between having the window behind them or to one side, or between facing the window or having it to one side. Where there was free standing furniture, it was placed either so the occupant would face the window or have the window to one side.

It is hoped that either GSA or tenants have guidelines on the orientation and placement of furniture in office areas with windows, or that occupants would have a choice as to how the furniture was positioned. Responses within the occupant survey suggest that this is not always the case. It appeared that no guidance was provided with regards to their seating position or location with regards to avoiding eye fatigue or making the most of available natural light, and that for example, the location selected for working at a computer was personal preference. In five private offices, there was a second computer desk to work at. These were normally positioned against the wall so the occupant would not be able to see the window, either in their peripheral vision, or as a reflection in the computer screen.

Lighting and Dimming

At only two sites (PB2N and DIB) did the lights switch off automatically in response to daylight, meaning that the only energy use would be ballast standby power – during bright conditions at the remaining 11 sites, lights dimmed to approximately 10 percent lighting output, which translates into approximately 25-30 percent power input.

D PROJECT IMPLEMENTATION

Typically, at least 3 companies were involved in the implementation of each project. The lighting manufacturers and /or control systems vendors (sometimes one and the same) usually were responsible parties in the design process. Installation often was subcontracted from a General Contractor to an electrical subcontractor. The commissioning agent often was the lighting manufacturer / control systems vendor.

1. INSTALLATION

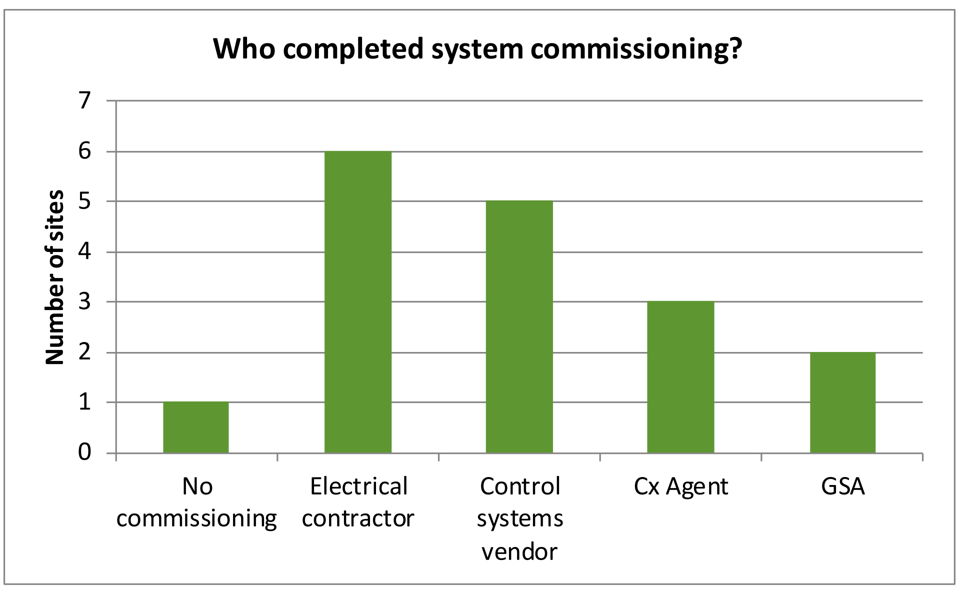
The obstacles and challenges experienced during the installation process reflect the inherent nature of installing complex building systems. There were no technical or design issues identified by Building Managers that suggest approach to installation was anything other than appropriate. Two sites experienced project snagging related to faulty wiring installation and ballast replacement due to excessive standby power requirements of the units originally specified.

2. COMMISSIONING

Ideally, the lighting project commissioning agent would be an independent party, and would critically examine the installation, operation and the means of monitoring performance through a third party lens. Apart from completing the commissioning tasks, they play a vital role in clearly and accurately codifying how the system is set up to operate and the process of continuing maintenance and management, and that industry or vendor jargon does not creep into operation and maintenance manuals. Critically, via their contract terms and conditions, a third party commissioning agent is incentivized to implement protocols or performance to meet design intent – such performance obligations are less clear and simple to assess when a vendor or installer is also the commissioning agent.

As Figure 113 illustrates, there was little consistency with regards to the approach adopted for commissioning, this complex and specialist task was completed by a range of organizations, often those that had been involved in project design and installation.

Figure 113: Organizations involved in the commissioning process



The extent of commissioning and associated documentation and records varied by site. The commissioning process appears not to have a standard protocol, a preferred contractual arrangement or a set of baseline deliverables which would contribute towards standardizing the process across the GSA portfolio. Therefore the requirements placed on designers, consultants and contractors varies from site to site – the lines along which these variations exist are not clear from the relatively limited sample of buildings represented in this study. Objectives of the commissioning process often were not clearly set out in tender documentation and this had knock-on effects in terms of the protocol adopted for sensor calibration, controls settings and system testing and meeting requirements of the work space occupants. There was no formal framework for verification of performance once commissioning had been completed, either to verify overall performance or to check for persistent performance six months down the line.

Commissioning was sometimes not complete in the sense that the vendor / installer was still involved in fixing minor issues with the software and also being called on to address specific issues, such as incorrect addressing of fixtures within the control system.

3. TRAINING

The approach to training varied across sites. At four sites, representatives of all user groups were or would be provided with training and supporting information to assist them with their adjustment to the new lighting and control systems. At one of the four, it was at the tenants discretion whether staff would be provided with training, the perception being that providing this information created more problems than it solved. At the remaining nine sites, only operations and maintenance staff received or would receive training. At one site, operations staff had received training on how to monitor and manage the lighting controls system but regarded it as insufficient in terms of being able to put it into practice. There were no guidelines as to how to train other user groups on the operation of the new lighting systems.

4. MAINTENANCE

At the majority of sites, there were no formal arrangements in place to ensure periodic deep maintenance of the IDS system with the aim of operating persistence. In part this reflects an inconsistency with regards to contractual obligations of the vendor / installer: at several of the buildings in California, the lighting system was under warranty for a specified term, which is normally satisfied through a vendor-let dedicated sub-contract. Conversely, in some cases, dedicated operations and maintenance staff are responsible for lighting system maintenance. In cases where this staff is responsible for multiple building energy systems, the degree of focus on lighting is significantly reduced and it is incumbent on the training process to ensure that they are able to meet the lighting system performance requirements and that they are adequately resourced to keep up to date on their training and to have the time to complete their tasks. Feedback from at least one site suggested that this process is not as well managed as it could be.

5. OCCUPANT SATISFACTION

It was acknowledged by many Building Managers that occupant satisfaction is often a reflection of to what extent occupants had been informed and engaged on changes associated with the new lighting systems. There was no consistent methodology or framework for undertaking the engagement and educative process and as such the approach to the issue was mixed.

Despite this, it was reported that occupants are largely satisfied with lighting at 12 of the 13 sites – how this satisfaction was assessed was not clear except for one location where an occupant survey was distributed.

Occupants could not change LMCS settings from their workspaces, even though the control system could accommodate these types of modifications. In order to adjust their light levels, occupants were required to contact the system operator / helpdesk with a request; when requests were made, it typically took 24 hours to implement them.

C. DETAILED TECHNOLOGY SPECIFICATION

LAMPS AND LUMINAIRES

Table 47: Lighting System Description for Long-term Sites

Site	Lighting Controls	Luminaire Type	Lamps
Ronald Dellums Federal Building, Oakland	• Active photocells • Electronic dimmable ballasts	• Suspended, louvered, direct/indirect 4' fixture with built-in occupancy/photo-sensor • Recessed, louvered, 2'x2' fixtures	• 4' fixtures: (3) F32T8 lamps (1 uplight and 2 downlight) • 2x2 fixtures: F17T8 lamps
Roybal Federal Building, Los Angeles		• Recessed, louvered, 2'x4' fixture	• 2x4 fixtures: F32T8 lamps
Cottage Way Federal Building, Sacramento		• Recessed, louvered, 2'x2' fixture	• 2x2 fixtures: F17T8 lamps
E.M Dirksen Federal Building, Chicago		• Ceiling-mounted, louvered 1' x 4' fixture	• 1x4 fixtures: F32T8 lamps
Hammond Court House, Hammond		• Recessed, louvered, 2'x2' fixture	• 2x2 fixtures: F32T8 lamps

LUMINAIRES

The projects that implemented IDS typically consisted of installation of new fixtures, lamps and controls infrastructure within an existing building space. These projects typically were not implemented at the whole building level but mainly on selected floors or façade orientations on selected floors. It was not possible to follow the decision-making process in terms of why some sites had implemented IDS and adjacent office space or floors had not. It is common for lighting retrofit projects to be limited to specific floors or zones of a building at any one time to minimize the burden associated with relocating staff and to manage project costs.

Configuration of the overhead lighting varied in layout and type: at some sites, overhead lighting was provided from recessed 2x4 and 2x2 fixtures; at others, pendant direct / indirect fixtures were installed. Typically, recessed fixtures were installed at regular intervals in the ceiling and did not correspond exactly with the layout of office furniture; this was true for both open office and private office locations. Pendant fixtures were installed to correspond with the office furniture layout: one pendant fixture per work cubicle. One site had pendant fixtures containing three lamps each, with uplight (one lamp controlled by a single ballast) and downlight (two lamps, controlled by a second ballast) components, the downlight component being for task specific lighting. All three lamps in the pendant were programmed to dim to available daylight. In some transitional office spaces, away from work areas and in non-office areas, can lights were common. In the locations studied, can lights always were peripheral to the daylighting zone and therefore not of interest to the analysis.

Lights turn on to a preset level when activated–either by a time clock, occupancy sensor or manually operated switch–and are set to dim to provide light levels at the workplane according to a) lighting output required to achieve a predetermined light level at the workplane; b) P100 design guidance; or c) according to occupant preferred light level. None of the locations being monitored are impacted by light output from can lights. The figures below show example of the different fixture types encountered at the various sites.

Figure 114: Example of two-lamp 2x4 recessed troffer lighting fixture with lens

Figure 115: Example of three-lamp pendant fixture

Figure 116: Example of two-lamp 2x4 recessed troffer lighting fixture without a lens

Figure 117: Example of one-lamp ceiling-mounted fixture

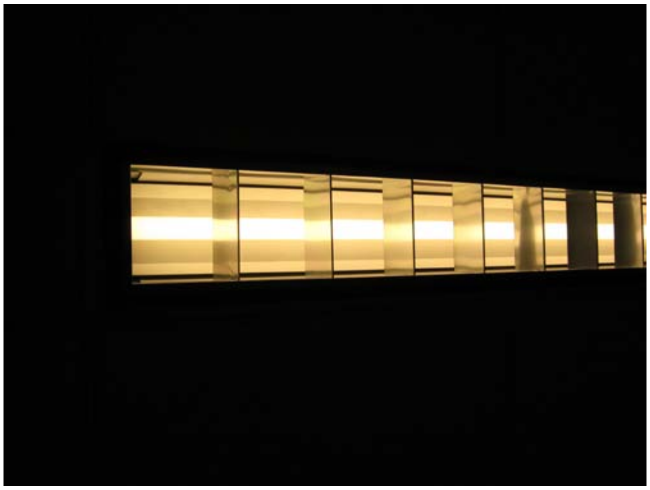


Figure 118: Example of a two-lamp 2x2 recessed troffer lighting fixture

BALLASTS, SENSORS AND CONTROLS

For each of the sites visited, IDS was a control strategy within an integrated lighting control system, which also incorporated time clocks and set schedules, occupancy-based control, and personal controls, controlled and monitored from a central location.

Typically, primary control of the electric lights was occupancy-based, so when someone entered the workspace, lights immediately would switch on. Once activated, lights would dim for daylight. Some private offices had manual wall switches, which activate and cut power to the ballasts when operated; these can be used to override the occupancy sensors so that lights are off while the space is occupied.

The 13 sites visited comprised six different space types: private office, open office cubicle, reception desk, conference room, cafeteria and entrance lobby. The control infrastructure varied by space type: private offices and conference rooms had dedicated photosensors that would control electric lighting in those spaces only, whereas the other areas were controlled by zonal daylight dimming. The maximum number of workstations within a daylight zone–controlled by a single photosensor–was eight.

Lighting control settings were accessible through a desktop computer and lighting controller located either on the same floor as the site or in a consolidated location for the building as a whole. In general, the facilities or operation and maintenance (O&M) contractor had control over the lighting system and the ability to change some or all lighting output settings. System programming was sometimes completed by the vendor and modifications to the system, such as adding devices, required a factory trained technician to complete.

Table 48: Lighting Control System Defaults

Space type	Typical control system defaults (details vary by site)
Perimeter open office cubicles and reception areas	Tuning, 50% - 80% of installed power For pendants, 50% tuning for downlights, 30% tuning for uplights, workstation-specific occupancy sensing, indirect personal control, photosensors controlling to 30-50 foot-candles at the work plane
Perimeter private offices	Tuning and daylight dimming (30-50 foot-candles constrained to 30%-70% power), occupancy sensors that override the control system, wall switches that override occupancy controls, indirect personal dimming control
Perimeter conference rooms	Tuning and daylight dimming (50 foot-candles constrained to 30-70% power), occupancy sensors that override the control system, wall switches with scene setting

Table 49: Data Collection Equipment

Measurement Type	Measuring Instrumentation	Range of Measurement	Measurement Type or Frequency
Light levels – illuminance	LI-COR SR Series Photometers	0 – 100 Klux	Incidence of light in horizontal and vertical planes for selected work locations
Light level data logging	Onset HOBOware Data logging equiment	n/a	Recording and scaling light data readings
Glare	Canon A570IS camera and Opteka Fisheye lens	Visible and infrared frequency radiation	7 bracketed photos every 5 minutes
Space characterization	Canon A570IS camera and Opteka Fisheye lens	n/a	Record of physical characteristics of the space
Power metering	Onset HOBOware U30	n/a	Current and voltage readings

OCCUPANT SURVEY

Email to building occupants (long-term monitoring sites)

The Lighting Study: As part of the Green Proving Ground initiative, the GSA is assessing lighting systems installed in several buildings. The objectives of the assessment are to understand whether the lighting system operation is successful from an energy savings point of view and whether the environment created by the electric lighting, and other systems that control the use of natural light, such as window blinds, meet the needs of building users. The data and information that we collect will feed into future lighting projects, understanding what aspects of a project are successful, and which are less so.

How can you help: As part of this analysis, we are conducting a survey of building occupants. This online survey consisting of 22 questions, most of which are multiple choice (it should take less than 10 minutes), gives you the opportunity to provide feedback on lighting conditions and comfort in your workspace. Once we have the final results, we will also be satisfied to share them with you. Taking part is completely voluntary and totally anonymous, but we encourage you to take part as your feedback is crucial in understanding the overall picture - this project is not just about energy savings, it is also about determining what works best for people.

Survey link: http://www.surveymonkey.com/sitespecificsurveycode

DAYLIGHTING SURVEY

Personal Workspace Information

Which of the following best describes your personal workspace?

( ) Enclosed private office
( ) Cubicles with partitions above standing eye level
( ) Cubicles with partitions below standing eye level
( ) Other (Please specify) ____________________________

What type of computer screen do you have?

( ) Laptop
( ) Flat Panel Screen
( ) Traditional Screen (CRT)
( ) Other (please specify) ____________________________

Which direction do you face most of the time?

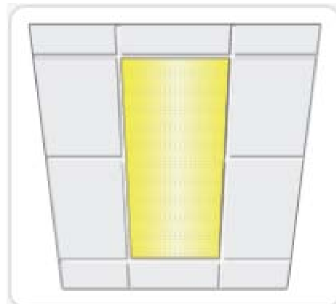
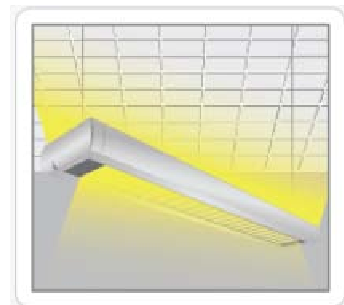
( ) Towards window
( ) With the window to one-side
( ) Away from the window
( ) Other (please specify)____________________________

Which primary direction does your window face?

( ) North
( ) East

( ) South
( ) West
( ) Do not know

Lighting Levels/Illuminance
Which of the following most closely resembles the overhead lighting in your immediate workspace?

Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?
( ) Under-cabinet task light
( ) Desktop task light
( ) I do not have a task light

Which of the following most closely resembles the lighting on the walls in your general office area?
( ) Uniformly bright walls
( ) Uneven light distribution on walls
( ) Accent lighting (on artwork only, for instance)
( ) Walls are dim
( ) Other
( ) Do not know

Overall are you comfortable with your workstation lighting levels?
( ) Yes
( ) No
( ) Not sure

Comments
Please feel free to submit any other comments or suggestions about your workstation lighting levels:

Lighting Controls

How overhead lights are adjacent to your workspace controlled (check all that apply)?
( ) Switch / dimmer at wall
( ) Handheld remote
( ) Interface at your computer
( ) Automated system/controlled by sensor or building management
( ) Other (please specify) ____________________________
( ) Do not know/ Does not apply

To what extent are light levels from your overhead light adjusted?
( ) Lights turn on and off only
( ) Light level settings are available for high, low, and/or medium
( ) Gradual dimming in response to daylight

Are you satisfied with your electric lighting controls?
( ) Yes
( ) No
( ) Not sure

Comments
Please feel free to submit any other comments or suggestions about your lighting controls:

Window Blinds and Shades
What type of shading system at/near your workstation to control the amount of daylight entering your windows?
( ) Manual blinds (e.g., Venetian blinds)
( ) Manual window shades (e.g., roller shades)
( ) Electrically-controlled blinds or shades
( ) No blinds or shades
( ) Other (please specify e.g. overhangs, trees or adjacent buildings) ____________________________
( ) I have no daylight in my workspace

If you have blinds or shades, are they usually open or closed?
( ) Open
( ) Closed
( ) Not sure

How often do you control/change the position of the blinds at/near your workstation?
( ) Daily or more
( ) Occasionally (less than daily)
( ) Depends on solar conditions
( ) Hardly ever/never

What are the reasons for operating blinds/shades (check all that apply)?
( ) To reduce glare from daylight/sunlight
( ) To reduce glare when sun is directly visible
( ) To reduce the overall brightness of the space
( ) To increase the overall brightness of the space
( ) To get a better view
( ) To increase visual privacy
( ) To reduce the heat from the sun
( ) To reduce the cold draft from the window
( ) To decrease visual distraction from outside
( ) Other (please specify)
____

Are you satisfied with your blind/shading controls?
( ) Yes
( ) No
( ) Not sure

Comments
Please feel free to submit any other comments or suggestions about your blinds / shading:

Daylighting Design
What issues have you encountered with regards to lighting (check all that apply)?
For the following selections, "glare" is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.
( ) Electric lights turn-on and off randomly throughout the day
( ) Electric light levels change noticeably throughout the day
( ) Light levels noticeably affected by operation of the blinds
( ) Window glare makes tasks difficult to see

( ) Window too bright when looking outside
( ) Glare from adjacent electric lighting
( ) Other glare (i.e. reflections from your monitor)

Comments

What would you like to see improved in the lighting/daylighting environment in your workspace?

Please feel free to submit any other comments about the survey below:

RONALD DELLUMS FB OCCUPANT SURVEY RESULTS

Question	Response	Number of respondents	Percentage of respondents
Which of the following best describes your personal workspace?	Enclosed private office	9	20%
	Cubicles with partitions above standing eye level	27	61%
	Cubicles with partitions below standing eye level	8	18%
	Total	**44**	**100%**
What type of computer screen do you have?	Laptop	1	2%
	Flat Panel Screen	41	98%
	CRT	0	0%
	Total	**42**	**100%**
Which direction do you face most of the time?	Towards Window	13	31%
	With the window to one-side	11	26%
	Away from the Window	18	43%
	Total	**42**	**100%**
Which primary direction does your window face?	North	4	9%
	East	11	25%
	South	5	11%
	West	9	20%

Question	Response	Number of respondents	Percentage of respondents
	Do not know	15	34%
	Total	**44**	**100%**
Which of the following pictures below most closely resembles the overhead lighting in your immediate workspace?	Recessed troffer visible lamp	14	31%
	Recessed troffer with screen	7	16%
	Pendant	24	53%
	Total	**45**	**100%**
Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?	Under-cabinet Task Light	25	56%
	Desktop Task Light	4	9%
	I do not have a task light	16	36%
	Total	**45**	**100%**
Which of the following most closely resembles the lighting on the walls in your general office area?	Uniformly Bright Walls	9	23%
	Uneven Light Distribution on walls	8	21%
	Accent Lighting (on artwork only, for instance)	0	0%
	Walls are Dim	9	23%
	Do Not Know	13	33%
	Total	**39**	**100%**
Overall are you comfortable with your workstation lighting levels?	Yes	21	50%
	No	21	50%
	Don't Know	0	0%
	Total	**42**	**100%**
How are overhead lights adjacent to your workspace controlled (check all that apply)?	Switch / dimmer at Wall	3	7%
	Handheld remote	0	0%
	Interface at your computer	0	0%
	Automated system/controlled by sensor or building management	39	91%
	Do not know/ Does not apply	1	2%
	Total	**43**	**100%**
To what extent are light levels from your overhead light adjusted?	Lights turn on and off only	32	74%
	Light level settings are available for high, low, and/or medium	5	12%
	Gradual dimming in response to daylight	6	14%
	Total	**43**	**100%**
Are you satisfied with your electric lighting controls?	Yes	14	33%
	No	25	58%

Question	Response	Number of respondents	Percentage of respondents
	Not sure	4	9%
	Total	**43**	**100%**
What type of shading system at/near your workstation to control the amount of daylight entering your windows?	Manual blinds (e.g., Venetian blinds)	36	88%
	Manual window shades (e.g., roller shades)	3	7%
	Electrically-controlled blinds or shades	1	2%
	No blinds or shades	1	2%
	I have no daylight in my workspace	0	0%
	Other	0	0%
	Total	**41**	**100%**
If you have blinds or shades, are they usually open or closed?	Open	22	51%
	Closed	17	40%
	Not sure	1	2%
	Does not apply	3	7%
	Total	**43**	**100%**
How often do you control/change the position of the blinds at/near your workstation?	Daily or more	9	21%
	Occasionally (less than daily)	4	9%
	Depends on solar conditions	10	23%
	Hardly ever/never	20	47%
	Total	**43**	**100%**
What are the reasons for operating blinds/shades (check all that apply)?	To reduce glare from daylight/sunlight	15	39%
	To reduce glare when sun is directly visible	14	37%
	To reduce the overall brightness of the space	3	8%
	To increase the overall brightness of the space	4	11%
	To get a better view	2	5%
	To increase visual privacy	0	0%
	To reduce heat from the sun	0	0%
	To reduce cold draft from the window	0	0%
	To decrease visual distraction from outside	0	0%
	Other	0	0%
	Total	**38**	**100%**

Question	Response	Number of respondents	Percentage of respondents
Are you satisfied with your blind/shading controls?	Yes	21	49%
	No	12	28%
	Not sure	4	9%
	Does not apply	6	14%
	Total	**43**	**100%**
What issues have you encountered with regards to lighting (check all that apply)? For the following selections, "glare" is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.	Electric lights turn-on and off randomly throughout the day	15	68%
	Electric light levels change noticeably throughout the day	2	9%
	Light levels noticeably affected by operation of the blinds	4	18%
	Window glare makes tasks difficult to see	0	0%
	Window too bright when looking outside	0	0%
	Glare from adjacent electric lighting	1	5%
	Other	0	0%
	Total	**22**	**100%**

ROYBAL FB OCCUPANT SURVEY RESULTS

Question	Response	Number of respondents	Percentage of respondents
Which of the following best describes your personal workspace?	Enclosed private office	3	11%
	Cubicles with partitions above standing eye level	12	43%
	Cubicles with partitions below standing eye level	13	46%
	Total	**28**	**100%**
What type of computer screen do you have?	Laptop	1	4%
	Flat Panel Screen	24	96%
	CRT	0	0%
	Total	**25**	**100%**
Which direction do you face most of the time?	Towards Window	3	11%
	With the window to one-side	6	22%
	Away from the Window	18	67%

Question	Response	Number of respondents	Percentage of respondents
	Total	**27**	**100%**
Which primary direction does your window face?	North	2	8%
	East	11	42%
	South	2	8%
	West	7	27%
	Do not know	4	15%
	Total	**26**	**100%**
Which of the following pictures below most closely resembles the overhead lighting in your immediate workspace?	Recessed troffer visible lamp	12	46%
	Recessed troffer with screen	10	38%
	Pendant	4	15%
	Total	**26**	**100%**
Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?	Under-cabinet Task Light	24	89%
	Desktop Task Light	1	4%
	I do not have a task light	2	7%
	Total	**27**	**100%**
Which of the following most closely resembles the lighting on the walls in your general office area?	Uniformly Bright Walls	7	27%
	Uneven Light Distribution on walls	3	12%
	Accent Lighting (on artwork only, for instance)	0	0%
	Walls are Dim	5	19%
	Do Not Know	11	42%
	Total	**26**	**100%**
Overall are you comfortable with your workstation lighting levels?	Yes	22	85%
	No	4	15%
	Don't Know	0	0%
	Total	**26**	**100%**
How are overhead lights adjacent to your workspace controlled (check all that apply)?	Switch / dimmer at Wall	4	15%
	Handheld remote	0	0%
	Interface at your computer	0	0%
	Automated system/controlled by sensor or building management	21	78%
	Do not know/ Does not apply	2	7%
	Total	**27**	**100%**
To what extent are light levels from your overhead light adjusted?	Lights turn on and off only	20	77%
	Light level settings are available for high, low, and/or medium	3	12%

Question	Response	Number of respondents	Percentage of respondents
	Gradual dimming in response to daylight	3	12%
	Total	**26**	**100%**
Are you satisfied with your electric lighting controls?	Yes	12	43%
	No	10	36%
	Not sure	6	21%
	Total	**28**	**100%**
What type of shading system at/near your workstation to control the amount of daylight entering your windows?	Manual blinds (e.g., Venetian blinds)	22	85%
	Manual window shades (e.g., roller shades)	3	12%
	Electrically-controlled blinds or shades	0	0%
	No blinds or shades	1	4%
	I have no daylight in my workspace	0	0%
	Other	0	0%
	Total	**26**	**100%**
If you have blinds or shades, are they usually open or closed?	Open	18	67%
	Closed	7	26%
	Not sure	0	0%
	Does not apply	2	7%
	Total	**27**	**100%**
How often do you control/change the position of the blinds at/near your workstation?	Daily or more	0	0%
	Occasionally (less than daily)	2	8%
	Depends on solar conditions	13	50%
	Hardly ever/never	11	42%
	Total	**26**	**100%**
What are the reasons for operating blinds/shades (check all that apply)?	To reduce glare from daylight/sunlight	7	30%
	To reduce glare when sun is directly visible	7	30%
	To reduce the overall brightness of the space	1	4%
	To increase the overall brightness of the space	5	22%
	To get a better view	2	9%
	To increase visual privacy	1	4%
	To reduce heat from the sun	0	0%

Question	Response	Number of respondents	Percentage of respondents
	To reduce cold draft from the window	0	0%
	To decrease visual distraction from outside	0	0%
	Other	0	0%
	Total	**23**	**100%**
Are you satisfied with your blind/shading controls?	Yes	18	67%
	No	4	15%
	Not sure	2	7%
	Does not apply	3	11%
	Total	**27**	**100%**
What issues have you encountered with regards to lighting (check all that apply)? For the following selections, "glare" is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.	Electric lights turn-on and off randomly throughout the day	5	45%
	Electric light levels change noticeably throughout the day	0	0%
	Light levels noticeably affected by operation of the blinds	3	27%
	Window glare makes tasks difficult to see	0	0%
	Window too bright when looking outside	0	0%
	Glare from adjacent electric lighting	3	27%
	Other	0	0%
	Total	**11**	**100%**

COTTAGE WAY FB OCCUPANT SURVEY RESULTS

Question	Response	Number of respondents	Percentage of respondents
Which of the following best describes your personal workspace?	Enclosed private office	3	13%
	Cubicles with partitions above standing eye level	16	67%
	Cubicles with partitions below standing eye level	5	21%
	Total	**24**	**100%**
What type of computer screen do you have?	Laptop	0	0%
	Flat Panel Screen	23	100%

Question	Response	Number of respondents	Percentage of respondents
	CRT	0	0%
	Total	**23**	**100%**
Which direction do you face most of the time?	Towards Window	8	38%
	With the window to one-side	9	43%
	Away from the Window	4	19%
	Total	**21**	**100%**
Which primary direction does your window face?	North	5	22%
	East	5	22%
	South	7	30%
	West	5	22%
	Do not know	1	4%
	Total	**23**	**100%**
Which of the following pictures below most closely resembles the overhead lighting in your immediate workspace?	Recessed troffer visible lamp	4	17%
	Recessed troffer with screen	2	8%
	Pendant	18	75%
	Total	**24**	**100%**
Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?	Under-cabinet Task Light	19	79%
	Desktop Task Light	0	0%
	I do not have a task light	5	21%
	Total	**24**	**100%**
Which of the following most closely resembles the lighting on the walls in your general office area?	Uniformly Bright Walls	4	17%
	Uneven Light Distribution on walls	5	22%
	Accent Lighting (on artwork only, for instance)	0	0%
	Walls are Dim	8	35%
	Do Not Know	6	26%
	Total	**23**	**100%**
Overall are you comfortable with your workstation lighting levels?	Yes	12	55%
	No	10	45%
	Don't Know	0	0%
	Total	**22**	**100%**
How are overhead lights adjacent to your workspace controlled (check all that apply)?	Switch / dimmer at Wall	2	8%
	Handheld remote	0	0%
	Interface at your computer	0	0%
	Automated system/controlled by sensor or building management	21	88%

Question	Response	Number of respondents	Percentage of respondents
	Do not know/ Does not apply	1	4%
	Total	**24**	**100%**
To what extent are light levels from your overhead light adjusted?	Lights turn on and off only	15	65%
	Light level settings are available for high, low, and/or medium	8	35%
	Gradual dimming in response to daylight	0	0%
	Total	**23**	**100%**
Are you satisfied with your electric lighting controls?	Yes	8	33%
	No	13	54%
	Not sure	3	13%
	Total	**24**	**100%**
What type of shading system at/near your workstation to control the amount of daylight entering your windows?	Manual blinds (e.g., Venetian blinds)	19	79%
	Manual window shades (e.g., roller shades)	3	13%
	Electrically-controlled blinds or shades	0	0%
	No blinds or shades	2	8%
	I have no daylight in my workspace	0	0%
	Other	0	0%
	Total	**24**	**100%**
If you have blinds or shades, are they usually open or closed?	Open	22	92%
	Closed	1	4%
	Not sure	0	0%
	Does not apply	1	4%
	Total	**24**	**100%**
How often do you control/change the position of the blinds at/near your workstation?	Daily or more	1	4%
	Occasionally (less than daily)	3	13%
	Depends on solar conditions	4	17%
	Hardly ever/never	16	67%
	Total	**24**	**100%**
What are the reasons for operating blinds/shades (check all that apply)?	To reduce glare from daylight/sunlight	3	23%
	To reduce glare when sun is directly visible	4	31%
	To reduce the overall brightness of the space	0	0%

Question	Response	Number of respondents	Percentage of respondents
	To increase the overall brightness of the space	5	38%
	To get a better view	1	8%
	To increase visual privacy	0	0%
	To reduce heat from the sun	0	0%
	To reduce cold draft from the window	0	0%
	To decrease visual distraction from outside	0	0%
	Other	0	0%
	Total	**13**	**100%**
Are you satisfied with your blind/shading controls?	Yes	19	79%
	No	2	8%
	Not sure	1	4%
	Does not apply	2	8%
	Total	**24**	**100%**
What issues have you encountered with regards to lighting (check all that apply)? For the following selections, "glare" is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.	Electric lights turn-on and off randomly throughout the day	14	78%
	Electric light levels change noticeably throughout the day	3	17%
	Light levels noticeably affected by operation of the blinds	0	0%
	Window glare makes tasks difficult to see	0	0%
	Window too bright when looking outside	0	0%
	Glare from adjacent electric lighting	1	6%
	Other	0	0%
	Total	**18**	**100%**

HAMMOND CH OCCUPANT SURVEY RESULTS

Question	Response	Number of respondents	Percentage of respondents
Which of the following best describes your personal workspace?	Enclosed private office	11	69%
	Cubicles with partitions above standing eye level	3	19%

Question	Response	Number of respondents	Percentage of respondents
	Cubicles with partitions below standing eye level	2	13%
	Total	**16**	**100%**
What type of computer screen do you have?	Laptop	0	0%
	Flat Panel Screen	18	100%
	CRT	0	0%
	Total	**18**	**100%**
Which direction do you face most of the time?	Towards Window	5	29%
	With the window to one-side	5	29%
	Away from the Window	7	41%
	Total	**17**	**100%**
Which primary direction does your window face?	North	2	12%
	East	7	41%
	South	5	29%
	West	2	12%
	Do not know	1	6%
	Total	**17**	**100%**
Which of the following pictures below most closely resembles the overhead lighting in your immediate workspace?	Recessed troffer visible lamp	1	33%
	Recessed troffer with screen	2	67%
	Pendant	0	0%
	Total	**3**	**100%**
Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?	Under-cabinet Task Light	9	53%
	Desktop Task Light	0	0%
	I do not have a task light	8	47%
	Total	**17**	**100%**
Which of the following most closely resembles the lighting on the walls in your general office area?	Uniformly Bright Walls	11	65%
	Uneven Light Distribution on walls	4	24%
	Accent Lighting (on artwork only, for instance)	0	0%
	Walls are Dim	1	6%
	Do Not Know	1	6%
	Total	**17**	**100%**
Overall are you comfortable with your workstation lighting levels?	Yes	12	75%
	No	4	25%
	Don't Know	0	0%
	Total	**16**	**100%**
How are overhead lights adjacent to your workspace	Switch / dimmer at Wall	9	50%
	Handheld remote	0	0%

Question	Response	Number of respondents	Percentage of respondents
controlled (check all that apply)?	Interface at your computer	0	0%
	Automated system/controlled by sensor or building management	8	44%
	Do not know/ Does not apply	1	6%
	Total	**18**	**100%**
To what extent are light levels from your overhead light adjusted?	Lights turn on and off only	7	41%
	Light level settings are available for high, low, and/or medium	8	47%
	Gradual dimming in response to daylight	2	12%
	Total	**17**	**100%**
Are you satisfied with your electric lighting controls?	Yes	9	53%
	No	7	41%
	Not sure	1	6%
	Total	**17**	**100%**
What type of shading system at/near your workstation to control the amount of daylight entering your windows?	Manual blinds (e.g., Venetian blinds)	2	13%
	Manual window shades (e.g., roller shades)	12	75%
	Electrically-controlled blinds or shades	0	0%
	No blinds or shades	2	13%
	I have no daylight in my workspace	0	0%
	Other	0	0%
	Total	**16**	**100%**
If you have blinds or shades, are they usually open or closed?	Open	9	56%
	Closed	7	44%
	Not sure	0	0%
	Does not apply	0	0%
	Total	**16**	**100%**
How often do you control/change the position of the blinds at/near your workstation?	Daily or more	1	6%
	Occasionally (less than daily)	2	13%
	Depends on solar conditions	7	44%
	Hardly ever/never	6	38%
	Total	**16**	**100%**
What are the reasons for operating blinds/shades (check	To reduce glare from daylight/sunlight	6	43%

Question	Response	Number of respondents	Percentage of respondents
all that apply)?	To reduce glare when sun is directly visible	6	43%
	To reduce the overall brightness of the space	1	7%
	To increase the overall brightness of the space	1	7%
	To get a better view	0	0%
	To increase visual privacy	0	0%
	To reduce heat from the sun	0	0%
	To reduce cold draft from the window	0	0%
	To decrease visual distraction from outside	0	0%
	Other	0	0%
	Total	**14**	**100%**
Are you satisfied with your blind/shading controls?	Yes	16	100%
	No	0	0%
	Not sure	0	0%
	Does not apply	0	0%
	Total	**16**	**100%**
What issues have you encountered with regards to lighting (check all that apply)? For the following selections, “glare” is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.	Electric lights turn-on and off randomly throughout the day	8	62%
	Electric light levels change noticeably throughout the day	3	23%
	Light levels noticeably affected by operation of the blinds	1	8%
	Window glare makes tasks difficult to see	0	0%
	Window too bright when looking outside	0	0%
	Glare from adjacent electric lighting	1	8%
	Other	0	0%
	Total	**13**	**100%**

DIRKSEN FB OCCUPANT SURVEY RESULTS

Question	Response	Number of respondents	Percentage of respondents
Which of the following best describes your personal workspace?	Enclosed private office	2	25%
	Cubicles with partitions above standing eye level	1	13%
	Cubicles with partitions below standing eye level	5	63%
	Total	**8**	**100%**
What type of computer screen do you have?	Laptop	3	43%
	Flat Panel Screen	4	57%
	CRT	0	0%
	Total	**7**	**100%**
Which direction do you face most of the time?	Towards Window	5	63%
	With the window to one-side	2	25%
	Away from the Window	1	13%
	Total	**8**	**100%**
Which primary direction does your window face?	North	3	38%
	East	1	13%
	South	1	13%
	West	3	38%
	Do not know	0	0%
	Total	**8**	**100%**
Which of the following pictures below most closely resembles the overhead lighting in your immediate workspace?	Recessed troffer visible lamp	4	50%
	Recessed troffer with screen	3	38%
	Pendant	1	13%
	Total	**8**	**100%**
Which of the following types of lighting fixtures most closely resembles the task lighting in your personal workspace?	Under-cabinet Task Light	0	0%
	Desktop Task Light	0	0%
	I do not have a task light	8	100%
	Total	**8**	**100%**
Which of the following most closely resembles the lighting on the walls in your general office area?	Uniformly Bright Walls	2	25%
	Uneven Light Distribution on walls	1	13%
	Accent Lighting (on artwork only, for instance)	0	0%
	Walls are Dim	1	13%
	Do Not Know	4	50%
	Total	**8**	**100%**
Overall are you comfortable	Yes	7	88%

Question	Response	Number of respondents	Percentage of respondents
with your workstation lighting levels?	No	1	13%
	Don't Know	0	0%
	Total	**8**	**100%**
How are overhead lights adjacent to your workspace controlled (check all that apply)?	Switch / dimmer at Wall	3	38%
	Handheld remote	0	0%
	Interface at your computer	0	0%
	Automated system/controlled by sensor or building management	5	63%
	Do not know/ Does not apply	0	0%
	Total	**8**	**100%**
To what extent are light levels from your overhead light adjusted?	Lights turn on and off only	0	0%
	Light level settings are available for high, low, and/or medium	2	25%
	Gradual dimming in response to daylight	6	75%
	Total	**8**	**100%**
Are you satisfied with your electric lighting controls?	Yes	5	63%
	No	1	13%
	Not sure	2	25%
	Total	**8**	**100%**
What type of shading system at/near your workstation to control the amount of daylight entering your windows?	Manual blinds (e.g., Venetian blinds)	7	100%
	Manual window shades (e.g., roller shades)	0	0%
	Electrically-controlled blinds or shades	0	0%
	No blinds or shades	0	0%
	I have no daylight in my workspace	0	0%
	Other	0	0%
	Total	**7**	**100%**
If you have blinds or shades, are they usually open or closed?	Open	6	86%
	Closed	1	14%
	Not sure	0	0%
	Does not apply	0	0%
	Total	**7**	**100%**
How often do you control/change the position of	Daily or more	0	0%
	Occasionally (less than daily)	1	14%

Question	Response	Number of respondents	Percentage of respondents
the blinds at/near your workstation?	Depends on solar conditions	2	29%
	Hardly ever/never	4	57%
	Total	**7**	**100%**
What are the reasons for operating blinds/shades (check all that apply)?	To reduce glare from daylight/sunlight	1	14%
	To reduce glare when sun is directly visible	4	57%
	To reduce the overall brightness of the space	0	0%
	To increase the overall brightness of the space	0	0%
	To get a better view	0	0%
	To increase visual privacy	1	14%
	To reduce heat from the sun	0	0%
	To reduce cold draft from the window	0	0%
	To decrease visual distraction from outside	0	0%
	Other	1	14%
	Total	**7**	**100%**
Are you satisfied with your blind/shading controls?	Yes	6	86%
	No	0	0%
	Not sure	0	0%
	Does not apply	1	14%
	Total	**7**	**100%**
What issues have you encountered with regards to lighting (check all that apply)? For the following selections, “glare” is defined to be unwanted light, i.e., loud noise is to sound, as glare is to light.	Electric lights turn-on and off randomly throughout the day	1	20%
	Electric light levels change noticeably throughout the day	0	0%
	Light levels noticeably affected by operation of the blinds	0	0%
	Window glare makes tasks difficult to see	3	60%
	Window too bright when looking outside	0	0%
	Glare from adjacent electric lighting	0	0%
	Other	1	20%

Question	Response	Number of respondents	Percentage of respondents
	Total	**5**	**100%**

D. LONG-TERM MONITORING SITE PLANS

Figure 119: Plan view of Ronald Dellums site

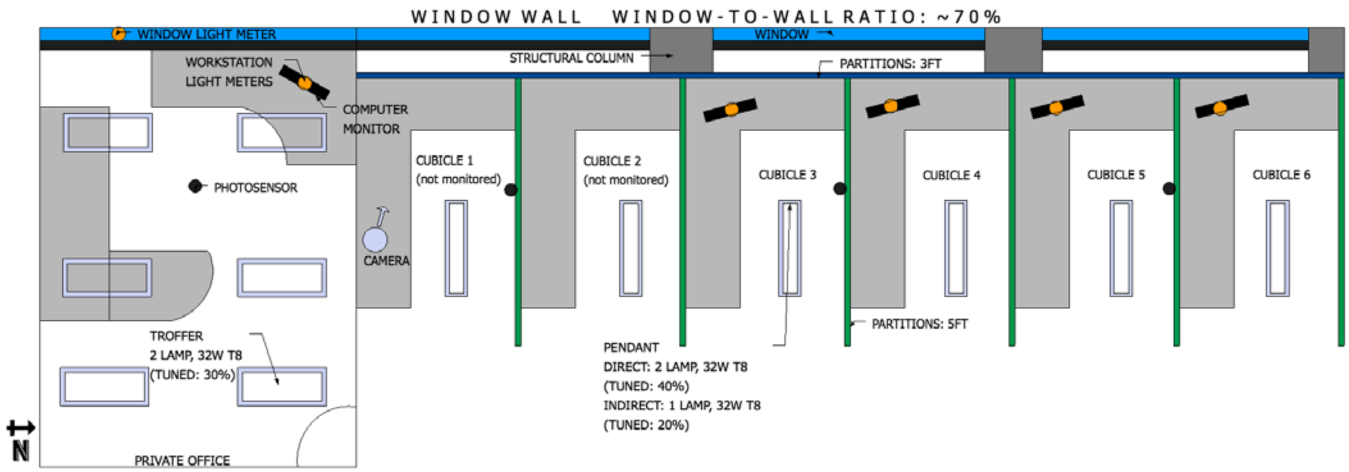


Figure 120: Plan view of Roybal site

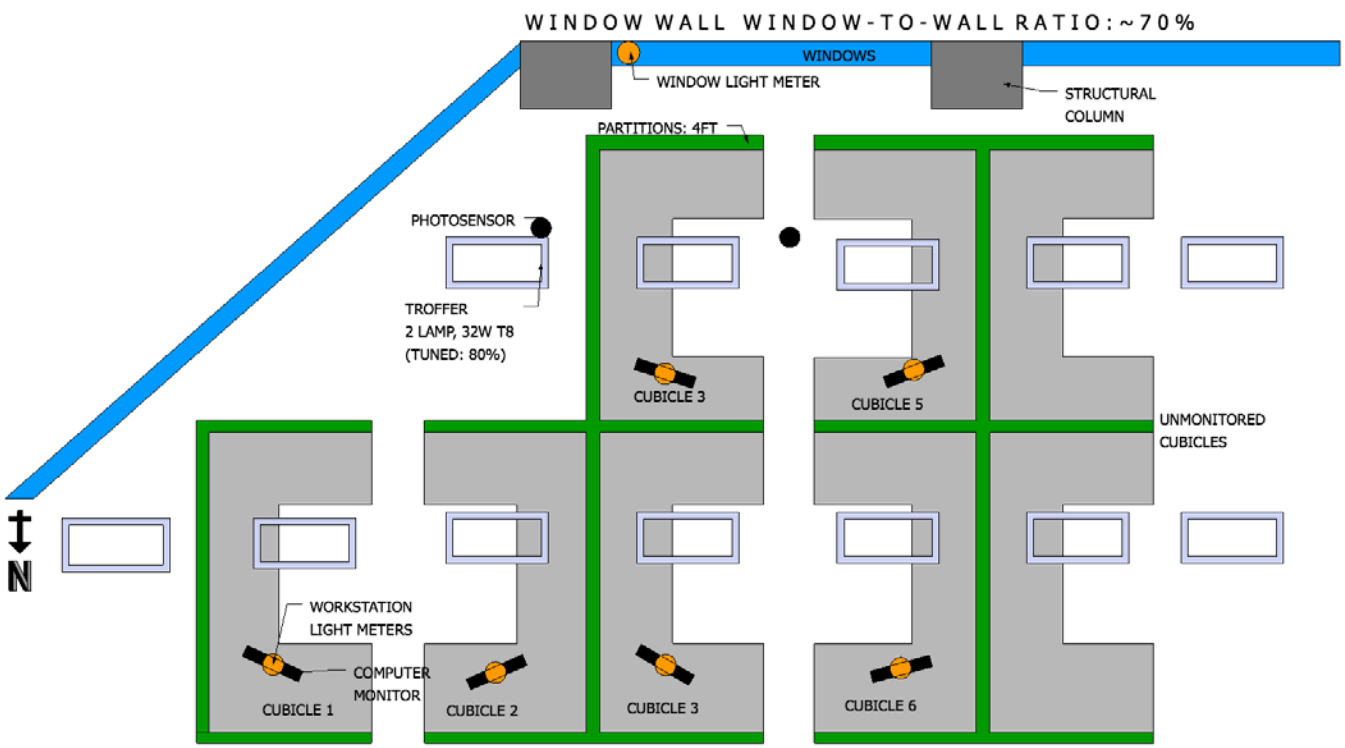


Figure 121: Plan view of Cottage Way site

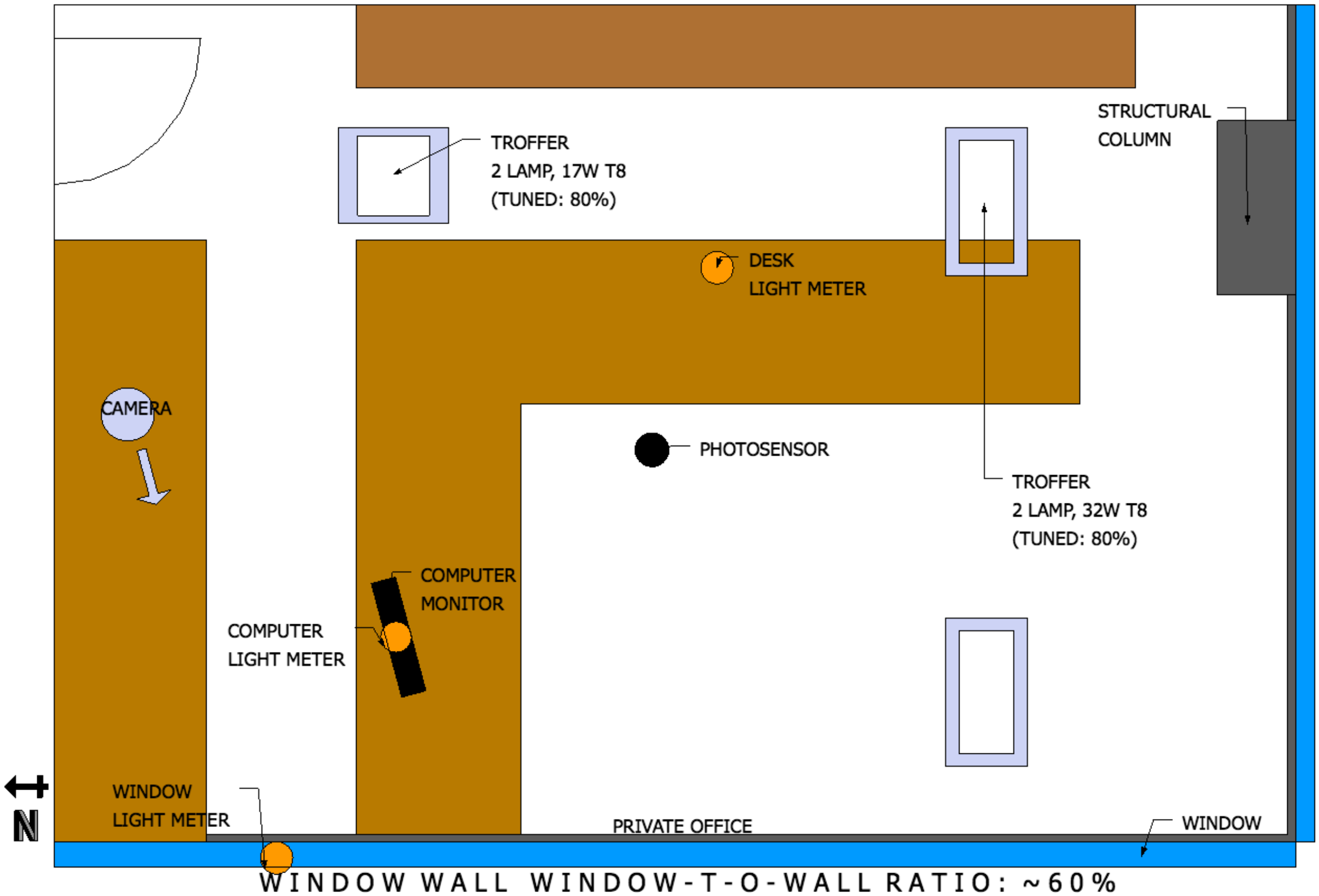


Figure 122: Plan view of Hammond site

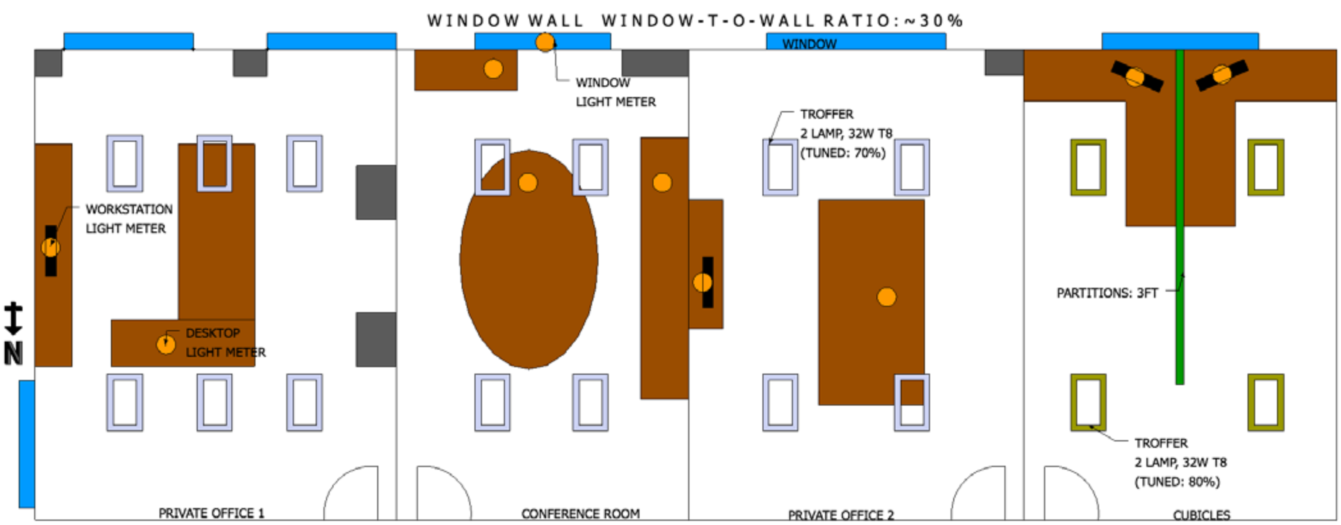
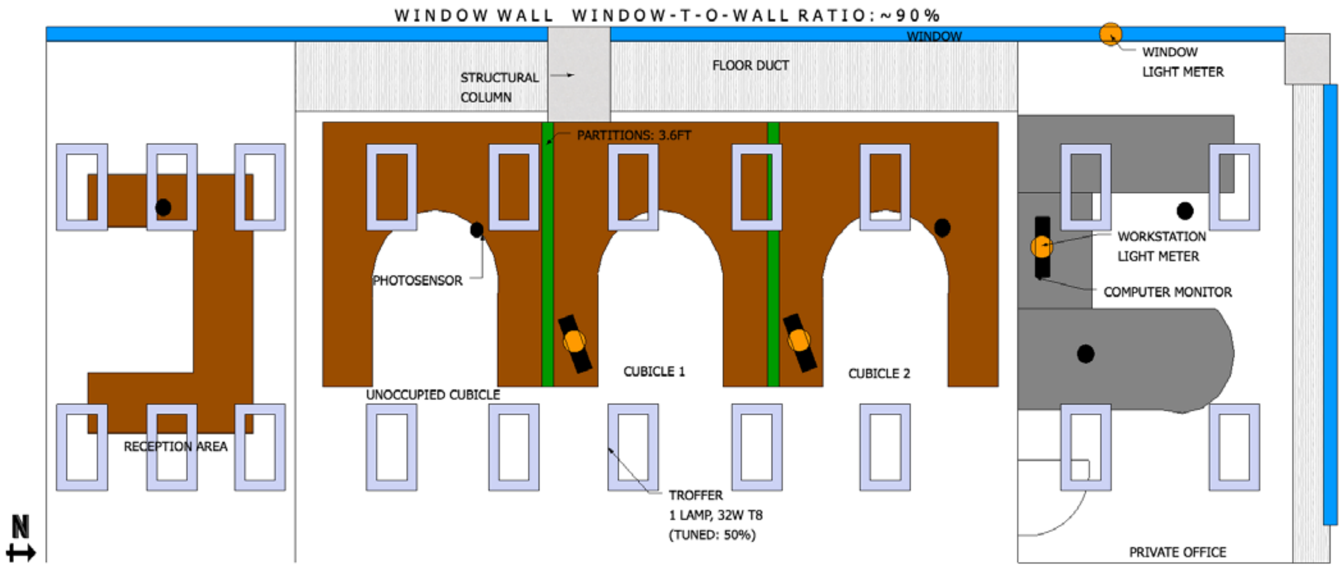


Figure 123: Plan view of Dirksen site



E. GLOBAL WARMING EFFECT CALCUALTIONS

The carbon intensity of electricity associated with the buildings monitored in this study are presented in below.

Table 50: Global Warming Effects of Electricity at Monitored Sites, for Regional and National Average Utility Fuel Mixes

Site	Regional GWE (g/CO2/kWh electricity)	National Average GWE (g/CO2/kWh electricity)
Ron Dellums	328	603
Roybal	328	
Cottage Way	698	
Hammond	698	
Dirksen	698	

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I. GLOSSARY

Advanced lighting controls	See Lighting controls.
Ambient light	General indirect lighting that illuminates the whole volume of a room softly.
Ballast	A device that regulates the current and voltage supplied to a lamp or lamps (e.g. a fluorescent lamp or LED).
Ballast Factor (BF)	The ratio of lumen output of lamps operated on a ballast compared to the lumen output of lamps operated on the reference ballast.
Commissioning	A process by which an installed building system is verified that it functions according to design objectives and/or specifications.
Control strategy	A particular method of regulating the timing or quantity of light levels in a space. See Lighting controls.
Daylight dimming	A control strategy that reduces electric light levels in the presence of available daylight, "harvesting" the daylight to save electrical lighting energy.
Diagnostics	A visual representation of a system (e.g. a lighting control system) that notifies the user of severe system faults, errors, or possible improvements.
DALI	DALI is short for Digital Addressable Lighting Interface; a two-way communication system which allows ballasts and control systems to "talk" to each other.
Dimmable ballast	A ballast that responds to external control signals by adjusting current flowing through the lamp(s), raising and lowering light output.
Energy Use Intensity (EUI)	A metric for characterizing energy use, defined as the amount of energy used in a space over a given time period divided by the area of the space and the time interval studied. In lighting, EUI is usually calculated in watt-hours per square foot per day or kilowatt-hours per square foot per year.
Fuel mix	The range of energy sources of a region, including both renewable and non-renewable sources. Also called an energy mix.
Global Warming Effect (GWE)	A metric for characterizing greenhouse gas emissions by summing the product of instantaneous greenhouse gas emissions and their specific time-dependent global warming potential. In this study, GWE was calculated for each utility provider (g CO2,eq /kWh electricity generated) and also normalized by floor area and calculated based off of annual energy savings (kg CO2,eq/ft2/year).
Greenhouse Gas (GHG)	A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range, resulting in the greenhouse effect in our atmosphere.

Hard timeout — The time difference between when an occupancy sensor registers an unoccupied event and when that event is logged in the control system.

IESNA acceptable light level — Illuminating Engineering Society of North America (IESNA) sets standards for light levels in different environments. For this study, the acceptable light level for an office task lighting is 350 lux.

Illuminance — The density of incident luminous flux on a surface. In less technical terms, a measure of the amount of incoming light reaching a surface.

Institutional / setpoint tuning — A control strategy which allows building managers and tenants to decrease energy consumption by programming default light levels with the lighting management system that reflect area and/or building policies.

Lamp — An electric light source. Also called a bulb or, in the case of linear fluorescent lamps, a tube.

Light sensor — See Photocell.

Lighting circuit — Wiring that provides power to light fixtures and ballasts.

Lighting controls — Systems that regulate the timing and quantity of light emitted by a light source. Advanced lighting controls include daylight harvesting, occupancy sensing, and institutional tuning.

Lighting Management Control System (LMCS) — A type of lighting control which allows operators control over a lighting system (either panel- or building-wide). Control configurations can be informed by schedules, institutional tuning, personal controls, as well as demand response.

Lighting Power Density (LPD) — A metric for characterizing the lighting power in a space at a given time, defined as the lighting power divided by the corresponding floor area. LPD is usually calculated in watts per square foot.

Luminaire — A complete lighting unit, including a light source, physical elements to distribute light, and the necessary electronics to power the light source.

Lux — The SI unit of illuminance, equal to one lumen per square meter.

Meta-analysis — A method of identifying patterns among multiple studies by comparing and combining results from the different studies.

Occupancy sensing — A control strategy in which lighting in a space is automatically turned on or off based on detected occupancy.

Occupancy sensor — A control device that detects the presence or absence of people.

Personal control A control strategy that gives occupants direct control over light operation and light levels.

Photometric characterization An analysis involving measured illuminances to assess the visible light performance of a lighting system.

Photocell/photosensor A sensor that detects the amount of light falling on its lens. Also called a light sensor.

Power metering A measurement strategy involving collecting power consumption data from various circuits.

Retrofit An addition or substitution to the current system. As related to this study, could involve any combination of activities from changing out lamp types to reconfiguring the lighting system.

RMS current The effective value of a current such that the heating effect is the same for equal values of alternating or direct current. RMS is an abbreviation for root mean square, a mathematical process of determining the effective value of an alternating current.

Standby power The power a device or system requires while in an off state.

Task lighting Directed lighting that focuses light output on a specific area within a workspace. Light location and levels depend on the tasks performed in the area.

Timeout A specified time period during which an area must remain unoccupied before occupancy controls shut off lights in that area.

Tuning A control strategy that caps light output below the maximum possible output.