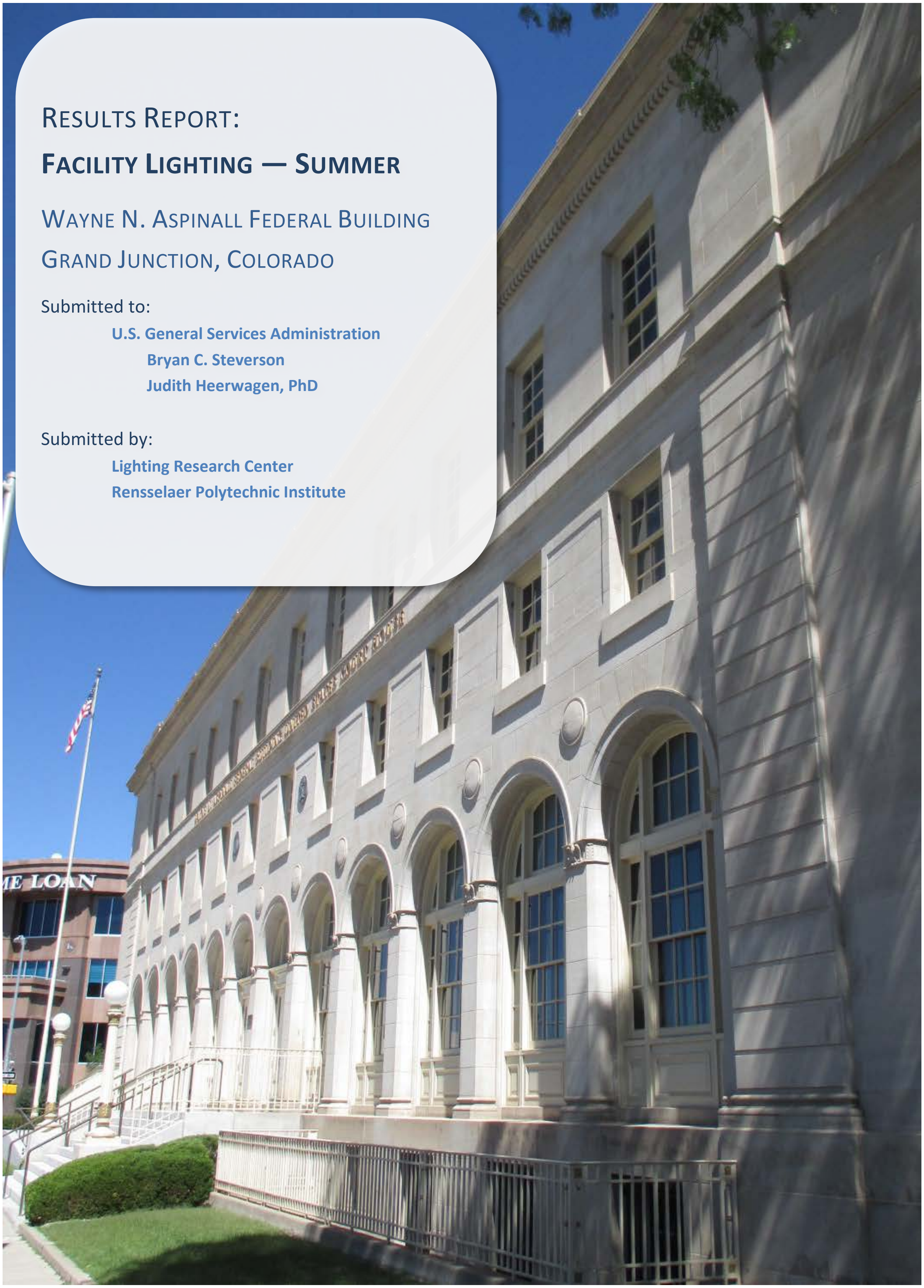

# Results Report:

# Facility Lighting — Summer

## Wayne N. Aspinall Federal Building

## Grand Junction, Colorado

Submitted to:

**U.S. General Services Administration**

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Submitted by:

**Lighting Research Center**

**Rensselaer Polytechnic Institute**

# Results Report: Facility Lighting — Summer

## Wayne N. Aspinall Federal Building, Grand Junction, Colorado

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# EXECUTIVE SUMMARY

The Wayne N. Aspinall Federal Building is a historic building in Grand Junction, Colorado. The building is a three-story Second Renaissance Revival style building constructed in 1918, managed by the U.S. General Services Administration (GSA). Recently, it was completely renovated with the goal of converting the building into one of the most energy-efficient and sustainable buildings in the country.

On June 18-19, 2014, a researcher from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute visited this building to perform summertime photometric measurements on open-plan deskspaces. Measurements were made at desks on the first and second floors; these were the same desks that were measured during the previous evaluation in winter 2014.

In addition to the field measurements, the 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. 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 LRC's previous work, CS values above 0.3 should provide enough CS to maintain entrainment of circadian rhythms to the local time on Earth. Due to availability of daylight and ease of access, research has continued to focus on open-plan offices.[1] 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 CS, as well as to document occupant behavior and acceptance of the lighting in their deskspaces. It is important to keep in mind that photometric measurements were only made on one day with variable weather.

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

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

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

- At many locations and times of day, light levels remained lower than the designer's intent, especially in the mornings and at B-desks.
- In the summer afternoons, direct shafts of sun are admitted from tall windows on the west side; there was one occupant complaint of sun glare on the computer screen.
- Occupant feedback about the lighting was largely positive, similar to winter feedback.
- Daylight dimming controls are active in the summer in some areas, but may need adjustment.
    - In the mornings on the west side, light levels are allowed to drop below the typical target illuminance on desks (300 lux). While it may mean sacrificing some energy savings, the lights on the west side should be readjusted to maintain the target illuminance at all desks, particularly at the second row of desks from the window. Furthermore, the controls increase to full output in the afternoon, just as the western windows admit copious sunlight. This indicates that the sensor controlling the western lights is not located in the same space as the lights. If recommissioning is possible, a sensor in the actual space should be used to control the western lights.
    - The LRC's monitoring device on the north side was lost in transit; however, one observation suggests that the north lights are controlled by the same sensor as the west lights.
    - As in the winter study, the lights in the south-facing office on the second floor do not appear to be dimming in response to daylight. Light levels at the desk measurement points ranged 400-600 lux, which is slightly higher than the illuminance target (300 lux). There seems to be an opportunity for energy savings by recommissioning these controls to trigger at a lower light level, if they are capable of continuous dimming.
- Spectral measurements indicated that few of the 15 desks measured had sufficient light to stimulate the circadian system, even when seated close to the windows; only 5 of the 27 A-desk measurements showed a CS greater than 0.3.
- Ongoing Daysimeter measurements at three desks indicated insufficient light for circadian stimulation, even in summer. However, these desks were vacant; other desks exist at Aspinall that are closer to windows, and/or face windows, that may have produced more positive results.

# INTRODUCTION

The Wayne N. Aspinall Federal Building is a historic building in Grand Junction, Colorado. The building is a three-story Second Renaissance Revival style building constructed in 1918, managed by the U.S. General Services Administration (GSA). It was the first permanent post office building constructed in Grand Junction. It is located in the central business area. Recently, it was completely renovated to convert the building into one of the most energy-efficient and sustainable buildings in the country. Some of the awards received after the renovation include:

- LEED Platinum
- Design Build Institute of America – Rocky Mountain Region Award for the Best Project in the category of Rehabilitation/Renovation/Restoration
- AIA Colorado – Honor Award for Built Architecture
- AGC Colorado – Award for Construction Excellence (ACE)

***Figure 1.The Aspinall building is a newly remodeled, historic building.***

## DAYLIGHT AND ELECTRIC LIGHTING DESIGN

The architects selected for the project were Beck Architecture of Dallas, TX. Lighting was designed by Westlake Reed Leskosky (WRL), headquartered in Cleveland, Ohio. Their lighting narrative stated that the lighting goals were to preserve the historic façade, while modernizing with energy-efficient technologies.[2]

[2] Westlake Reed Leskosky (WRL), two design narratives, undated. http://wrldesign.com/files/papers/designnarrative2620131.pdf and http://wrldesign.com/files/papers/aspinallsustainableenergydes2520131.pdf

As shown in Figure 2, linear fluorescent 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).[3] With task lighting, target illuminance was 50 fc (500 lx).

***Figure 2. Linear fluorescent pendants provide the general lighting in open-plan offices. Wireless sensors (upper left) help to reduce energy use by dimming the lights in response to daylight and switching them off when the offices are vacant.***

At desks on the first floor, linear fluorescent task lights are available to augment the general lighting (Figure 3); these are controlled by additional occupancy sensors located at the desk level.

***Figure 3.Task lighting is available at desks on the first floor.***

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. The row of luminaires closest to the windows is intended to be dimmed in response to

[3] Per correspondence with Roger Chang, Director of Engineering at WRL.

daylight. On the west side there is a second row of luminaires, not intended to be controlled by the daylighting system.

In open-plan offices on the first floor, most desks are arranged in cubicles, with one row of desks close to windows (Row A), and another row of desks further from windows (Row B). In the office on the second floor, there is only one row of desks; these are located close to the south-facing windows (Row A).


**Figure 4. On early summer mornings, some direct sun falls on the north side of the building. The skylight on the first floor is well-shaded on this north side of building.**

The Aspinall building is surrounded by other low- and medium-height office buildings. On early summer mornings, the sun briefly falls on the north side of the building (Figure 4). Daylight is admitted primarily through window openings punched through the historic masonry. Historic windows have a new storm window layer with tinted film (45% visible transmittance, 0.53 solar heat gain coefficient). The skylight on the first floor was also tinted (60% visible transmittance, 0.49 solar heat gain coefficient), and shaded by the building itself (Figure 4). Black mesh shades are provided for most windows. Windows on the south façade are also provided with blackout shades.

## OVERVIEW

On June 18-19, 2014, Lighting Research Center (LRC) researcher Jennifer Brons conducted photometric measurements at the facility. The goal of the research was to measure photometric conditions as they relate to occupant comfort, productivity, and circadian health. The LRC researcher was escorted and assisted by Timothy Gasperini of GSA and contractor Andy Teta.

# METHODS

Six types of measurements were undertaken at the Aspinall Building:

## ILLUMINANCE

Illuminance is a measure of the amount of light falling on a surface, in units of lux (lx [SI]) or footcandles (in the U.S.). Illuminance measurements are important because they are used conventionally as design criteria. The LRC measured illuminance three times over the measurement day, on horizontal and vertical surfaces, at desks on two floors, and three window orientations. The researcher collected these illuminance data using a Gigahertz-Optik (model: X91) lux meter.

## 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. The researcher collected luminance data using a Minolta luminance meter (model LS-110).

## 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 to allow researchers to calculate, using different response functions, measures such as brightness, glare, and circadian stimulus. SPD data were collected at the same locations as luminance and illuminance measurements. The researcher collected these data using a spectroradiometer system consisting of an Ocean Optics spectrometer (model USB650) 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 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 three desks and three windows. These collected data for 20 days after LRC visited the site. These were removed by Mr. Gasperini after 3 weeks on site, and were returned by mail to LRC for data analysis.

### 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 20 days after the LRC visited the site. These were removed by Mr. Gasperini after 3 weeks on site, and were returned by mail to the LRC.

### Questionnaires

The LRC administered questionnaires to 13 employees at the Aspinall Building. The questions were the same as those used during the previous GSA site evaluation in winter 2014.

On Day 1 (June 18), measurement locations were identified and set up at the same 15 desks as were evaluated in winter. Also on Day 1, questionnaires were administered and battery-powered measurement equipment was installed and documented. The LRC placed the Daysimeter devices in stationary positions on the selected desk spaces and windows.

Photometric data were collected on Day 2 (June 19). For each desk, LRC collected illuminance, luminance, and SPD measurements. Questionnaires were also administered on Day 2.

# RESULTS

## ILLUMINANCE RESULTS

The LRC measured photometric conditions (illuminance and luminance) at the locations shown in Figures 5 and 6 below. Photometric data were organized by perimeter proximity, by perimeter window orientation, and by collection time. Data were collected for 15 desks: 12 on the first floor and 3 on the second floor. The weather on the measurement day was primarily sunny with occasional clouds.

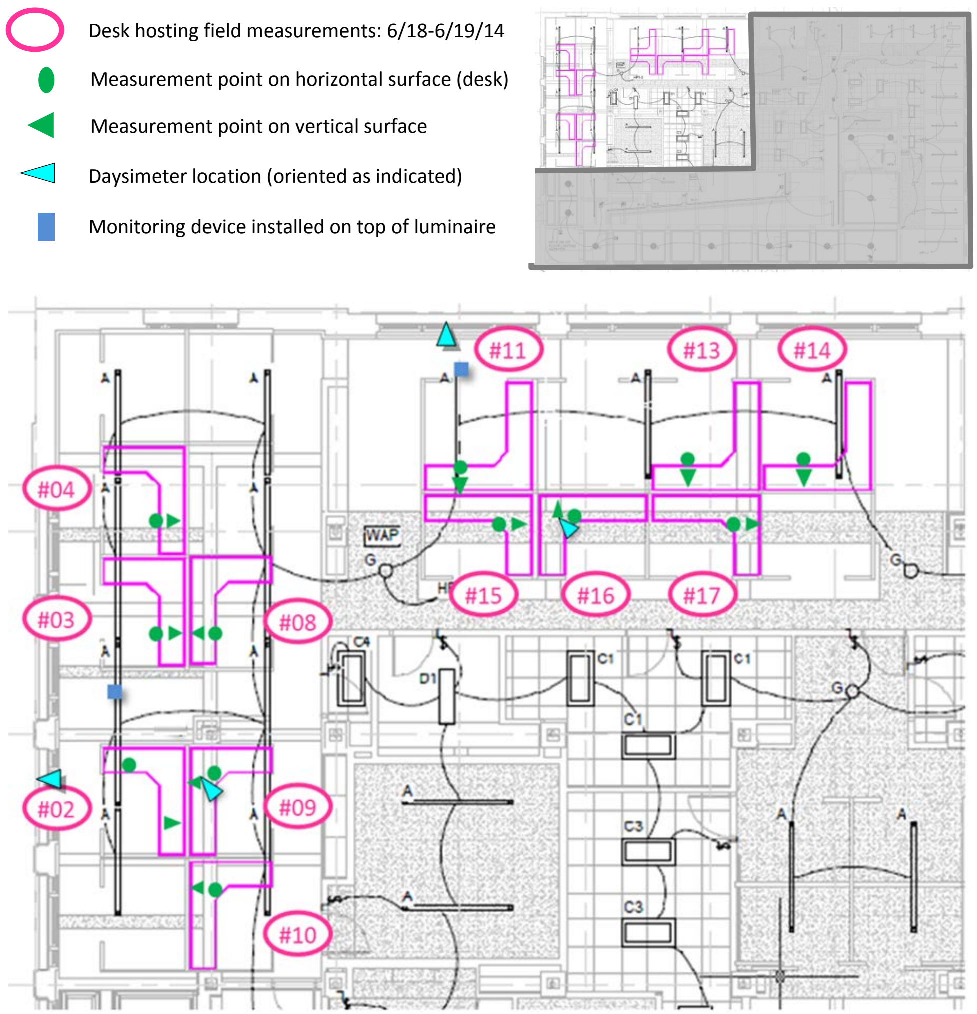


*Figure 5. First floor measurement locations: north and west orientations.*

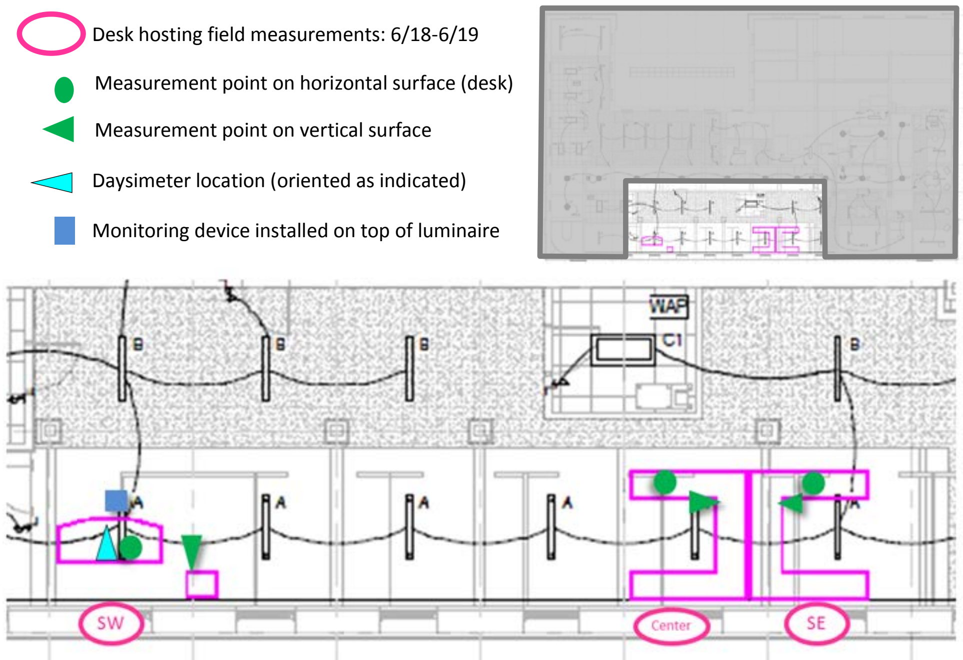


***Figure 6. Second floor measurement locations: north and west orientations.***

Measurements occurred in the morning, midday, and in the afternoon. At the Aspinall Building it was not possible to access the building after dark (after 9 p.m. or before 6 a.m.). As a result, measurements included additional daylight contribution, and reduction of electric lighting in response to daylight (see Luminaire Activity).

The resulting measurements are shown below (and in detail in Appendix A) compared to the winter measurements.

As shown in Figure 7, on the north side of the building, summer illuminance measurements were similar to winter measurements throughout the day, particularly at the B desks. The B desks remained lower than the designers' intended illuminance (300 lux), largely because the skylight prevented use of overhead lighting. It should be noted that the LRC observed the overhead lights abruptly increasing to full output in the afternoon; the summer afternoon measurements in Figure 7 probably show a greater contribution of electric light than the morning and afternoon measurements (see Luminaire Activity). This could explain why horizontal illuminance measured at the A desks was lower at midday during the summer than in winter. The north side does not have shading in winter or summer.

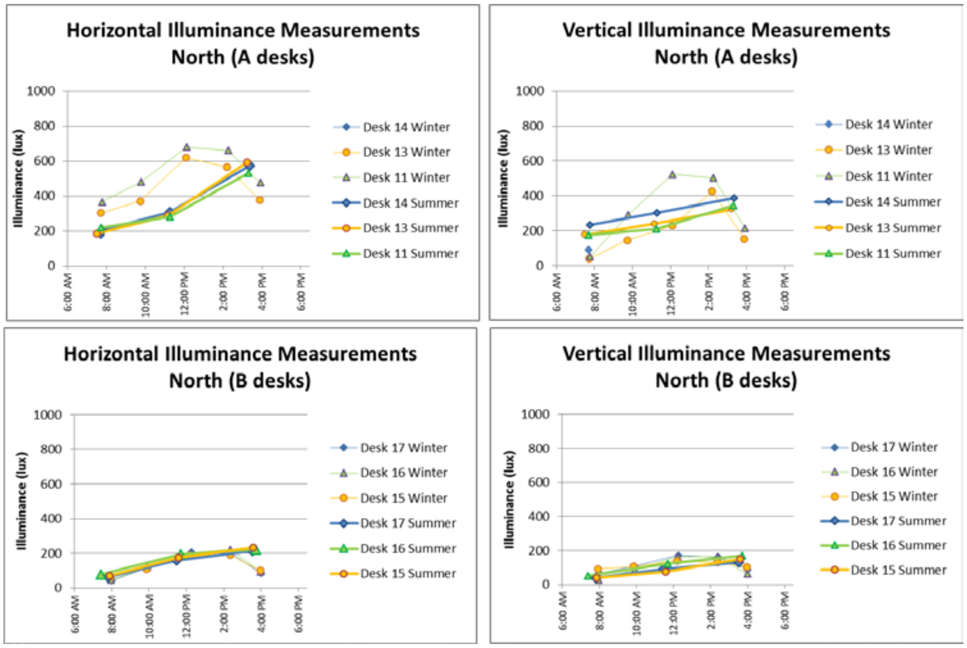


***Figure 7. Illuminance measurements at north desks***

As shown in Figure 8, the western exposure showed more seasonal differences than the northern exposure. Lower measurements in the summer mornings may be partly due to greater tree foliage shading in summer and partly due to dimming of electric lighting (see Luminaire Activity). Higher measurements in the summer afternoon were caused by shafts of sun entering the high western windows and falling on row A desks. Also, luminaire monitoring showed that these lights were operating at full output during the afternoon measurements. Horizontal illuminance at row A desks were dramatically higher light levels (2100-3700 lux) in the summer afternoon compared to winter afternoon (600-700 lux). Row B was deep enough in the space that the clerestory windows did not contribute directly, but rather bounced light indirectly throughout the space. Task lights were in use at desks 2 and 3 in both summer and winter.

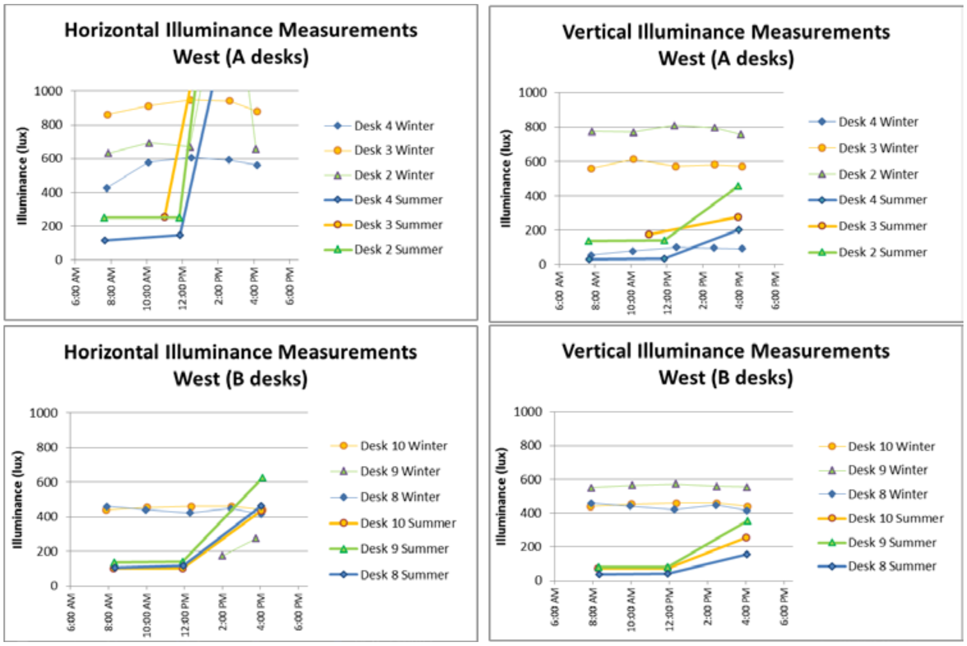


***Figure 8. Illuminance measurements at west desks***

It appears from Figure 8 that the daylight dimming system allows the light levels at the west-facing desks to drop too low in the summer mornings. There may also be potential for energy savings by dimming western lights in the afternoon. Therefore, the controls at the western desks may need to be recommissioned to achieve the designers' target illuminances.

As shown in Figure 9, the southern exposure had similar light levels in both summer and winter.

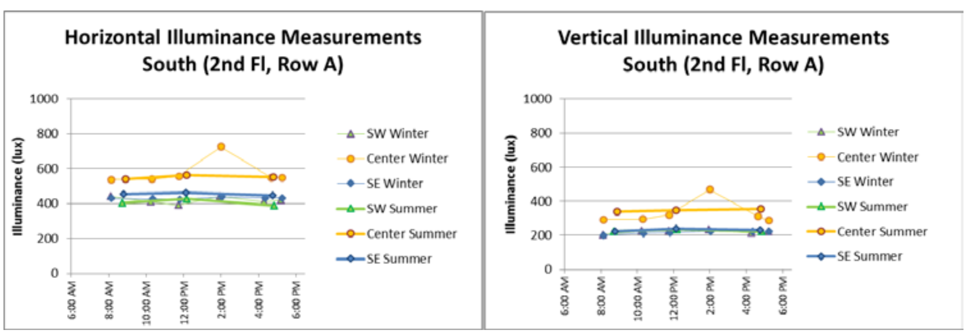


***Figure 9. Illuminance measurements at south desks***

## Luminance Results

The LRC measured luminance at the same time interval and desk locations used for illuminance measurements. The LRC measured luminance of the nearest window when viewed from a typical seating position.

As shown in Figure 10, window luminance for the north desks did not seem to be different due to season or seating position. The view of the windows from desks 13 and 14 may have included more reflective clouds in the afternoon than in the morning, but since the afternoon luminance was similar to the winter measurements, there does not seem to be a seasonal effect.

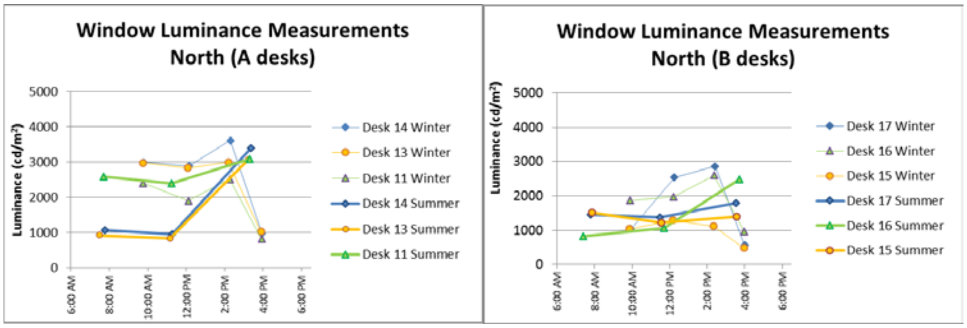


***Figure 10. Window luminance measurements, north desks***

As shown in Figure 11, window luminance for the west desks was higher in the summer afternoons, due to the clerestory shafts of sun described above.

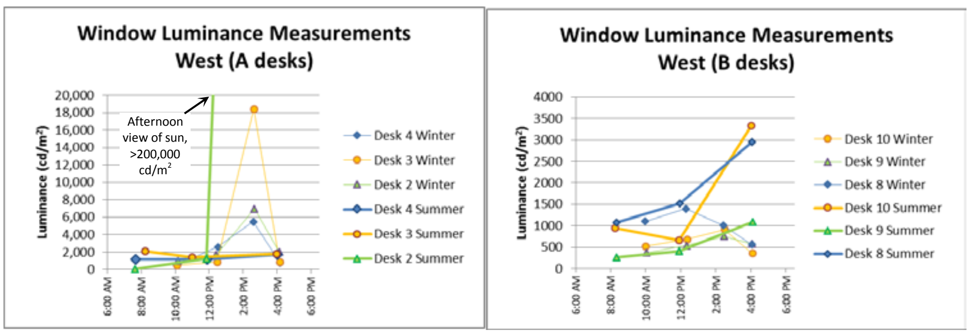


***Figure 11. Window luminance measurements, west desks***

As shown in Figure 12, south window luminance at two desks were higher in the summer; in the winter, all luminance measurements were less than 500 cd/m$^2$, but in the summer the view from the center and south desks was around 1000-2000 cd/m$^2$.

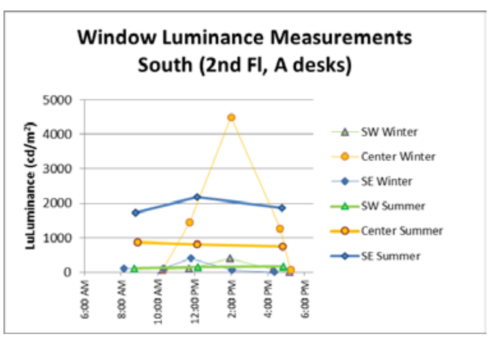


***Figure 12. Window luminance measurements, south desks***

## LUMINAIRE ACTIVITY RESULTS

*Figure 13. An LRC researcher installs a battery-powered light meter in a luminaire.*

Three battery-powered light meters were placed on top of operating luminaires to verify whether the lights were dimming in response to daylight (Figure 13). The devices were placed on luminaires located in the same control zone as the desks where illuminance measurements took place: on the north and west sides of the first floor, and the south side of the second floor. These were the same luminaires that were monitored in January 2014.

The devices were set to record for 20 days: 13 work days and 7 weekend/holiday days.

The device for monitoring the north side was lost in transit, thus Figure 14 shows the results for two devices. However, the west data may be similar to what the north data would have been; on 6/19 LRC noted that the lights increased to full output on the north side at exactly the same time as was recorded by the device on the west side. Luminaires on the north and the west sides may therefore be controlled by the same sensor.

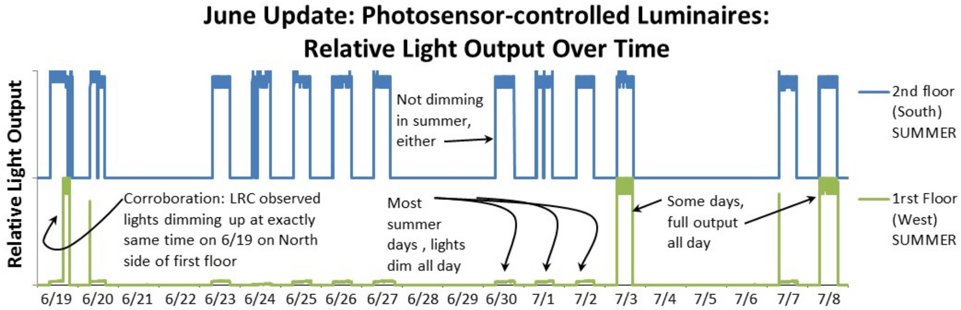


*Figure 14. Dimming. Electric light output is not reduced during the day on the south side (top), but is dimming during most days on the west side (bottom). (Device for north side was lost in transit.)*

As shown in Figure 14, monitoring confirmed that dimming occurs, but not in all areas, nor every day during this summer evaluation period. On the south side, the data indicate that the lights are not dimming in response to daylight, as was the case in January. On the west side, the relative light output is low on most days, which indicates that the luminaire is being dimmed by the photosensor. Some days (7/3, 7/8) the lights stayed at full output all day; a few mornings (6/20, 7/7) the lights started at full output, then dropped to the dim level for the rest of the day. On the measurement day (6/19) the lights increased to full output just as the afternoon measurements were starting. On the weekends, luminaires in both the west and south sides are turned off, thus monitoring devices measured little/no light. Overall, the daylighting control system is allowing light levels to drop below the target illuminance on the first floor, and may not be taking advantage of energy saving potential on the second floor or west side on some afternoons.

## Questionnaire Results

Researchers administered a brief questionnaire to 13 people working in this facility. Appendix B shows detailed questionnaire results. Where possible, the questionnaire data were compared to results from other office case study publications, and to the January evaluation at this site.

Figure 15 shows that questionnaire respondents were located on all four sides of the building on two floors. Most (85%) were located immediately adjacent to a window.

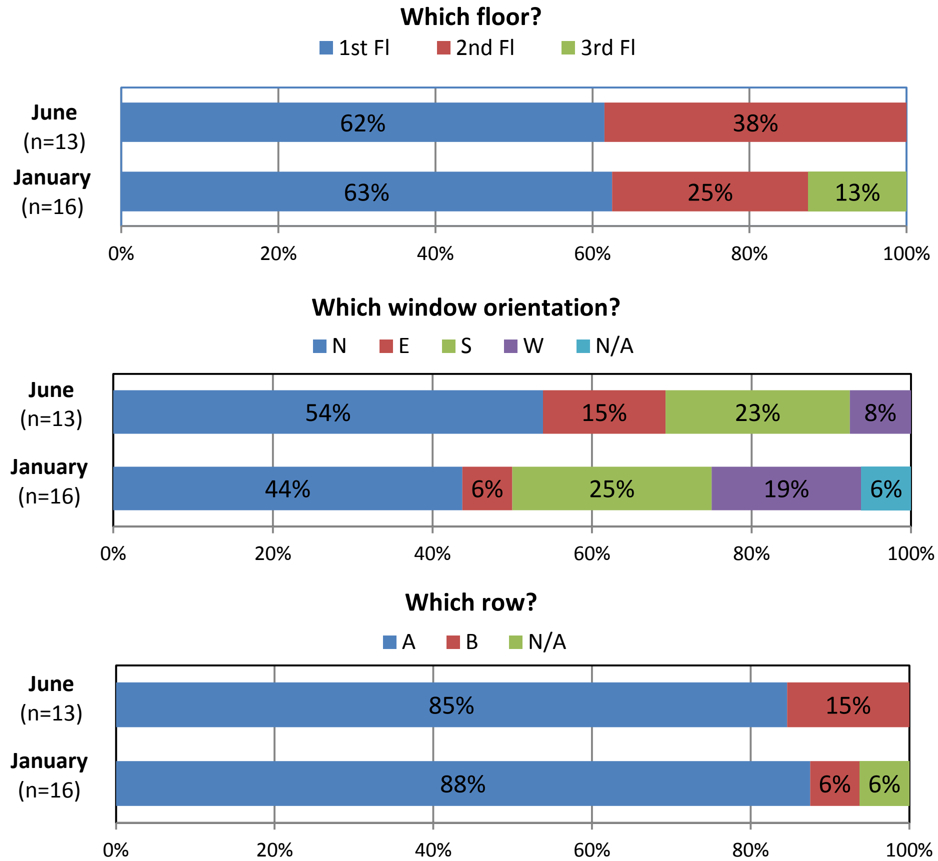


***Figure 15. Location of questionnaire respondents.***

As shown in Appendix B, most (92%) of the summer respondents only work during the day. This percentage was higher than reported in the winter (75%), when darkness falls before people leave work.

Workers answered the questionnaire on both days that LRC evaluated the site. For much of that time, skies were sunny; other data (see Luminaire Activity) indicate that the electric lights were dimming in response to daylight when many of the people responded to the questionnaire.

Most workers were still satisfied by the amount of light provided; 69% reported that the amount of light on their desk was neither too much nor too little, compared to 63% in the winter visit. B desks with light levels lower than the target (300 lux) remained largely vacant on this June visit and thus were not reflected in these questionnaire data. If more of the B desks had been occupied, acceptance rates may have been lower.

Use of task lights was reported by about one-third of the June respondents. Most (62%) reported that they "never" use their task light. It should be noted that not all desks have furniture that can accommodate a task light.

On this summer visit, the LRC noted that many respondents had shades fully up (69%) or partially up (31%) when responding. One person on the second floor commented that the ability to choose between blackout shades and mesh shades was appreciated. Another said that blackout shades were never in use at that desk. One person on the west side commented, "Shafts of sun make it hard to focus on (my computer) monitor."

Most June respondents (85%) reported that the windows are comfortable to look at; this is more positive than the January responses (56%) from this site. Most respondents (69%) also rated their luminaires as comfortable to look at; this compares favorably to the winter visit (50%), and is similar to other LRC office lighting case studies.

Overall, compared to other offices, the lighting was rated as "better" or "much better" by almost half (46%) of the respondents. About a quarter (23%) considered the lighting to be "about the same." The same percentage (23%) considered the lighting to be "worse," which was a higher percentage than other case studies. As shown in Figure 16 below, these results are slightly less positive than other office lighting case studies.

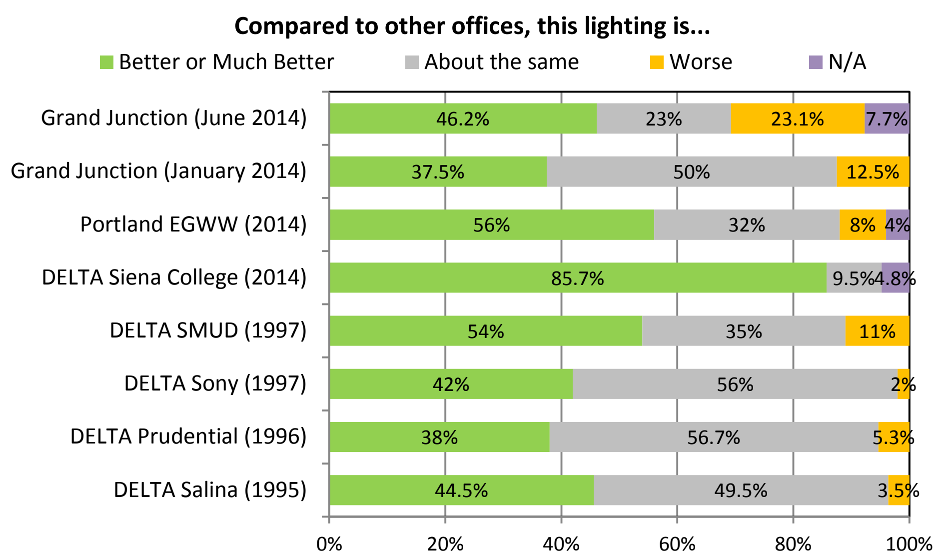


***Figure 16. Overall questionnaire results at the Aspinall Building in Grand Junction, compared to other office lighting evaluations by the LRC.***

## Spectral Power Distribution (SPD) Results

For measurement of spectral characteristics, LRC used the same equipment as described in previous reports. 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. SPDs were measured at the same desk locations as used for other photometric measurement equipment. (See Illuminance Results, page 11.)

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 a minimum of 5.76 fc[4] (62 lx) on the desk surface (horizontal illuminance).

Detailed results are shown in Appendices C, D, and E. The following table shows average results during the daytime measurements.

***Table 1. Average daytime measurements using spectroradiometer.***

| Deskspace Location | Lux | Fluor % | Day % | CCT(K) | $CL_A$ | CS | Brightness |
|---|---|---|---|---|---|---|---|
| A | 190 | 52% | 48% | 4337 | 172 | 0.204 | 130 |
| B | 161 | 50% | 50% | 4197 | 154 | 0.170 | 115 |
| **Orientation** | | | | | | | |
| W | 188 | 67% | 33% | 3938 | 145 | 0.1691 | 125 |
| N | 160 | 25% | 75% | 4837 | 166 | 0.1922 | 125 |
| S | 195 | 71% | 29% | 3857 | 202 | 0.2280 | 119 |

These data show that window proximity is not contributing to light exposure to the same extent as buildings with a glass curtain wall, such as the Edith Green-Wendell Wyatt Federal Building in Portland, Oregon. At the Aspinall Building, for only 5 of the 27 A-desk spectrometer measurements, CS values were above 0.3.[5] This value (0.3) is considered to be the lower end of the threshold boundary for circadian stimulation and it is not known whether longer exposures can maintain entrainment. Only four of the measurements at the B deskspaces had CS values below this criterion amount.

## Daysimeter Stick and Window Results

Daysimeter devices were all installed at the same three (vacant) desks as in the winter study. The two devices on the first floor were both installed at Row B desks. The device on the second floor was installed at a vacant Row A desk that faces away from the window. Because of the limited data set, the data will not enable reporting about the relative importance of window proximity on light exposure. The data will enable comparison for seasonal effect, as well as building orientation.

[4] Minimum horizontal illuminance measurement at Grand Junction, desk #17 at 7:34 a.m., per Appendix A. RVP calculation assumed age of observer was 50 years, background reflectance 0.8, luminance contrast 0.85, and target size 8 point font.

[5] The range of CS values for A desks was 0.07-0.34; for B desks, the range was even wider, 0.05-0.44.

The summer study added devices mounted on adjacent windows, to demonstrate the impact of architectural shading on light at the desk.

Appendix F shows 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, values at all three desks were low, especially compared to their adjacent windows. The results did not show that building orientation improved potential for delivering the circadian stimulation to employees working in the Aspinall Building.

The devices measured light levels that are likely to be within the comfort range for glare. None of the three deskspaces had light levels that were bordering discomfort (between 900 lx and 1780 lx). The western desk device was located in Row B, thus did not measure shafts of sun; if it had been installed at an occupied A desk, it may have measured high light levels associated with discomfort glare.

Because all three desk spaces were far below the level of circadian stimulation, even in summer, no additional seasonal analyses are attempted here.

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, the three devices did not identify a location in the building capable of delivering the ideal dose of daily circadian light.

# DISCUSSION

A summary of the findings is shown in Figure 17. 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. None of the three deskspaces achieved the desired light levels during the regular work day, with only the west desk approaching those levels at 5:00 p.m. 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).

Several caveats should be stressed, however:

- CS values are based upon melatonin suppression for a standard observer after 1 hour of light exposure. Longer exposures to light are probably sufficient to entrain subjects, but estimates of the trade-off between light level and duration are not available. Functionally, CS levels as low as 0.1 may be sufficient for circadian entrainment for extended (i.e., 5-8 hours) exposures. 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.

For another comparison, Figure 18 shows winter vs. summer results for three desks at the Aspinall Building. In both seasons, CS levels at these three desks were below threshold. In some cases, the CS level was slightly higher in winter, but this may be due to increased use of electric lighting (e.g., less dimming in winter), rather than increased daylight penetration in winter.

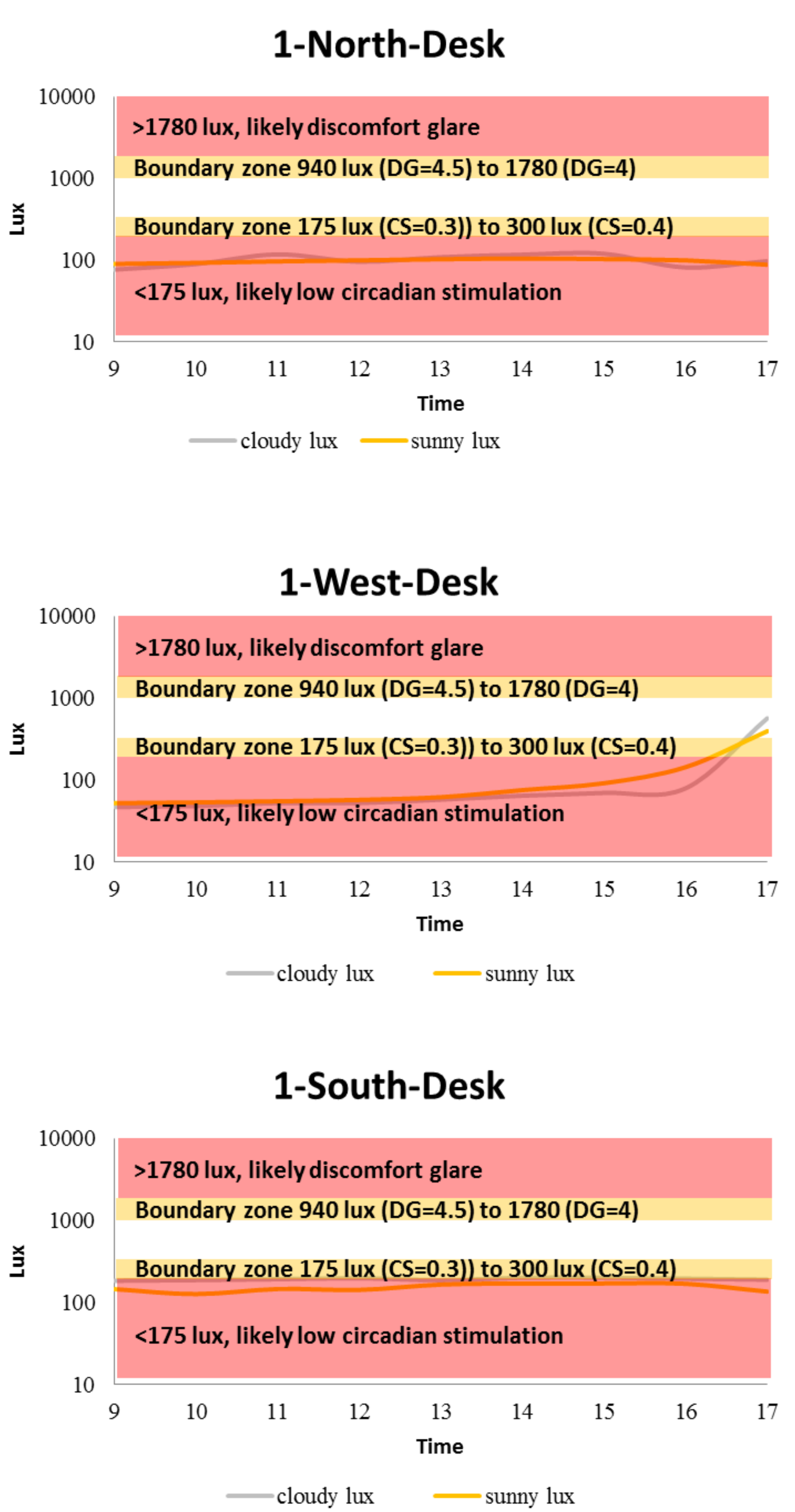


***Figure 17: Vertical illuminance at the eye at the three desks at different times of day. The photopic sensor making measurements was oriented so that it faced the same direction as the occupant, at a common eye height.***

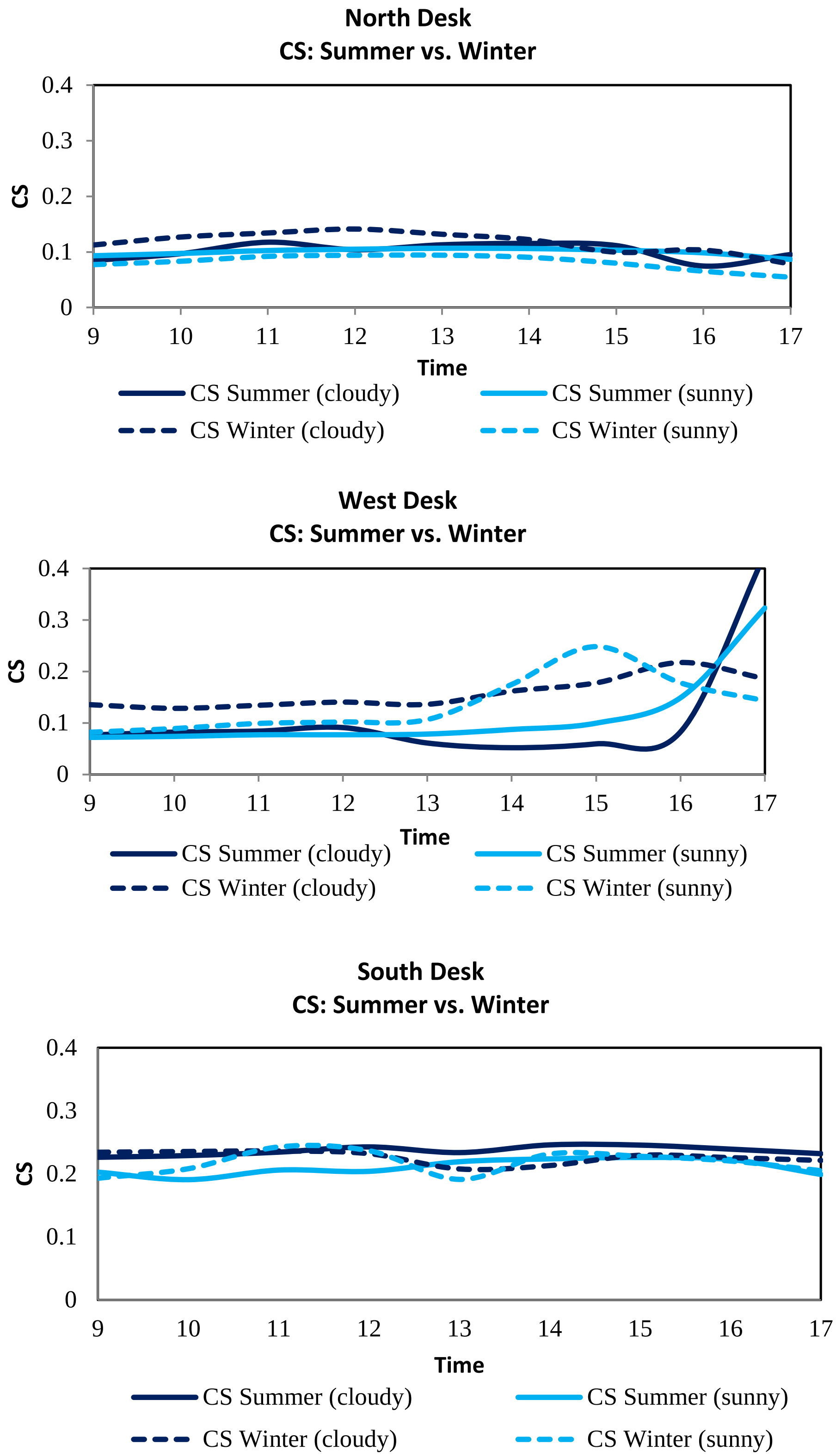


*Figure 18. Comparing CS at three desks for summer and winter.*

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:

- At many locations and times of day, light levels remained lower than the designer's intent.
- On summer afternoons, direct shafts of sun are admitted from tall windows on the west side; there was one occupant complaint of sun glare on the computer screen.
- Occupant feedback about the lighting was similar to winter feedback and largely positive, although a few more people did rate the lighting as "worse."
- Daylight dimming controls are active in the summer in some areas, but may need adjustment.
    - In the mornings on the west side, light levels are allowed to drop below the typical target illuminance on desks (300 lux). While it may mean sacrificing some energy savings, the lights on the west side should be readjusted to maintain the target illuminance at all desks, particularly at the second row of desks from the window. Furthermore, the controls increase to full output in the afternoon, just as the western windows admit copious sunlight. This indicates that the sensor controlling the western lights is not located in same space as the lights. If re-commissioning is possible, a sensor in the actual space should be used to control the western lights.
    - The LRC's monitoring device on the north side was lost in transit; however, one observation suggests that the north lights are controlled by the same sensor as the west lights.
    - As in the winter study, the lights in the south-facing office on the second floor do not appear to be dimming in response to daylight. Light levels at the desk measurement points ranged 400-600 lux, which is slightly higher than the illuminance target (300 lux). There seems to be an opportunity for energy savings by recommissioning these controls to trigger at a lower light level, if they are capable of continuous dimming.
- Spectral measurements indicated that few of the 15 desks measured had sufficient light to stimulate the circadian system, even when seated close to the windows. Above threshold were 5 out of 27 measurements at A-desks, and 4 out of 18 measurements at B-desks.
- Ongoing Daysimeter measurements at three desks indicated insufficient light for circadian stimulation, even in summer. However, these desks were vacant; other desks exist at Aspinall that are closer to windows, and or face windows, that may have produced more positive results.

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LRC. (1997). DELTA Portfolio: SONY Disc Manufacturing, Administration and Support Spaces.

LRC. (1997). DELTA Portfolio: Sacramento Municipal Utility District (SMUD), Office Building

LRC. (2014). DELTA Portfolio: LED Lighting in a Campus Building.

Westlake Reed Leskosky (WRL), (undated) "Design Narrative 2620131" http://wrldesign.com/files/papers/designnarrative2620131.pdf

Westlake Reed Leskosky (WRL), (undated) "Aspinall Sustainable Energy Design 2520131" http://wrldesign.com/files/papers/aspinallsustainableenergydes2520131.pdf

# CREDITS

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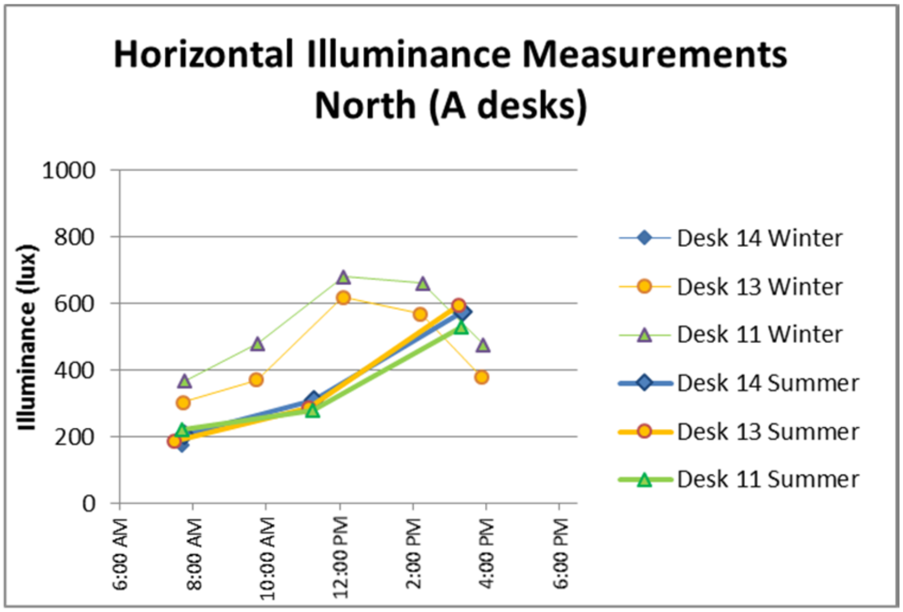
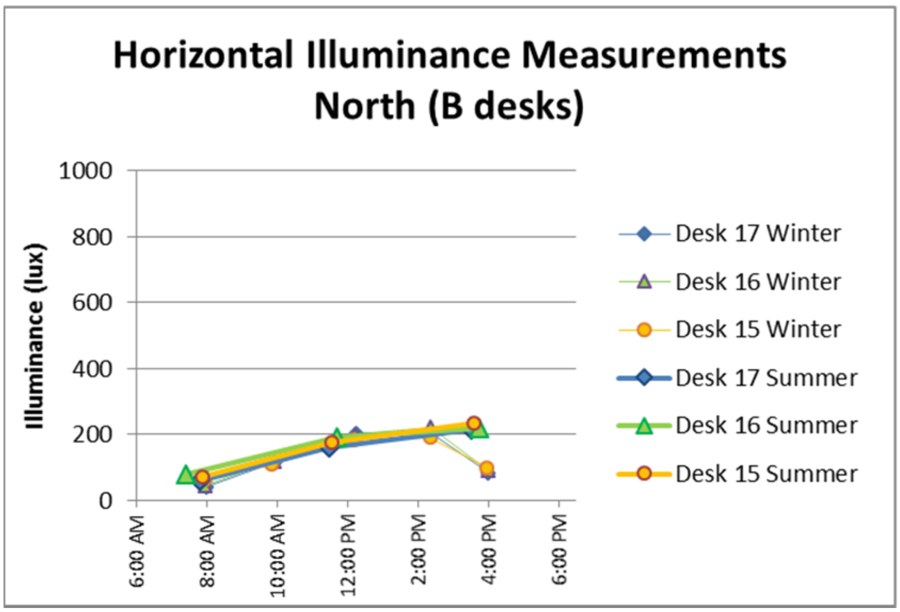
**Editors:** Rebekah Mullaney, Dennis Guyon, Sarah Hulse

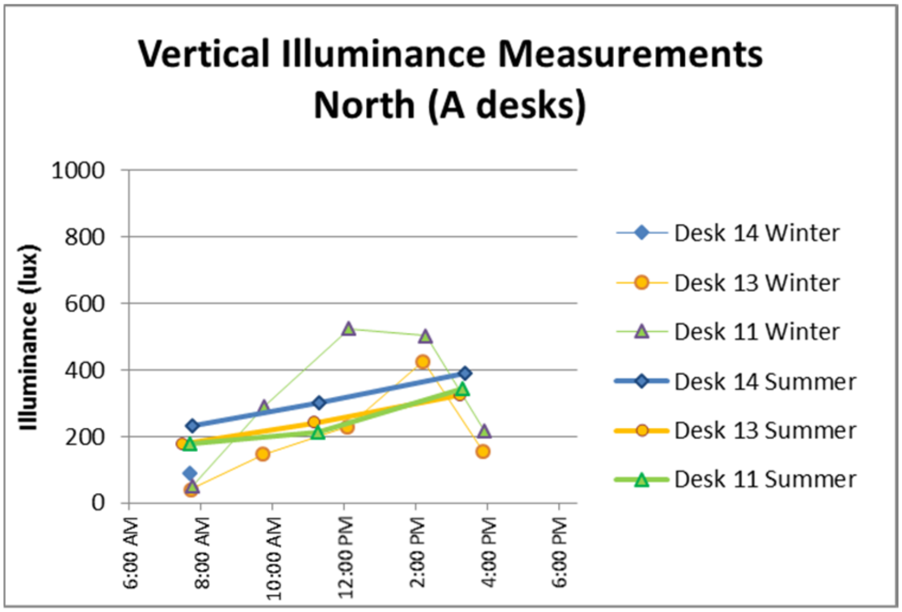
# Appendix A: Photometric Data (Illuminance and Luminance Measurements), Summer Evaluation

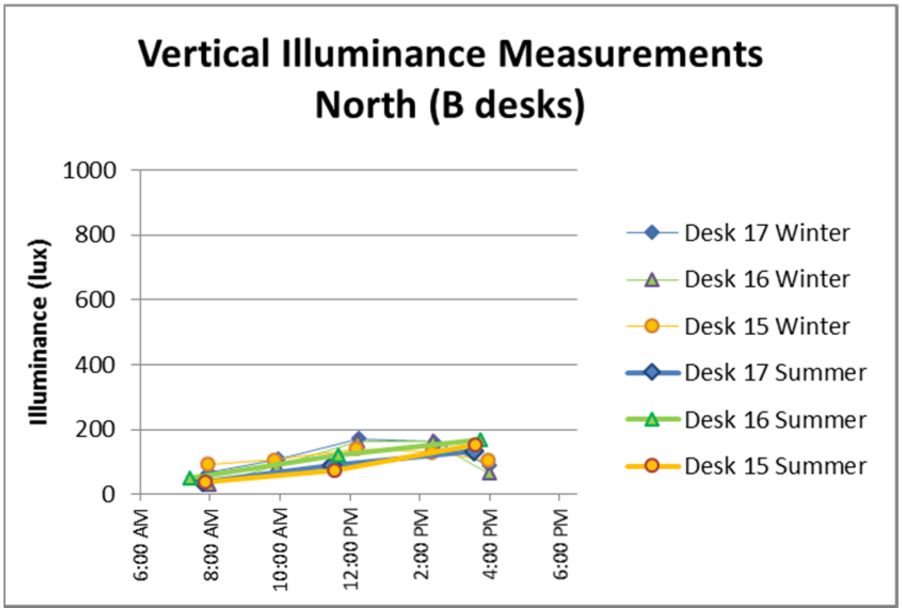
## North Side of Aspinall Building

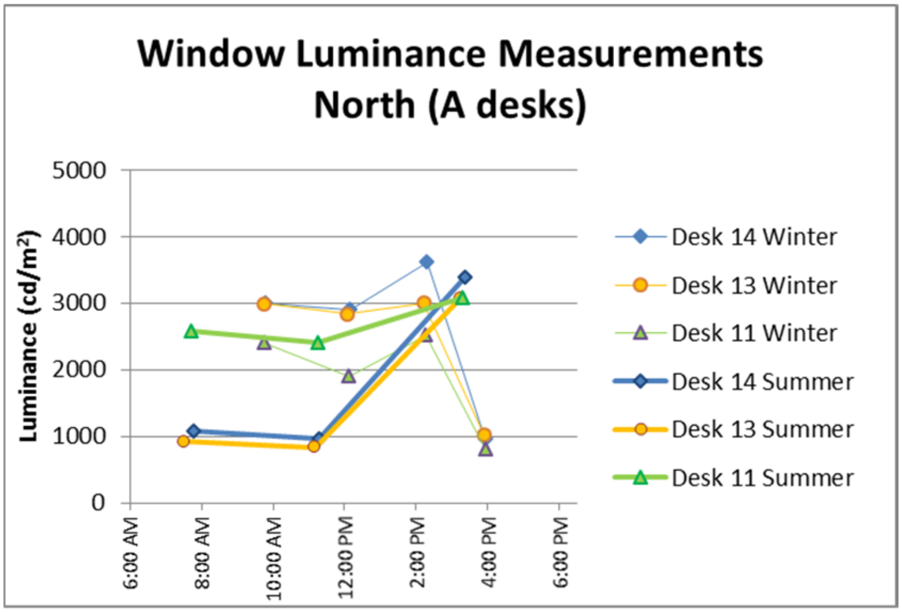
| Date, time | Floor | Orientation | Row | Desk | Task Light On Horiz Desk (lux) | Task Light On Vert Surface (lux) | Task Light Off Horiz Desk (lux) | Task Light Off Vert Surface (lux) | Window Luminance (cd/m2) |
|---|---|---|---|---|---|---|---|---|---|
| 6/19/14 7:31 AM | 1 | North | A | #14 | | | 205 | 233 | 1073 |
| 6/19/14 11:11AM | 1 | North | A | | | | 309 | 302 | 960 |
| 6/19/14 3:09 PM | 1 | North | A | | 914 | 668 | 575 | 390 | 3400 |
| 6/19/14 7:30 AM | 1 | North | A | #13 | | | 186 | 178 | 925 |
| 6/19/14 11:10 AM | 1 | North | A | | | | 288 | 241 | 840 |
| 6/19/14 3:19 PM | 1 | North | A | | | | 594 | 323 | 3070 |
| 6/19/14 7:29 AM | 1 | North | A | #11 | | | 220 | 177 | 2585 |
| 6/19/14 11:15 AM | 1 | North | A | | | | 280 | 211 | 2405 |
| 6/19/14 12:00 AM | 1 | North | A | | | | 530 | 345 | 3090 |
| 6/19/14 7:32 AM | 1 | North | B | #15 | | | 71 | 40 | 1520 |
| 6/19/14 11:26 AM | 1 | North | B | | | | 176 | 73.9 | 1233 |
| 6/19/14 3:30 PM | 1 | North | B | | | | 233.7 | 152.7 | 1399 |
| 6/19/14 7:33 AM | 1 | North | B | #16 | | | 78 | 51.5 | 819 |
| 6/19/14 11:25 AM | 1 | North | B | | | | 193 | 122.8 | 1063 |
| 6/19/14 3:29 PM | 1 | North | B | | | | 219.9 | 170 | 2489 |
| 6/19/14 7:34 PM | 1 | North | B | #17 | | | 62 | 40 | 1459 |
| 6/19/14 11:24 AM | 1 | North | B | | | | 159.3 | 90.1 | 1380 |
| 6/19/14 3:28 PM | 1 | North | B | | | | 215 | 132 | 1802 |

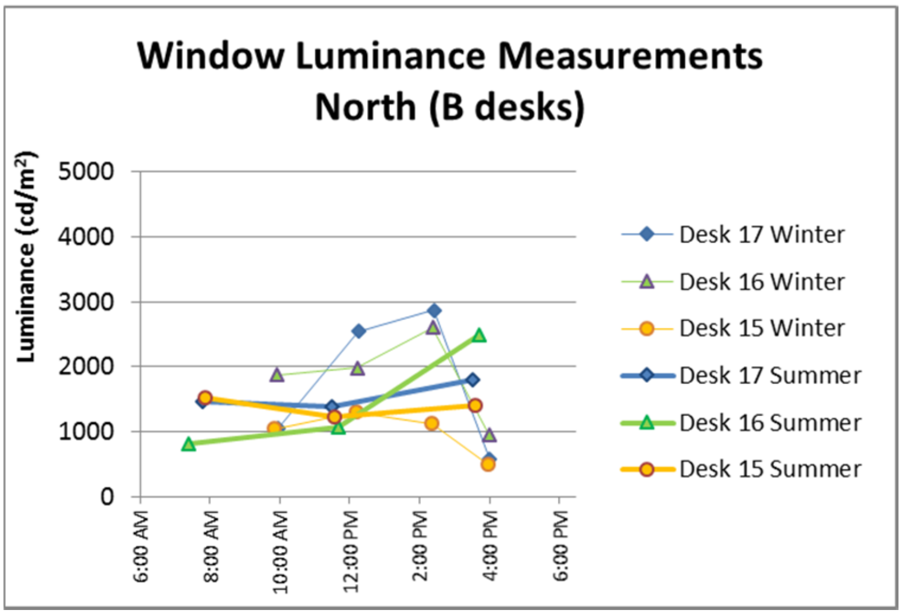

Horizontal Illuminance Measurements North (A desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 14 Winter
Desk 13 Winter
Desk 11 Winter
Desk 14 Summer
Desk 13 Summer
Desk 11 Summer


Horizontal Illuminance Measurements North (B desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 17 Winter
Desk 16 Winter
Desk 15 Winter
Desk 17 Summer
Desk 16 Summer
Desk 15 Summer


Vertical Illuminance Measurements
North (A desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 14 Winter
Desk 13 Winter
Desk 11 Winter
Desk 14 Summer
Desk 13 Summer
Desk 11 Summer

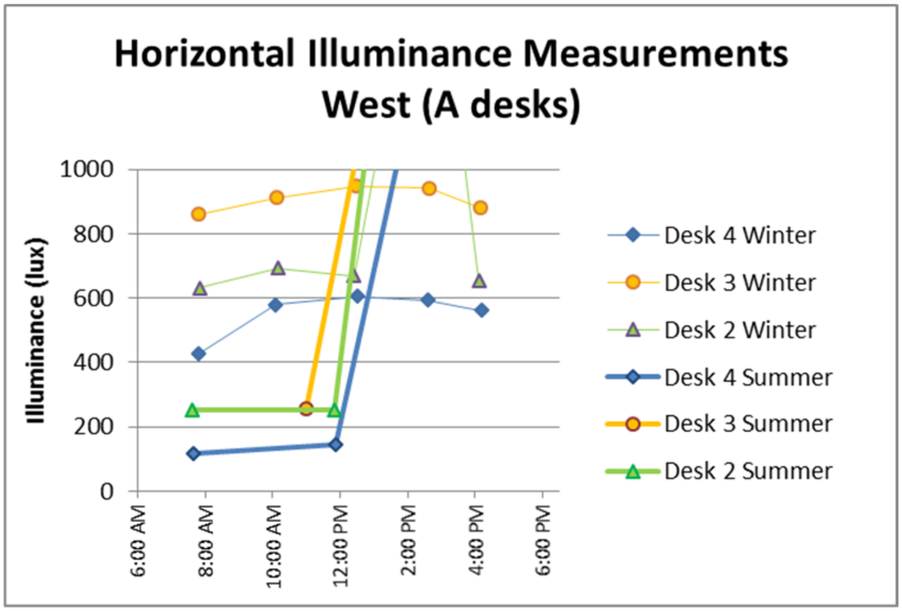

Vertical Illuminance Measurements
North (B desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 17 Winter
Desk 16 Winter
Desk 15 Winter
Desk 17 Summer
Desk 16 Summer
Desk 15 Summer

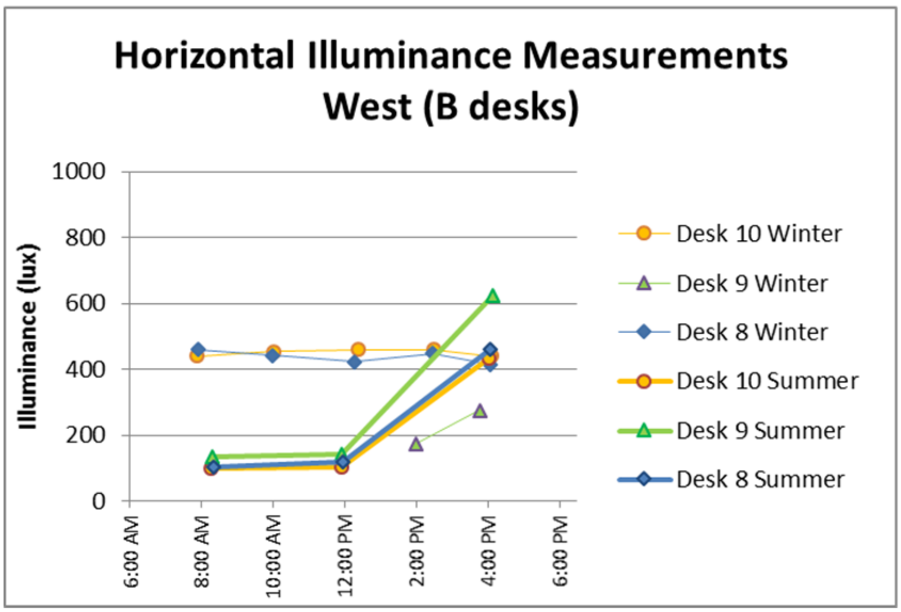

Window Luminance Measurements
North (A desks)
Luminance (cd/m²)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 14 Winter
Desk 13 Winter
Desk 11 Winter
Desk 14 Summer
Desk 13 Summer
Desk 11 Summer

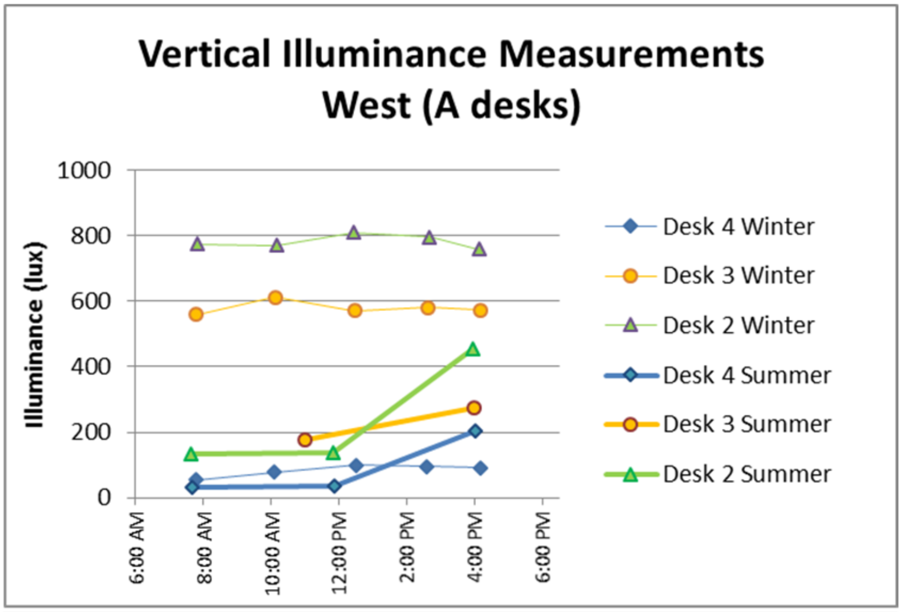

Window Luminance Measurements
North (B desks)
Luminance (cd/m²)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 17 Winter
Desk 16 Winter
Desk 15 Winter
Desk 17 Summer
Desk 16 Summer
Desk 15 Summer

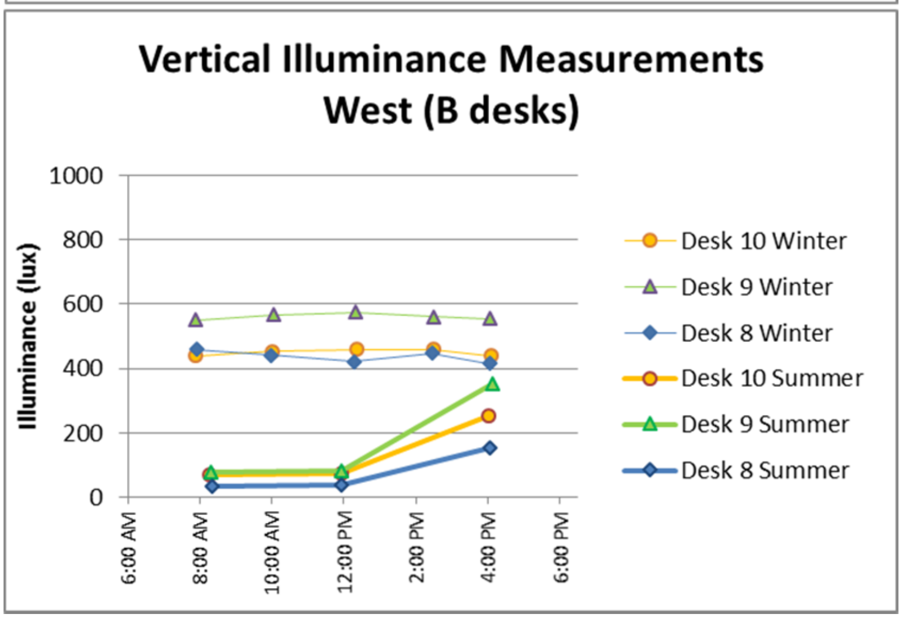
## WEST SIDE OF ASPINALL BUILDING

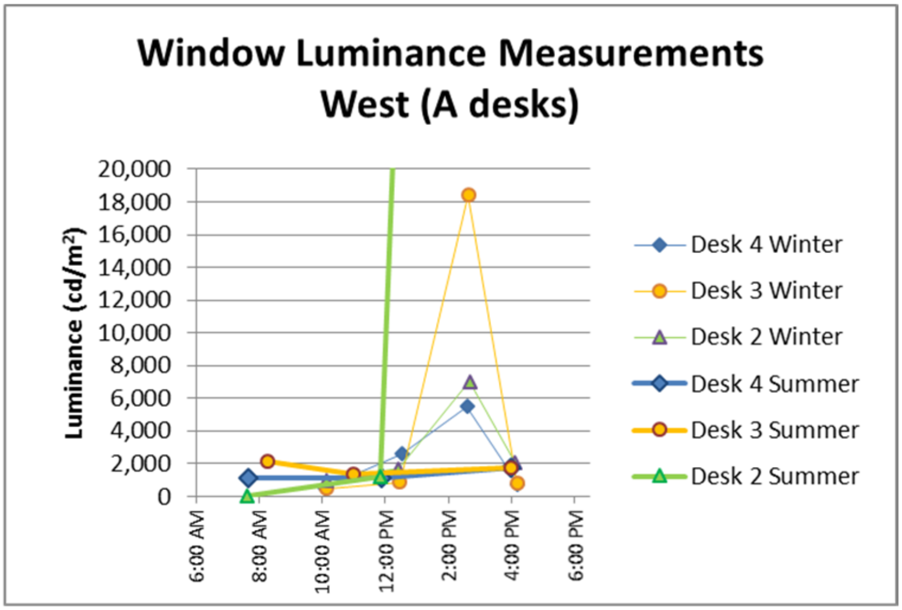
| Date, time | Floor | Orientation | Row | Desk | Task Light On Horiz Desk (lux) | Task Light On Vert Surface (lux) | Task Light Off Horiz Desk (lux) | Task Light Off Vert Surface (lux) | Window Luminance (cd/m2) |
|---|---|---|---|---|---|---|---|---|---|
| 6/19/14 7:19 AM | 1 | West | A | | | | 117 | 30 | 1141 |
| 6/19/14 11:44 AM | 1 | West | A | #4 | | | 146.6 | 33.7 | 1130 |
| 6/19/14 3:46 PM | 1 | West | A | | | | 2129 | 203 | 1745 |
| 6/19/14 7:20 AM | 1 | West | A | | | | 96.5 | 13.6 | 2133 |
| 6/19/14 11:43 AM | 1 | West | A | #3 | 256 | 175 | 114 | 14.6 | 1367 |
| 6/19/14 3:48 PM | 1 | West | A | | 2891 | 276 | 2727 | 126 | 1764 |
| 6/19/14 7:24 AM | 1 | West | A | | 251 | 134 | 93 | 62 | 43 |
| 6/19/14 11:41 PM | 1 | West | A | #2 | 252 | 139 | 110 | 61 | 1208 |
| 6/19/14 3:43 PM | 1 | West | A | | 3769 | 455 | 3700 | 401 | 200100 |
| 6/19/14 7:21 AM | 1 | West | B | | | | 100 | 71 | 940 |
| 6/19/14 11:47 AM | 1 | West | B | #10 | | | 103 | 73 | 654 |
| 6/19/14 3:51 PM | 1 | West | B | | | | 433.7 | 255 | 3337 |
| 6/19/14 7:22 AM | 1 | West | B | | | | 135 | 80 | 264 |
| 6/19/14 11:48 AM | 1 | West | B | #9 | | | 142 | 81 | 403 |
| 6/19/14 3:52 PM | 1 | West | B | | | | 624 | 354 | 1098 |
| 6/19/14 7:23 AM | 1 | West | B | | | | 105 | 35.9 | 1069 |
| 6/19/14 11:48 AM | 1 | West | B | #8 | | | 118 | 39.4 | 1519 |
| 6/19/14 3:53 PM | 1 | West | B | | | | 462 | 154 | 2960 |

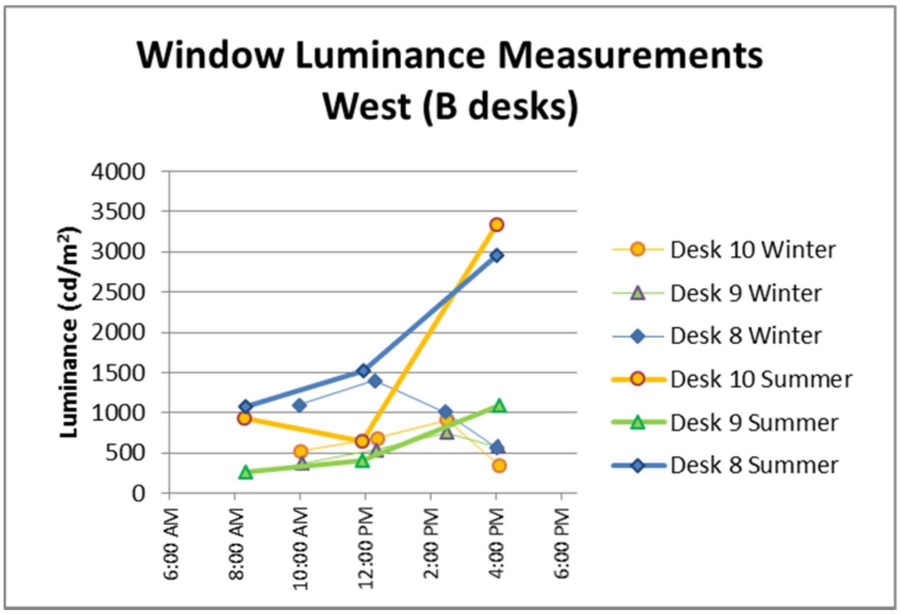

Horizontal Illuminance Measurements
West (A desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 4 Winter
Desk 3 Winter
Desk 2 Winter
Desk 4 Summer
Desk 3 Summer
Desk 2 Summer


Horizontal Illuminance Measurements
West (B desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 10 Winter
Desk 9 Winter
Desk 8 Winter
Desk 10 Summer
Desk 9 Summer
Desk 8 Summer


Vertical Illuminance Measurements
West (A desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 4 Winter
Desk 3 Winter
Desk 2 Winter
Desk 4 Summer
Desk 3 Summer
Desk 2 Summer

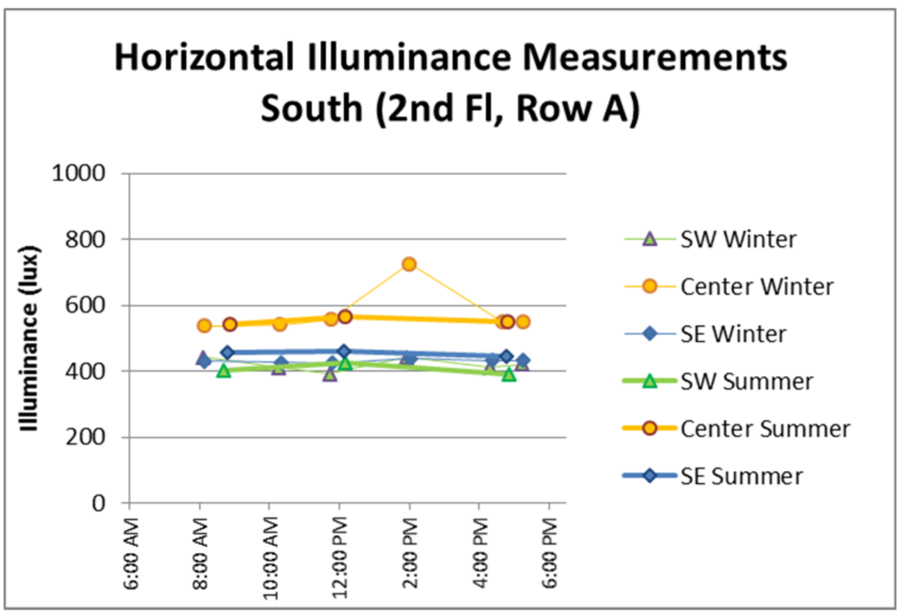

Vertical Illuminance Measurements
West (B desks)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 10 Winter
Desk 9 Winter
Desk 8 Winter
Desk 10 Summer
Desk 9 Summer
Desk 8 Summer

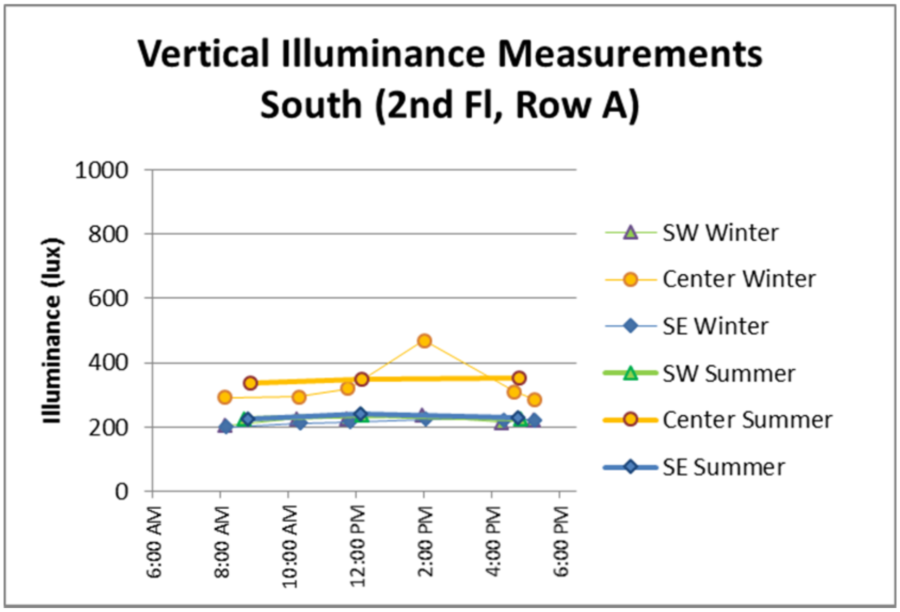

Window Luminance Measurements
West (A desks)
Luminance (cd/m²)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 4 Winter
Desk 3 Winter
Desk 2 Winter
Desk 4 Summer
Desk 3 Summer
Desk 2 Summer

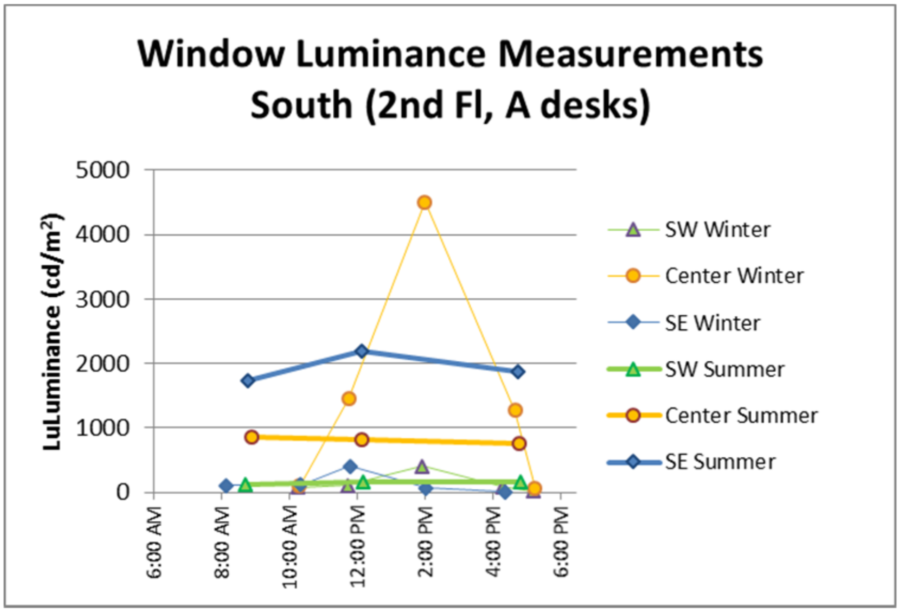

Window Luminance Measurements
West (B desks)
Luminance (cd/m²)
4000
3500
3000
2500
2000
1500
1000
500
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk 10 Winter
Desk 9 Winter
Desk 8 Winter
Desk 10 Summer
Desk 9 Summer
Desk 8 Summer

## South Side of Aspinall Building

| Date, time | Floor | Orientation | Row | Desk | Task Light On Horiz Desk (lux) | Task Light On Vert Surface (lux) | Task Light Off Horiz Desk (lux) | Task Light Off Vert Surface (lux) | Window Luminance (cd/m2) |
|---|---|---|---|---|---|---|---|---|---|
| 6/19/14 8:42 AM | 2 | South | A | SW Vacant desk | | | 404 | 225 | 114 |
| 6/19/14 12:03 PM | 2 | South | A | | | | 426 | 236 | 155 |
| 6/19/14 4:38 PM | 2 | South | A | | | | 390 | 224 | 163 |
| 6/19/14 8:44 AM | 2 | South | A | S Center | | | 541 | 337 | 866 |
| 6/19/14 12:02 PM | 2 | South | A | | | | 565 | 347 | 809 |
| 6/19/14 4:38 PM | 2 | South | A | | | | 551 | 353 | 750 |
| 6/19/14 8:36 AM | 2 | South | A | SE desk | | | 456 | 225 | 1724 |
| 6/19/14 12:01 PM | 2 | South | A | | | | 461 | 240 | 2184 |
| 6/19/14 4:37 PM | 2 | South | A | | | | 445 | 231 | 1866 |

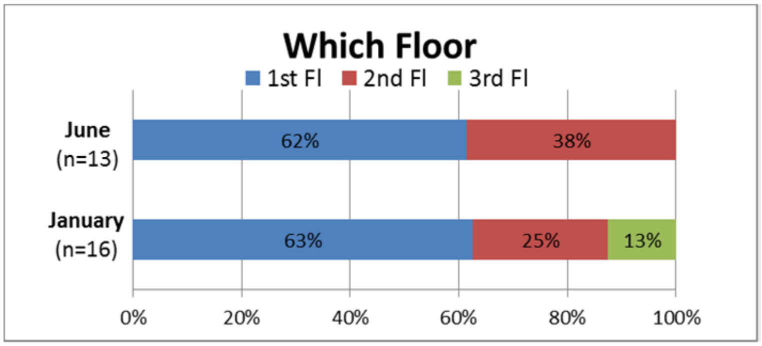


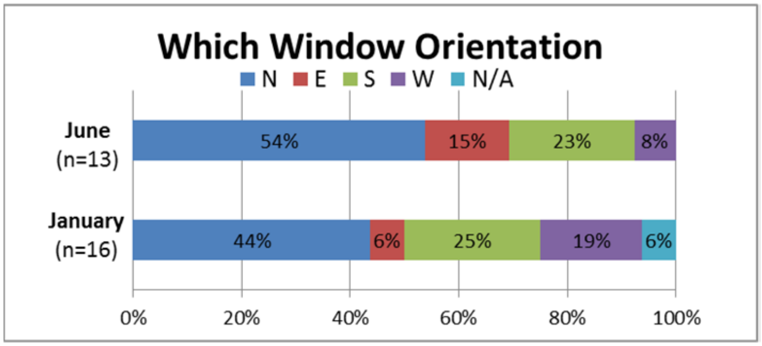

Vertical Illuminance Measurements
South (2nd Fl, Row A)
Illuminance (lux)
1000
800
600
400
200
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
SW Winter
Center Winter
SE Winter
SW Summer
Center Summer
SE Summer

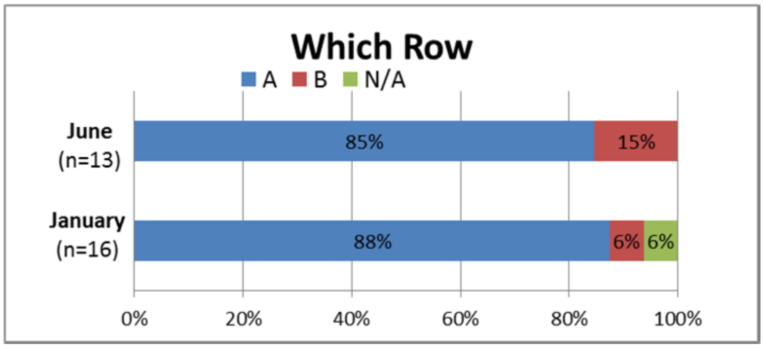

Window Luminance Measurements
South (2nd Fl, A desks)
LuLuminance (cd/m²)
5000
4000
3000
2000
1000
0
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
SW Winter
Center Winter
SE Winter
SW Summer
Center Summer
SE Summer

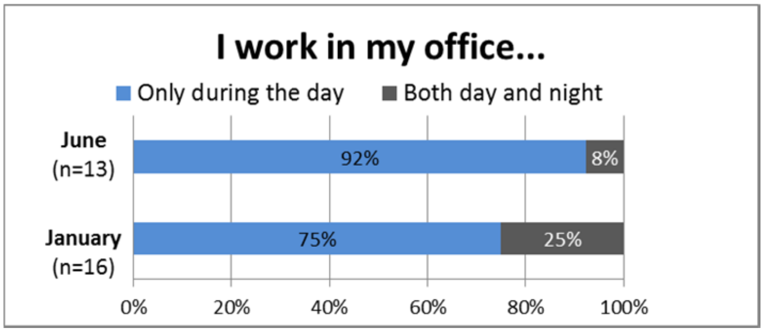
# Appendix B: Questionnaire Results

## Questionnaire Demographics

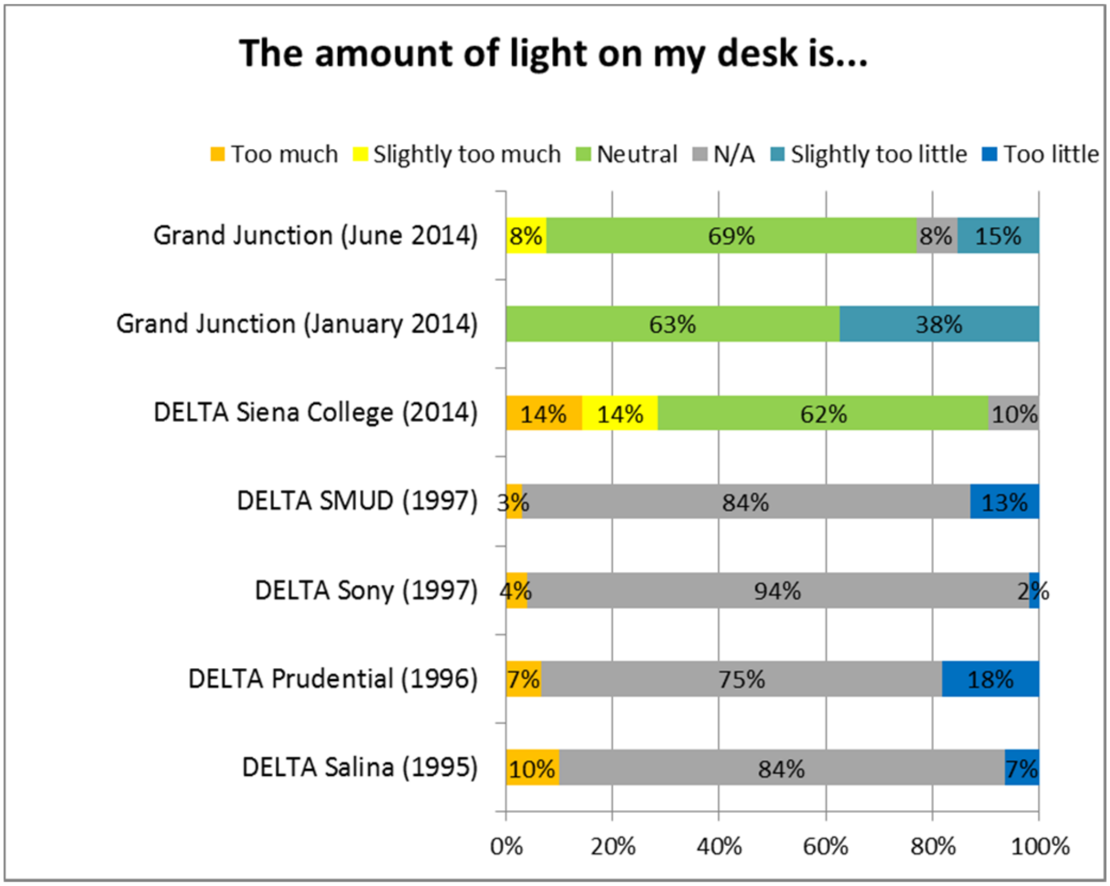


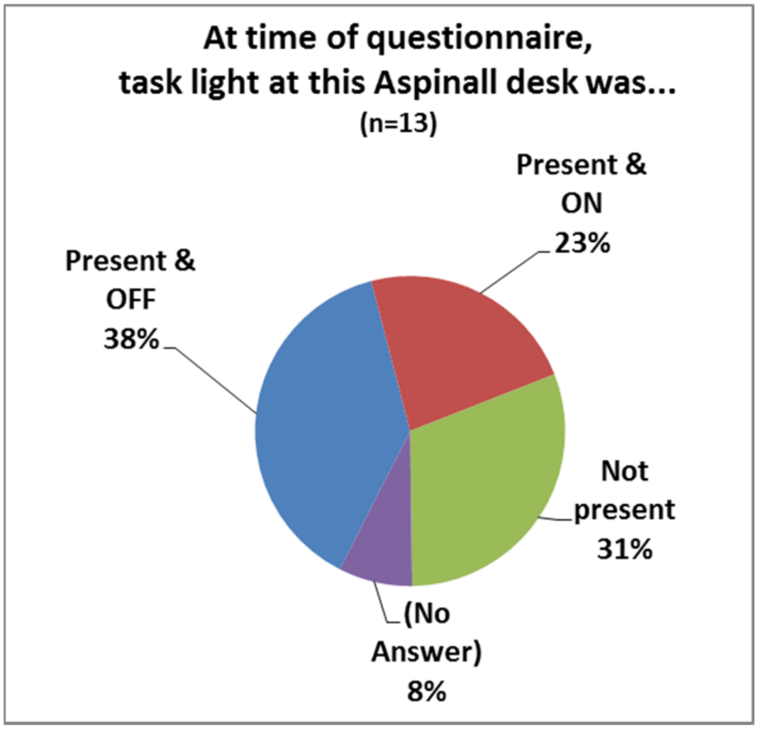



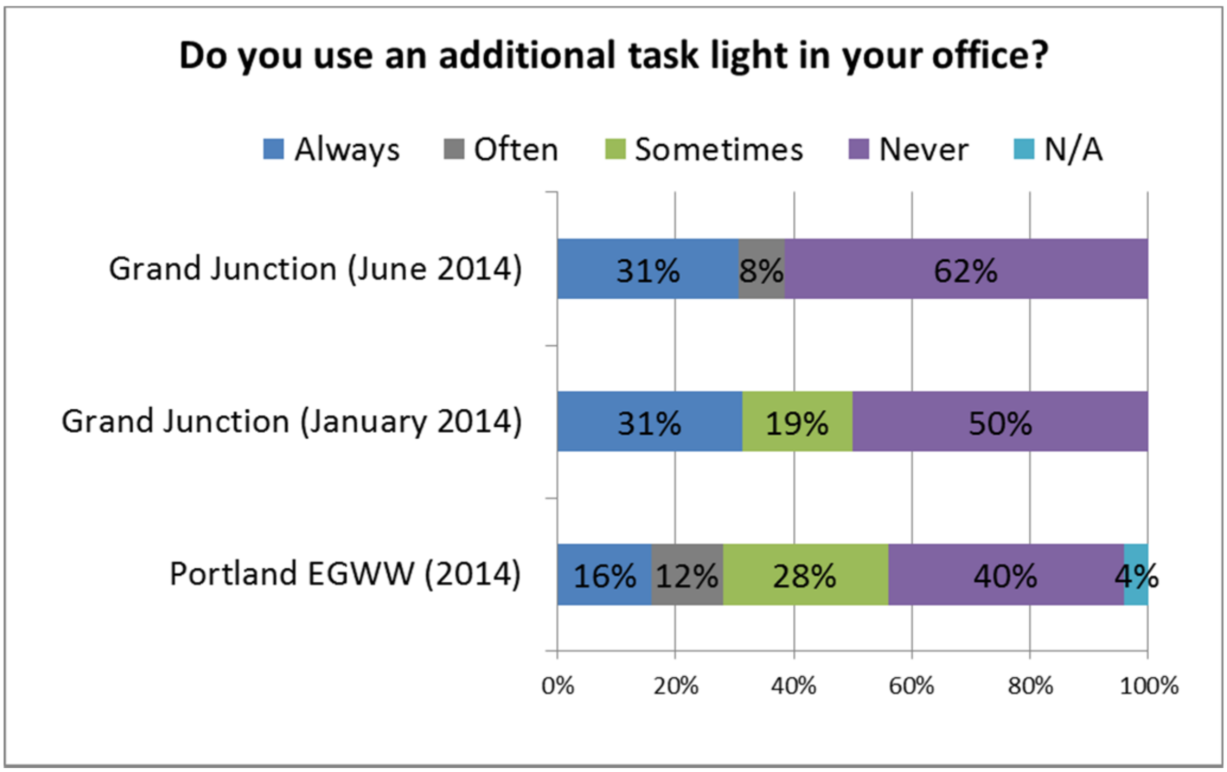



## Questionnaire Results (Grand Junction, compared to other sites, as available)

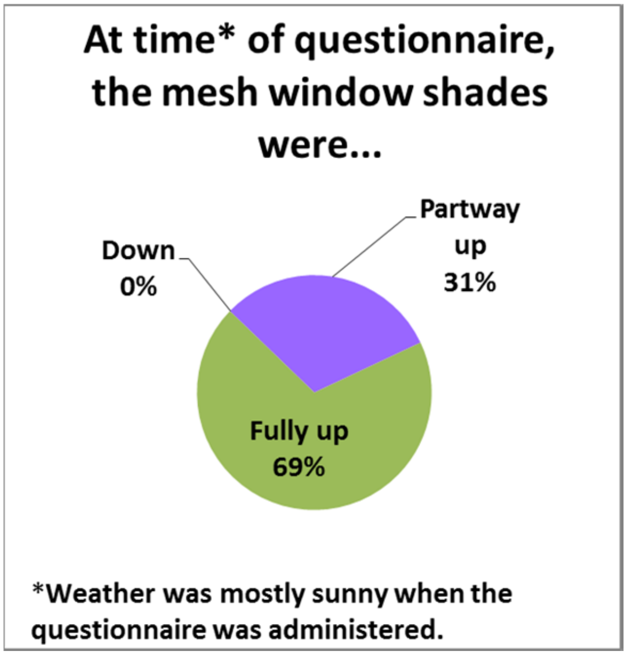




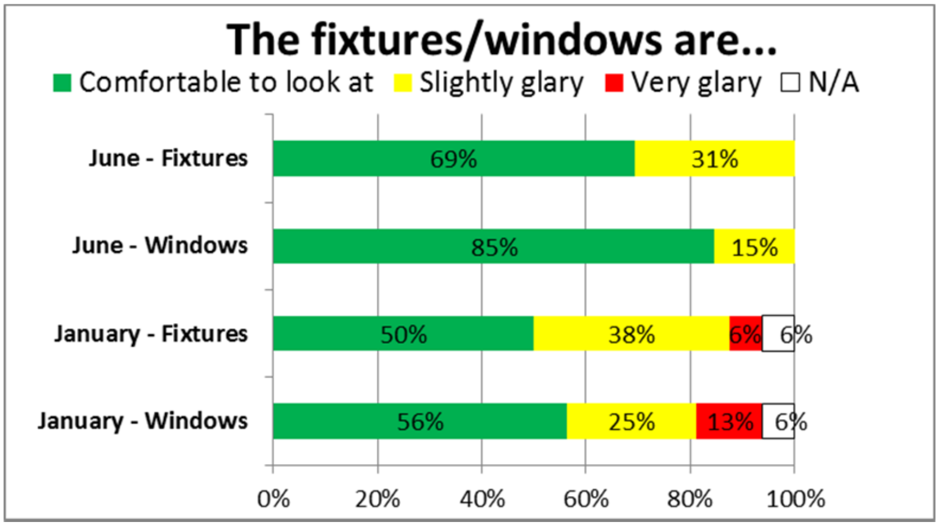

### GRAND JUNCTION, JUNE TASK LIGHT COMMENTS:

- Regarding task lights "I never use them."



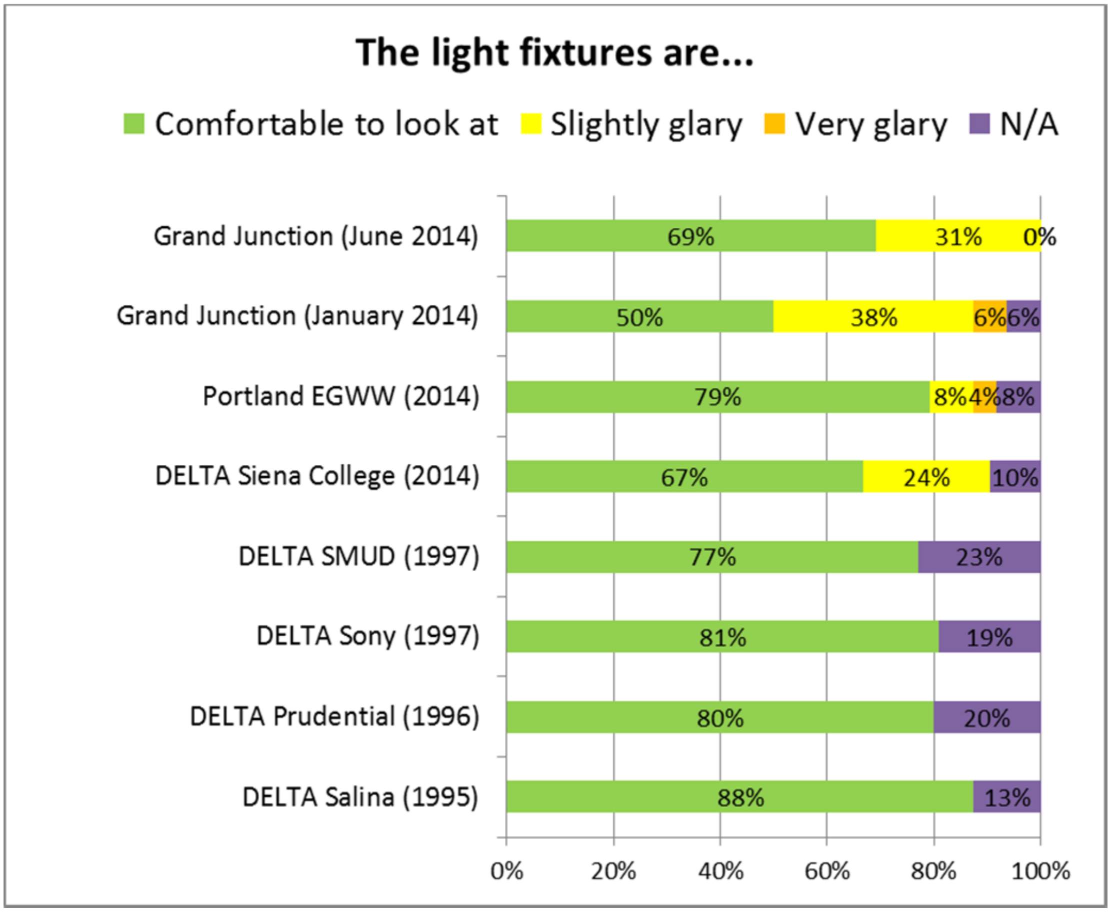

### *GRAND JUNCTION, JUNE SHADES COMMENTS:*

- In the morning, the east exposure causes the subject to use the mesh shades. He retracts the shades in the afternoon.
- "I like the variability of the blackout and partial (mesh) shade."
- "I don't put the blackout shades down, ever, if at all."
-



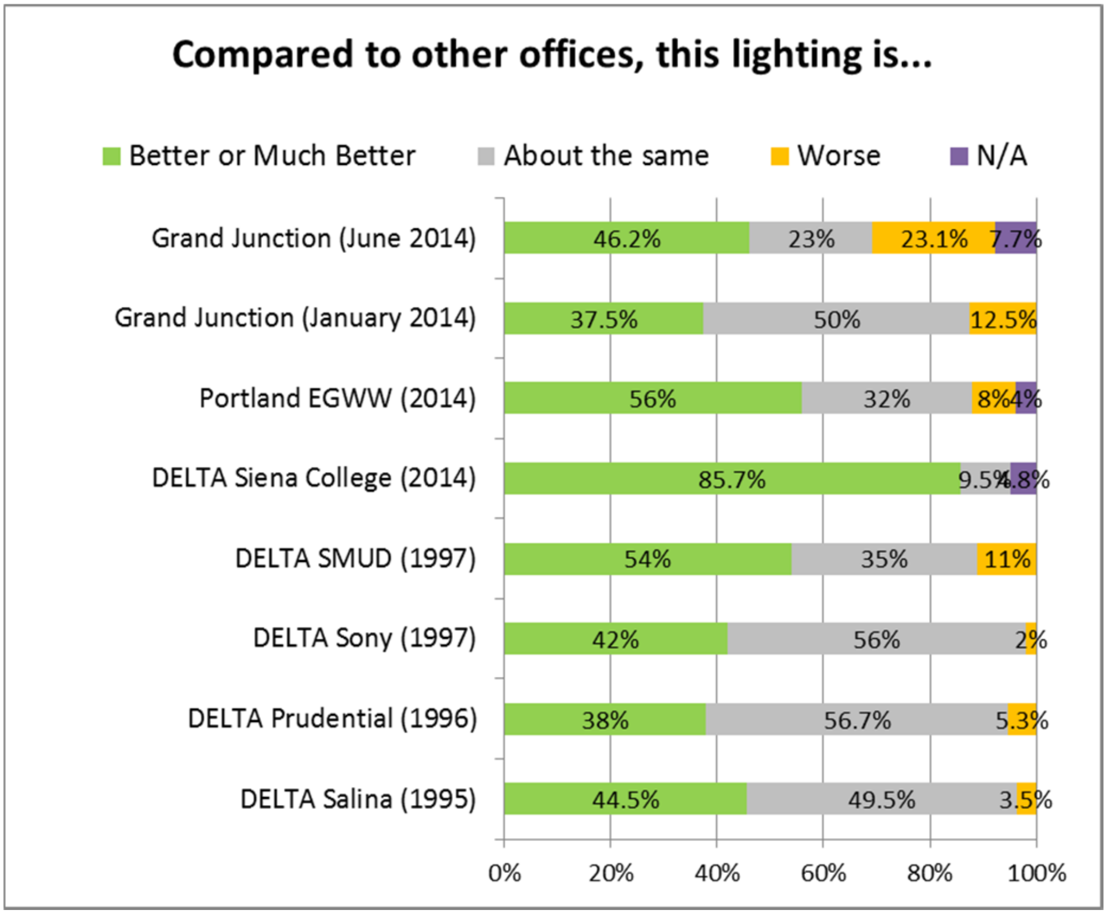
### *Grand Junction, June Window Glare Comments:*

- "I like natural light."
- "Shaft of sun makes it hard to focus on monitor."




### *Grand Junction, June Luminaire Comments:*

- "I am not a fan of fluorescent light, but the lighting in this building is more pleasant than the lighting in my home office in the Mobile District."
- Subject reports he primarily uses decorative table lamps instead of overhead lights. "Aesthetically, I'm not a huge fan. Our old office had historic sconces. I prefer the atmosphere of (these) table lamps." Subject indicated that the plug load table lamps are controlled with the same wireless occupancy sensors.




### *Grand Junction, June Overall Comments:*

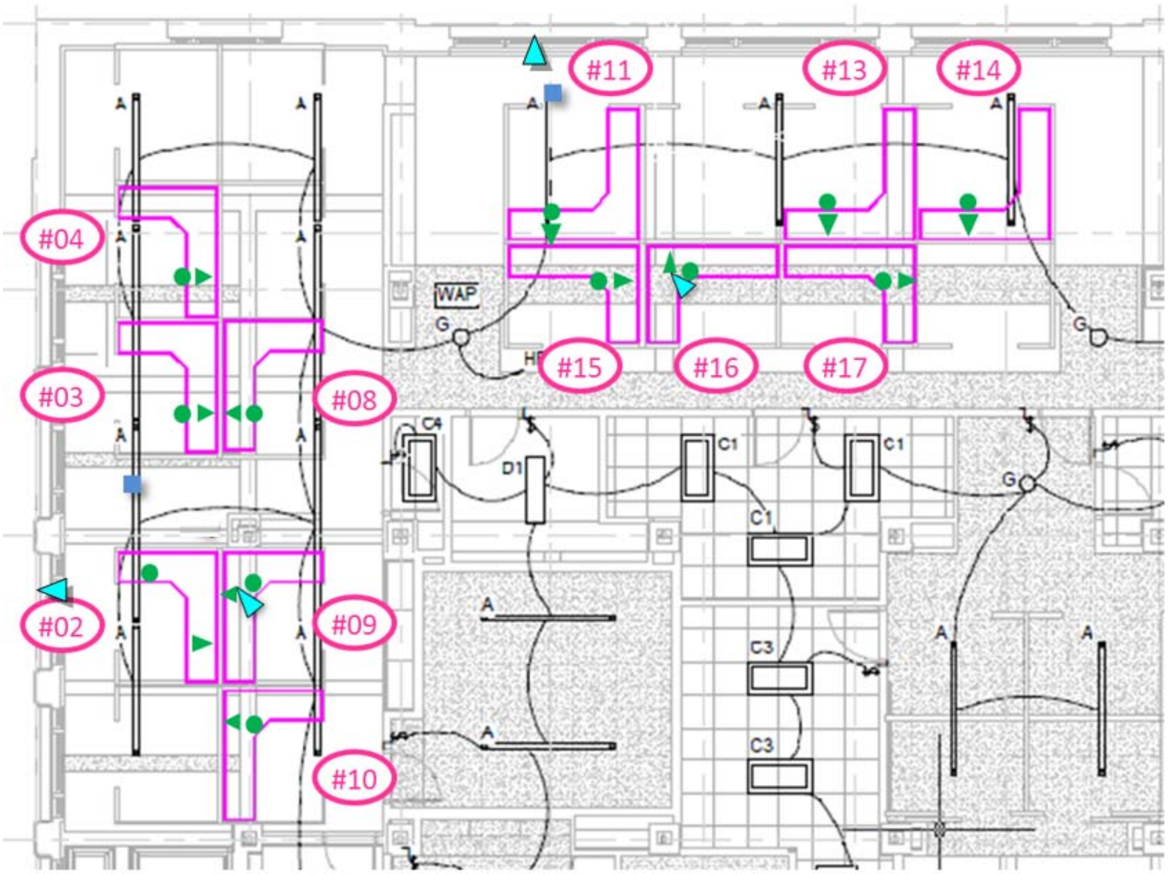
- (none)

### *Other controls comments*

- A subject has a POSITIVE connotation to the occupancy sensor false off "it just means it's about time that I got up and moved!"
- A subject in a private office subject likes dimmer lighting controls, "when I have a migraine I can use the dimmer or turn it off."
- Subject doesn't commonly use the overhead lights.  "If I've had lights on (which is not really common) the lights will turn off automatically."

# APPENDIX C: SPECTRAL PHOTOMETRIC DATA, FIRST FLOOR

Spectral power distribution (SPD) was measured at 12 desks on the 1st floor. Six were located on the North side, and six were located on the west side. These were the same desks where illuminance and luminance were measured (Appendix A). SPDs were measured three times over the day; the building is not open after dark or before sunrise.

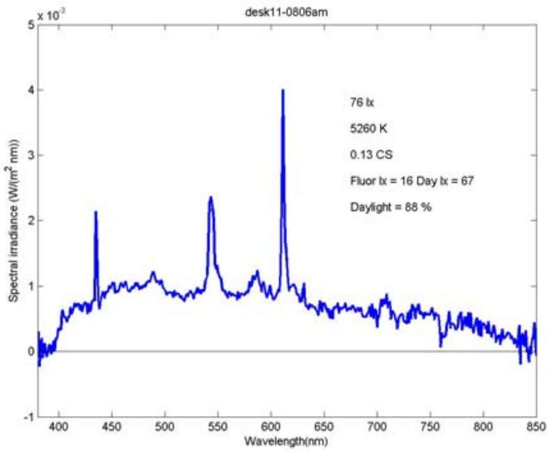



Desks on the first floor where SPD measurements were collected

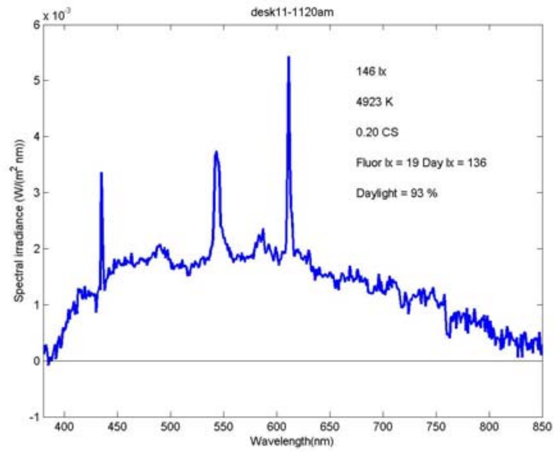
As shown below, the resulting SPD curves change as daylight contribution changes.

## FLOOR1-NORTH-ROWA-DESK11

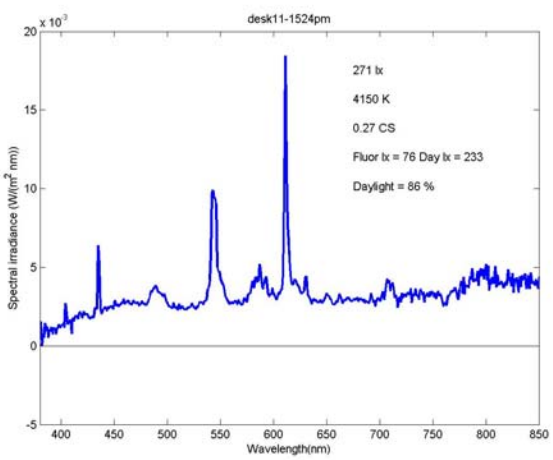
*(SPECTRAL POWER DISTRIBUTION)*




**8:06 AM**




**11:20 AM**



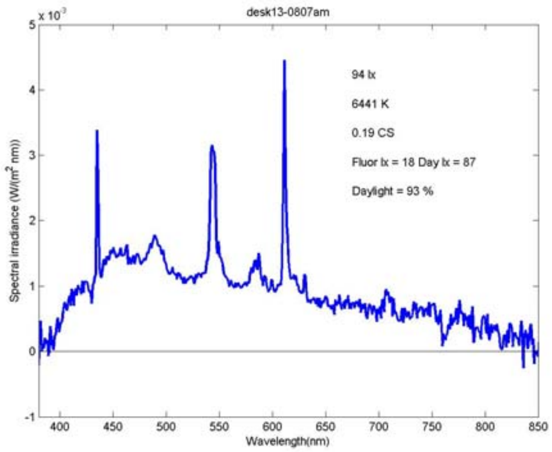

**3:24 PM**

***Note: Desk 11 faces away from north windows***

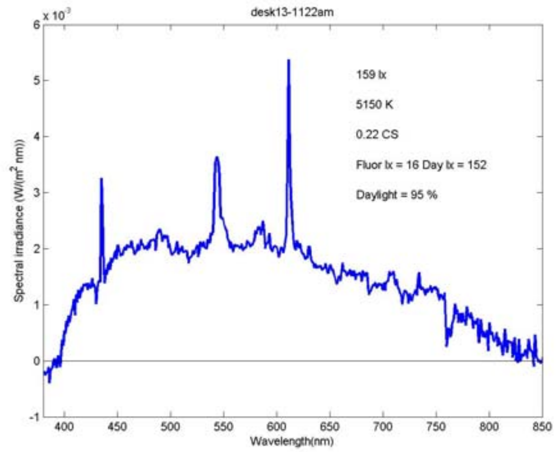
***(photos of windows not permitted)***

# FLOOR1-NORTH-ROWA-DESK13

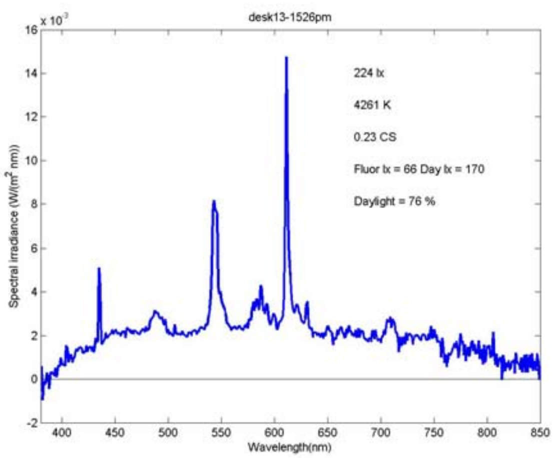
## *(SPECTRAL POWER DISTRIBUTION)*




***8:07 AM***




***11:22 AM***



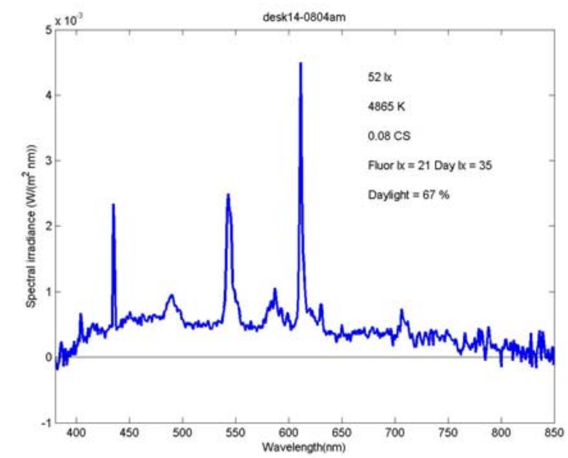

***3:27 PM***

***Desk 13 also faces away from North windows***

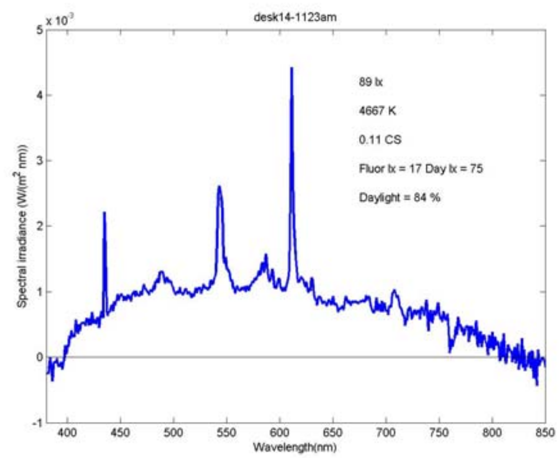
***(photos of windows not permitted)***

## FLOOR1-NORTH-ROWA-DESK14

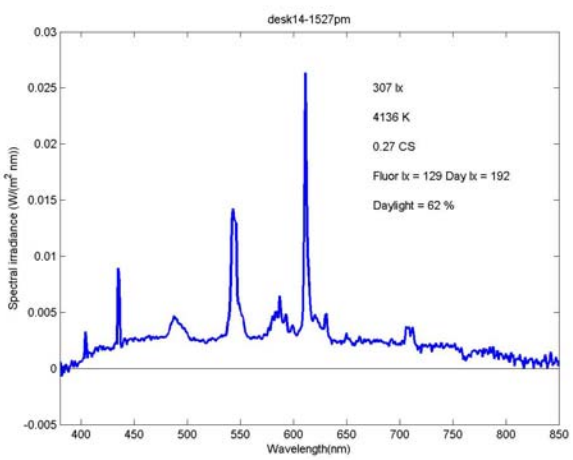
*(SPECTRAL POWER DISTRIBUTION)*



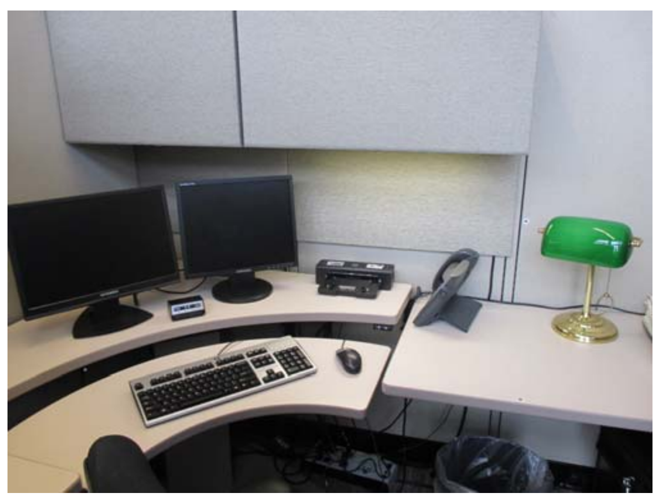

***8:04 AM***




***11:23 AM***

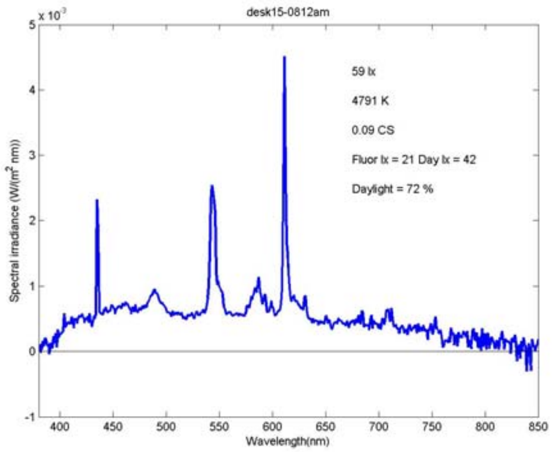



***3:27 PM***

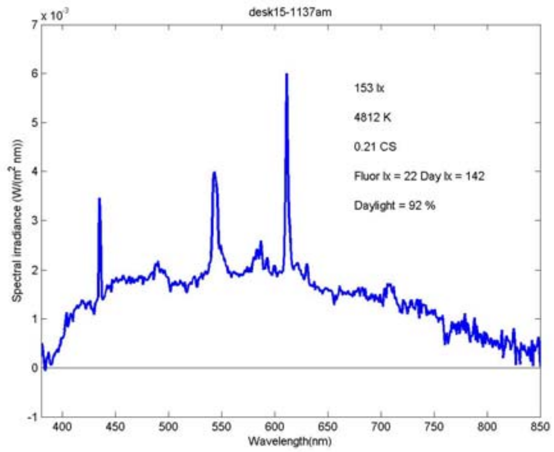


***Windows are behind desk 14***

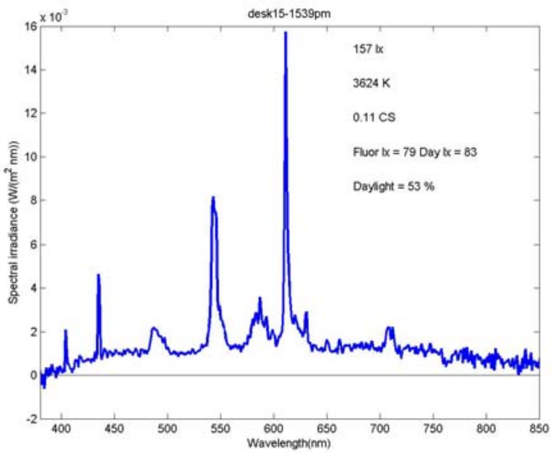
## FLOOR1-NORTH-ROWB-DESK15
### *(SPECTRAL POWER DISTRIBUTION)*



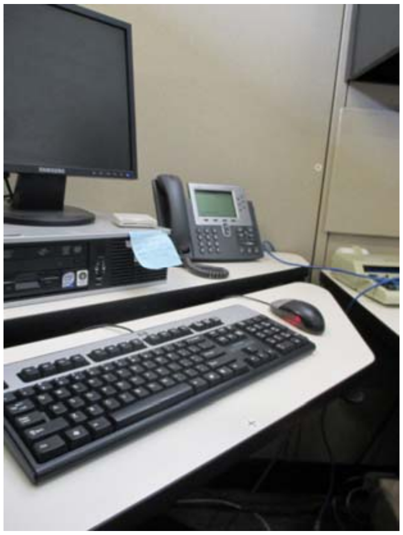

***8:12 AM***




***11:37 AM***



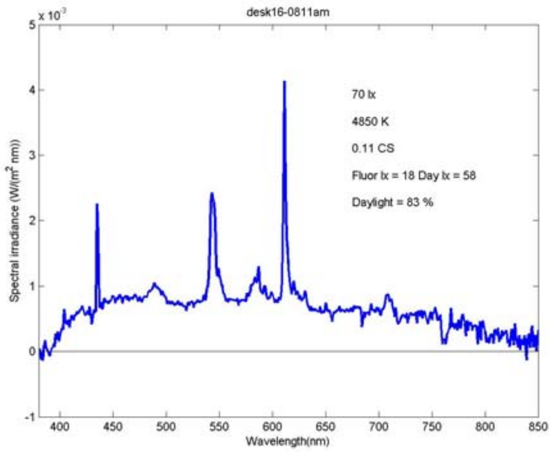

***3:39 PM***



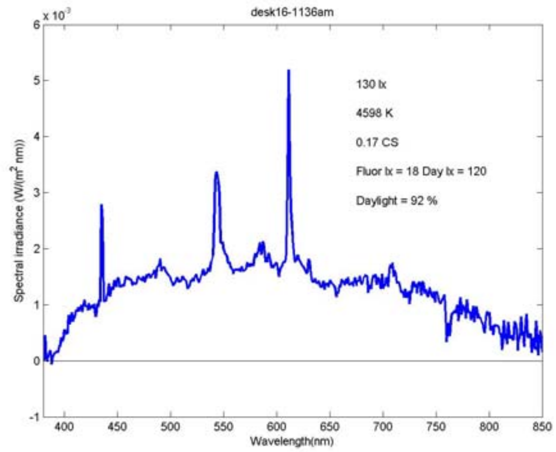
***Vacant visitor's desk 15***

# FLOOR1-NORTH-ROWB-DESK16

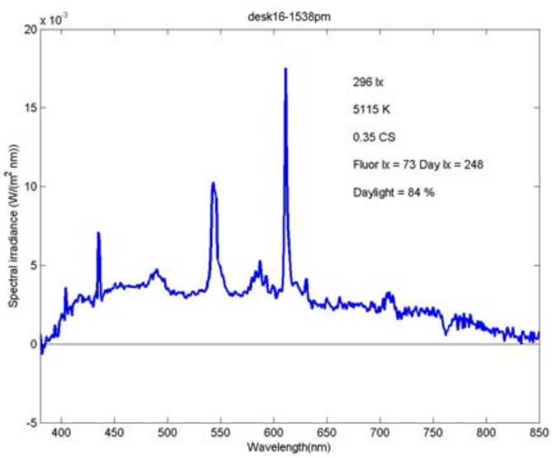
## *(SPECTRAL POWER DISTRIBUTION)*



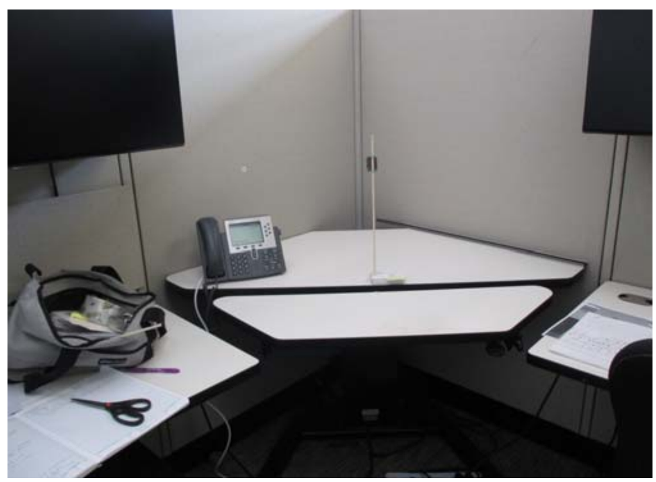

***8:11 AM***




***11:36 AM***



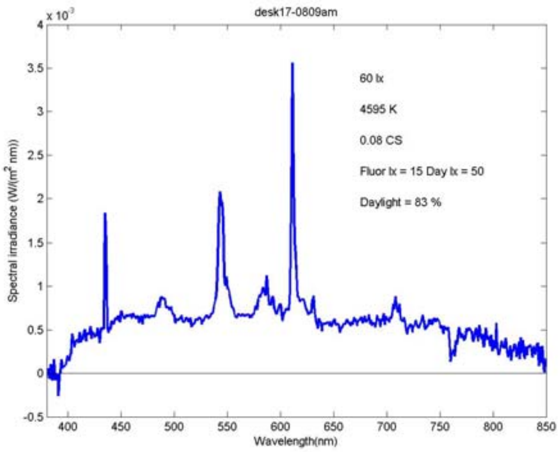

***3:38 PM***



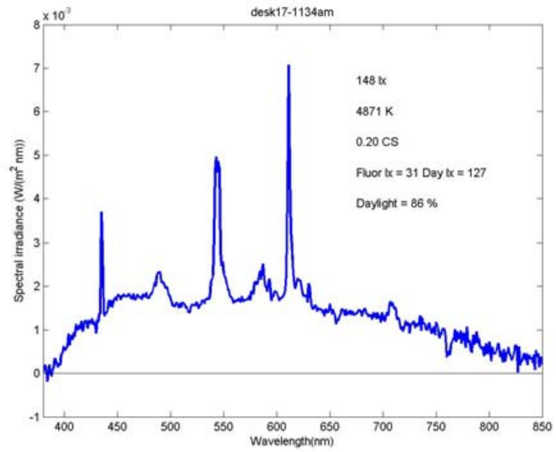
***Vacant desk 16; north windows to right of this image***

## FLOOR1-NORTH-ROWB-DESK17

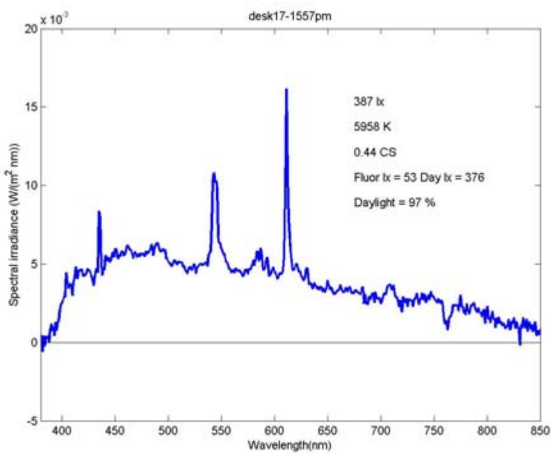
### *(SPECTRAL POWER DISTRIBUTION)*




***8:09 AM***




***11:34 AM***



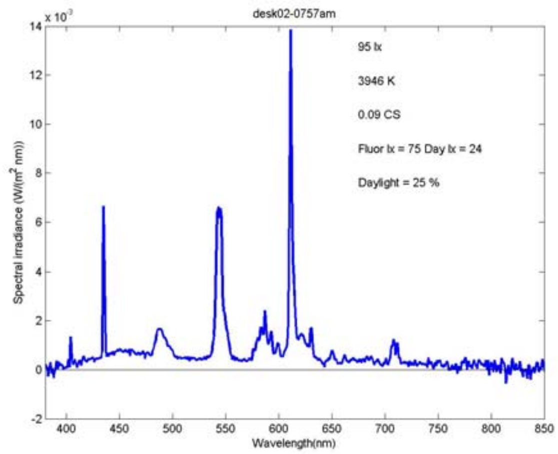

***3:57 PM***

***Desk 17 faces an interior wall, not a window***

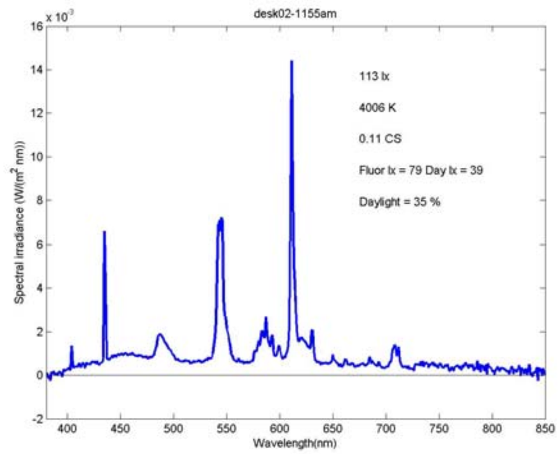
***(photos not permitted)***

## FLOOR1-WEST-ROWA-DESK2

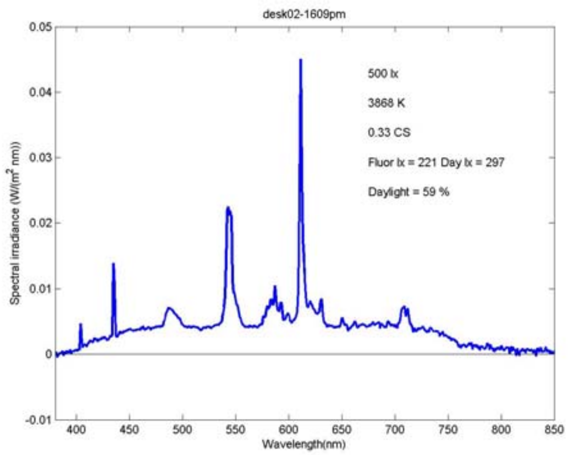
***(SPECTRAL POWER DISTRIBUTION)***




***7:57 AM***




***11:55 AM***



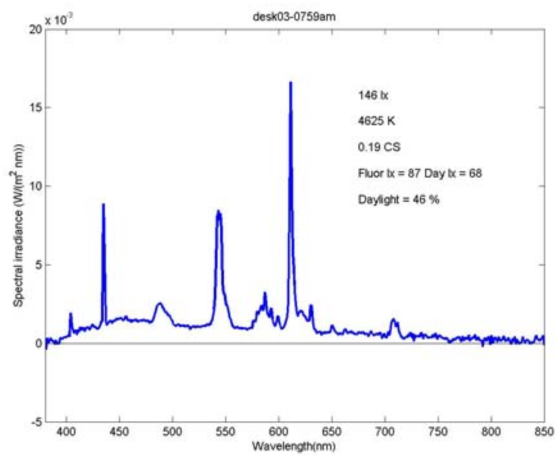

***4:09 PM***

***Occupant of Desk 2 faces away from west windows***

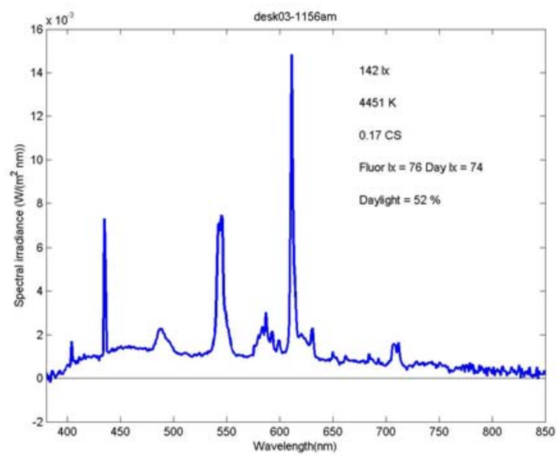
***(photos not permitted)***

# FLOOR1-WEST-ROWA-DESK3

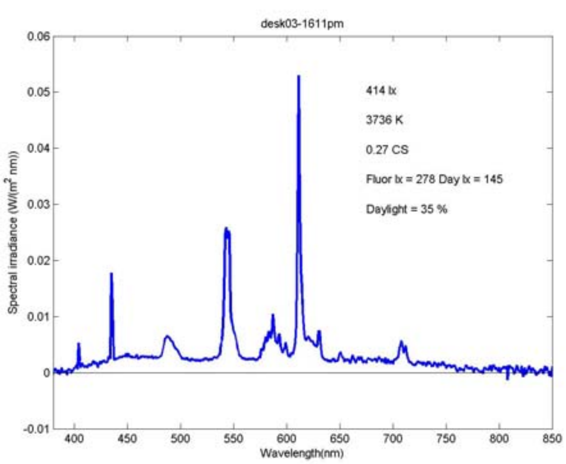
***(SPECTRAL POWER DISTRIBUTION)***




***7:59 AM***




***11:56 AM***



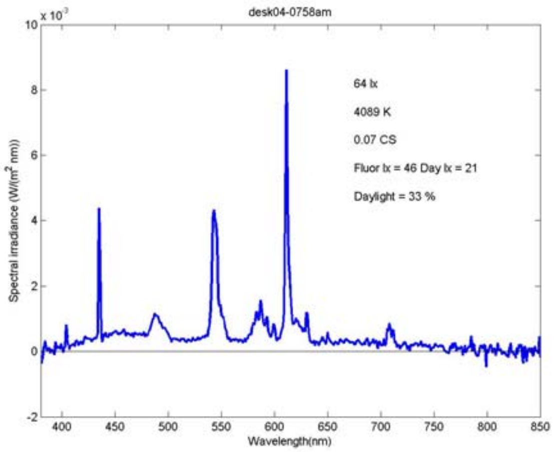

***4:11 PM***

***Occupant of Desk 3 faces away from west windows***

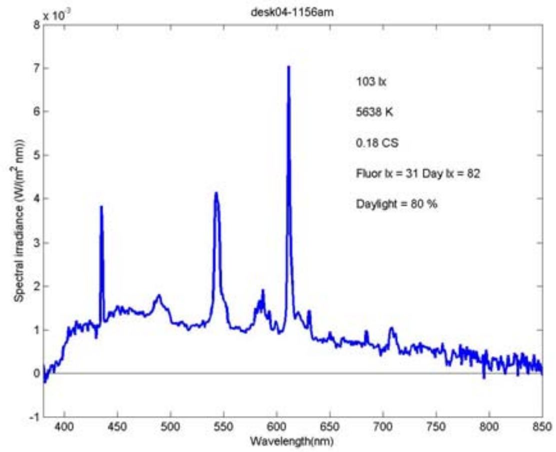
***(photos not permitted)***

## FLOOR1-WEST-ROWA-DESK4

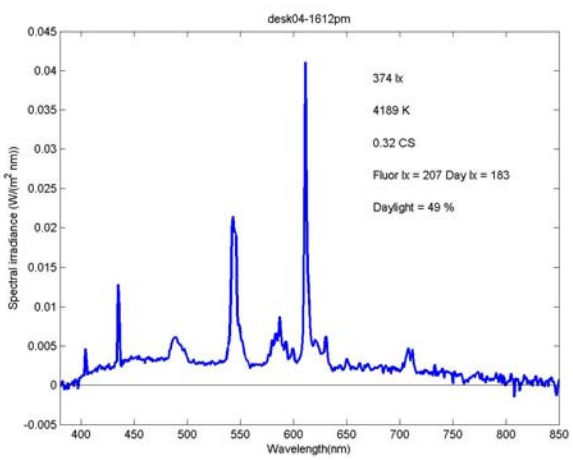
***(SPECTRAL POWER DISTRIBUTION)***




***7:58 AM***




***11:56 AM***

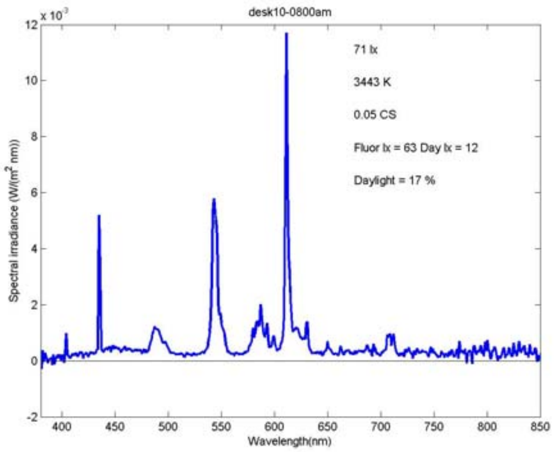



***4:12 PM***

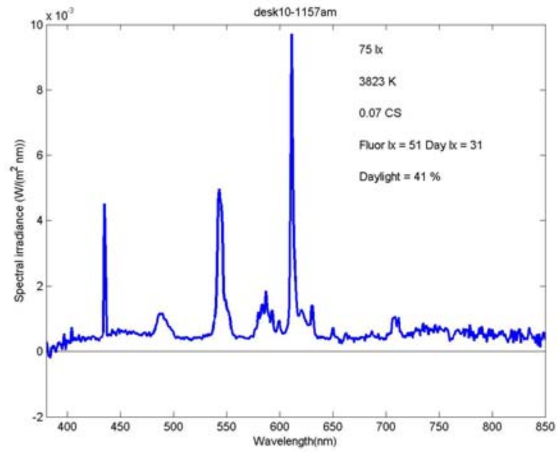
***Occupant of Desk 4 faces away from west windows***

***(photos not permitted)***

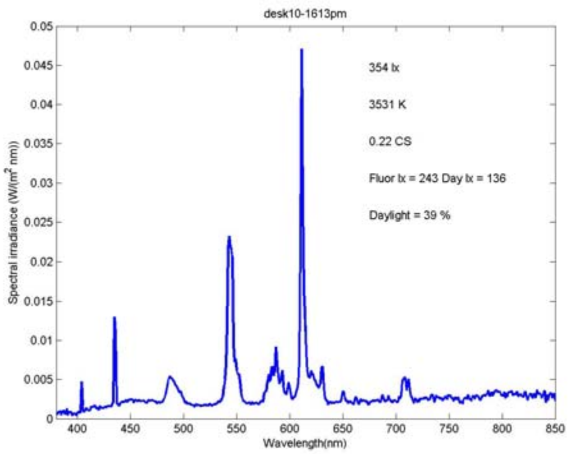
# FLOOR1-WEST-ROWB-DESK10
## *(SPECTRAL POWER DISTRIBUTION)*




***8:00 AM***




***11:57 AM***

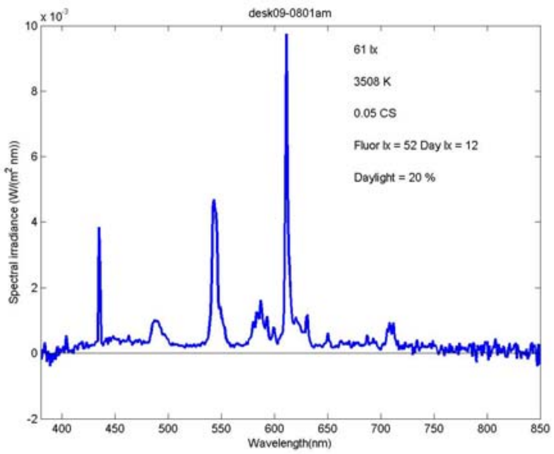



***4:13 PM***

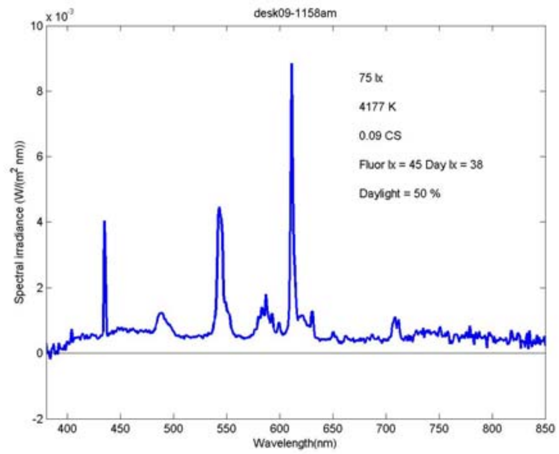
***Vacant desk 10***

## FLOOR1-WEST-ROWB-DESK9

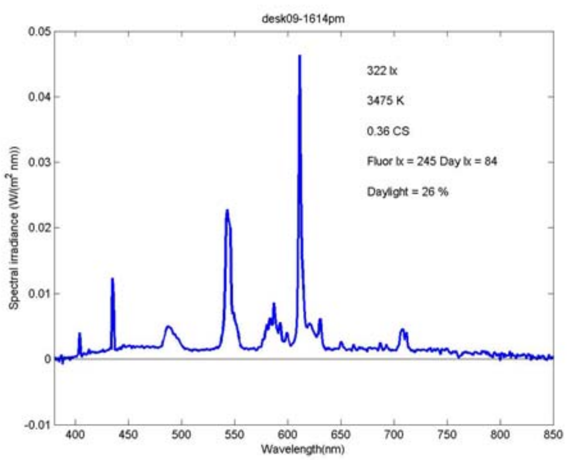
***(SPECTRAL POWER DISTRIBUTION)***




***8:01 AM***




***11:58 AM***

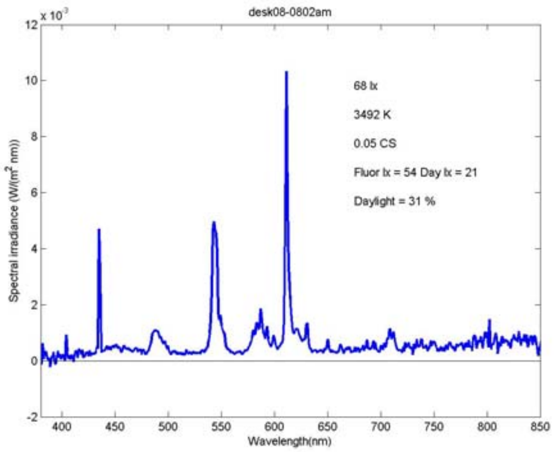



***4:14 PM***

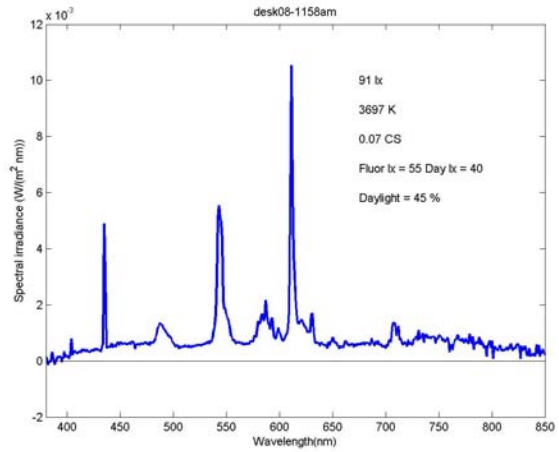
***Vacant desk 9, with stick Daysimeter***

## FLOOR1-WEST-ROWB-DESK8

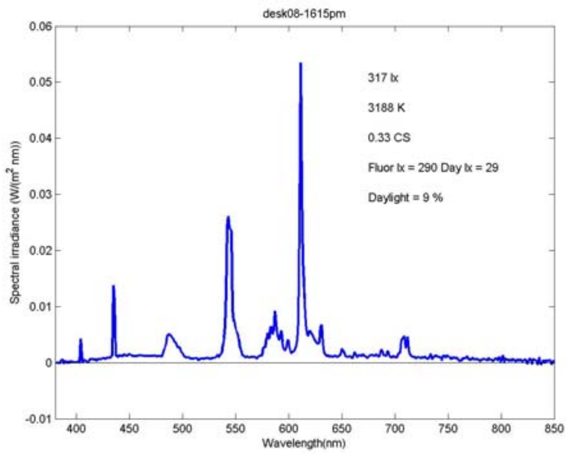
### *(SPECTRAL POWER DISTRIBUTION)*




*8:02 AM*




*11:58 AM*




*4:15 PM*

*Vacant desk 8*

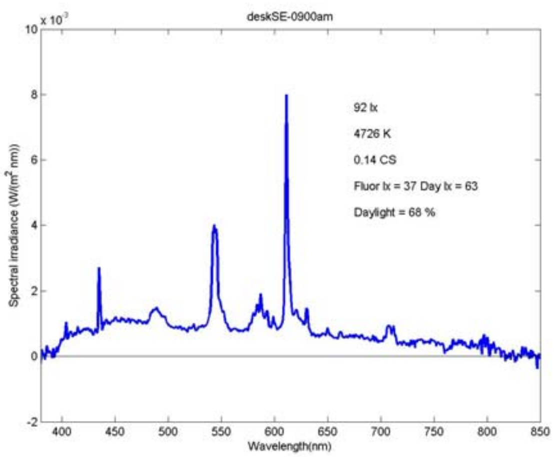
# Appendix D: Spectral Photometric Data, Second Floor

Spectral power distribution (SPD) was measured at 3 desks on the 2nd floor. These were the same desks where illuminance and luminance were measured (Appendix A). SPDs were measured repeatedly over the day.

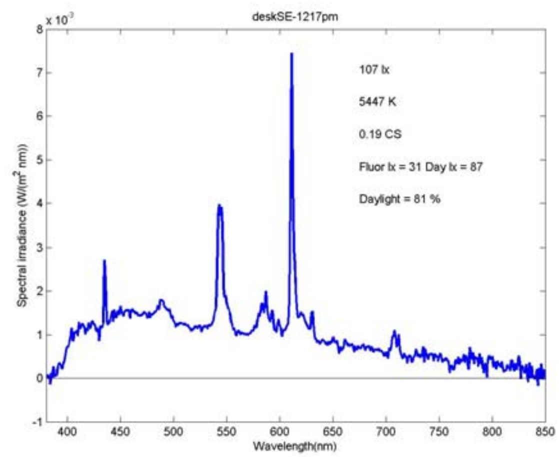

*Desks on the second floor where SPD measurements were collected*

As shown below, the resulting SPD curves change as daylight contribution changes.

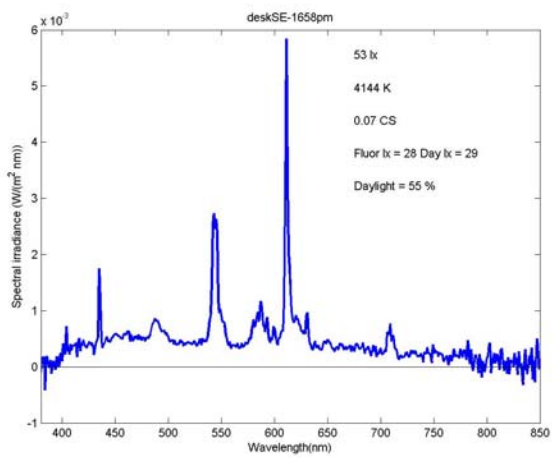
## FLOOR2-SOUTH-ROWA-SOUTHEAST
### *(SPECTRAL POWER DISTRIBUTION)*




***9:00 AM***



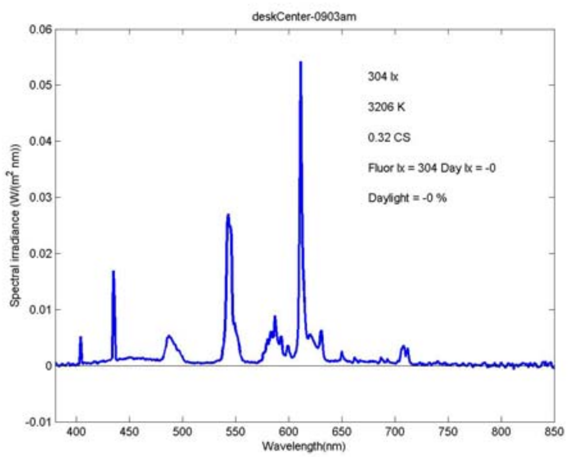

***12:17 PM***



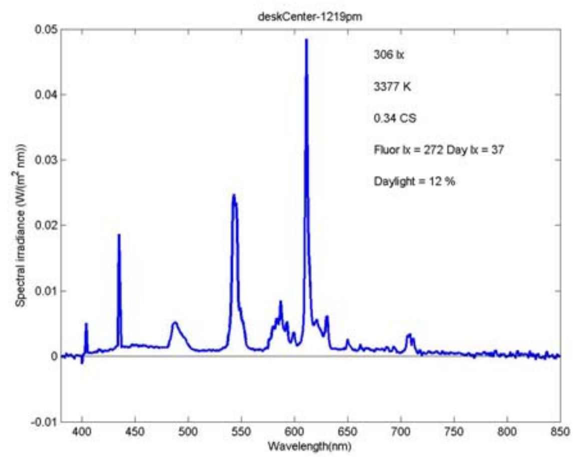

***4:58 PM***

***View from 2nd Floor Sutheast desk***

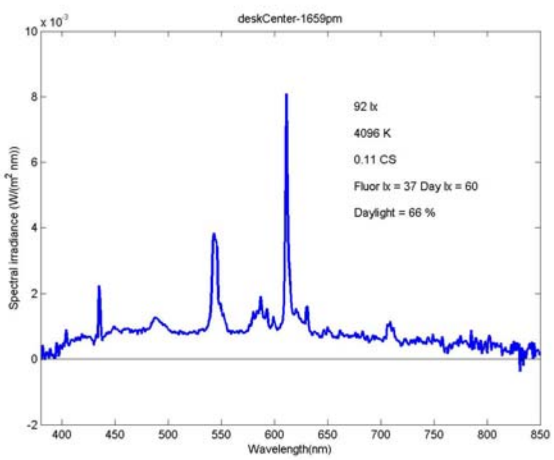
## FLOOR2-SOUTH-ROWA-CENTER
### *(SPECTRAL POWER DISTRIBUTION)*




***9:03 AM***




***12:19 AM***

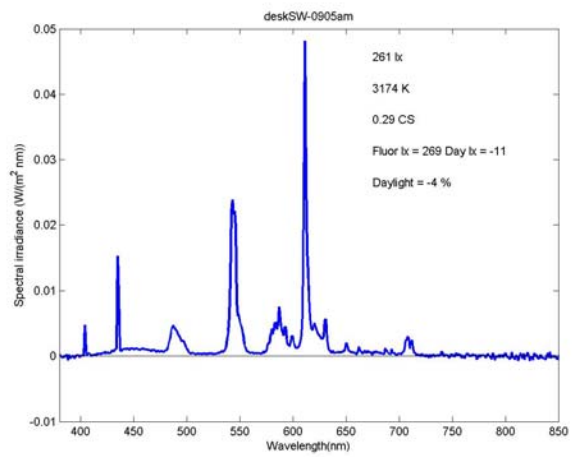



***4:59 PM***

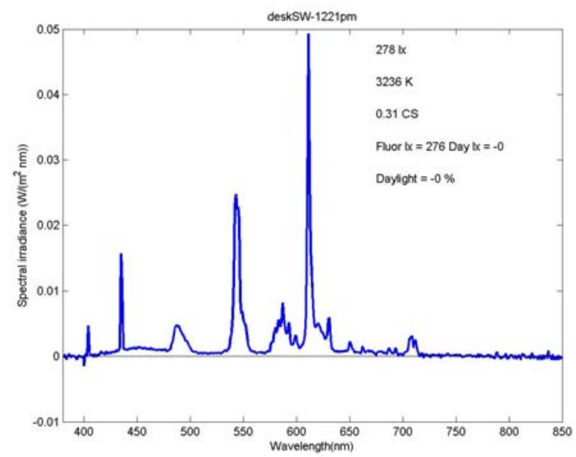
***2$^{nd}$ Floor Center desk***

# FLOOR2-SOUTH-ROWA-SOUTHWEST

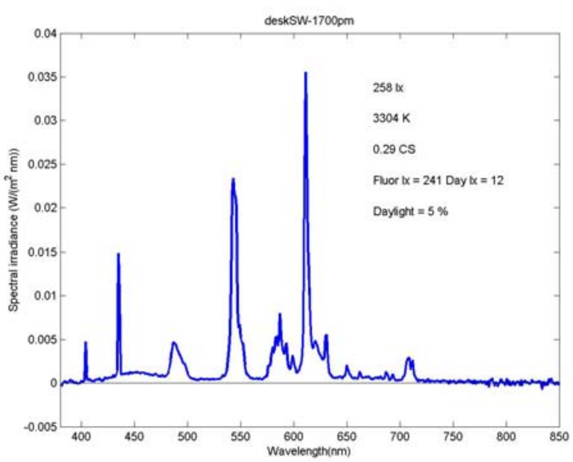
## *(SPECTRAL POWER DISTRIBUTION)*



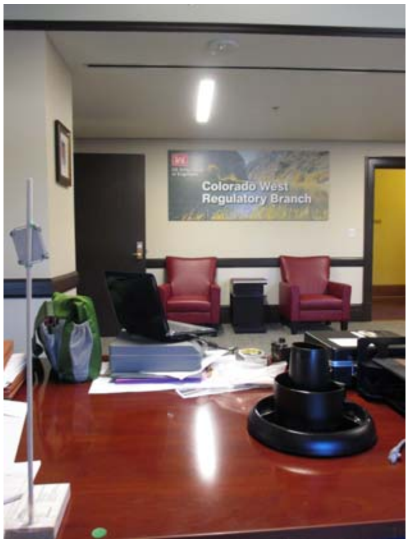

***9:05 AM***




***12:21 PM***




***5:00 PM***




***View from 2nd Floor Southwest desk***

# APPENDIX E: SPECTRORADIOMETRY RESULTS TABLE

| | | | | **Illuminance** | **Approximate Contribution (+/- 10%)** | | **Color Coordinates** | | **Color Temp** | **Circadian Light** | **Circadian Stimulus** (up to 0.7) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orientation** | Row | Desk | Time | Lux | **Fluor** | **Daylight** | **CIEx** | **CIEy** | CCT(K) | **$CL_A$** | **CS** | **Bright-ness** |
| N | A | desk11 | 8:06 AM | 76.0 | 20% | 80% | 0.34 | 0.35 | 5260 | 91.2 | 0.13 | 63.6 |
| N | A | desk11 | 11:20 AM | 146.3 | 13% | 87% | 0.35 | 0.36 | 4923 | 156.6 | 0.20 | 115.9 |
| N | A | desk11 | 3:24 PM | 270.8 | 28% | 72% | 0.37 | 0.37 | 4150 | 235.6 | 0.27 | 198.3 |
| N | A | desk13 | 8:07 AM | 94.1 | 19% | 81% | 0.31 | 0.33 | 6441 | 143.9 | 0.19 | 88.5 |
| N | A | desk13 | 11:22 AM | 159.1 | 10% | 90% | 0.34 | 0.36 | 5150 | 179.5 | 0.22 | 128.4 |
| N | A | desk13 | 3:26 PM | 223.9 | 29% | 71% | 0.37 | 0.37 | 4261 | 183.0 | 0.23 | 159.9 |
| N | A | desk14 | 8:04 AM | 52.5 | 41% | 59% | 0.35 | 0.36 | 4865 | 56.5 | 0.08 | 42.1 |
| N | A | desk14 | 11:23 AM | 89.5 | 19% | 81% | 0.36 | 0.37 | 4667 | 81.3 | 0.11 | 66.0 |
| N | A | desk14 | 3:27 PM | 307.1 | 42% | 58% | 0.38 | 0.38 | 4136 | 234.7 | 0.27 | 214.1 |
| N | B | desk15 | 8:12 AM | 59.0 | 36% | 64% | 0.35 | 0.35 | 4791 | 63.2 | 0.09 | 47.5 |
| N | B | desk15 | 11:37 AM | 153.3 | 14% | 86% | 0.35 | 0.36 | 4812 | 160.7 | 0.21 | 120.9 |
| N | B | desk15 | 3:39 PM | 157.2 | 50% | 50% | 0.40 | 0.39 | 3624 | 79.1 | 0.11 | 98.1 |
| N | B | desk16 | 8:11 AM | 70.2 | 25% | 75% | 0.35 | 0.36 | 4850 | 74.9 | 0.11 | 56.2 |
| N | B | desk16 | 11:36 AM | 130.2 | 14% | 86% | 0.36 | 0.37 | 4598 | 123.4 | 0.17 | 98.4 |
| N | B | desk16 | 3:38 PM | 295.6 | 25% | 75% | 0.34 | 0.35 | 5115 | 351.1 | 0.35 | 244.9 |
| N | B | desk17 | 8:09 AM | 60.2 | 25% | 75% | 0.36 | 0.36 | 4595 | 57.9 | 0.08 | 46.1 |
| N | B | desk17 | 11:34 AM | 148.1 | 21% | 79% | 0.35 | 0.36 | 4871 | 156.7 | 0.20 | 117.0 |
| N | B | desk17 | 3:57 PM | 387.2 | 14% | 86% | 0.32 | 0.34 | 5958 | 563.9 | 0.44 | 351.1 |

| | | | | **Illuminance** | **Approximate Contribution (+/- 10%)** | | **Color Coordinates** | | **Color Temp** | **Circadian Light** | **Circadian Stimulus** (up to 0.7) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orientation** | Row | Desk | Time | Lux | **Fluor** | **Daylight** | **CIEx** | **CIEy** | CCT(K) | **$CL_A$** | **CS** | **Bright-ness** |
| S | A | deskCenter | 9:03 AM | 303.6 | 100% | 0% | 0.43 | 0.41 | 3206 | 307.5 | 0.32 | 170.7 |
| S | A | deskCenter | 12:19 PM | 306.4 | 89% | 11% | 0.41 | 0.40 | 3377 | 341.5 | 0.34 | 182.2 |
| S | A | deskCenter | 4:59 PM | 91.6 | 40% | 60% | 0.38 | 0.37 | 4096 | 74.9 | 0.11 | 66.0 |
| S | A | deskSE | 9:00 AM | 92.3 | 40% | 60% | 0.35 | 0.35 | 4726 | 100.4 | 0.14 | 74.5 |
| S | A | deskSE | 12:17 PM | 107.3 | 29% | 71% | 0.33 | 0.34 | 5447 | 144.4 | 0.19 | 95.2 |
| S | A | deskSE | 4:58 PM | 53.4 | 52% | 48% | 0.37 | 0.36 | 4144 | 47.3 | 0.07 | 39.8 |
| S | A | deskSW | 9:05 AM | 260.5 | 100% | 0% | 0.43 | 0.41 | 3174 | 255.8 | 0.29 | 144.1 |
| S | A | deskSW | 12:21 PM | 277.9 | 99% | 1% | 0.42 | 0.41 | 3236 | 283.2 | 0.31 | 156.6 |
| S | A | deskSW | 5:00 PM | 257.9 | 93% | 7% | 0.42 | 0.41 | 3304 | 262.1 | 0.29 | 145.4 |

| | | | | Illuminance | Approximate Contribution (+/- 10%) | | Color Coordinates | | Color Temp | Circadian Light | Circadian Stimulus (up to 0.7) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orientation** | Row | Desk | Time | Lux | **Fluor** | **Daylight** | **CIEx** | **CIEy** | CCT(K) | **$CL_A$** | **CS** | **Bright-ness** |
| W | A | desk02 | 7:57 AM | 94.9 | 79% | 21% | 0.38 | 0.38 | 3946 | 64.8 | 0.09 | 65.4 |
| W | A | desk02 | 11:55 AM | 113.4 | 69% | 31% | 0.38 | 0.38 | 4006 | 79.1 | 0.11 | 78.5 |
| W | A | desk02 | 4:09 PM | 499.5 | 44% | 56% | 0.39 | 0.39 | 3868 | 319.8 | 0.33 | 325.4 |
| W | A | desk03 | 7:59 AM | 145.6 | 60% | 40% | 0.36 | 0.36 | 4625 | 143.3 | 0.19 | 113.6 |
| W | A | desk03 | 11:56 AM | 141.7 | 54% | 46% | 0.36 | 0.36 | 4451 | 128.7 | 0.17 | 107.0 |
| W | A | desk03 | 4:11 PM | 413.8 | 67% | 33% | 0.39 | 0.39 | 3736 | 238.0 | 0.27 | 266.6 |
| W | A | desk04 | 7:58 AM | 63.6 | 72% | 28% | 0.37 | 0.37 | 4089 | 50.6 | 0.07 | 46.1 |
| W | A | desk04 | 11:56 AM | 102.7 | 31% | 69% | 0.33 | 0.34 | 5638 | 139.2 | 0.18 | 91.6 |
| W | A | desk04 | 4:12 PM | 373.7 | 55% | 45% | 0.37 | 0.37 | 4189 | 300.5 | 0.32 | 265.8 |
| W | B | desk08 | 8:02 AM | 68.0 | 79% | 21% | 0.40 | 0.38 | 3492 | 36.5 | 0.05 | 44.2 |
| W | B | desk08 | 11:58 AM | 90.7 | 61% | 39% | 0.40 | 0.39 | 3697 | 49.9 | 0.07 | 58.5 |
| W | B | desk08 | 4:15 PM | 317.4 | 91% | 9% | 0.43 | 0.41 | 3188 | 317.6 | 0.33 | 174.1 |
| W | B | desk09 | 8:01 AM | 61.1 | 85% | 15% | 0.40 | 0.38 | 3508 | 32.1 | 0.05 | 39.3 |
| W | B | desk09 | 11:58 AM | 75.4 | 59% | 41% | 0.37 | 0.36 | 4177 | 64.2 | 0.09 | 55.9 |
| W | B | desk09 | 4:14 PM | 322.3 | 76% | 24% | 0.41 | 0.40 | 3475 | 379.9 | 0.36 | 194.7 |
| W | B | desk10 | 8:00 AM | 71.4 | 88% | 12% | 0.41 | 0.39 | 3443 | 34.7 | 0.05 | 45.2 |
| W | B | desk10 | 11:57 AM | 74.6 | 68% | 32% | 0.39 | 0.37 | 3823 | 51.4 | 0.07 | 51.7 |
| W | B | desk10 | 4:13 PM | 353.9 | 69% | 31% | 0.40 | 0.39 | 3531 | 178.6 | 0.22 | 221.0 |

## Average Spectroradiometry Results

The following table shows average results during the measurements.

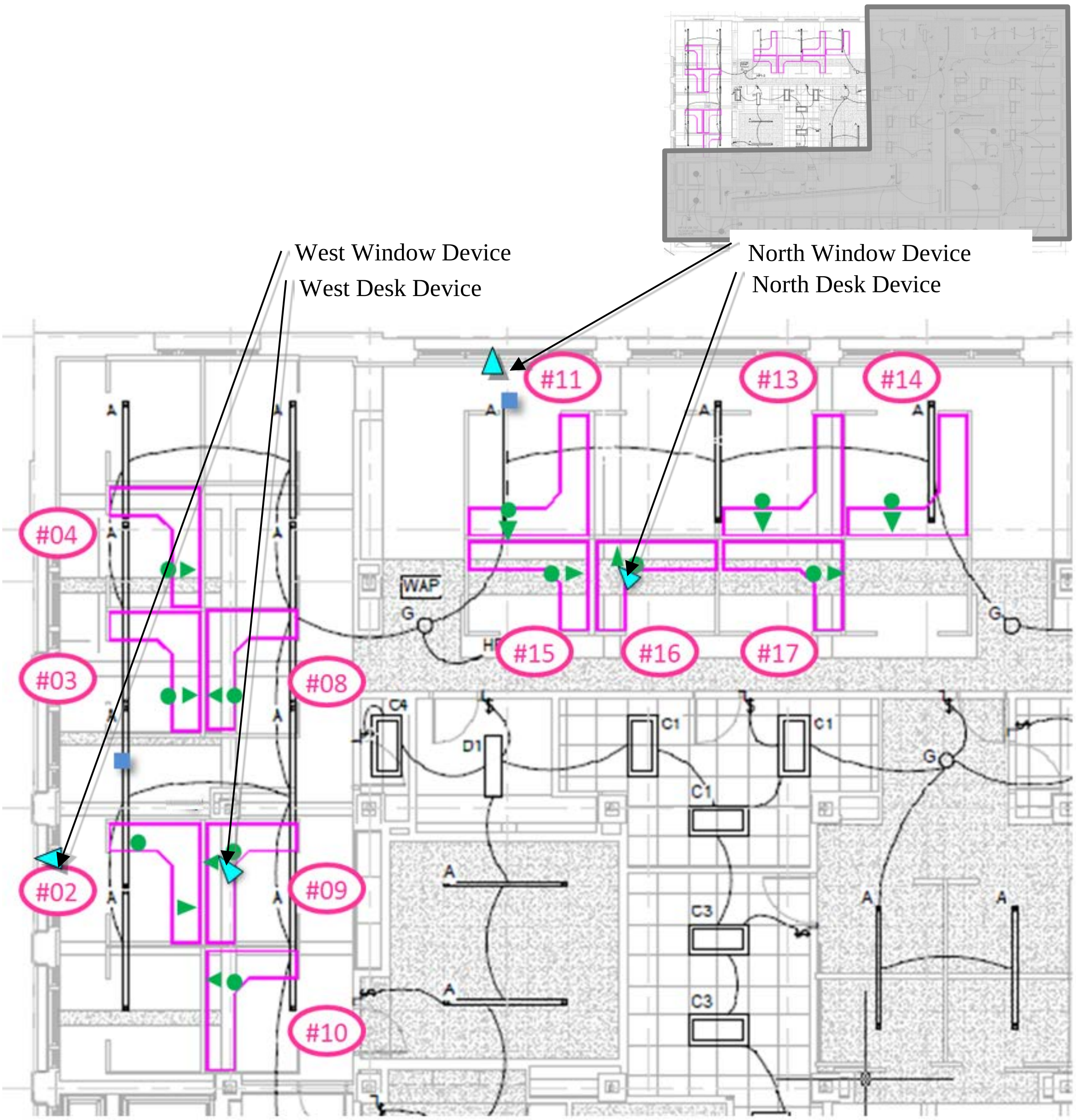
| Deskspace Locations | Lux | Fluor % | Day % | CCT(K) | $CL_A$ | CS | Bright-ness |
|---|---|---|---|---|---|---|---|
| A | 190 | 52% | 48% | 4337 | 172 | 0.204 | 130 |
| B | 161 | 50% | 50% | 4197 | 154 | 0.170 | 115 |
| **Orientations** | | | | | | | |
| W | 188 | 67% | 33% | 3938 | 145 | 0.1691 | 125 |
| N | 160 | 25% | 75% | 4837 | 166 | 0.1922 | 125 |
| S | 195 | 71% | 29% | 3857 | 202 | 0.2280 | 119 |

## Uncertainty of Spectroradiometric Measurements

There are three main types of measurement uncertainty associated with the spectrometer used for the spectral measurements: 1) accuracy of the spectral calibration and maintaining it over time, 2) thermal noise due to the nature of the CCD detector employed in the device, and 3) a spatial response that deviates from an ideal cosine response. The accuracy of calibration is estimated to be ± 5% of the reading. The effect of thermal detector noise varies with wavelength and from an analysis of the resulting spectra is it estimated to be ± 0.004, ± 0.00018, and ± 0.007 W/($m^2$ nm) for the spectral ranges $\lambda < 450$ nm; $450 < \lambda < 730$ nm; and $\lambda > 730$ nm, respectively. The corresponding uncertainty (1-sigma) in photopic illuminance is ± 3 lux. Combining these uncertainties leads to an uncertainty of ± (5% of reading + 3 lux).

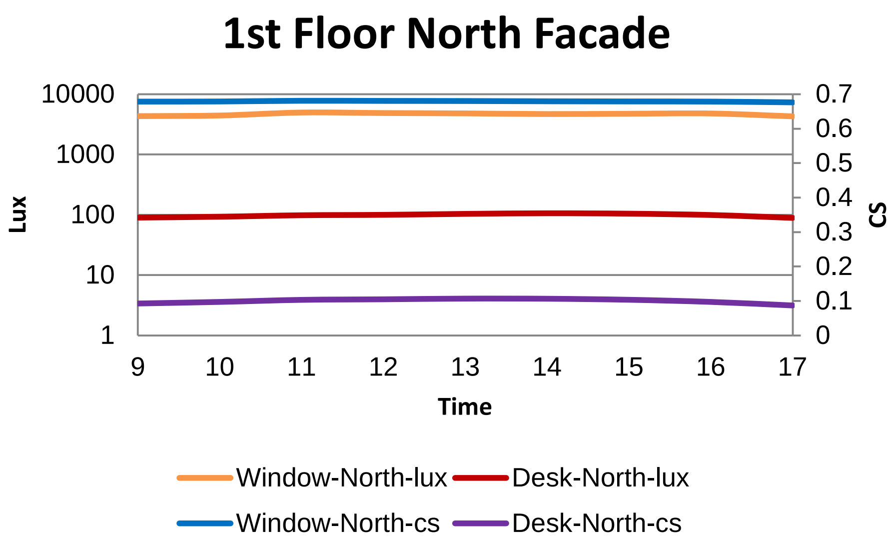
The spatial uncertainty depends greatly on the spatial distribution of light for each measurement; for light of normal incidence the error is near zero, but the error increases significantly, always underreporting the illuminance, for light incident at large angles. An estimate of the spatial uncertainty for the range of diffuse and direct illuminance commonly found in office environments for these measurements is +0, -5% of the reading.

# Appendix F: Photometric Data for Stationary Devices (Mounted on sticks and in windows)

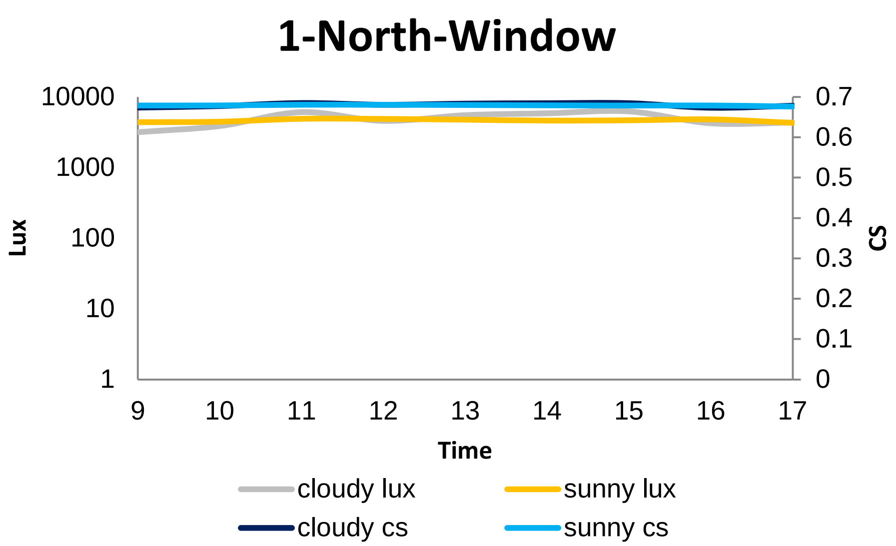



***Measurements locations on the first floor (photos not allowed).***

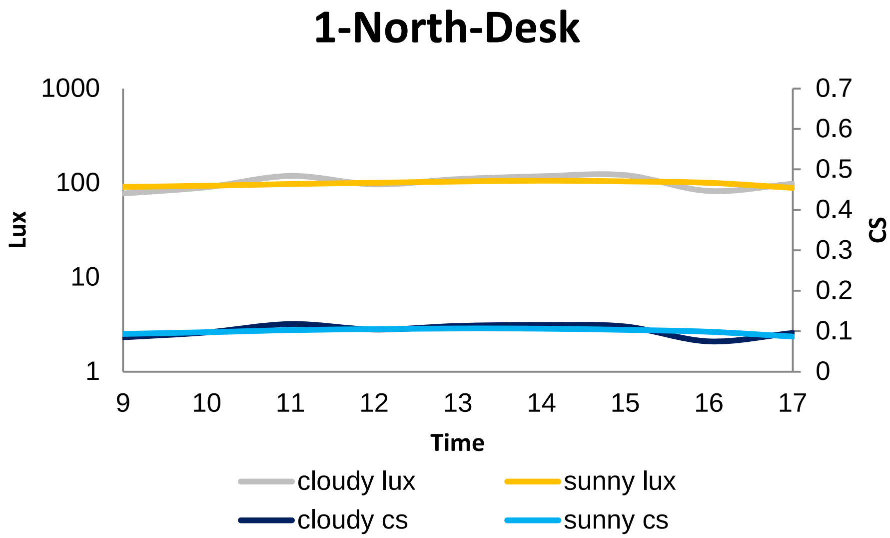
## North Facade (First Floor)




***Average Lux and CS***

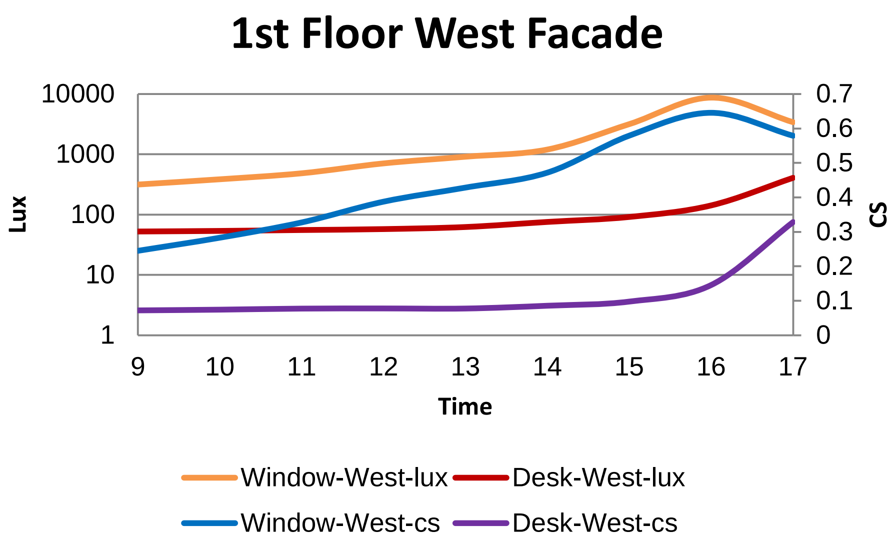



North-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 4872 ± 1084 lux on cloudy days. The mean CS value on was 0.68 ± 0.005 on cloudy days. On sunny days mean photopic light level during working hours was 4640 ± 221 lux. The mean CS value on was 0.68 ± 0.001 on sunny days.

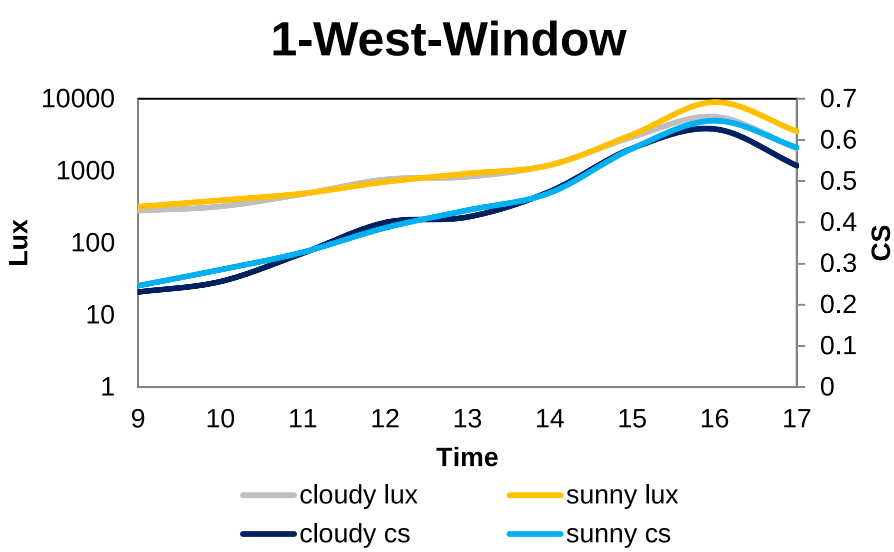



North-Desk. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 101 ± 16 lux on cloudy days. The mean CS value on was 0.10 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 98 ± 6 lux. The mean CS value on was 0.10 ± 0.007 on sunny days.

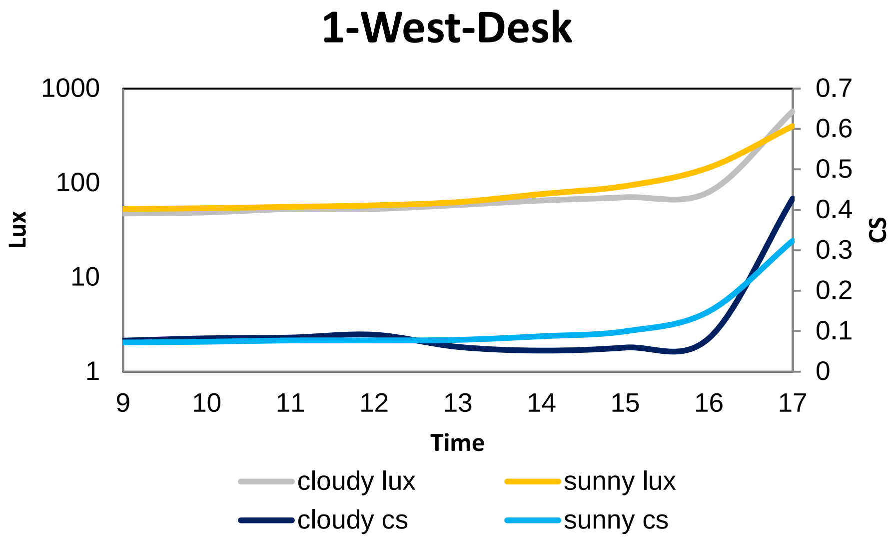
## West Facade (First Floor)




*Average Lux and CS*

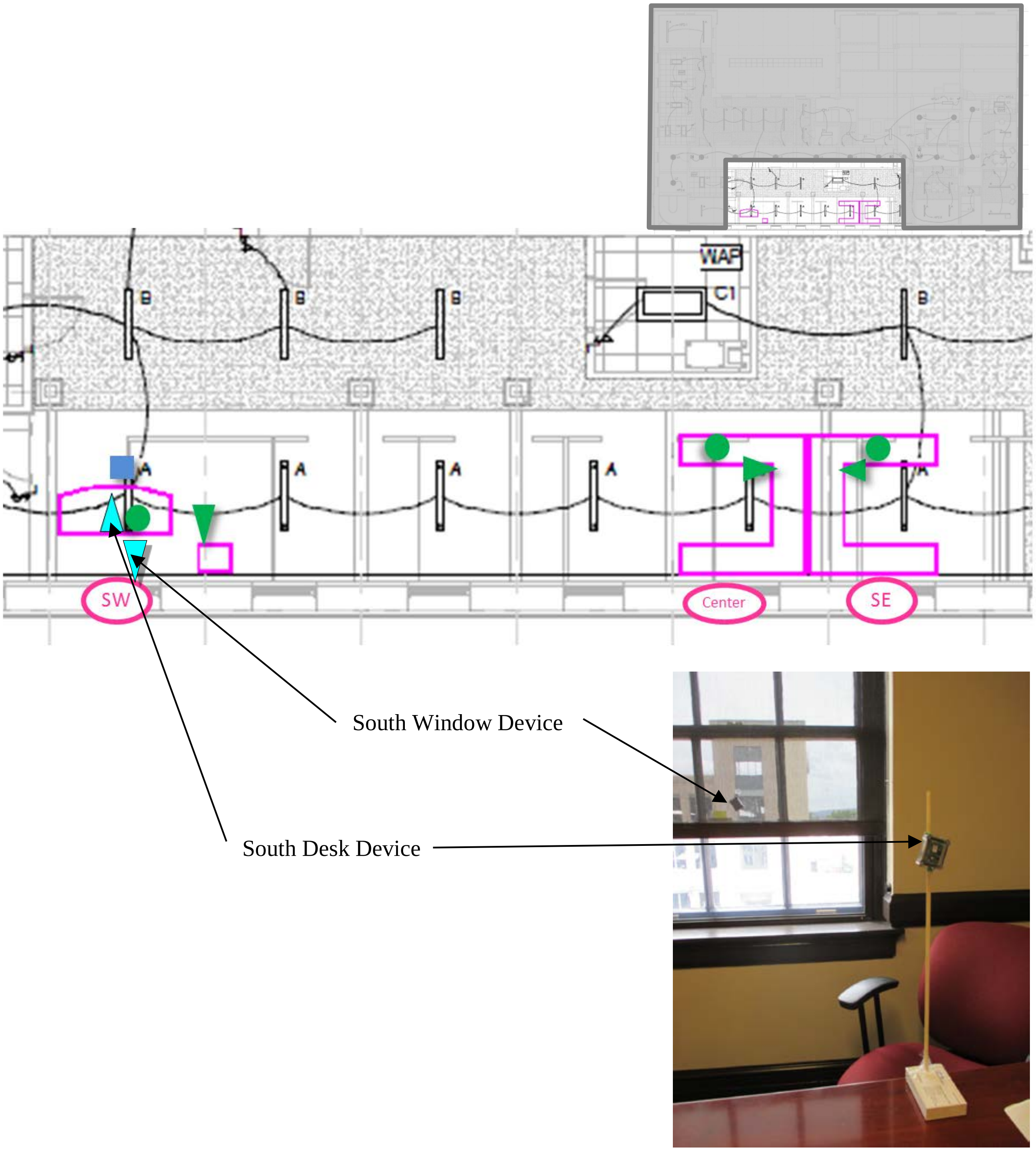



West-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1612 ± 1747 lux on cloudy days. The mean CS value on was 0.43 ± 0.14 on cloudy days. On sunny days mean photopic light level during working hours was 2191 ± 2818 lux. The mean CS value on was 0.44 ± 0.14 on sunny days.

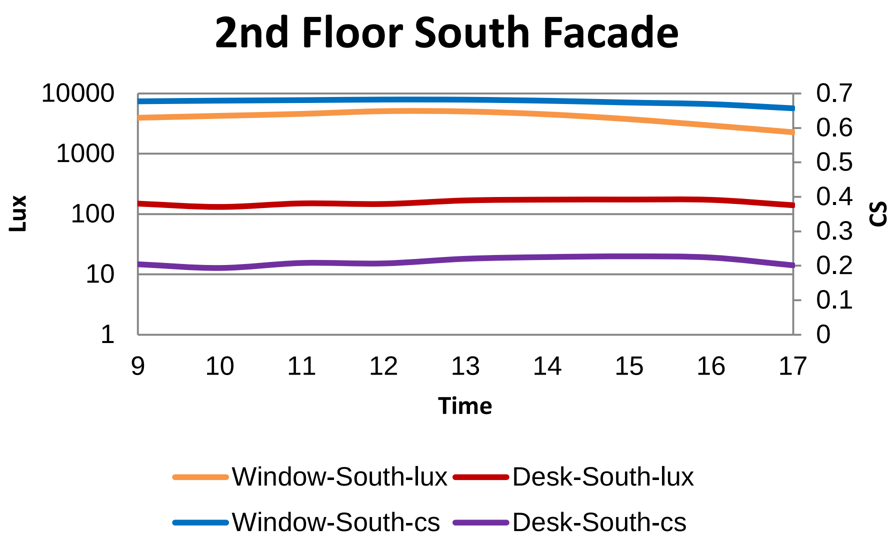



West-Desk. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 117 ± 171 lux on cloudy days. The mean CS value on was 0.11 ± 0.12 on cloudy days. On sunny days mean photopic light level during working hours was 111 ± 112 lux. The mean CS value on was 0.12 ± 0.08 on sunny days.

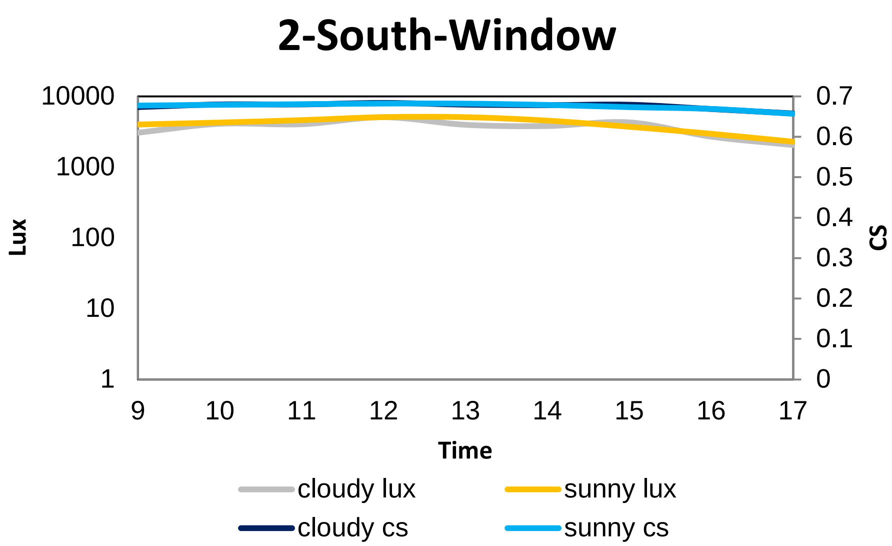
## SOUTH FACADE (SECOND FLOOR)



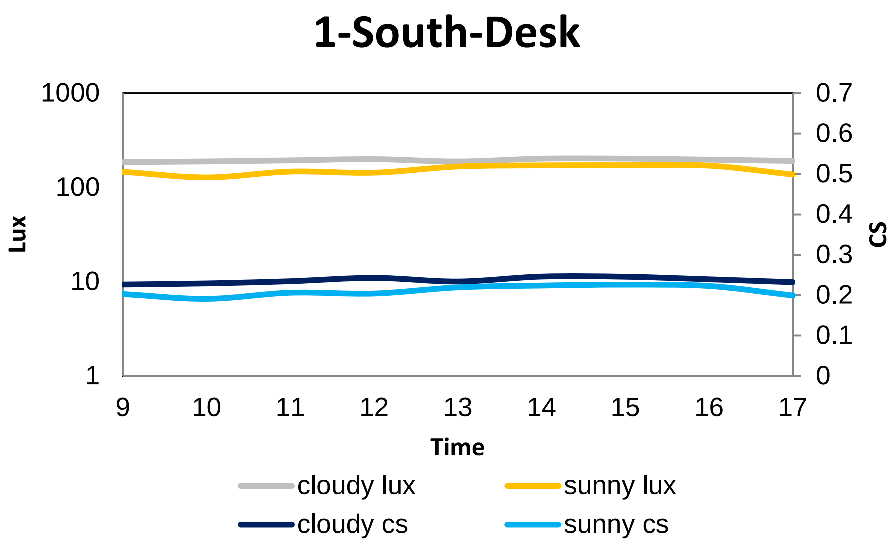

***Measurement locations on the second floor.***




*Average Lux and CS*




South-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 3674 ± 916 lux on cloudy days. The mean CS value on was 0.68 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 4057 ± 945 lux. The mean CS value on was 0.68 ± 0.01 on sunny days.




South-Desk. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 194 ± 6 lux on cloudy days. The mean CS value on was 0.24 ± 0.007 on cloudy days. On sunny days mean photopic light level during working hours was 154 ± 17 lux. The mean CS value on was 0.21 ± 0.01 on sunny days.