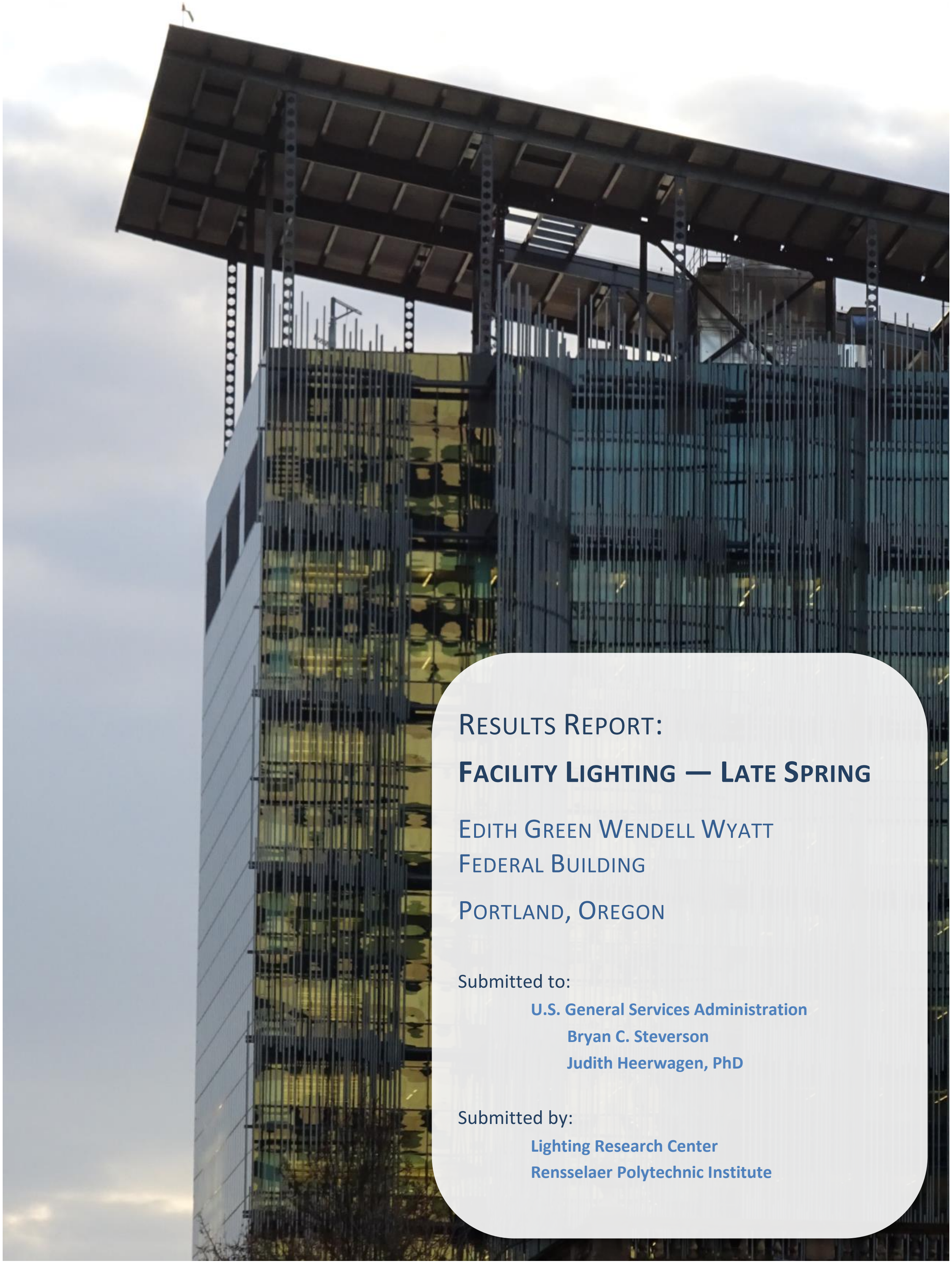

Results Report:

Facility Lighting — Late Spring

Edith Green Wendell Wyatt
Federal Building

Portland, Oregon

Submitted to:

U.S. General Services Administration
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Submitted by:

Lighting Research Center
Rensselaer Polytechnic Institute

RESULTS REPORT:
FACILITY LIGHTING — LATE SPRING

EDITH GREEN WENDELL WYATT
FEDERAL BUILDING
PORTLAND, OREGON

SUBMITTED AUGUST 12, 2014

V2: UPDATED/REVISED MAY 18, 2015

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EXECUTIVE SUMMARY

The Edith Green Wendell Wyatt (EGWW) Federal Building is a 525,000 square foot high-rise office building in downtown Portland, Oregon. This 18-story building accommodates over 1200 workers from 16 federal agencies, and is managed by the U.S. General Services Administration (GSA). The building was originally constructed in 1974 and underwent a major renovation between 2009 and 2013. Today the building is a cornerstone of GSA's green building portfolio with all new mechanical, electrical, plumbing and data systems designed to make it one of the most energy-efficient office buildings in the country.

On April 22-23, 2014, researchers from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute and GSA staff performed photometric measurements on open-plan deskspaces located on floors 4, 12, and 17. In addition to the field measurements, LRC placed Daysimeter devices on selected deskspaces to continously measure photopic lux and circadian light over the course of several days. Daysimeters measure continuous light exposures, allowing researchers to perform calculations of how much light that is effective for the circadian system may be reaching deskspaces (i.e., circadian stimulus, or CS).

Biological rhythms that repeat approximately every 24 hours are called circadian rhythms. Light is the main stimulus that helps the circadian clock, and thus circadian rhythms, synchronize with the 24-hour day. In other words, light tells our body to stay awake during the day and to sleep at night so that our sleep-wake cycle mirrors the earth’s 24-hour cycle of night and day (dark and light). Light of the appropriate quantity, spectrum, timing, duration, and distribution can have a profound effect on sleep, alertness, and performance, along with overall wellbeing. Lack of synchrony between our internal clock and the local environment (such as what happens when travelling across multiple time zones) has been associated with a series of maladies such as diabetes, obesity, cardiovascular disease, and cancer.

Based on the LRC’s previous work, CS values above 0.3 should provide enough circadian stimulation to maintain entrainment of circadian rhythms to the local time on Earth. Due to availability of daylight and ease of access, research has continued[1] to focus on open-plan offices. While Daysimeters placed at deskspaces in the building may not be representative of workers’ overall personal light exposures, they give an indication of how much circadian light is available in that part of the building. Another component of this research project, not discussed in this report, is the data collection of personal light exposures by building occupants.

The purpose of this report is to document measured photometric conditions as they relate to occupant visibility, comfort and circadian stimulus, as well as to document occupant behavior and acceptance of the lighting in their deskspaces. It is important to keep in mind that measurements were only made on one day with variable weather. Photometric

[1] Previous LRC/GSA site evaluations also focused on open-plan offices with proximity to daylight.

values will vary substantially in many spaces due to daily and seasonal changes in daylight.

Below are some of the main findings from the site evaluation:

- Deskspaces close to the windows receive greater circadian stimulation than those away from the windows. Lower level floors receive less circadian stimulation than higher level floors.
- Although all of the deskspaces measured met the target horizontal illuminance of 30 footcandles (approximately 300 lux), and most workers reported the amount of light on their desks was neither too much nor too little, some workers still felt the need to use task lights, while others complained about the space being "too bright" for computer use.
- The use of shades to reduce discomfort glare on perimeter deskspaces located on the east and south façades reduce vertical illuminances and circadian stimulation at these deskspaces, in particular on those located away from the windows.
- The use of reeds on the west façade helped increase light levels on perimeter deskspaces compared to other buildings, because shades were found to be open.
- Furniture layout at deskspaces located in the perimeter promotes circadian stimulation because workers are sitting in such a way that they are facing the windows, increasing exposure to light. However, this setting may also increase discomfort glare on sides where there is direct sunlight, explaining why the deskspaces on the south and east façade do not receive enough circadian stimulation.

INTRODUCTION

The Edith Green Wendell Wyatt (EGWW) Federal Building is a 525,000 square foot high-rise office building in downtown Portland, Oregon, and is managed by the U.S. General Services Administration (GSA). This 18-story building accommodates over 1200 workers from 16 federal agencies. The building was originally constructed in 1974 and underwent a major renovation between 2009 and 2013. Today the building is a cornerstone of GSA's green building portfolio with all new mechanical, electrical, plumbing and data systems designed to make it one of the most energy efficient office buildings in the country. EGWW earned LEED Platinum[2] in 2013.

The most distinctive exterior feature of EGWW is the "reed" structure on the west façade of the building; the south and east façades employ other external shading devices. The north façade of EGWW is not shaded (Figure 1).

Figure 1. EGWW is a newly-remodeled, high-rise office building with "reeds" on its west side (center) and other exterior shading devices on the south and east sides (lower).

[2] Leadership in Energy and Environmental Design (LEED) Platinum certification from the U.S. Green Building Council.

It should be noted that Portland's underlying street grid, and thus the building, is not oriented to true North. As a result, the nominal east side of the building faces slightly south, and the nominal south side faces slightly west. The skewed orientation impacts what time of day shafts of sun fall inside the building, and the need for shading elements to limit glare.

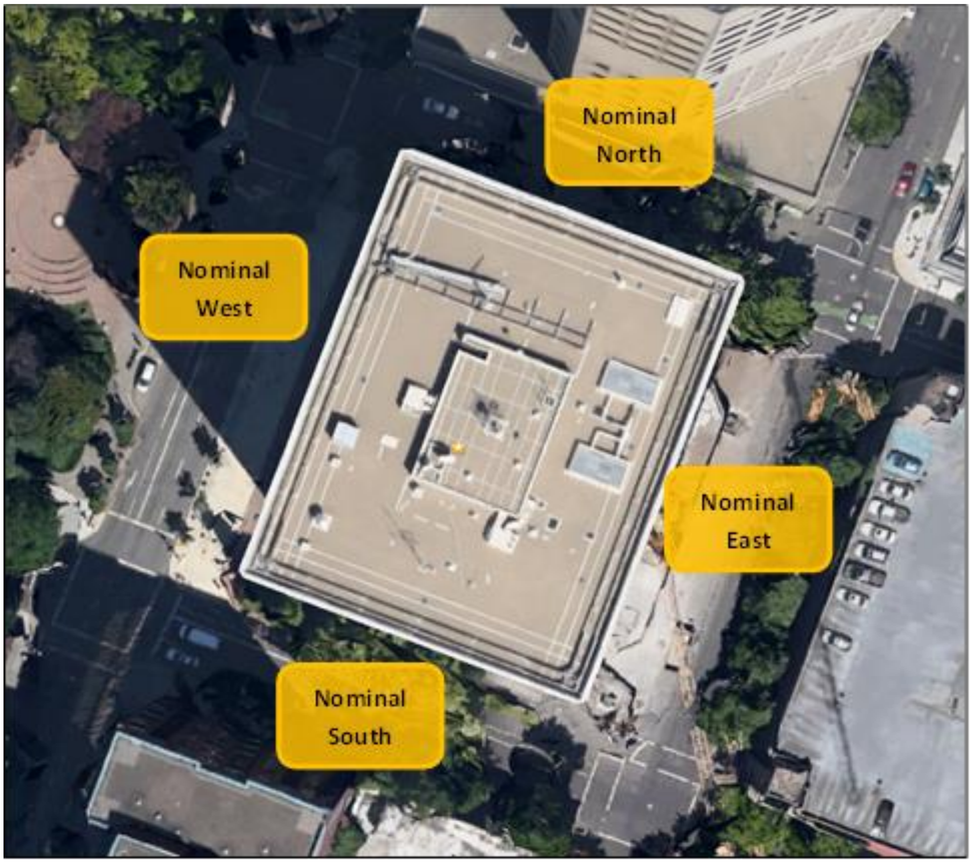


Figure 2. The EGWW building orientation is slightly skewed due to Portland's underlying street grid. The nominal east side of the building faces slightly south, while the nominal south side faces slightly west.

EGWW is also surrounded by other high-rise office buildings, some of which have mirror-type windows; some occupants did comment about reflected glare. (Occupant comments are further detailed in the Questionnaire Results.)

DAYLIGHT AND ELECTRIC LIGHTING DESIGN

The architects selected for the project were SERA Architects of Portland, Oregon. Their lighting narrative[3] stated that the lighting goals were energy efficiency and embrace of daylight:

"Maximizing daylight in the work areas is a primary goal of this project. Because this is an existing building, the existing structure at the windows is the limiting factor for daylight penetration into the space. Electric light, which will supplement daylight, will be primarily from a direct/indirect pendant mounted fixture."

As shown in Figure 3 below, linear fluorescent (T5HO) luminaires were specified in open-plan offices. The target illuminance on the work plane in open offices was 30 footcandles (fc), or approximately 300 lux (lx). LED task lights are available to augment the general lighting (Figure 4).

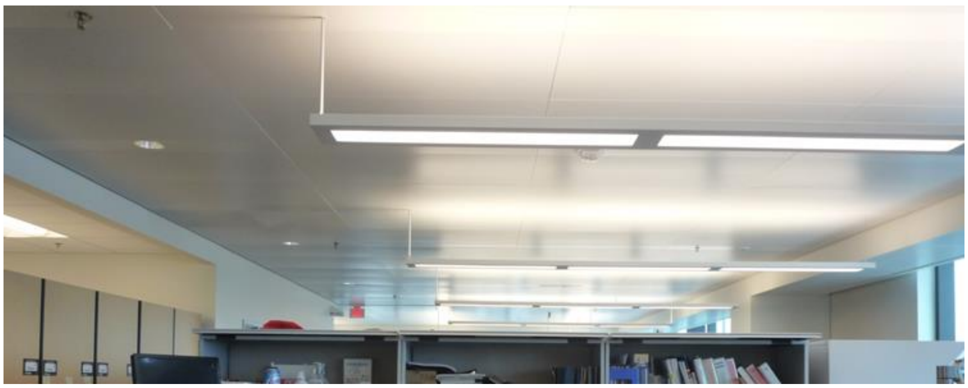


Figure 3. Linear fluorescent pendants provide the general lighting in open-plan offices at EGWW.

Lighting was designed with a daylight harvesting system that includes battery-powered wireless photosensors and dimming ballasts in linear fluorescent luminaires. The designers established zones in which electric lights are dimmed in response to daylight. On the north, east, and south sides of the building, the two luminaire segments closest to the windows are intended to be dimmed in response to daylight. The remaining luminaire segments, as well as the west side on the building are simply switched on and off by wireless occupancy sensor controls.

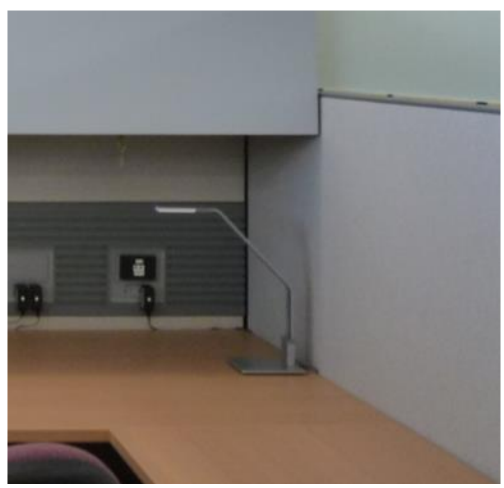


Figure 4. LED task lighting is available.

[3] SERA Architects "Snapshot 5" Lighting Narrative, undated.

In open-plan offices at EGWW, most desks are arranged in cubicles, with one row of desks (Row A) immediately adjacent to windows, and another row of desks (Row B) further from windows (see Figure 5).

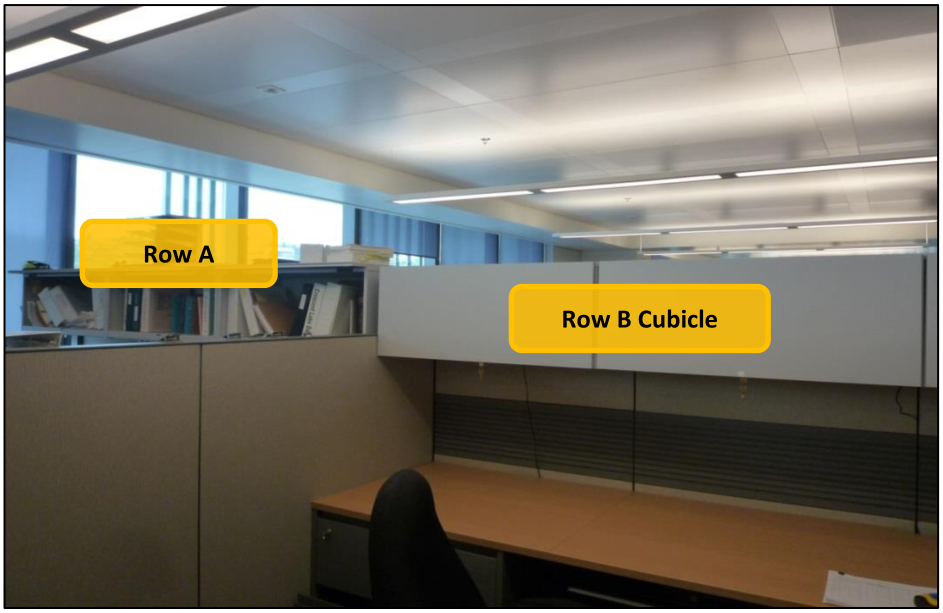


Figure 5. Typical cubicle offices in EGWW. Cubicles are arranged in rows: Row A is immediately adjacent to windows, while Row B is further from the window.

Perimeter windows consist of bands of tinted glass (59% visible transmittance, 0.3 solar heat gain coefficient). On the west façade, architectural "reeds" provide exterior shading. On the south and east façades, other exterior shading elements are used. Black mesh shades are also provided, and are adjustable by the occupants (see Figure 6).

Figure 6. As seen from inside, architectural "reeds" provide exterior shading on the west side of the building (left), while other exterior shading devices are used on the south and east sides (center). Adjustable mesh shades are also provided (right).

RESEARCH OBJECTIVES

The Lighting Research Center (LRC) conducted photometric measurements at EGWW in late spring 2014. The goal of the research was to measure photometric conditions as they relate to occupant comfort, productivity, and circadian health.

The evaluation took place on April 22-23, 2014. Daylighting conditions were similar to summer, as sunset occurred after 8 pm. The LRC researchers included Dr. Mark Rea (LRC Director), Dr. Mariana Figueiro (LRC Light and Health Program Director), and Jennifer Brons (LRC DELTA Program Director[4]). The LRC team was escorted and assisted by Frederick Moorehead, Bryan Steverson, and Paul Witherspoon of GSA.

Figure 7. Dr. Mark Rea collecting data at EGWW.

[4] The Demonstration and Evaluation of Lighting Technologies and Applications (DELTA) program is a case study program run by the LRC to design, evaluate, and publicize energy-efficient lighting solutions.

METHODS

On Day 1 (April 22), measurement locations were identified and set up at two rows of desks on three floors with open-plan offices (floors 4, 12, and 17). The locations of the deskspaces were chosen to represent the four building orientations. Also on Day 1, questionnaires were administered and battery-powered measurement equipment was installed and documented.

Data collection started on the evening of Day 1, then resumed at 8:30 a.m. until 4:00 p.m. on Day 2 (April 23). Each member of the research team was responsible for one aspect of data collection (detailed below). Two researchers collected illuminance and luminance measurements while one researcher performed all of the spectral power distribution measurements and placed the Daysimeter devices in stationary positions on the selected deskspaces. Questionnaires were also administered on Day 2.

Six types of measurements were undertaken at EGWW.

ILLUMINANCE

Illuminance is a measure of the amount of light falling on a surface, in units of lux (lx [SI]) or footcandles (fc [in the U.S.]). Illuminance measurements are important because they are used conventionally as design criteria. LRC measured illuminance multiple times over the measurement day, on horizontal and vertical surfaces, at desks on three floors, and at all window orientations. Two researchers collected these illuminance data using Cooke Hagner (model E207 01X) and Gigahertz-Optik (model X91) lux meters.

LUMINANCE

Luminance is a measure of the amount of light emitted or reflected by a surface. Luminance relates to perceptions of brightness and glare. Luminance is measured in units of candela per square meter (cd/m^2), using a meter device that resembles the viewfinder of a camera aimed at luminous surfaces. Because viewing position impacts luminance, measurements were collected at the desk chair location when facing key surfaces, such as a computer monitor, and the nearest window. Two researchers collected luminance data using Minolta (models LS-110 and LS-100) luminance meters.

SPECTRAL POWER DISTRIBUTION (SPD)

SPD is a measure of the wavelengths of light in the visible spectrum (380-770 nanometers [nm]). SPD will vary between light sources as well as time of day. SPD was measured at EGWW to allow researchers to calculate, using different response functions, measures such as brightness, glare, and circadian stimulus. SPD data were collected on the 4^{th}, 12^{th} and 17^{th} floors at EGWW. A researcher collected these data at EGWW using a spectroradiometer system consisting of an Ocean Optics (model USB650) spectrometer and a remote sensor, as well as a laptop. Raw SPD data were collected using the spectroradiometer system, and post-processed using Matlab version R2012a to generate curve functions.

Daysimeter photopic and circadian light exposure devices

Daysimeter devices collected continuous light exposures that allowed researchers to perform calculations of how much light that is effective for the circadian system was reaching deskspaces. Briefly, light sensing by the Daysimeter is performed with an integrated circuit (IC) sensor array (Hamamatsu model S11059-78HT) that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR). The R, G, B, and IR photo-elements have peak spectral responses at 615 nm, 530 nm, 460 nm, and 855 nm, respectively. The Daysimeter is calibrated in terms of orthodox photopic illuminance (lux) and of circadian illuminance (CL_A). CL_A calibration is based upon the spectral sensitivity of the human circadian system. From the recorded CL_A values it is then possible to determine the circadian stimulus (CS) magnitude, which represents the input-output operating characteristics of the human circadian system from threshold to saturation. These measurements are representative of light exposures one would receive while sitting at the desk working at a computer. However, it may not represent the person's daily light exposures, such as exposure to outdoor lighting to and from work. Daysimeter devices were installed at 24 desks and 12 windows. These collected data for at least 21 days after LRC researchers visited the site. These were removed by Mr. Moorehead after 3 weeks on site, and were returned by mail to the LRC for read-out.

Luminaire activity

The LRC placed battery-powered light meters atop operating luminaires to confirm whether the lights were dimming in response to daylight. These devices were set to collect data for 10 days after LRC visited the site. These were removed by Mr. Moorehead after 2 weeks on site, and were returned by mail to the LRC for read-out.

Questionnaires

The LRC administered questionnaires to 25 employees at EGWW. The questions were the same as LRC used at other GSA site evaluations, with an additional question about the use of mesh window shades.

RESULTS

ILLUMINANCE RESULTS

LRC researchers measured photometric conditions (illuminance and luminance) at the locations shown in Figure 8 below. Photometric data were organized by perimeter proximity, by perimeter window orientation, and by collection time. Data were collected for 24 desks: eight per floor, on three floors. The weather was primarily cloudy and rainy, but there were occasional shafts of sun on the measurement day.

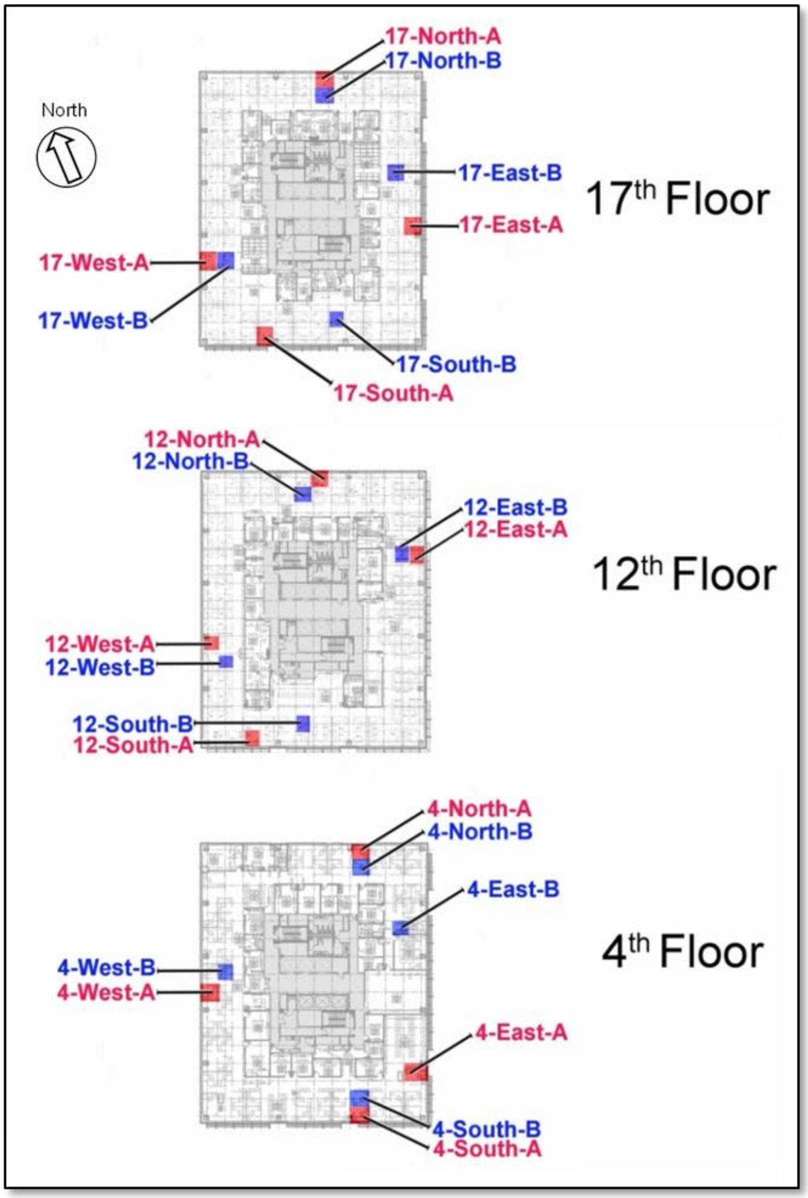


Figure 8. Locations of desks hosting repeated Illuminance and luminance measurements. Desks marked A are in Row A, nearest the windows, while desks marked B are in the adjacent row, Row B.

The resulting measurements are shown below, and in detail in Appendix A.

Figure 9 (at right) shows an example of typical horizontal and vertical illuminance measurement locations at the 24 desks. Measurements occurred in the morning, midday, in the afternoon, and after dark. Measurements included additional daylight contribution, and reduction of electric lighting in response to daylight (see Luminaire Activity).

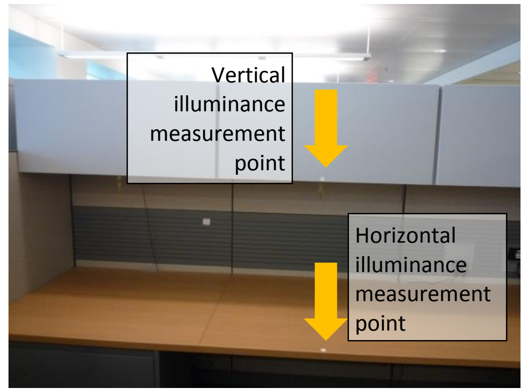


Figure 9. Typical horizontal and vertical illuminance measurement points.

Figure 10 below shows the results of horizontal illuminance measurements on the 24 desks. The horizontal illuminance measurements show higher overall light levels on the north side of the building at the A desks; mesh shades on the east, south, and west side of the building showed lower light levels than the north side A desks. Windows on the north side of the building have mesh shades, but because the sun is diffusely reflected before entering the north windows, the use of shades may be less prevalent than other orientations.

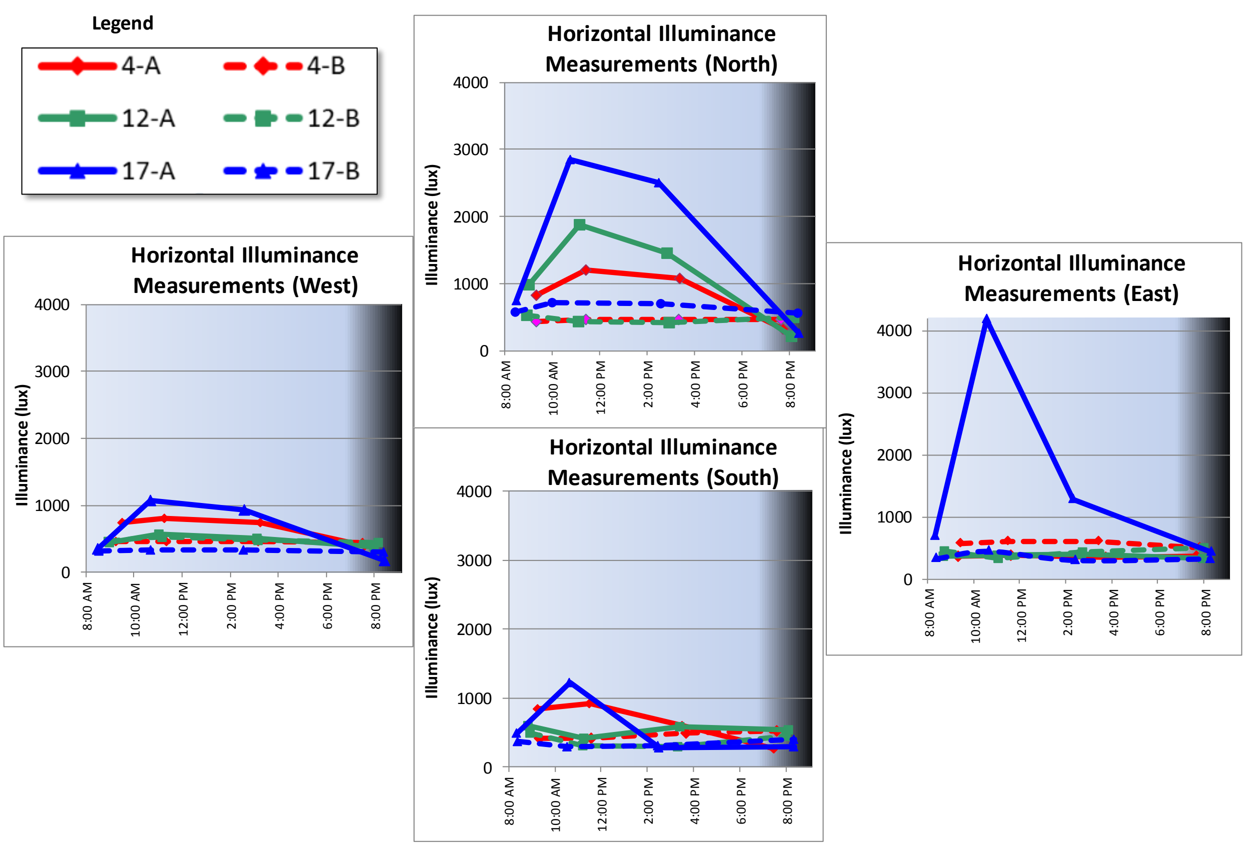


Figure 10. Horizontal illuminance measurements at 24 desks, during the day and in the evening.

On the east side of the 17th floor, there was a shaft of sun at the midday measurement time; this represents a potential source of glare. At the B desks, measurement points achieved the design illuminance target (323 lx, 30 fc) throughout the day.

Figure 11 below shows the results of vertical illuminance measurements on overhead desk shelving. Measurements occurred in the morning, midday, in the afternoon, and after dark. Measurements included additional daylight contribution, and reduction of electric lighting in response to daylight.

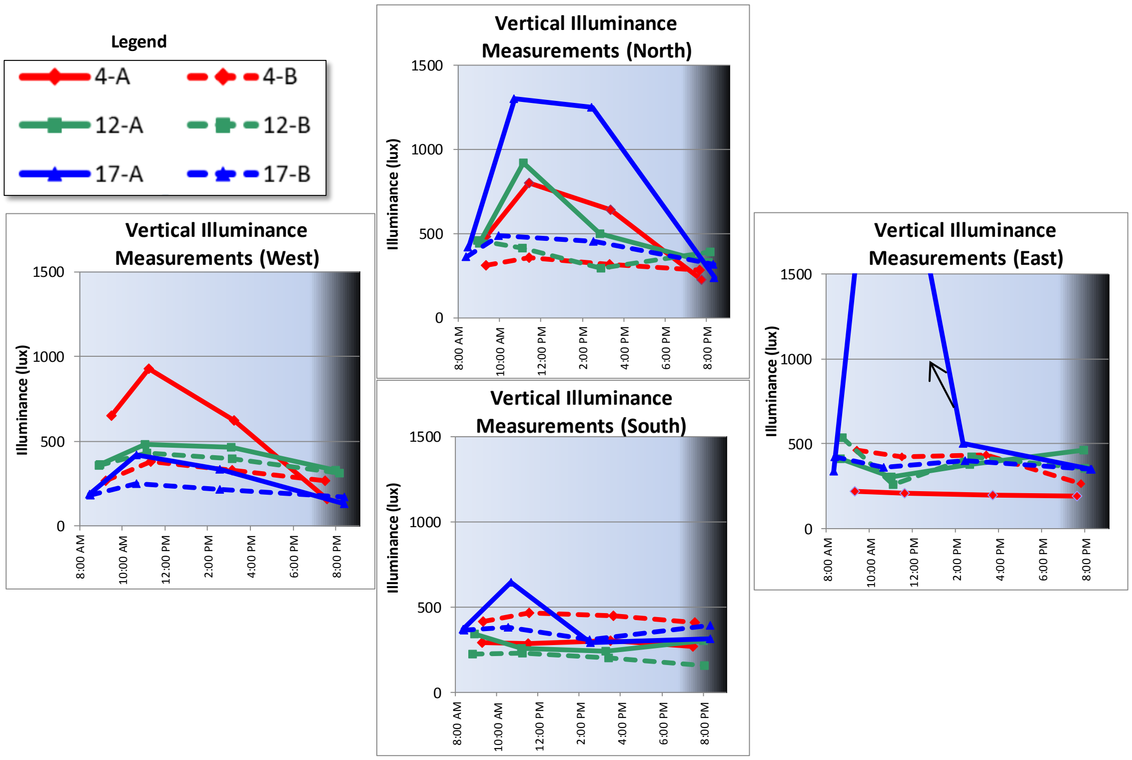


Figure 11. Vertical illuminance measurements at 24 desks, during the day and in the evening.

Once again, the vertical illuminance measurements showed higher illuminance at Row A compared to Row B. Once again the highest illuminances overall were on the north side. Vertical illuminances were not always higher on upper floors than lower floors. At the B desks, there was not much variation in vertical illuminance throughout the day, apart from a shaft of sun falling near the measurement point at midday on the east side, 17th floor.

Luminance Results

The LRC measured luminance at the same time interval and desks locations used for illuminance measurements (see Figure 8). For each of the A desks and many of the row B desks, LRC measured luminance of the nearest window during the daytime measurements.

As shown in Figure 12, the highest luminance was the midday measurement at the east-facing window on the 17th floor (16,770 cd/m^2). Window luminance was highest at midday measurements, particularly on the south side. Window luminance was higher at A desks compared to B desks. Floor elevation was not predictive of window luminance; upper floors did not consistently produce the highest window luminance.

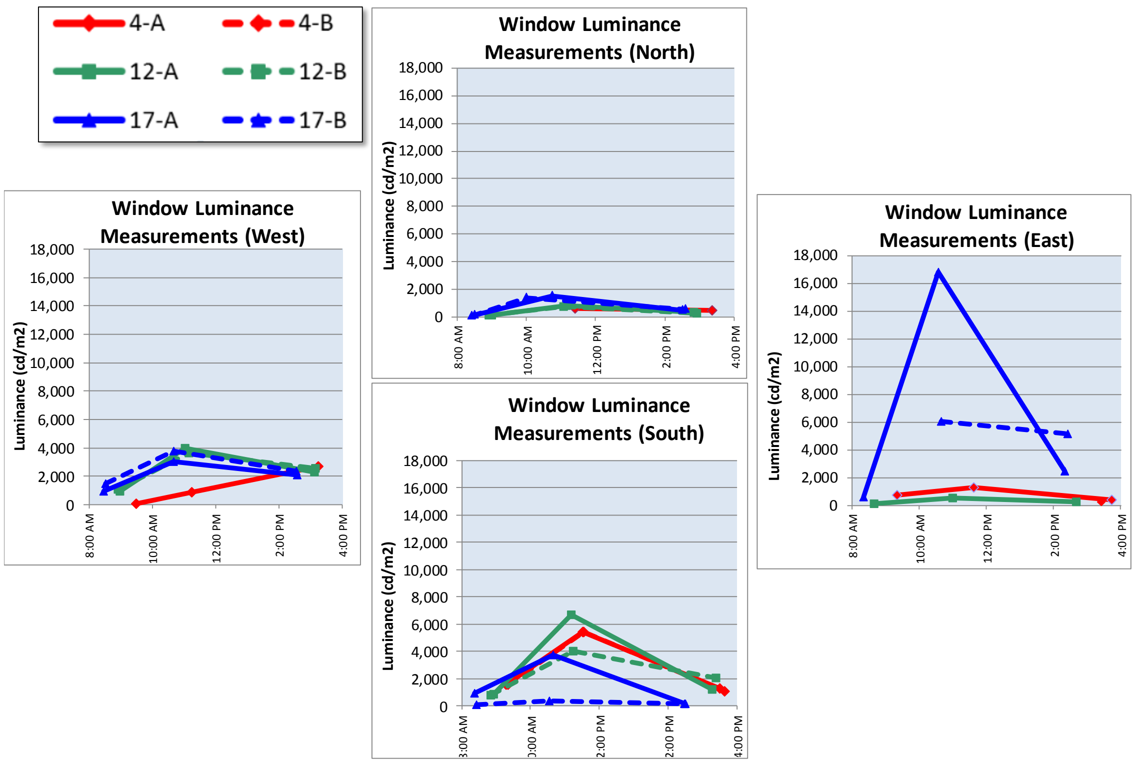


Figure 12. Window luminances during measurement day (Day 2).

The LRC also measured luminance of the key surfaces commonly viewed at the desk: on the desk and on the computer monitor bezel. As shown in Figures 13 and 14 below, the desk typically has higher luminance than the computer bezel because it is a more reflective (lighter) color. When the eye shifts from these lower luminance surfaces to the window, cubicle occupants may experience glare.

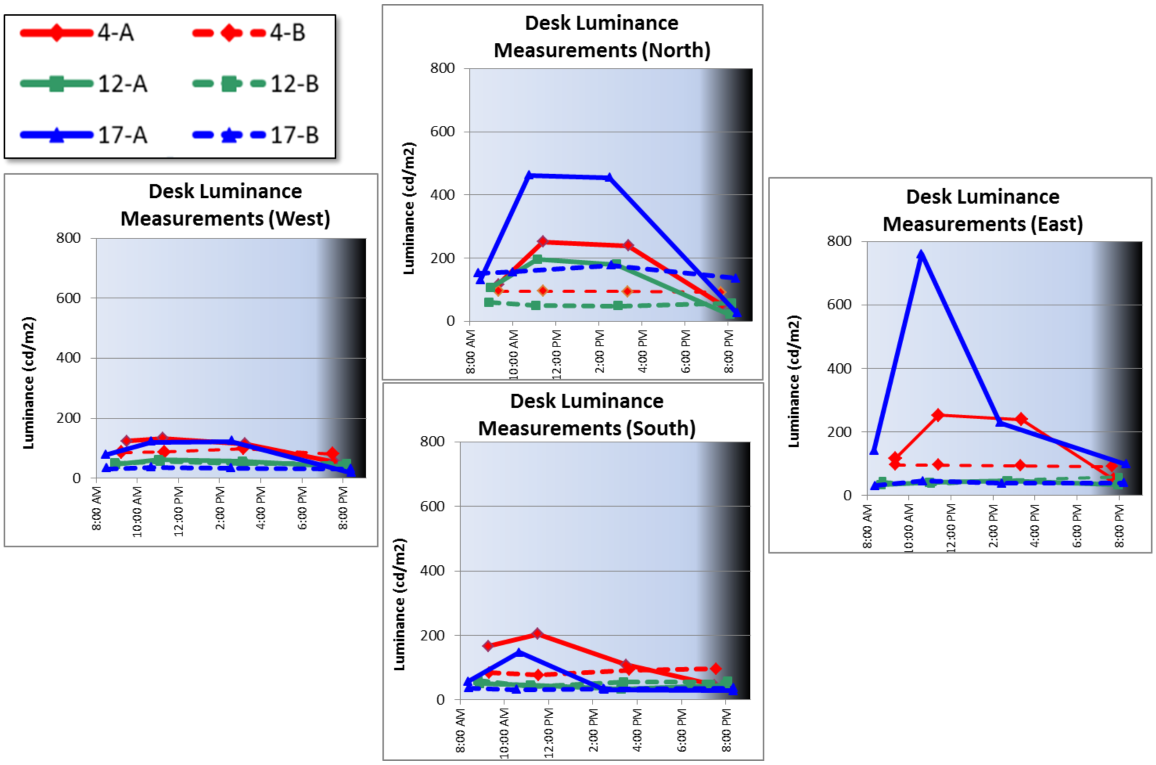


Figure 13. Desk luminances at different orientations.

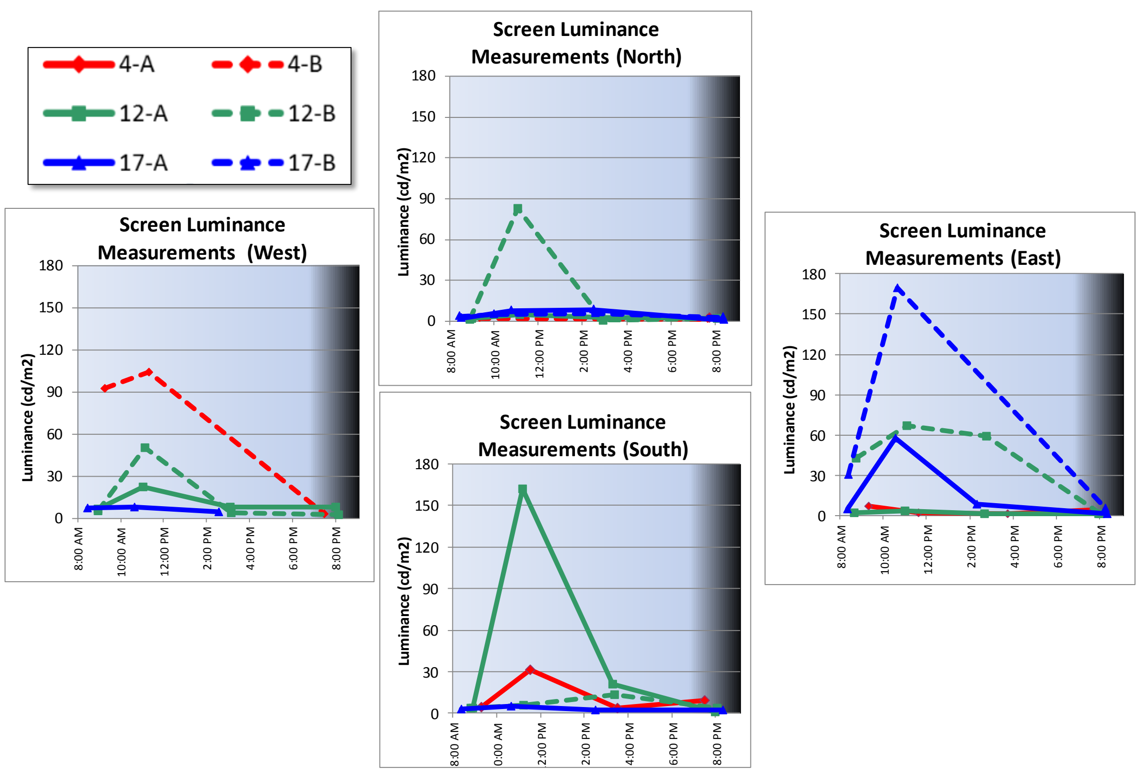


Figure 14. Screen luminances at four different orientations.

LUMINAIRE ACTIVITY RESULTS

The LRC placed 12 battery-powered light meters on top of operating luminaires to verify whether the lights were dimming in response to daylight (Figure 15). The devices were placed in luminaires located in the same control zone as the desks where illuminance measurements took place on floors 4, 12, and 17.

An example of a typical dimming profile is shown in Figure 16. The devices were set to record for 10 days: 3 work days, a weekend, and another 5 work days. As annotated, when the relative light output reduces in the middle of the day, this indicates that the luminaire is being dimmed by the photo-sensor. On weekends, luminaires are mostly off, thus monitoring devices measured less light.

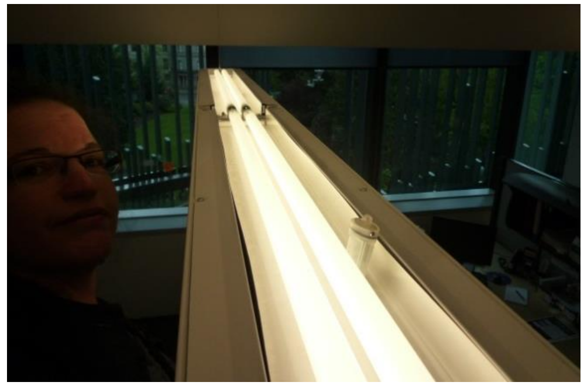


Figure 15. LRC researcher installs a battery-powered light meter in a luminaire at EGWW.

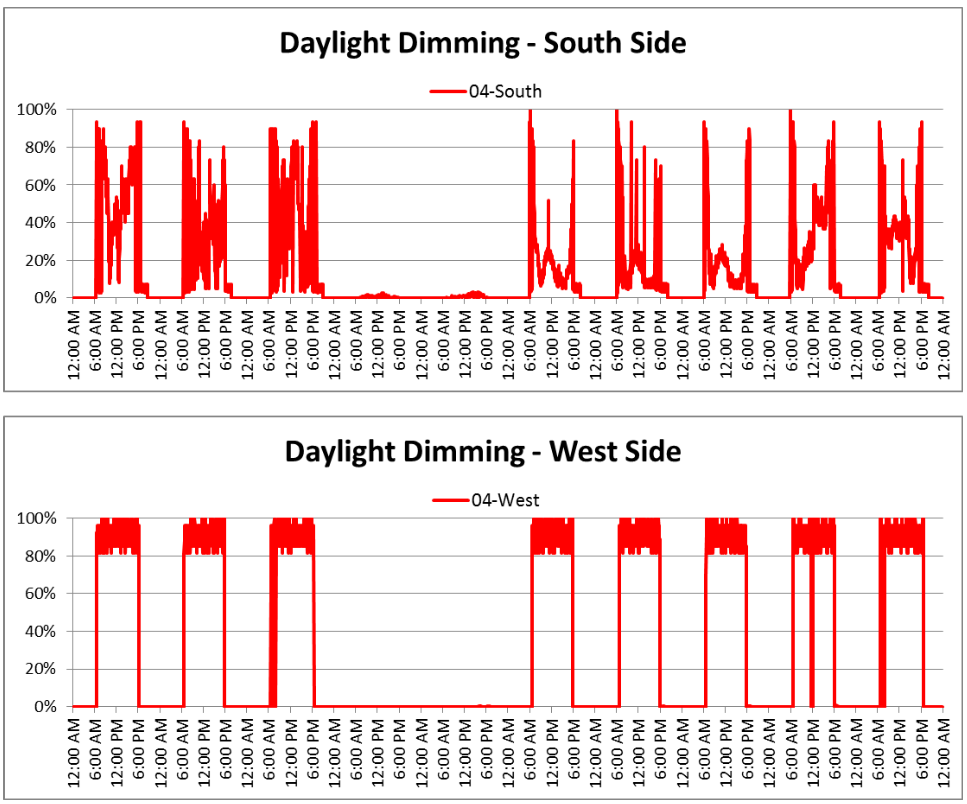


Figure 16. Dimming in EGWW. As expected, electric light output is reduced during the day on the south side (top), and not on the west side (bottom).

As shown in Appendix B, monitoring confirmed that dimming occurs at EGWW, but not in all areas, nor every day during this spring evaluation period.

On the east side, dimming occurs in the morning on floors 4, 12 and 17. On the south side, dimming occurs on all three floors throughout the day, even turning lights off entirely.

Luminaires on the north side showed minimal dimming. However, illuminance measurements showed that desks closest to the window had light levels 2-4 times higher than the target illuminance (30 fc) even on a cloudy day. It is possible that the photosensor controls on the north side could be recommissioned to save energy.

As expected, the lights on the west side do not dim in response to daylight. However, the data do reveal that the occupancy sensors in this area do sometimes turn off despite the space being occupied. LRC received a comment from an occupant about lights turning off; building personnel were notified and immediately began the process of adjusting the programming to reduce occupant annoyance. Even after this adjustment, monitoring data demonstrated one area (17th floor, west side) with frequent switching consistent with the need for occupancy sensor adjustment.

Questionnaire Results

LRC researchers administered a brief questionnaire to 25 people working in EGWW. Appendix C shows detailed questionnaire results. Where possible, the questionnaire data for EGWW were compared to results from other office case study publications and to the GSA evaluation site at Grand Junction, Colorado[5] (see References).

EGWW questionnaire respondents were located on all four sides of the building, and on several different floors. Most respondents work in open-plan offices (96%). Most (84%) only work during the day, which was similar to the Grand Junction site.

Workers answered the questionnaire on both days that the LRC evaluated the site. For much of that time, skies were cloudy and rainy; despite the weather, other data (see Appendix B) indicate that the electric lights were dimming in response to daylight when many of the people responded to the questionnaire.

Most workers were satisfied by the amount of light provided; 72% reported that the amount of light on their desk was neither too much nor too little. A few commented that they would prefer a darker work environment. Over-lighting was not a problem at this site; measurement data (see Illuminance Results) confirmed that the minimum target illuminance (30 fc) is being provided in most cases.

Use of task lights at EGWW was reported by over half of the respondents. At EGWW, 16% reported that they “always” use a task light, compared to 31% at Grand Junction.

Mesh window shades are often adjusted by the EGWW occupants, partly due to changes in weather, and partly due to time-of-day sun position. Over a quarter (28%) reported that they keep shades up all the time. Almost half (40%) reported opening the shades fully when the weather is cloudy; in fact, researchers noted that 48% of the respondents had shades up when responding. Respondents most commonly (40%) reported pulling shades down when the weather is sunny; since it was mostly cloudy during the visit, only 8% of shades were fully down when the questionnaire was administered. In addition to weather

[5] Wayne N. Aspinall Federal Building in Grand Junction, Colorado.

and time of day, a few people commented that the glare from neighboring buildings motivated their use of mesh shades.

Most respondents (83%) reported that the windows at EGWW are comfortable to look at; this is more positive than the January responses (56%) from the Grand Junction site. Most EGWW respondents (79%) also rated their luminaires as comfortable to look at; this compares favorably to the Grand Junction site (50%), and is similar to other LRC office lighting case studies.

Overall, compared to other offices, the lighting at EGWW was rated as "better" or "much better" by about half (56%) of the respondents. About a third (32%) considered the lighting to be "about the same." As shown in Figure 17 below, these results are similar to other office lighting case studies, and more positive than the Grand Junction site.

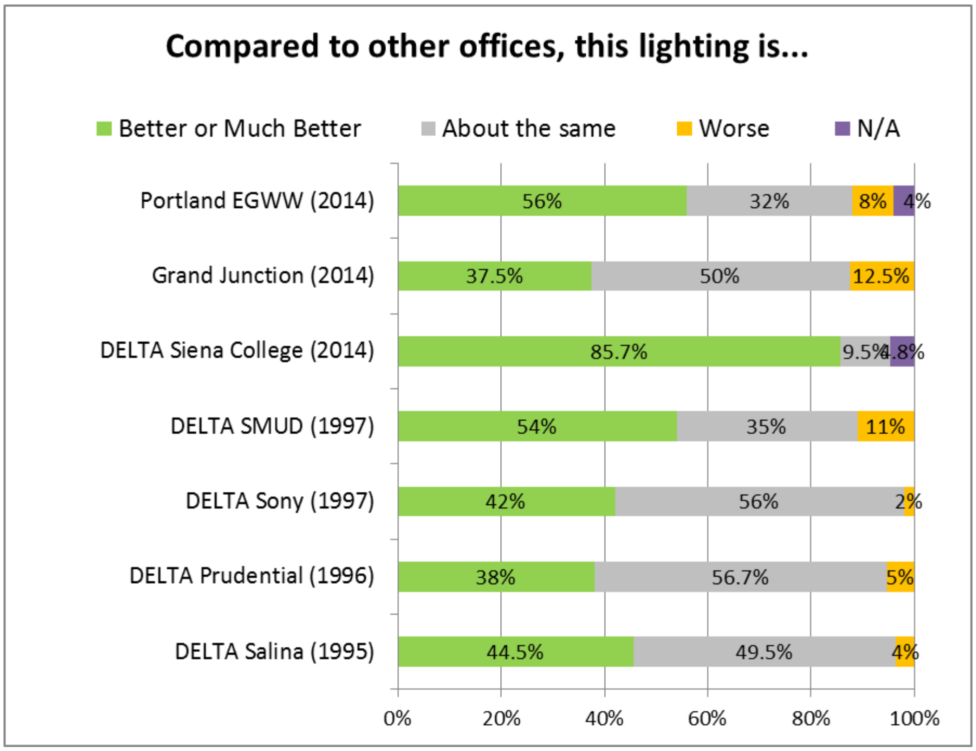


Figure 17. Overall questionnaire results at EGWW, compared to other office lighting evaluations by the LRC.

Spectral Power Distribution (SPD) Results

Shown at right is a photo of the equipment used for measurement of spectral characteristics (Figure 18). The measurement probe was held at the eye and aimed at the computer screen to simulate the eye position of the person working at each desk. Measurements were collected three times during the day, as well as after dark, with only electric light and no daylight contribution.

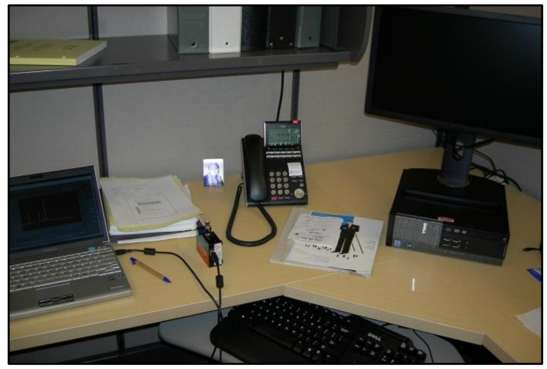


Figure 18. A spectroradiometer taking measurements at desk level.

As shown in Figure 19, SPDs were measured at the same desk locations as used for hosting other measurement equipment (see Daysimeter Stick and Window Results).

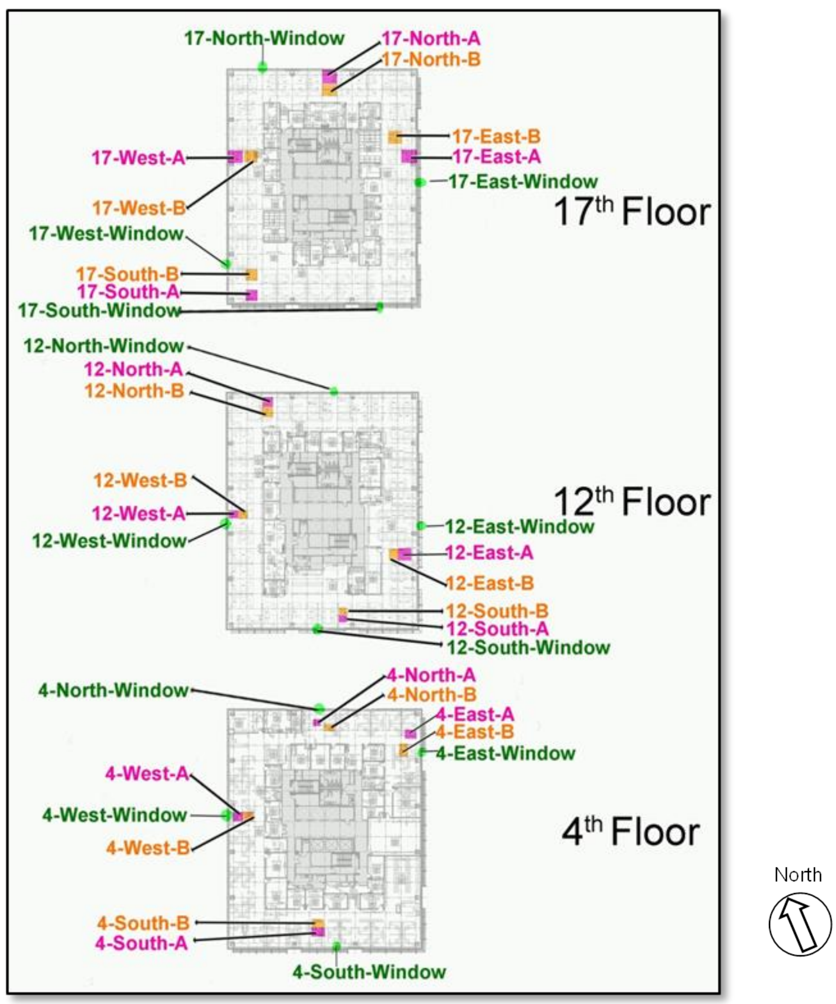


Figure 19. SPD measurements were collected at desks in Rows A and B desks on three floors; the same locations were used to host other measurement equipment.

The SPD measurements were later used to calculate the percentage of daylight and electric light in the space, as well as photopic lux and circadian stimulus.

Relative visual performance (RVP), or the speed and accuracy of reading, are high (RVP > 0.95) for all conditions, because the computer monitors provide high contrast/large font size, and any printed materials are illuminated to at least 30 fc (approximately 300 lx) on the desk surface (horizontal illuminance).

Detailed results are shown in Appendices D-G. The following table shows average results during the daytime measurements (excluding evening measurements, since workers are not present after dark).

Table 1. Average daytime measurements using spectroradiometer

Deskspace Locations	Lux	Fluor %	Day %	CCT(K)	CL_A	CS	Bright-ness
A	865	30%	70%	5321	1178	0.446	709
B	344	81%	19%	3632	344	0.288	230
Orientations							
E	675	59%	41%	4272	836	0.360	514
N	1001	40%	60%	5017	1375	0.490	812
S	302	65%	35%	4170	329	0.288	217
W	413	57%	43%	4396	462	0.324	313
Floors							
4	415	68%	32%	3968	439	0.328	292
12	487	63%	37%	4242	595	0.343	369
17	896	35%	65%	5175	1224	0.426	733

These data show the impact of window proximity on light exposure. At many of the A-desk measurements, CS values were above 0.3, which is considered the lower end of the threshold boundary for circadian stimulation. Most of the measurements at the B deskspaces on the south and west sides of the building had CS values below the desired amount.

The table also demonstrates that workers on the north side of the building were exposed to higher light levels than the other sides of the building. Consistent with our observations in other buildings, the use of shades to remove direct sunlight on the other façades reduces the amount of available daylight. The data also show that occupants of the 17th floor were exposed to higher light levels than lower floors. These data are, however, snapshots of what the exposures are over the course of the working day. Daysimeter measurements, discussed below, may be a better representation of the continuous light availability during the workday.

Daysimeter Stick and Window Results

Appendices H-J show the hourly average from 8:00 a.m. to 5:00 p.m. of the CS values and the photopic lux values for each Daysimeter. In general, the deskspaces located near the windows (Row A) had the highest potential for delivering the highest circadian stimulation, especially between 10:00 a.m. and 3:00 p.m. As expected, the deskspaces located on the north side tended to have the greatest CS values, given that shades were up most of the time. CS values also tended to increase from the 4^{th} to the 17^{th} floor. In fact, all deskspaces facing north that were close to the window (Row A) had CS values above 0.3, the lower end of the threshold boundary for circadian stimulation. Deskspaces located away from the windows (Row B) had CS values below the desired amount in the 4^{th} floor; Row B desks on the 12^{th} and 17^{th} floor showed CS values at or above 0.4 on the north and east sides. These results are consistent with the spectroradiometer measurements previously described. Except for a few deskspaces located in the south and east façades that did not have the shades pulled down and, therefore, had vertical light levels above 1780 lx, all other deskspaces had light levels that are likely to be within the comfort range for glare. Some deskspaces had light levels that were bordering discomfort (between 900 lx and 1780 lx).

There was one interesting case on the 4^{th} floor, where sun reflected from a building across the street hit the window sill of a deskspace in Row A and reflected light directly onto the worker's eyes, causing a very high rating of discomfort glare. The occupant covered the window sill with cloth and added a "personal shade" to her deskspace to mitigate the problem (see Figure 20).

Figure 20. One worker used fabric and cardboard to limit direct and reflected glare.

With the exception of a few desks on floors 12 and 17, the deskspaces located in the south façade had CS values ranging from 0.03 to less than 0.3. The main reason for the lower light levels in this part of the building was the shade use; the shades tended to be pulled down because of sunlight penetration. One difference noted in this building was that the deskspaces located close to the perimeter on the west side had enough circadian stimulation because shades were generally up. This was because the "reeds" helped reduce sunlight penetration in the space, making it possible for workers to keep their shades up and still comfortably perform their computer and paper work.

Overall, while these measurements cannot be considered representative of the daily light exposure that office occupants are experiencing, it gives the researchers an idea of the potential for receiving enough circadian stimulation at these deskspaces. In summary, those workers located in the perimeter of the building on the north side and at higher floors are likely receiving the ideal dose of daily circadian light.

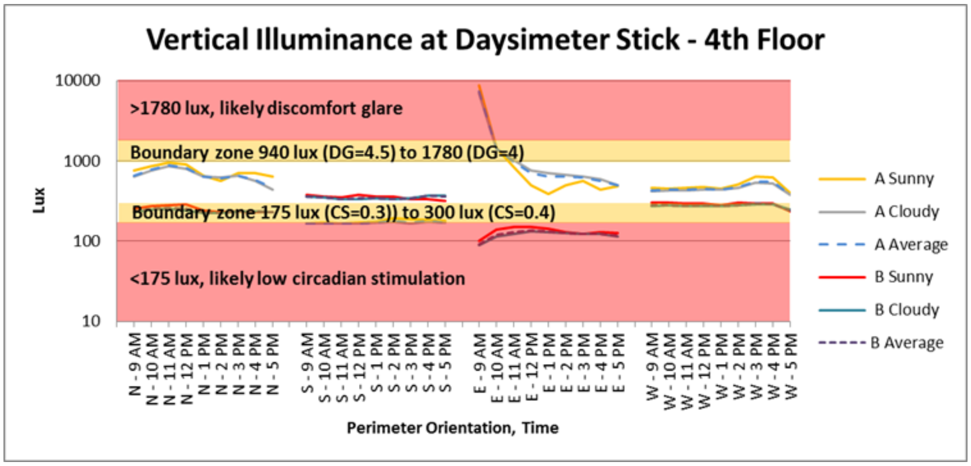
DISCUSSION

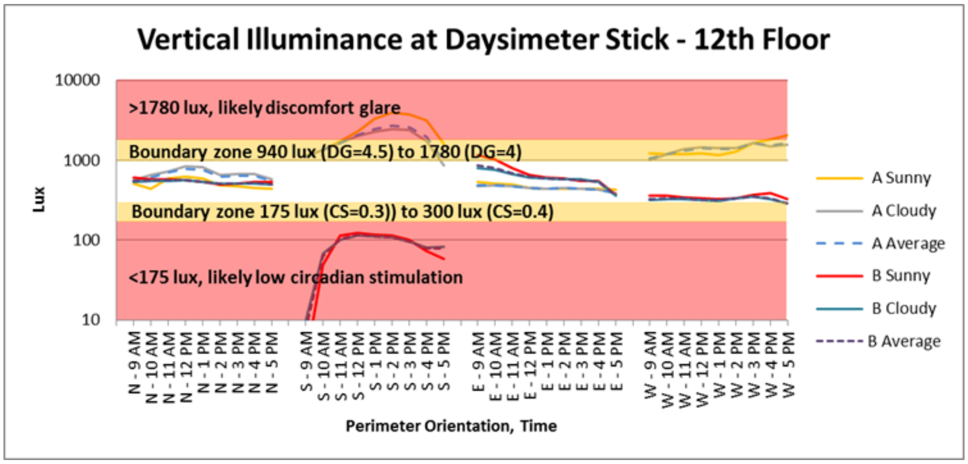
A summary of the findings is shown in Figure 21. Pink-shaded portions of the figure reflect areas likely to cause discomfort glare (DG), above 1780 lx, or likely to provide low circadian stimulation (CS), below 175 lx, for a daylight source. The yellow-shaded boundary, between 940 lx and 1780 lx, is considered at or near threshold for evoking a discomfort glare response from occupants. The lower end of the threshold boundary for discomfort glare represents a DG rating of 4.5 whereas the upper boundary represents a DG rating of 4.0. The yellow-shaded boundary, between 175 lx and 300 lx, is considered to be at or near threshold for reliable stimulation of the human circadian system. The lower end of the threshold boundary for circadian stimulation represents a CS value of 0.3, whereas the upper boundary represents a CS value of 0.4.

The "ideal" vertical levels of photopic illuminance from daylight, lower than the discomfort glare threshold boundary and above the circadian stimulus threshold boundary, are between 300 lx and 940 lx. Except for one deskspace on the south side, all other deskspaces on the 17th floor were above the desired CS value. The fact that CS values are below 0.3 at night is actually desirable to help reduce circadian stimulation for those who might be working after normal working hours (e.g., evening hours). Perimeter deskspaces on the 12th floor achieved the desired circadian stimulus most of the time, as did north and east interior (Row B) offices. On the 4th floor most of the measurements met the criterion, except for the south side and the interior (Row B) desks.

Several caveats should be stressed, however:

- CS values are based upon melatonin suppression for a standard observer after one hour of light exposure. Longer exposures to light are probably sufficient to entrain subjects, but estimates of the trade-off between level and duration are not available. Functionally, CS levels as low as 0.1 may be sufficient for circadian entrainment for extended exposures (i.e., 5-8 hours). More research is needed to determine the relationship between light level and exposure duration as it may affect the circadian system.
- Ideal conditions at work where high levels of CS are provided in the morning hours may be compromised by light exposure after work.
- DG ratings are highly variable among people and for different contexts.





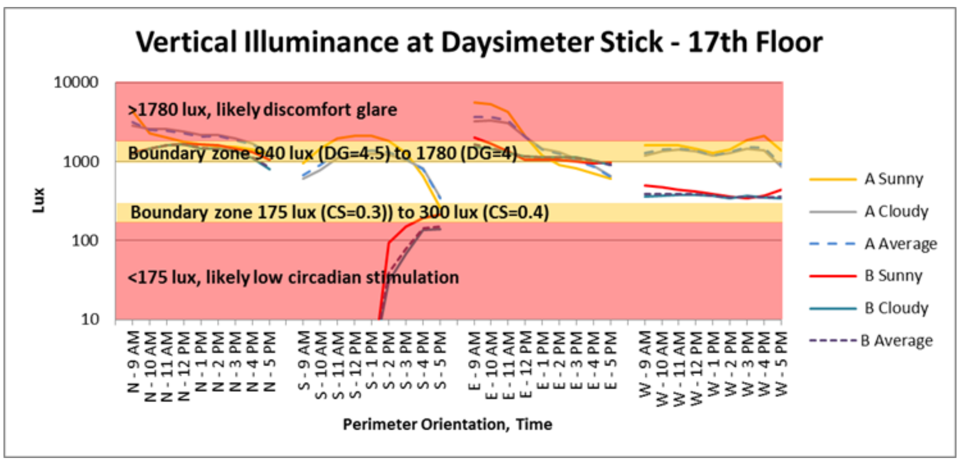


Figure 21. Vertical illuminance at the eye in different workstations at different times of day. The photopic sensor making measurements was oriented so that it faced the same direction as the occupant, at a common eye height.

While researchers were not able to assess many occupants' responses in this building, the photometric measurements and the Daysimeter measurements provided some lessons learned that are consistent with other site evaluations performed by the LRC and by other researchers (see References). Some of the lessons learned include:

- Deskspaces close to the windows receive greater circadian stimulation than those away from the windows. Lower level floors receive less circadian stimulation than higher level floors.
- Although all of the deskspaces measured met the target horizontal illuminance of 30 footcandles (approximately 300 lux), and most workers reported the amount of light on their desks was neither too much nor too little, some workers still felt the need to use task lights, while others complained about the space being "too bright" for computer use.
- The use of shades to reduce discomfort glare on perimeter deskspaces located on the east and south façades reduce vertical illuminances and circadian stimulation at these deskspaces, in particular on those located away from the windows.
- The use of reeds on the west façade helped increase light levels on perimeter deskspaces compared to other buildings, because shades were found to be open.
- Furniture layout at deskspaces located in the perimeter promotes circadian stimulation because workers are sitting in such a way that they are facing the windows, increasing exposure to light. However, this setting may also increase discomfort glare on sides where there is direct sunlight, explaining why the deskspaces on the south and east façades do not receive enough circadian stimulation.

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