Results Report:

Facility Lighting — Winter

Federal Center South

Seattle, Washington

Submitted to:

U.S. General Services Administration
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RESULTS REPORT:
FACILITY LIGHTING — WINTER

FEDERAL CENTER SOUTH
SEATTLE, WASHINGTON

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EXECUTIVE SUMMARY

Federal Center South (FCS) construction was completed in the fall of 2012 and was opened in 2013. It is the headquarters of the U.S. Army Corps of Engineers, Seattle District. It is a Leadership in Energy and Environmental Design (LEED) Gold certified building. The building is approximately 330 feet wide and 1100 feet long and is located to the west of the Albert Kahn-designed Ford Motor Company Assembly Plant at 4735 East Marginal Way, Seattle, Washington. The building was designed to achieve aggressive energy performance targets; the building is on target to receive an ENERGY STAR® score of 100, which means it would be placed in the top 1% of comparable buildings. The lead designer was ZGF Architects LLP.

On February 17, 2014, researchers from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, together with U.S. General Services Administration (GSA) staff, performed photometric measurements on deskspaces located in the first, second and third floors of the building. In addition to the field measurements, the LRC placed Daysimeter devices on selected deskspaces to continuously measure photopic lux and circadian light over the course of several days. The goal of the research was to measure photometric conditions as they related to occupant comfort, productivity, and circadian health.

Prior to the field measurements, the LRC team had informal conversations with a designated spokesperson for the building and learned that after the building's occupancy, there had been numerous complaints about "too much light" in the building, especially on desks located on the third floor, facing the main atrium. Some measures to minimize discomfort glare from direct sunlight were taken, including the addition of roll-down shades that were installed in front of offices facing the main atrium. Because of these complaints, the LRC brought a portable spectroradiometer to the site and used these data to evaluate glare.

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

- Daylight makes a large contribution to light levels at the perimeter, but did not penetrate deep into the architecture during these winter measurements.
- The atrium skylight contributes too much light to adjacent desks on the north side of the third floor. Roll-down shades that were installed to reduce discomfort glare reduce the vertical illuminances at these deskspaces, but they also considerably diminish the light levels on deskspaces located in two rows behind. Daylight from roof skylights on the third floor contributed to higher light levels on some of the deskspaces, but this was not the case on the first and second floors.
- Desks located far from the perimeter windows on the first and second floors did not show enough light for circadian stimulation.
- Desks at the perimeter and on the third floor showed enough light for circadian stimulation due to windows and skylights. However, too much light was contributed to desks with the atrium to their south, resulting in too much glare. Occupants used roll-down shades and large golf umbrellas to shade their desks from excessive sun.
- Spot measurements showed high light levels in the south side when the sun was out; it is not known, however, whether users would get up and change window shade positions to avoid discomfort/disability glare from sunlight hitting their faces or computer screens.

- Desks located away from the perimeter windows on the first and second floors showed illuminances on the desk that are generally lower than the architect's target (30 footcandles). Use of the task light allows users to address low light levels. These floors showed evidence that most of these lights are, in fact, being dimmed in the winter. It is possible that the photosensors on these floors were dimming the lights too low. If there are complaints about darkness, these devices may need to be recommissioned to reduce dimming. However, this may translate to less energy savings.
- On the third floor, half of the luminaires monitored did not appear to be dimming in response to winter daylight, despite light levels that exceeded the architect's criterion. It is possible that these controls on the third floor could be commissioned more aggressively to save lighting energy.
- LRC researchers compared illuminance at desks with and without blinds in use. At this site, isolated use of blinds did not have as large an effect as at other sites because glazing was widespread, rather than small punched openings. This may not be true, however, when sunlight hits the deskspace.

INTRODUCTION

Federal Center South (FCS) was opened in 2013 as the headquarters of the U.S. Army Corps of Engineers, Seattle District (Figure 1). Its curved shape is representative of the original course of the adjacent Duwamish waterway; the building overlooks this waterway to reflect on this agency's work with waterways. FCS is intended to be extremely energy-efficient, earning LEED Gold certification.[1] This three-story building accommodates several hundred federal workers, and is not accessible by the public without security clearance.

Figure 1. Federal Center South (FCS), located in Seattle, WA. (Photo courtesy of Litecontrol, Inc.)

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

DAYLIGHT AND ELECTRIC LIGHTING DESIGN

The architect's lighting narrative[2] clearly states that the lighting goals were energy efficiency, embrace of daylight, and to enhance the appearance of the architecture:

"Lighting will be designed to highlight the architecture and task areas while providing a highly energy efficient lighting system. A task/ambient approach to lighting will provide lower ambient light levels with higher light levels at tasks provided by tasklights or directional light fixtures.

Light fixtures will be carefully placed to integrate with the daylight zones and daylight control system.

Light sources will achieve energy efficiency with a high lumen per watt ratio, have long lamp life to reduce replacement and maintenance costs and aid visibility by having a color rendering index of at least 80 CRI."

Lighting in open offices was designed with a daylight harvesting system that includes battery-powered wireless photosensors (Figure 2) and dimming ballasts in linear fluorescent luminaires.

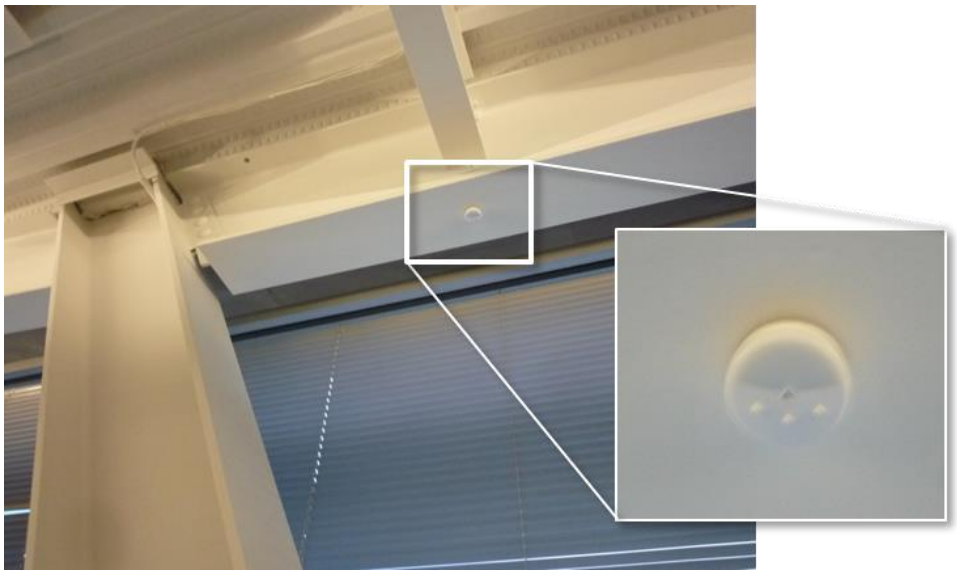

Figure 2. Wireless photosensor.

The narrative states that the lighting should comply with the requirements described in the GSA "Facilities Standards for the Public Buildings Service" (USGSA 2010) for light level requirements. The narrative articulates a target of 30 footcandles (fc) for open office areas, and at a very aggressive power density of 0.7 watts per square foot.

[2] Sellen Construction/ZGF Architects LLP. (January 2011). "Doc Rel 08 Lighting Narrative."

Linear pendant luminaires are mounted on 22’ centers, operating a single T5 linear fluorescent lamp in cross-section. Task lighting is provided by LED adjustable units (Figure 3).

Figure 3. Typical luminaires in open office areas.

Perimeter windows consist of bands of tinted glass (44% visible transmittance, 0.25 solar heat gain coefficient). Architectural shading of perimeter windows is provided by exterior horizontal light shelves and vertical baffles. Additional shading of perimeter windows is provided by manually-operated venetian blinds on each floor.

Other daylight penetrations include rectangular skylights above the third floor offices, and large-scale skylights surrounding the atrium core.[3] These skylights do not have exterior shading devices. Interior shades have been implemented, as will be discussed later in this report.

Figure 4. Examples of rectangular and atrium skylights at FCS.

[3] Atrium glazing is composed of a layer of tinted glass similar to the perimeter windows (52% visible transmittance, 0.29 solar heat gain coefficient) and a layer of translucent fritted glass (60% dots). Rectangular skylight data was not made available.

RESEARCH OBJECTIVES

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

On February 17, 2014, LRC researchers performed a site evaluation at the Federal Center South Building. 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 Dr. Judith Heerwagen and Donald Horn, both of the U.S. General Services Administration (GSA).

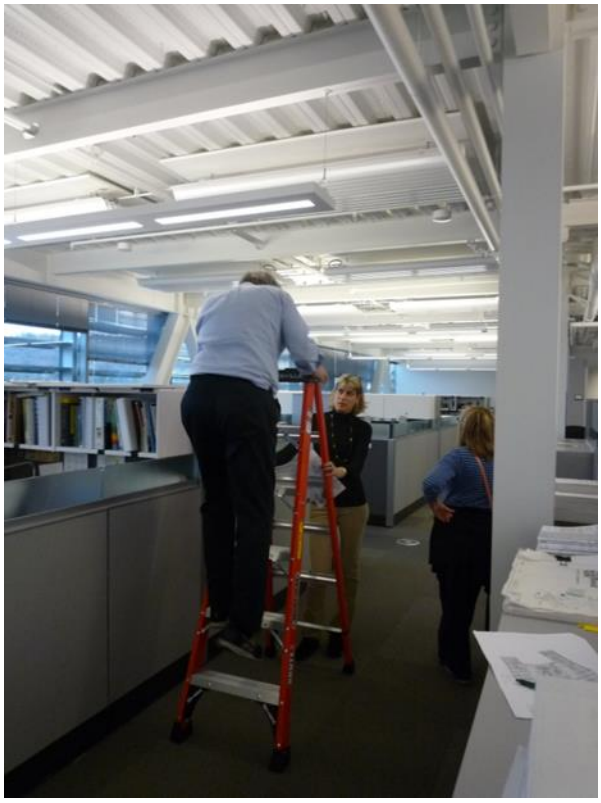

Figure 5. LRC researchers Dr. Mark Rea (left) and Dr. Mariana Figueiro (center) install monitoring devices at FCS, as Dr. Judith Heerwagen (right) observes.

[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

Data collection started around 8:30 a.m. and concluded around 7:00 p.m. Each member of the research team was responsible for one aspect of the data collection: one researcher collected illuminance and luminance measurements on deskspaces located on the first and second floors; one researcher collected illuminance and luminance measurements on the third floor; and one researcher performed all of the spectral power distribution measurements and placed the Daysimeter devices in stationary positions on the selected deskspaces.

The location of the deskspaces was chosen so that data could be gathered from various orientations and locations within the building. Once a location was chosen, the complete row of desks (from atrium to perimeter) was evaluated in all three floors.

Five types of measurements were performed at FCS:

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. LRC measured illuminance multiple times over the measurement day, on horizontal and vertical surfaces, at desks on all 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 computer monitor, nearest window, and in the case of the third floor desks, an adjacent skylight. 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 FCS to allow researchers to calculate, using different response functions, measures such as brightness, glare, and circadian stimulus. SPD data were primarily collected on the third floor at FCS. A researcher collected these data at FCS 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 CIRCADIAN LIGHT-MEASUREMENT DEVICES

Daysimeters 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 nanometers (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 20 desks and four windows, primarily on the third floor at FCS (only one Daysimeter was placed on the second floor). (Details will be listed below.) These collected data for at least four days after LRC researchers visited the site. These were removed by Mr. Horn and Dr. Heerwagen after three weeks on site, and were returned by mail to LRC for read-out.

LUMINAIRE ACTIVITY

LRC researchers placed battery-powered light meters atop operating luminaires to confirm whether the lights were dimming in response to daylight. These devices were launched before installation, and were set to collect data for at least 10 days after visiting the site. These were removed by Mr. Horn and Dr. Heerwagen after three weeks on site, and were returned by mail to the LRC for read-out.

RESULTS

LRC measured photometric conditions (illuminance and luminance) at the locations shown in Figure 6. Photometric data were organized by perimeter proximity, by perimeter window orientation, and by collection time. Data were collected for 59 of the 60 desks in this configuration (one of the desks was being used as storage and researchers did not have access to it).

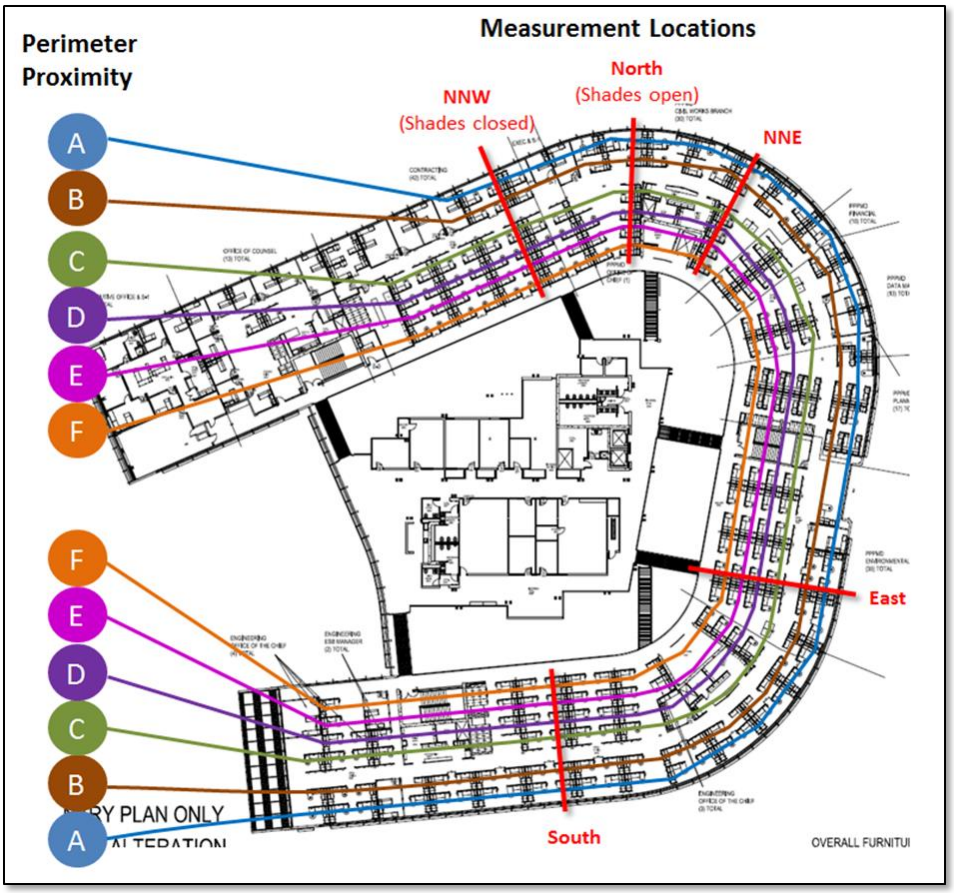

Figure 6. Desk measurement location diagram. The letter A denotes the outside perimeter of the building, while F is the perimeter closest to the atrium. Results for each location are shown in greater detail in the Appendices.

ILLUMINANCE RESULTS

Figure 7 shows horizontal illuminance on each of the 59 desks, plotted on a log scale to enable the reader to discern both low and high measurement results. The results for each cross section are shown in greater detail in Appendices A-J.

These results show that the third floor has the highest light levels on the desk. Seating position F has very high light levels (1800-4900 lx [170-450 fc]) for those desks facing the south/atrium. At the eastern exposure, light levels are not as high as other areas of the third floor; this could indicate that the skylight in that area is occluded by other rooftop equipment. At one desk on the south side of the building, there was a high illuminance (25,000 lx [2400 fc]) when a shaft of sun fell on the illuminance meter at the 10 a.m. measurement. On the third floor, the LRC compared a bay with closed shades (north-northwest [NNW]) to one with open window shades (north). As shown below, these

measurements did not reveal a large difference between the desk measurements; because of the unobstructed design of this architecture and furniture, as well as skylights, use of blinds at the A seating position did not dramatically alter light levels on the other desks.

On the second floor, peak illuminances were measured at the expected times for the various window orientations. The A seating position at the east orientation had the peak illuminance on the desk in the morning. On the first floor, the A seating position had the peak illuminance on the desk at the midday measurement for the southern exposure, and in the afternoon for the northwestern exposure. People located at core seating positions (C-E) had similar illuminances (~200 lx [~20 fc]) over the course of the day, and not much difference after dark. Perimeter desks had a larger difference between daytime exposure and nighttime.

As shown in Figure 7, many of the desks that were measured on the first and second floors were below the architect's target illuminance of 323 lx (30 fc), without use of a task light (task lighting provides an additional 700-1000 lx [70-100 fc] on the work plane).

These results show that daylight makes a large contribution to light levels at the perimeter, but does not penetrate deep into the architecture during these winter measurements. The atrium skylight contributes too much light to adjacent desks on the north side of the third floor.

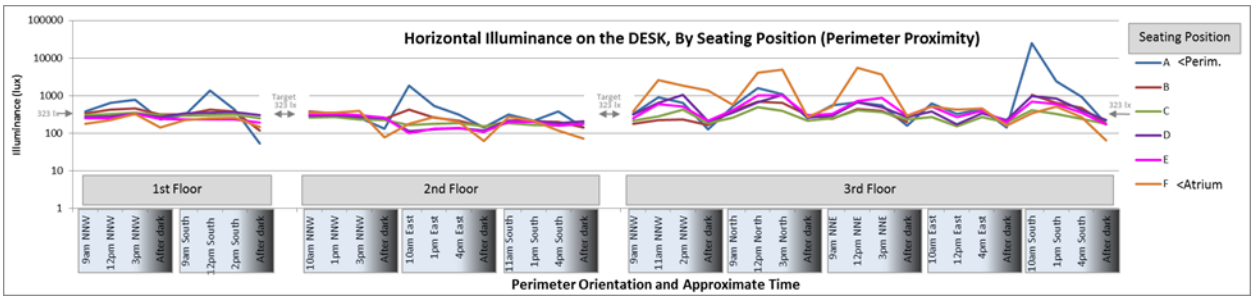

Figure 7. Horizontal illuminance on 59 desks by perimeter proximity.

The LRC measured illuminance on a vertical cabinet above each desk, as well as at the eye when seated at the desk (Figure 8). The LRC measured vertical illuminance repeatedly throughout the day and evening at 59 desks.

Figure 8. Vertical illuminance measurement examples at cabinet (left) and at the eye (right).

The results showed that the highest light levels on the cabinet occurred at the perimeter locations and the third floor desks with the atrium to the south. Highest light levels were also occurring in the middle of the day (Figure 9).

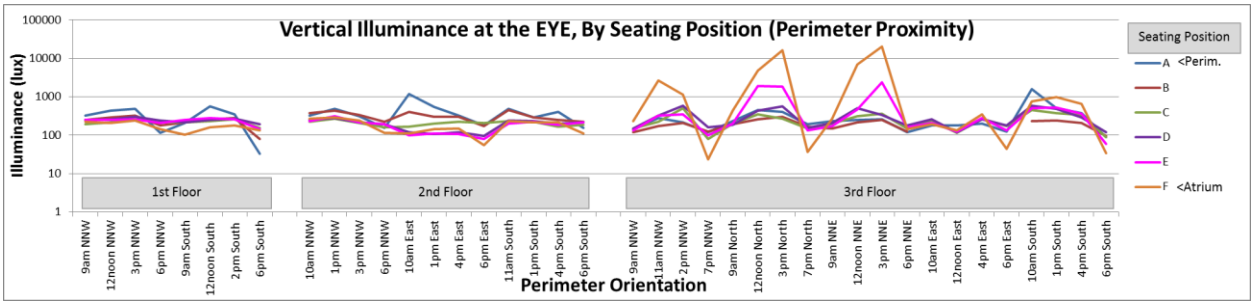

Figure 9. Vertical illuminance at the eye.

As shown in Figure 10, similar results were found for vertical illuminances at the eye. The Discussion section will introduce further analysis of circadian stimulation and glare using these data.

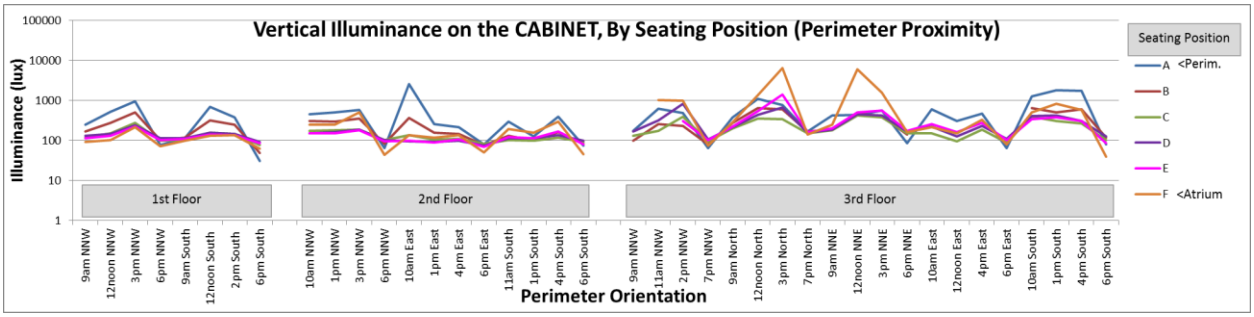

Figure 10. Vertical illuminance on the cabinet.

LUMINANCE RESULTS

For each desk, LRC measured luminance of the nearest window or skylight during the daytime measurements. For the third floor desks, shown below is the highest of the three possible views: window, overhead rectangular skylight, or the atrium skylight. As shown in Figure 11, the highest luminance was measured in the morning at an east-facing window on the second floor (90,000 cd/m^2).

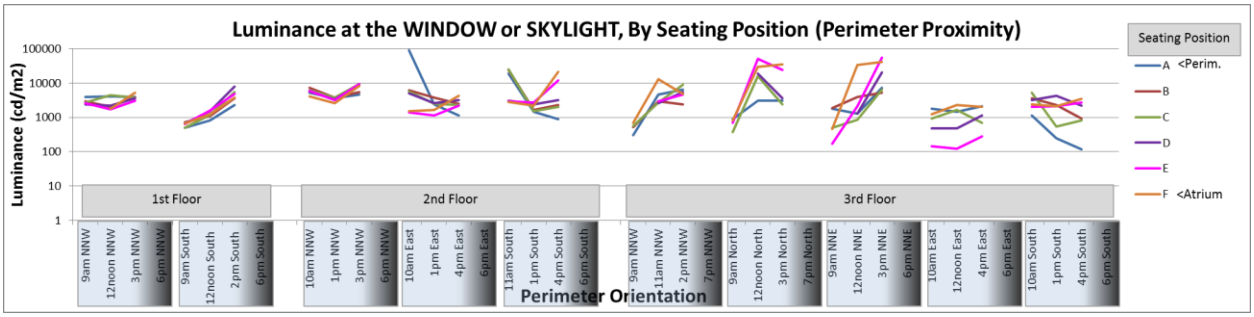

Figure 11. Luminance at the window or skylight, by perimeter proximity.

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 Figure 12, 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 window or skylight, occupants may experience glare. (For more about glare, see Discussion.) It is also important to note that some computer screens that received direct sunlight had high luminance (with monitor off), suggesting that it might be at risk for some disability glare. Desk spaces facing the south may have disability glare on the screen.

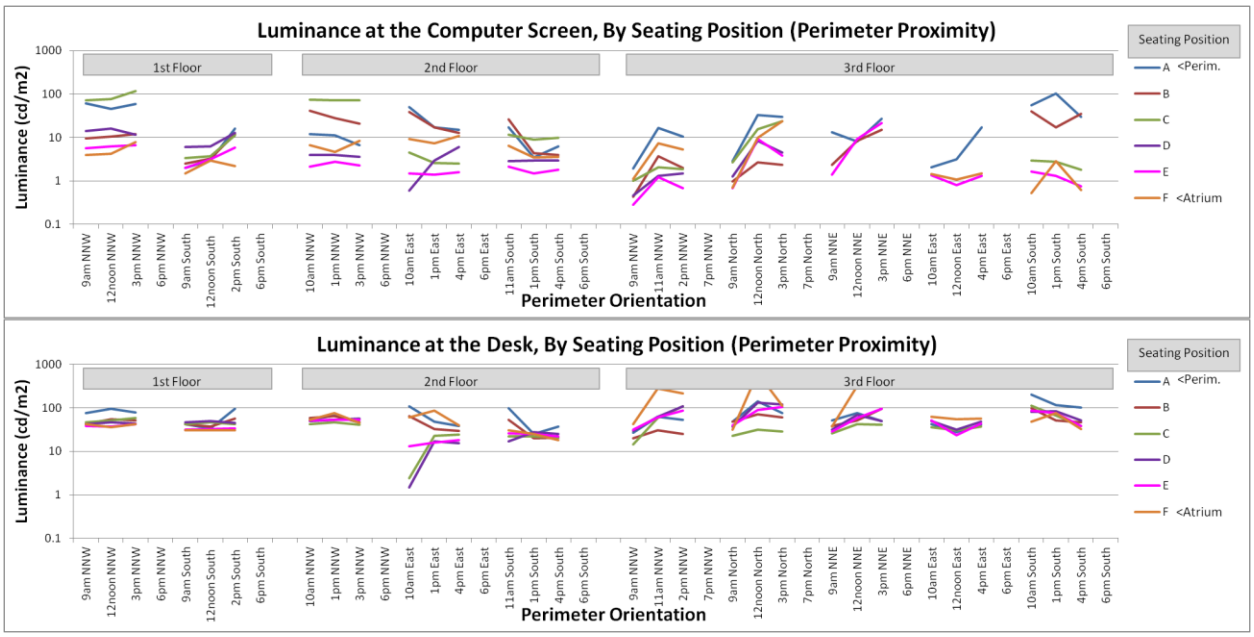

Figure 12a (top). Luminance at computer screen. Figure 12b (bottom). Luminance at the desk.

Spectral Power Distribution (SPD) Results

Shown here is a photo of the equipment used for measurement of spectral characteristics (Figure 13). The measurement probe was placed on each desk, facing upward. The experimenter collected SPD measurements for 30 desks and one window (see Appendices A-J, and L). Most of these SPD measurement locations corresponded to locations where Daysimeter stick or window devices were mounted. A few of the SPD measurement locations corresponded to desks where illuminance and luminance were measured. In a few locations, the experimenter returned to the desk after dark, with no daylight contribution, only electric light.

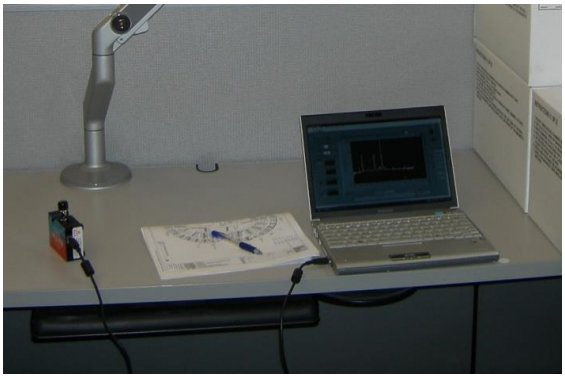

Figure 13. A spectroradiometer taking measurements at desk level.

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. These SPDs were also convolved with spectral response functions that can predict brightness and glare (see Appendix L). As shown in Appendix M, LRC performed follow-up research in the laboratory to validate the use of vertical illuminance in a daylighted office space as a preliminary metric for discomfort glare within the office space. The results from this preliminary validation study suggest that there is a relationship between the vertical illuminance at the eye from daylight and the level of discomfort experienced by occupants.

A summary of the findings is shown in Figure 14. 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 blue-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.

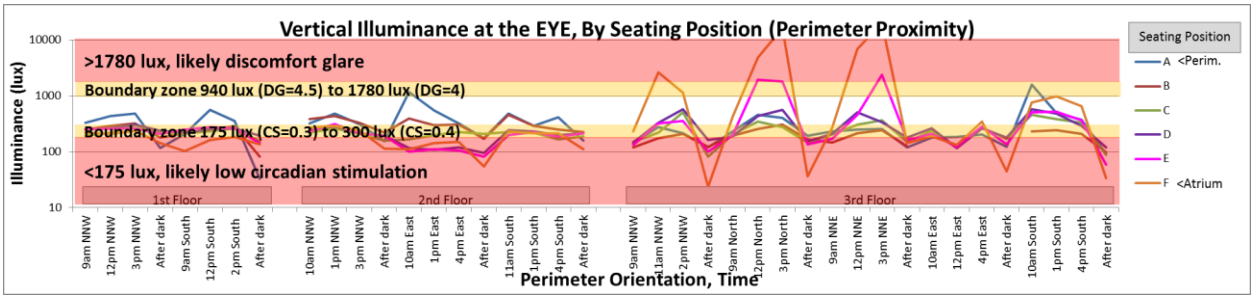

Figure 14. Vertical illuminance at the eye in different work stations at different times of day. The photopic sensor making measurements was oriented so that it faced the work station computer screen at a common eye height. Consequently, as a result of the work-station layout, all illuminance measurements were made with the sensor facing the atrium.

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

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. These levels are commonly achieved on the third floor, but less commonly on the first and second floors, and never at night. The fact that they are not achieved at night is actually desirable to help ensure circadian entrainment for those who might be working after normal working hours.

For position F on the north side of the building, many of the daytime measurements exceeded the DG range, thus it is not surprising that additional shading measures are in use. Occupants use roll-down shades and umbrellas to improve the comfort of their workspace (Figure 15).

Figure 15. Examples of shading due to atrium skylight. Occupants use golf umbrellas (left) and roll-down shades (right) to diminish glare.

Several caveats should be stressed, however:

- Measurements were only made on one day with variable weather. Photometric values will vary substantially in many spaces due to daily and seasonal changes in daylight.
- 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 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.

Luminaire Activity Results

LRC placed 14 battery-powered light meters on top of operating luminaires to verify whether the lights were dimming in response to daylight (Figure 16). An example of a typical dimming profile is shown in Figure 17. As annotated, when the relative light output reduces in the middle of the day, this indicates that the luminaire is being dimmed by the photosensor. On one day (February 21, 2014) light output does not appear to reduce, which corresponds to weather reports of overcast/rainy skies. On the weekends, this luminaire was off, thus the device measured less light.

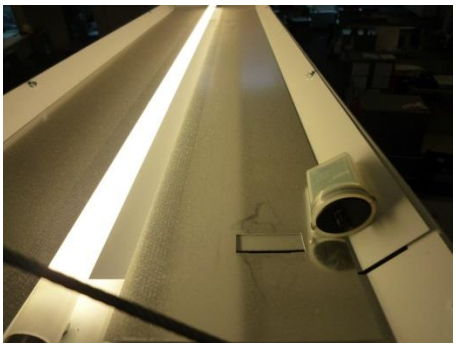

Figure 16. A battery-powered light meter sits atop an operating luminaire.

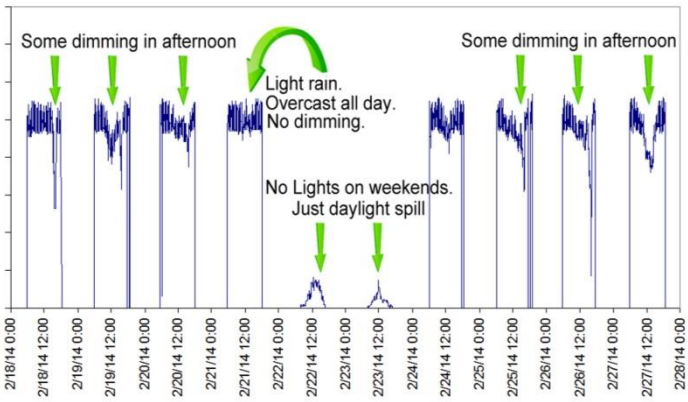

Figure 17. Typical dimming profile at FCS.

The results showed that there is in fact dimming occurring at FCS, but not in all areas, nor all days during this winter evaluation period. Figure 18 shows that three of the four luminaires monitored on the first floor do seem to be dimming in response to daylight. All three luminaires monitored on the second floor seem to be dimming. Figure 19 shows that three of the six luminaires monitored on the third floor seem to be dimming. None of the luminaires dimmed on February 21, the day with dark skies.

The lower floors appear to have more dimming, yet they had illuminances below the architect's target (30 fc). It is possible that the luminaires were dimming during the measurement day, and may therefore be dimming too much in winter. Because it was not possible to install the devices until the end of the measurement day, it is not known whether dimming occurred during measurements. It is possible that the photosensors on the first and second floors were dimming the lights too low. If there are complaints about darkness, these devices may need to be re-commissioned to reduce dimming. However, this may translate to less lighting energy savings. It is possible that the controls on the third floor could be re-commissioned to be more aggressive to save lighting energy.

The reason why dimming did not occur at some of these luminaires may not be problematic; it is possible that the sensors are working as intended, and simply did not "see" enough light during the winter evaluation to justify dimming down the lights. Dimming may become more prevalent if luminaires are re-monitored in the summertime.

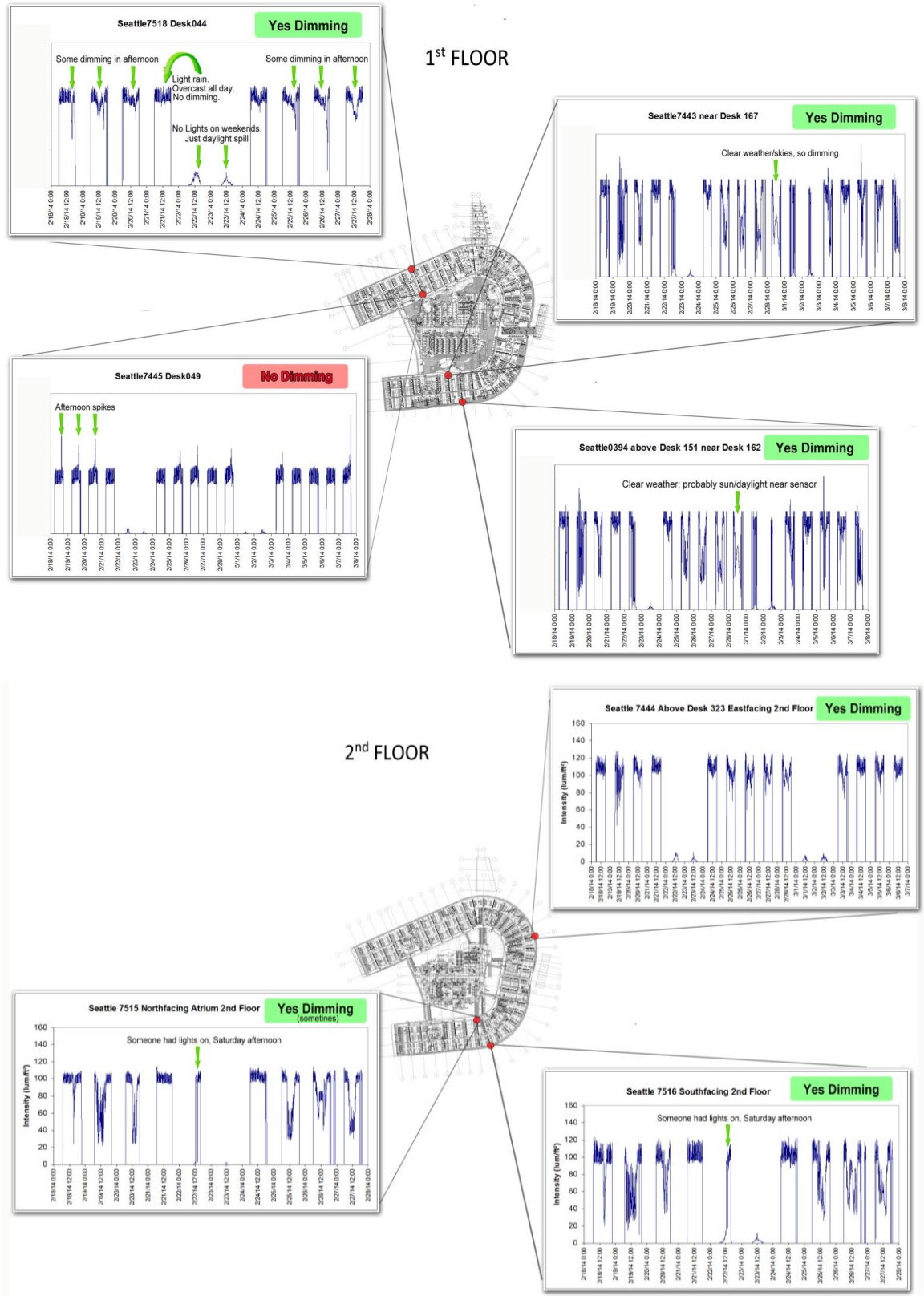

Figure 18. First and second floor luminaire monitoring results over the course of one week. Dimming did not occur in all areas.

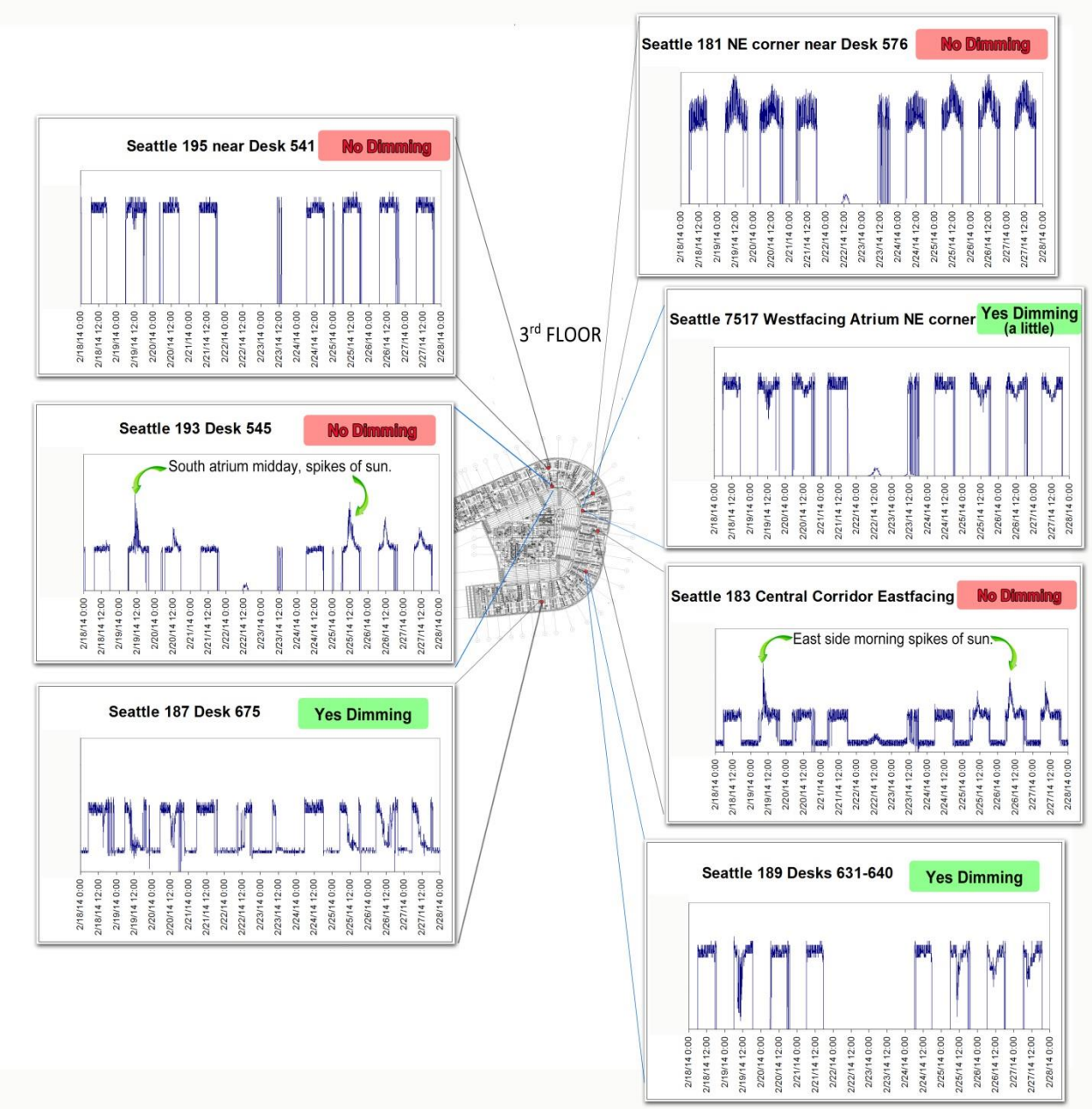

Figure 19. Third floor luminaire monitoring results over the course of one week.

DAYSIMETER RESULTS

There was an issue with the programming of the Daysimeters, so while we have data collected for all of the devices, not all of them recorded data for the entire 2-week period. Of the 20 Daysimeters placed in the building, 3 devices collected 17 days of data, 9 devices collected 10 days of data and 7 devices collected 4 days of data. After checking the weather forecast, it was determined that during the data collection period, there was one sunny day in Seattle; therefore, not all of the devices collected data on sunny days. Nevertheless, the data available seem to provide us with good information about the amount of light received in various deskspaces in the building.

Appendix K 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. As expected, the deskspaces located near the atrium had the highest potential for delivering the highest circadian stimulation to those employees, especially between 10:00 a.m. and 3:00 p.m. However, light levels higher than 1000 lux at the eye increase CS values by a small amount, and yet, the likelihood of causing discomfort glare increases at light levels above 1000 lux at the eye. The roll-down shades seem to help reduce the vertical illuminance at these desks and control for discomfort glare, while still maintaining sufficient circadian stimulation. The deskspaces located on the perimeter of the building and on the north façade were either within the expected CS range or slightly below the desired range. This may have been because of furniture arrangement. All of the deskspaces had the seating arranged so that the person using that deskspace had their back to the window, drastically reducing the eye-level light exposures. The deskspaces located in the row next to those located on the perimeter received the least amount of circadian stimulation, most likely because they were not close to a window, nor were they close to the atrium or overhead skylights.

The deskspaces located in the south/southeast part of the building had CS values ranging from 0.1 to 0.3. Two main reasons for the lower light levels in this part of the building include use of shades (the shades tended to be pulled down because of sunlight penetration) and the architectural structures at the corners of the building that reduced the amount of daylight penetration in that space.

Overall, while these measurements cannot be considered representative of the daily light exposure that an occupant is experiencing, it gives the researchers an idea of the potential for receiving enough circadian stimulation at these deskspaces. In summary, those located in the perimeter of the building by the north façade are likely receiving the ideal dose of daily circadian light. Those sitting close to the atrium, especially those sitting on the third floor are receiving very high amounts of circadian stimulation, but they are also likely to experience discomfort glare, especially on sunny days.

DISCUSSION

While occupants' responses were not assessed in this building, the photometric measurements and the Daysimeter measurements provided some results that are consistent with other site evaluations performed by the LRC and by other researchers (Konis 2013). Some of the lessons learned include:

- On the third floor of the building, contribution from daylight to vertical illuminances is dependent on the desk location. It is the greatest near the atrium and lowest in the middle rows (rows B and D). Middle row C received some daylight contribution from the skylights placed on the roof.
- Desks located on the first and second floors (especially those located away from the atrium and perimeter) showed illuminances on the desk that are generally lower than the target illuminance of 30 fc.
- Vertical illuminances at deskspaces near the atrium are high and likely to create discomfort glare. The LRC's human factors laboratory study (Appendix M) showed that light levels above approximately 1000 lux at the eye are within the discomfort glare zone.
- The use of roll-down shades to reduce discomfort glare on deskspaces facing the atrium reduce vertical illuminances at desks closest to the atrium, but they also reduce illuminance on the desk and circadian stimulation at deskspaces located between the atrium and the perimeter of the building (mainly rows B and D).
- Furniture layout may have played a role on the lower CS values collected from stationary Daysimeters placed near the perimeter of the building. This is particularly true in north facing deskspaces, where the shades were, for the most part, completely up. The layout is such that occupants sit facing away from the windows, considerably reducing the amount of daylight reaching eye level. The overcabinets may have also played a role in reducing the horizontal illuminance on deskspaces located on the first and second floors because it created shadows. Luminaires are located right above these overcabinets, reducing the direct light contribution from the electric lighting.
- Deskspaces located near the perimeter on the south/southeast side of the building tend to have their window shades down, reducing the overall amount of daylight at these desks.
- Some of the luminaires on the third floor, where there is daylight availability, did not appear to dim in response to daylight. Luminaires on the first and second floors were dimmed, perhaps contributing to the low levels observed on these two floors.

The present building was designed to be energy efficient, embrace daylight and enhance the appearance of the architecture. Informal discussions with the spokesperson for the occupants revealed some initial dissatisfaction with the building. The main complaint was that there was "too much light" in the building. Our evaluation showed that the deskspaces that are located near the atrium indeed receive high vertical illuminance that is likely to cause discomfort glare, especially on sunny days between the hours of 10:00 and 3:00 p.m.

Table 1 shows a series of calculations performed using the SPDs obtained on site. For each deskspace location row (rows A through F, see Figure 6), we convolved the SPD with the spectral efficiency function proposed by Rea (2012). As shown below, deskspaces located close to the atrium have the highest photopic illuminance (vertical illuminance), the coolest correlated color temperature (CCT), the highest circadian light

(CL_A) and circadian stimulus (CS), the highest brightness, and the highest contribution to daylight (Day Lux). These results are consistent with expectations because daylight is rich in short-wavelength radiation, and the short-wavelength cone, which is maximally sensitive to optical radiation close to 440 nm is involved in both, circadian and brightness responses. As shown in Table 1 and consistent with Daysimeter measurements, deskspaces in rows B and D receive low circadian stimulation mainly because most of the light contribution comes from the electric lighting. These calculations underscore the benefit of using daylight in buildings, but also underscore the fact that too much daylight, such as the amount received on the atrium deskspaces, can result in discomfort glare.

Table 1. Calculations performed using the SPDs measured on site.

Deskspace Location*	Photopic Lux	CCT (K)	CL_A[1]	CS[1]	Brightness[1]	Fluor Lux	Day Lux
A	598	4558	829	0.29	492	67	545
B	203	3594	193	0.21	130	140	65
C	404	5492	558	0.38	351	42	405
D	168	3659	121	0.15	110	116	54
E	389	4663	452	0.30	309	75	320
F	2208	5329	3542	0.43	1734	11	2164

*Measurements were taken at eye level.

[1] Based on spectral efficiency functions published in Rea's *Value Metrics for Better Lighting* (2012).

Figures 20-23 show the photopic lux and CS values for the Daysimeter measurements placed on desks located on the north, east and south/southeast facades, together with the photopic lux and CS values for the Daysimeter placed on windows. It is interesting to note that the ratio between window photopic illuminance measurements and deskspace illuminance measurements is the lowest on the north side of the building and the highest (10 times more) on the south/southeast side of the building. This difference is most likely due to shade use and sunlight hitting the south/southeast façade. We were not able to place a window unit on the skylight at the atrium; therefore, the unit was located indoors, close to the deskspaces, and as expected, the ratio between the window unit and the deskspace units was much smaller (2.2). This is shown in Figure 23.

The LRC is awaiting approval to collect employee-worn Daysimeter and questionnaire data. These will be very interesting data that will complement the findings of this report.

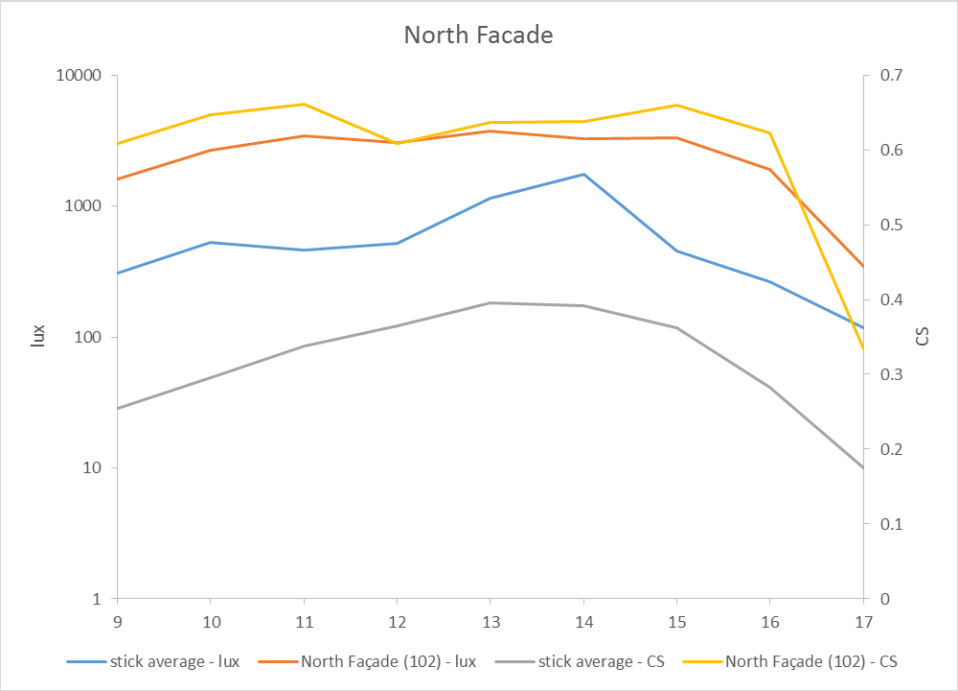

Figure 20. Average photopic lux and CS values for the Daysimeter placed at deskspaces located on the north side of the building over the course of the working day (08:00 am to 05:00 pm). Photopic light levels indoors are reduced by about a factor of 5 compared to those on the north façade.

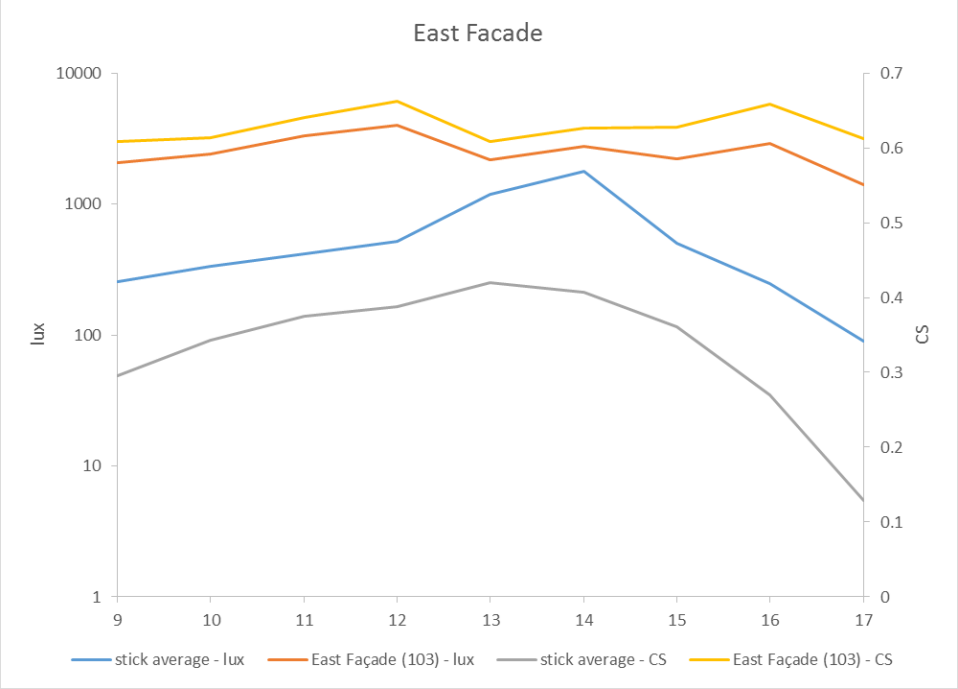

Figure 21. Average photopic lux and CS values for the Daysimeter placed at deskspaces located on the east side of the building over the course of the working day (08:00 am to 05:00 pm). Photopic light levels indoors are reduced by about a factor of 7.5 compared to those on the east façade.

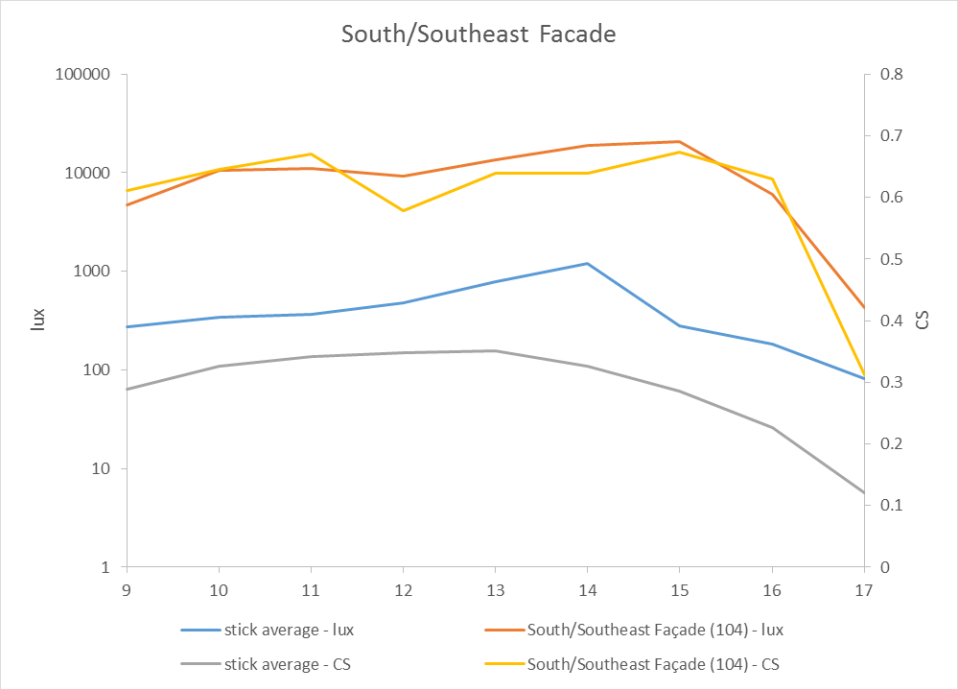

Figure 22. Average photopic lux and CS values for the Daysimeter placed at deskspaces located on the south/southeast side of the building over the course of the working day (08:00 am to 05:00 pm). Photopic light levels indoors are reduced by about a factor of 27 compared to those on the south/southeast façade.

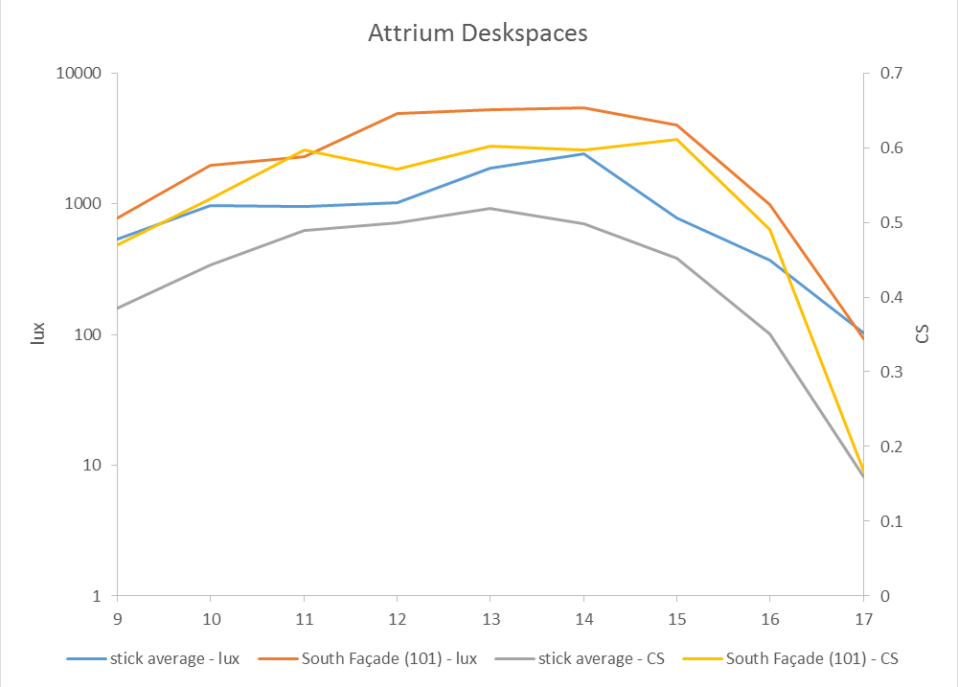

Figure 23. Average photopic lux and CS values for the Daysimeter placed at deskspaces located closest to the atrium's skylight over the course of the working day (08:00 am to 05:00 pm).

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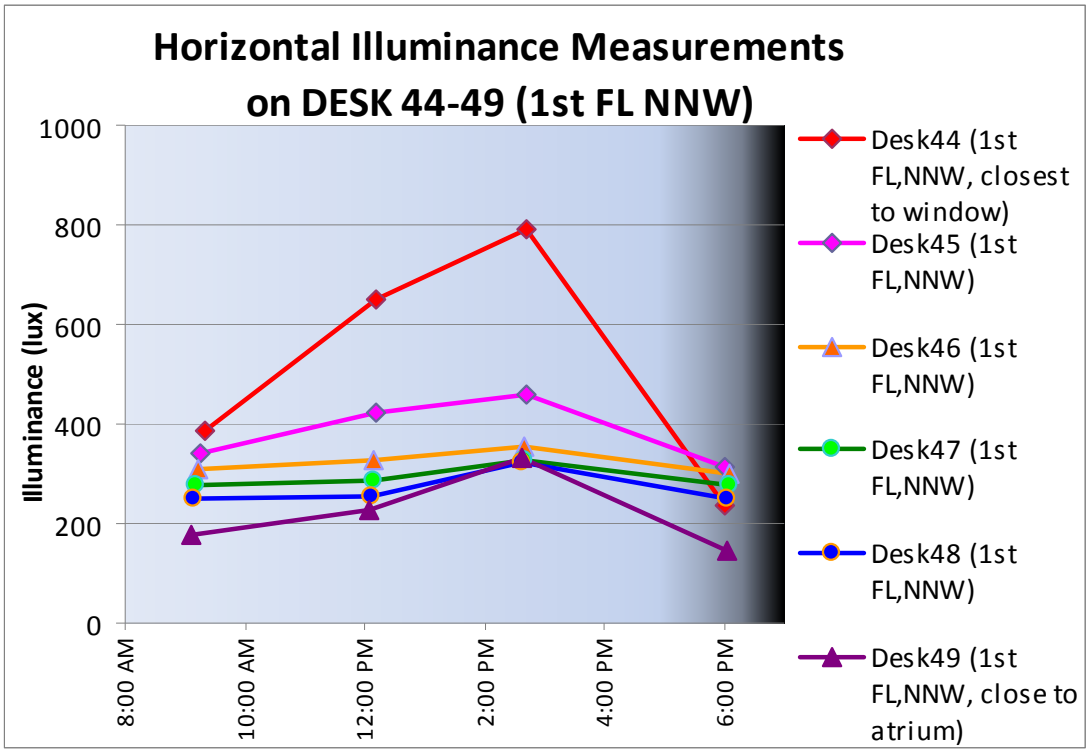
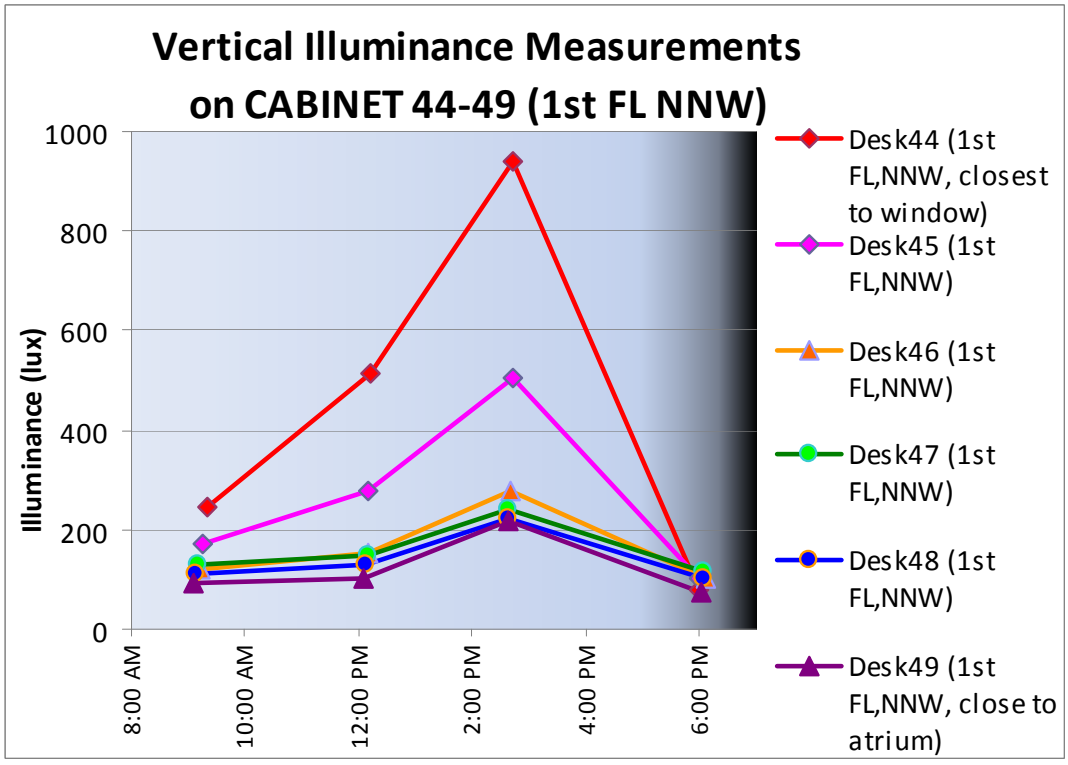
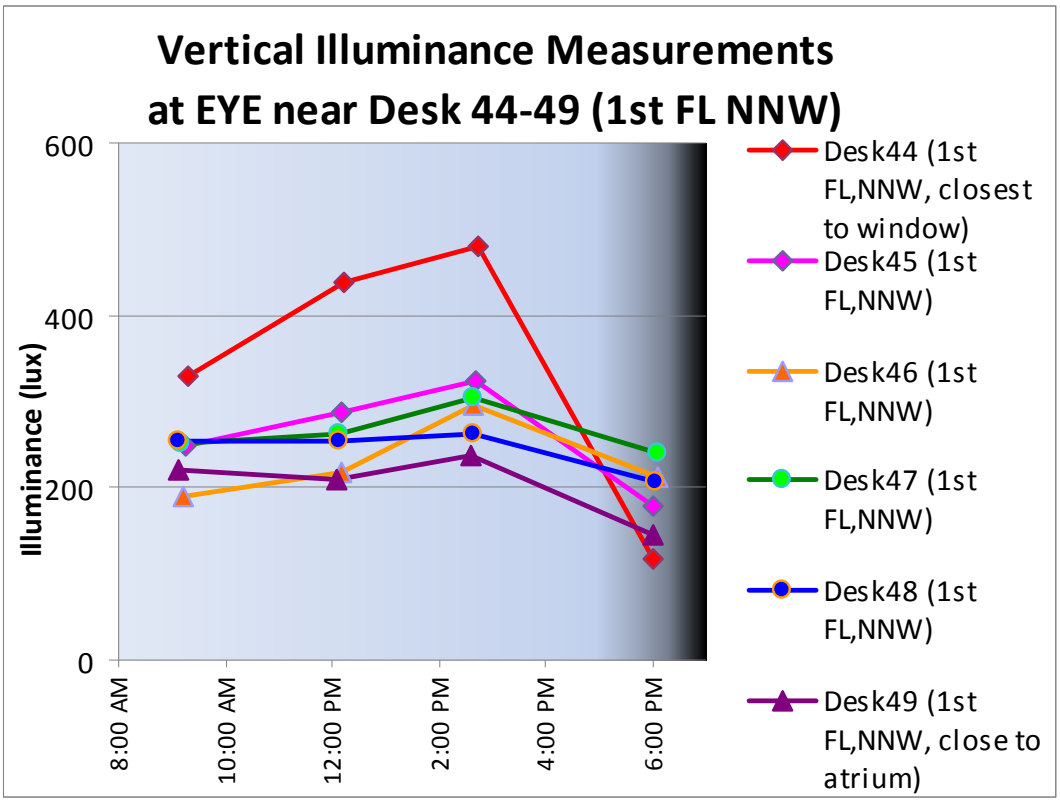
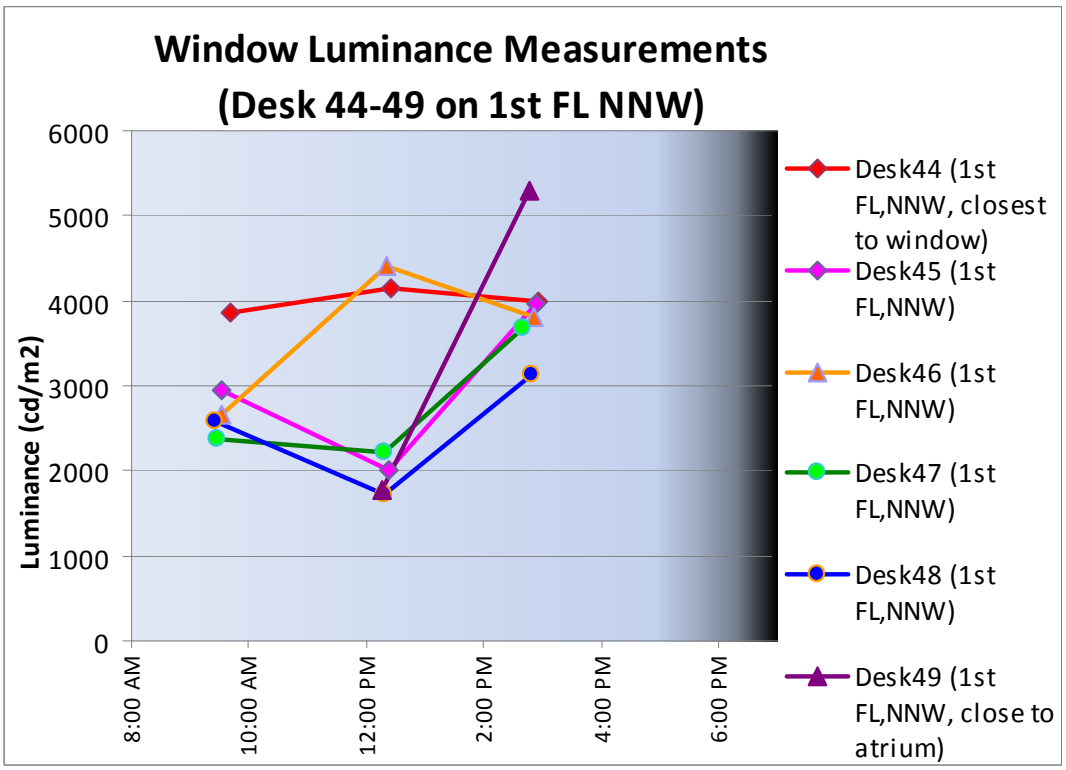
APPENDIX A: PHOTOMETRIC DATA FOR DESKS 044-049 (ILLUMINANCE AND LUMINANCE MEASUREMENTS)

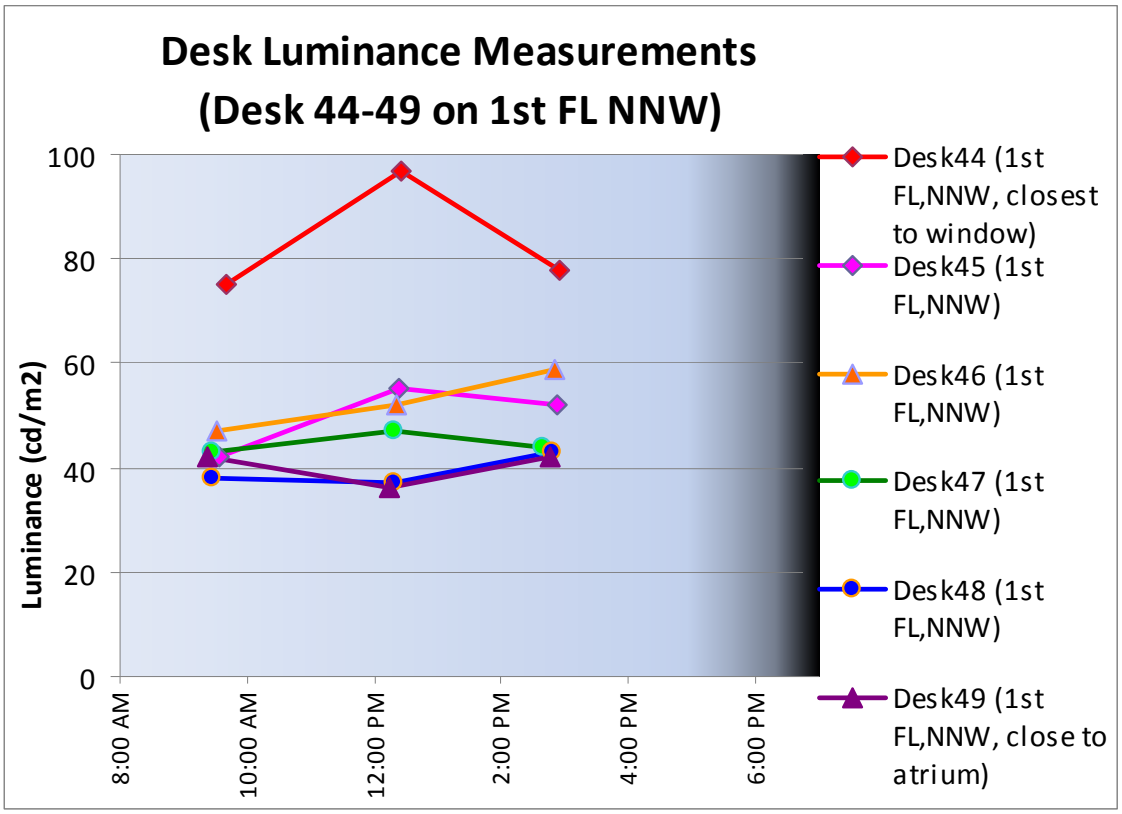
 # Desk with illuminance measures

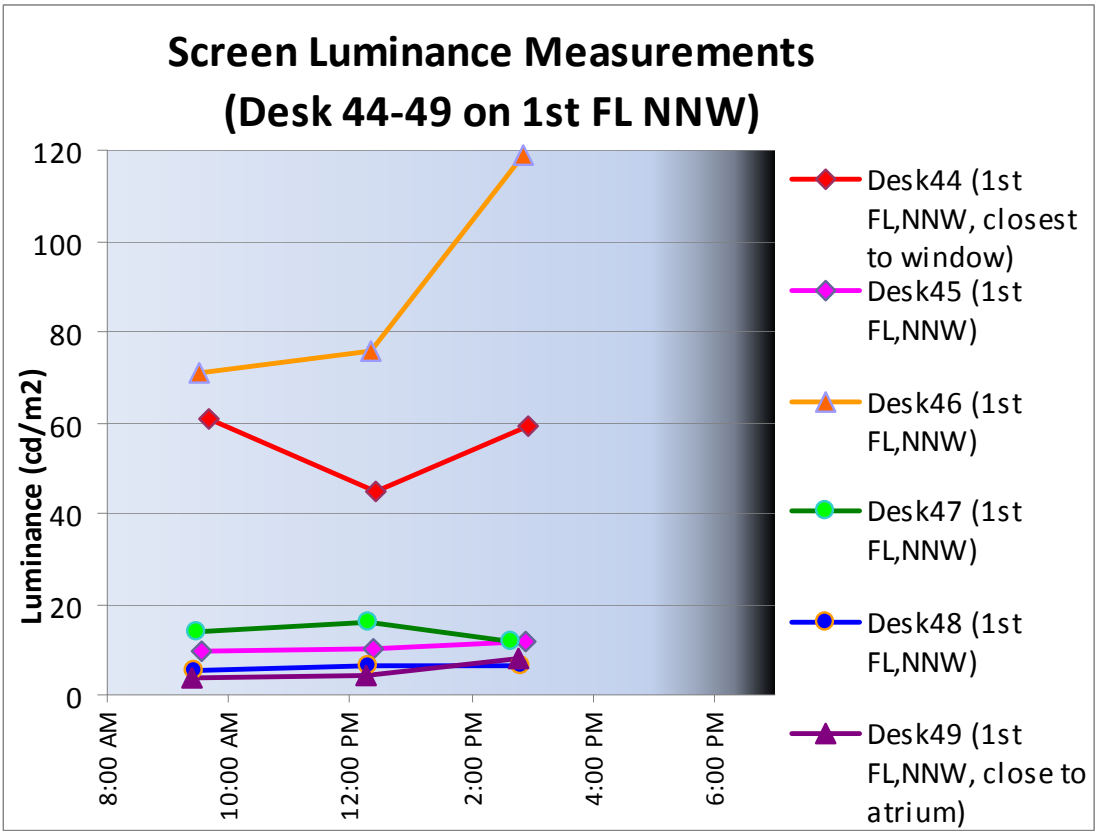

Horizontal Illuminance Measurements
on DESK 44-49 (1st FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)


Vertical Illuminance Measurements
on CABINET 44-49 (1st FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)


Vertical Illuminance Measurements
at EYE near Desk 44-49 (1st FL NNW)
Illuminance (lux)
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)


Window Luminance Measurements
(Desk 44-49 on 1st FL NNW)
Luminance (cd/m2)
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)

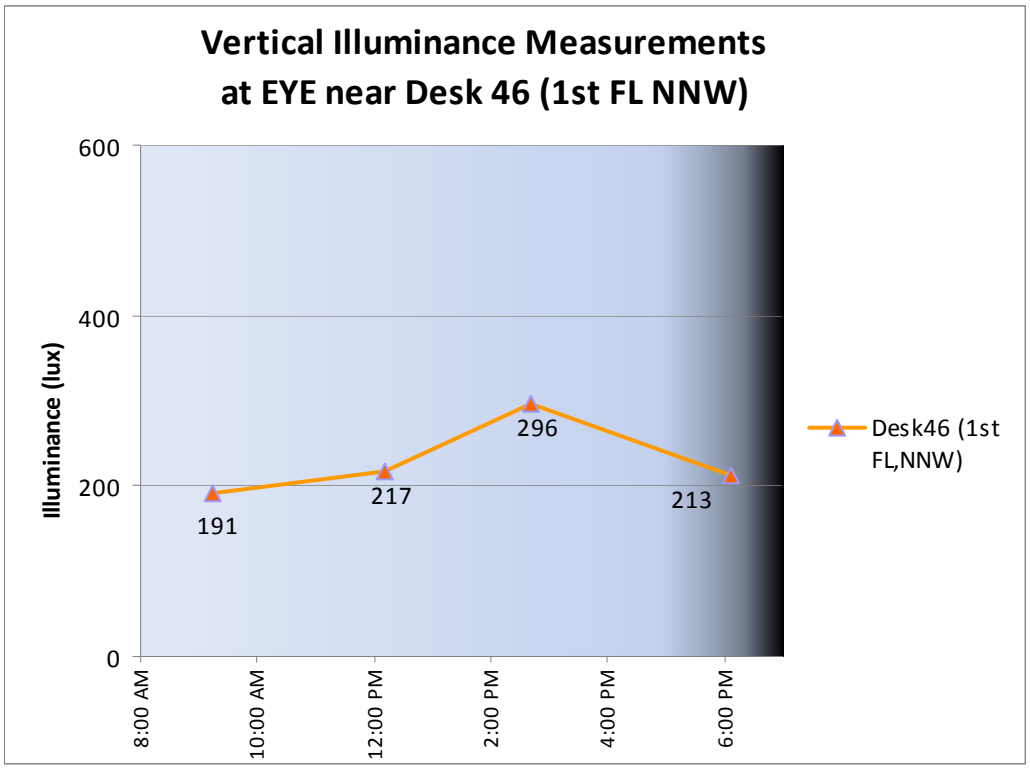

Desk Luminance Measurements
(Desk 44-49 on 1st FL NNW)
Luminance (cd/m2)
100
80
60
40
20
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)


Screen Luminance Measurements
(Desk 44-49 on 1st FL NNW)
Luminance (cd/m2)
120
100
80
60
40
20
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk44 (1st FL,NNW, closest to window)
Desk45 (1st FL,NNW)
Desk46 (1st FL,NNW)
Desk47 (1st FL,NNW)
Desk48 (1st FL,NNW)
Desk49 (1st FL,NNW, close to atrium)

DESK 046

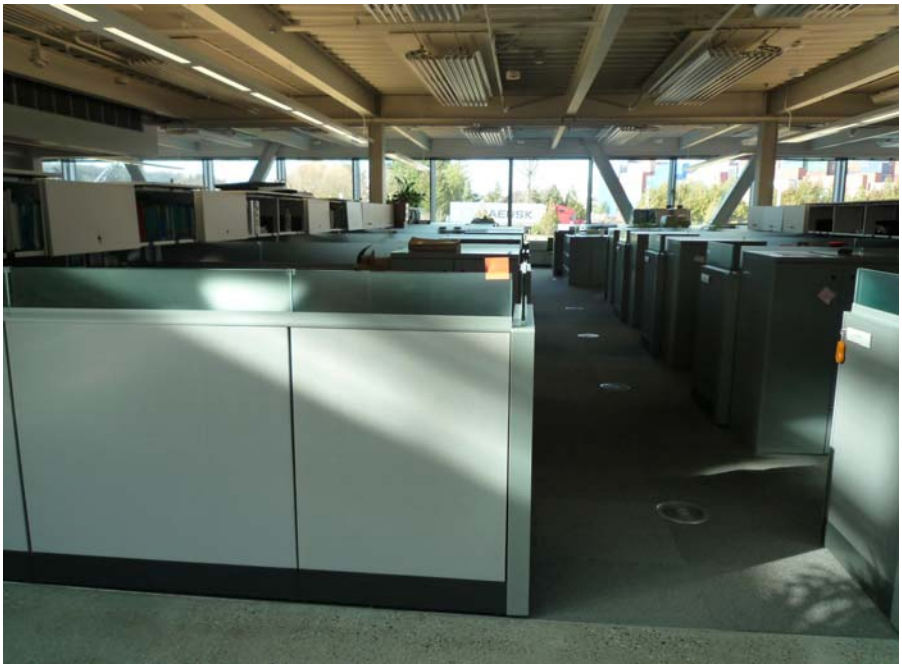
14:51, Desk 046, Looking West

14:51, Desk 046, Looking West

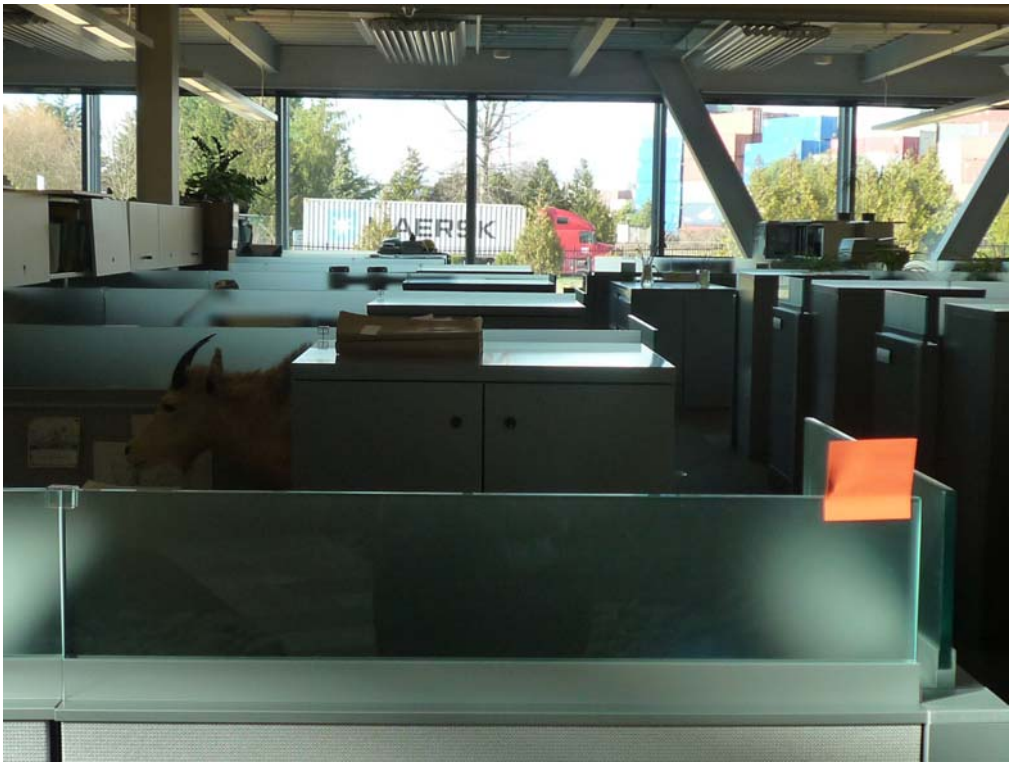

Vertical Illuminance Measurements
at EYE near Desk 46 (1st FL NNW)
Illuminance (lux)
600
400
200
0
191
217
296
213
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk46 (1st FL,NNW)

DESK 049

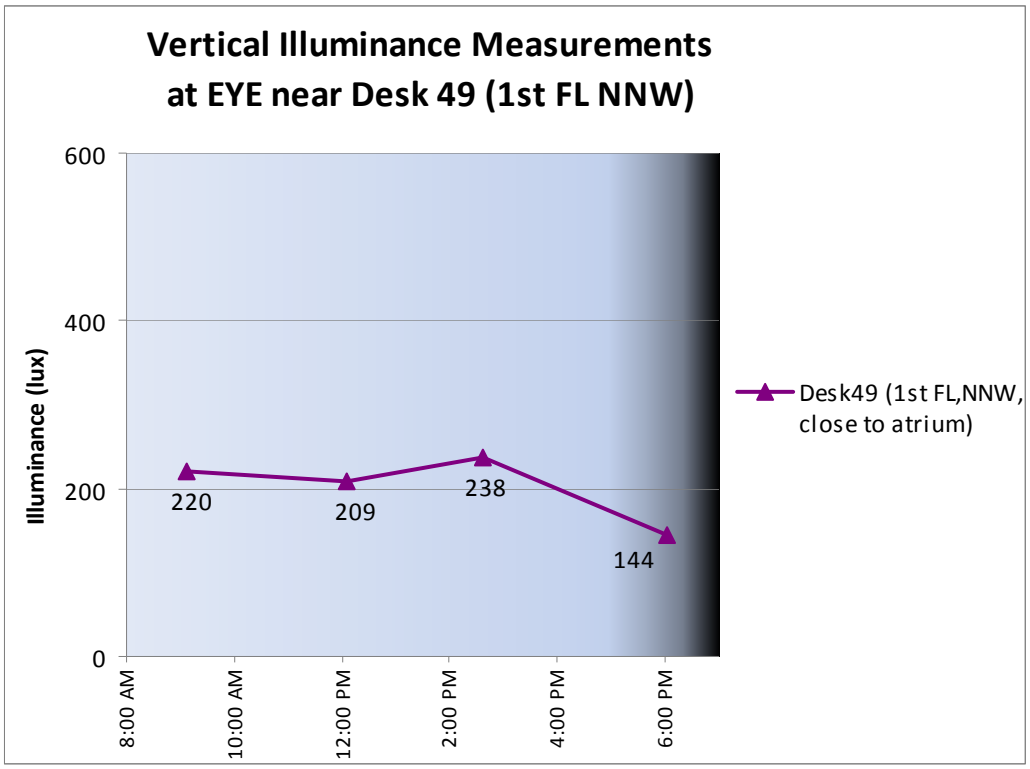
14:45, Desk 049, Looking West



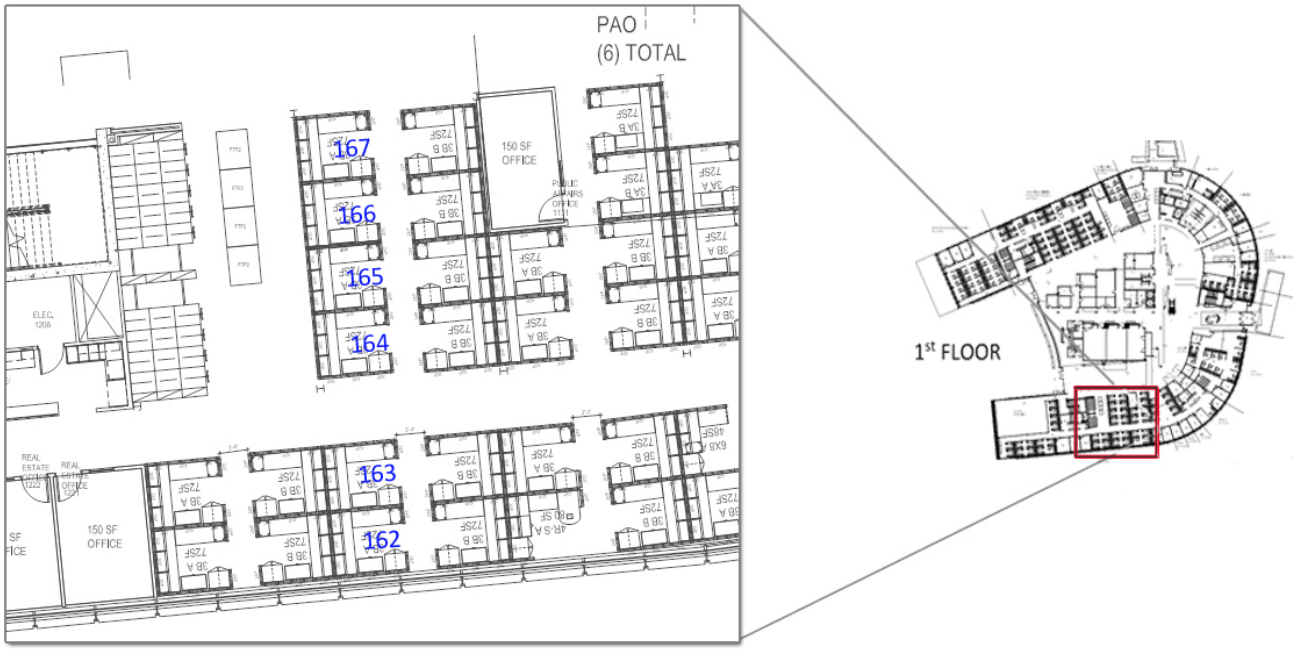
14:45, Desk 049, Looking North



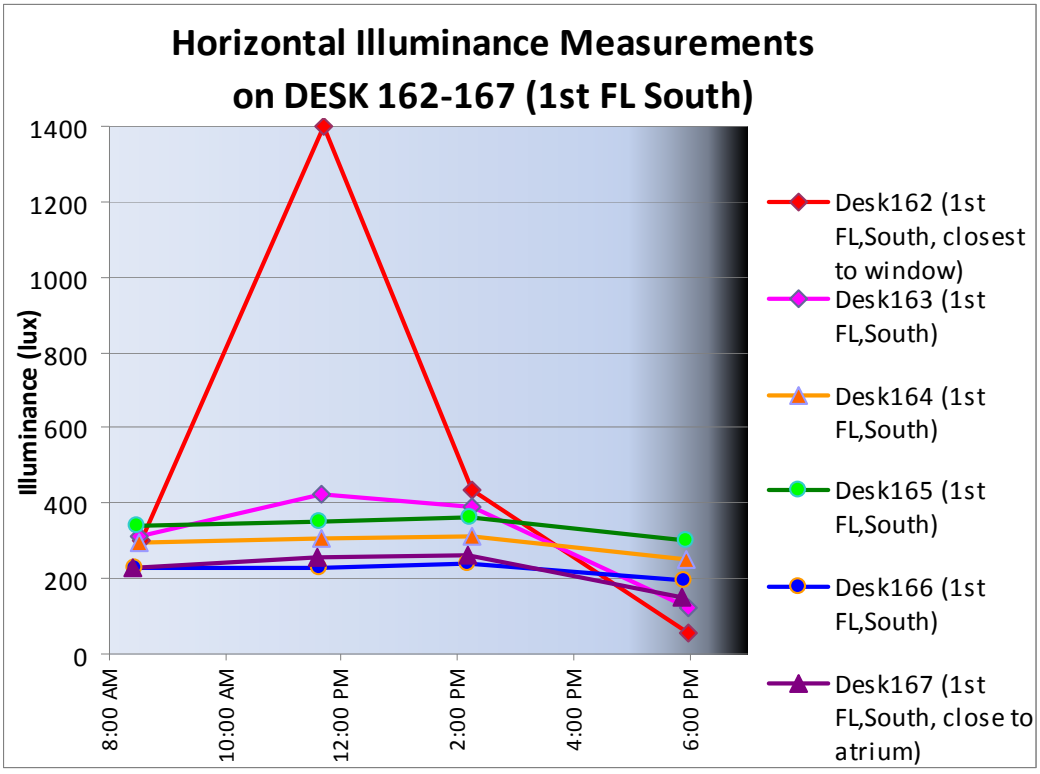
14:45, Desk 049, Looking North

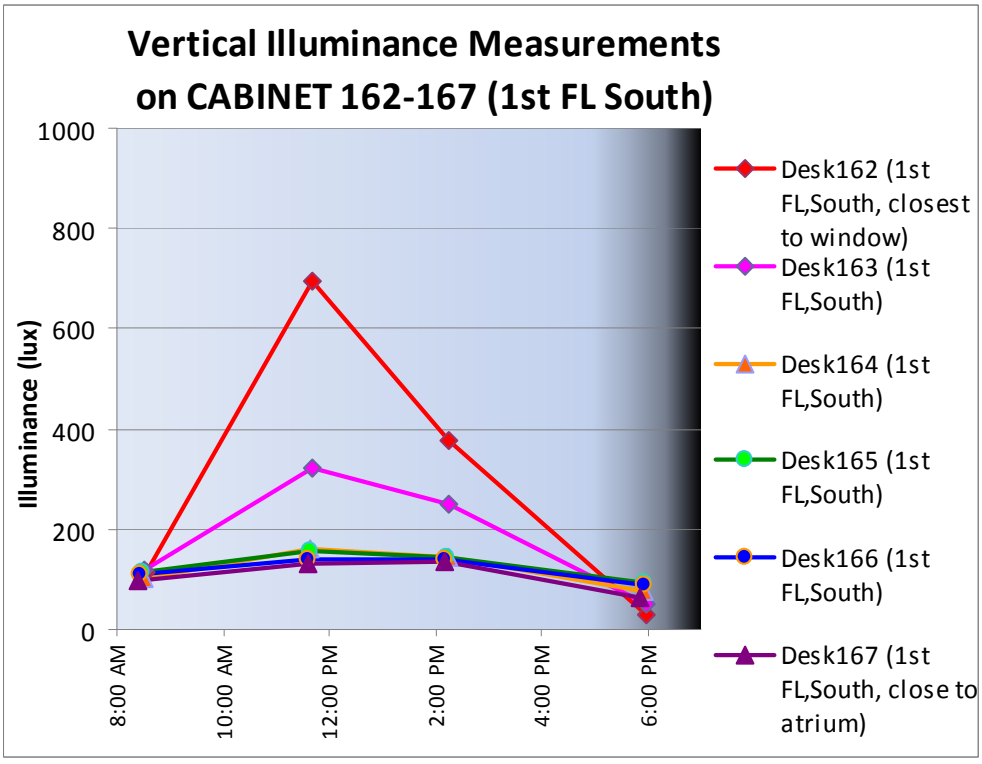


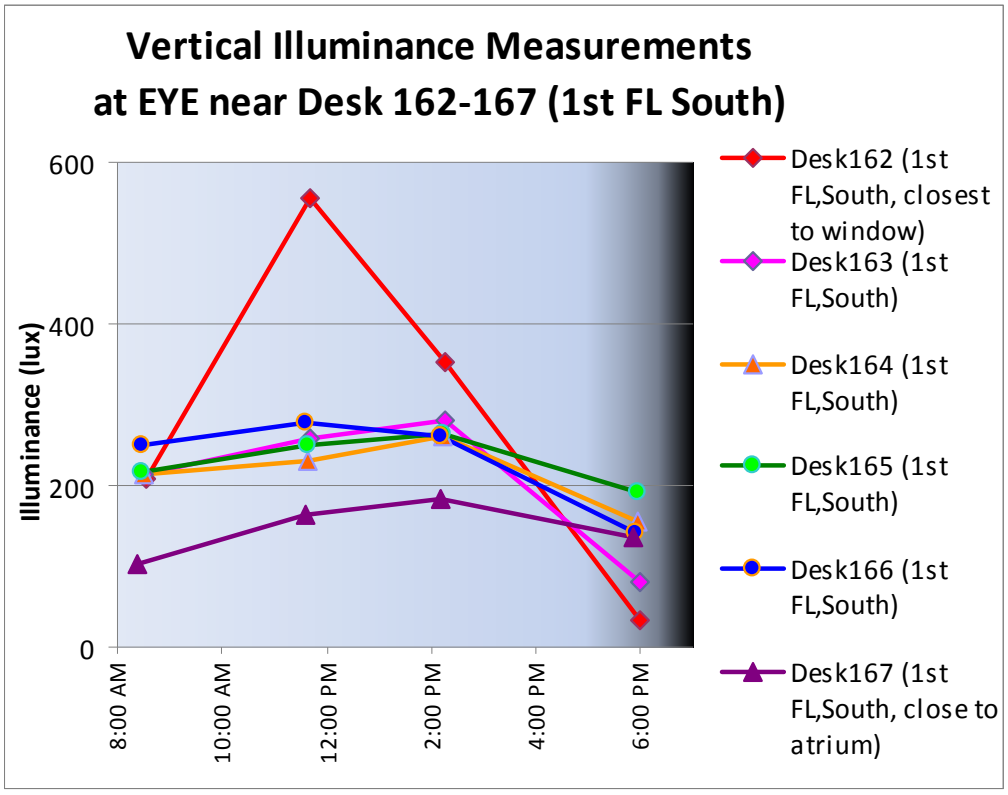
APPENDIX B: PHOTOMETRIC DATA FOR DESKS 162-167 (ILLUMINANCE AND LUMINANCE MEASUREMENTS)

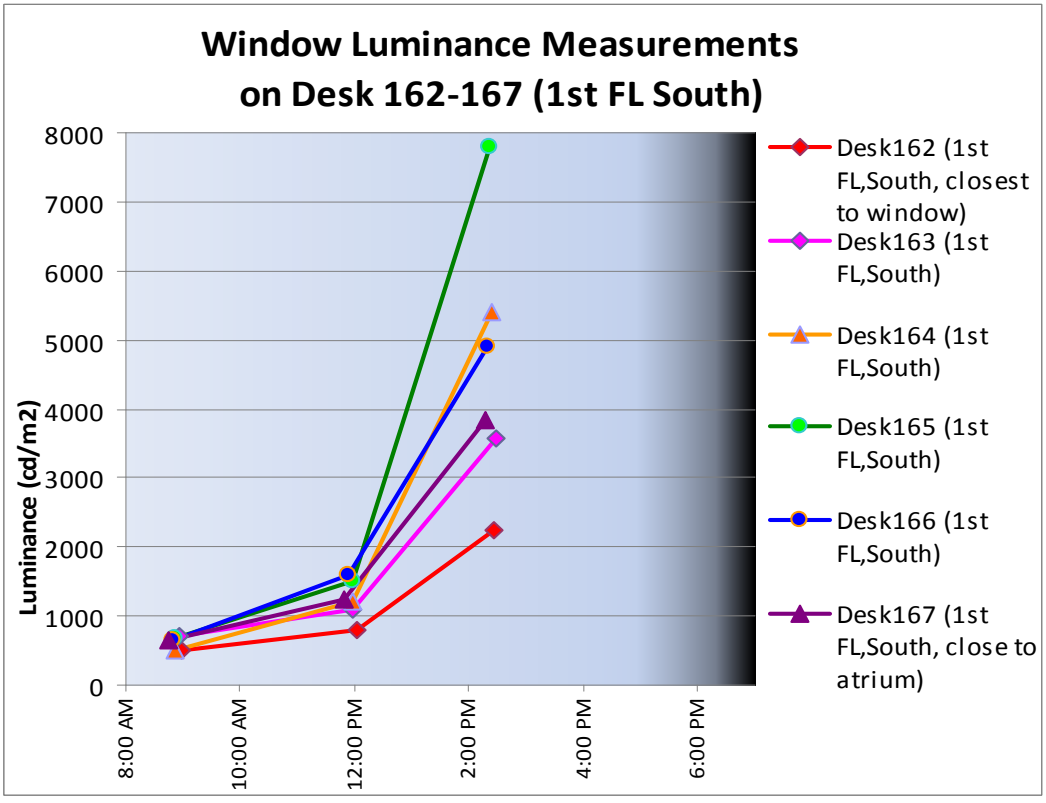


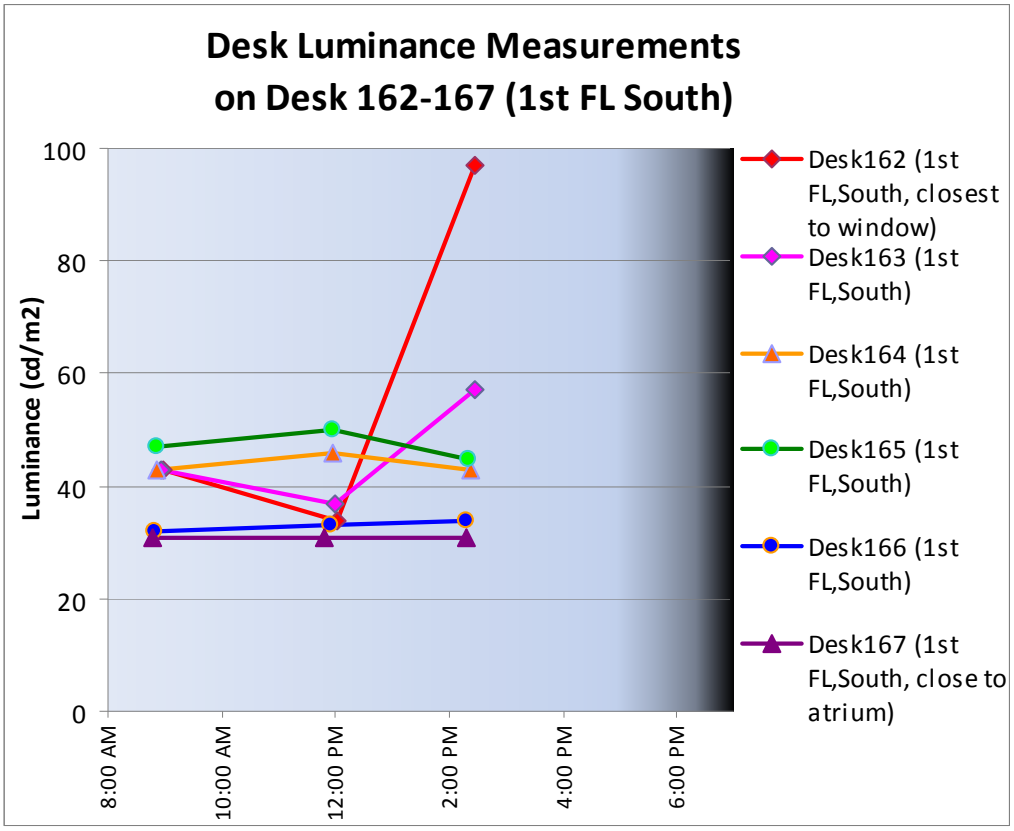
Desk with illuminance measures

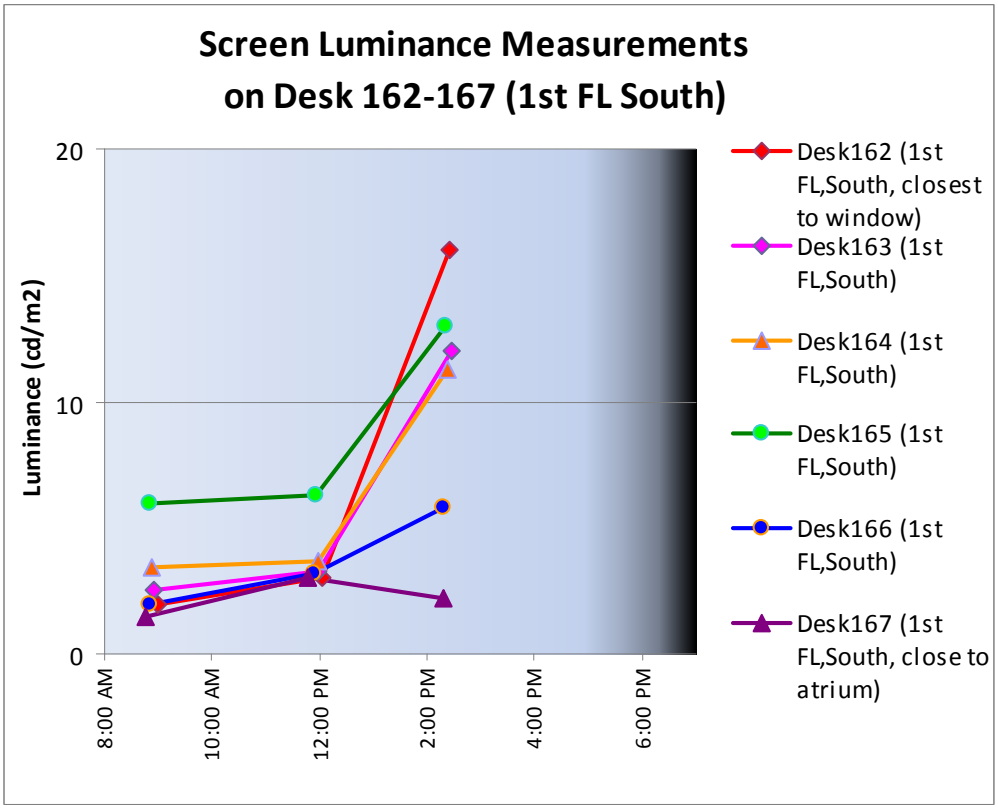

Horizontal Illuminance Measurements
on DESK 162-167 (1st FL South)
Illuminance (lux)
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)


Vertical Illuminance Measurements
on CABINET 162-167 (1st FL South)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)

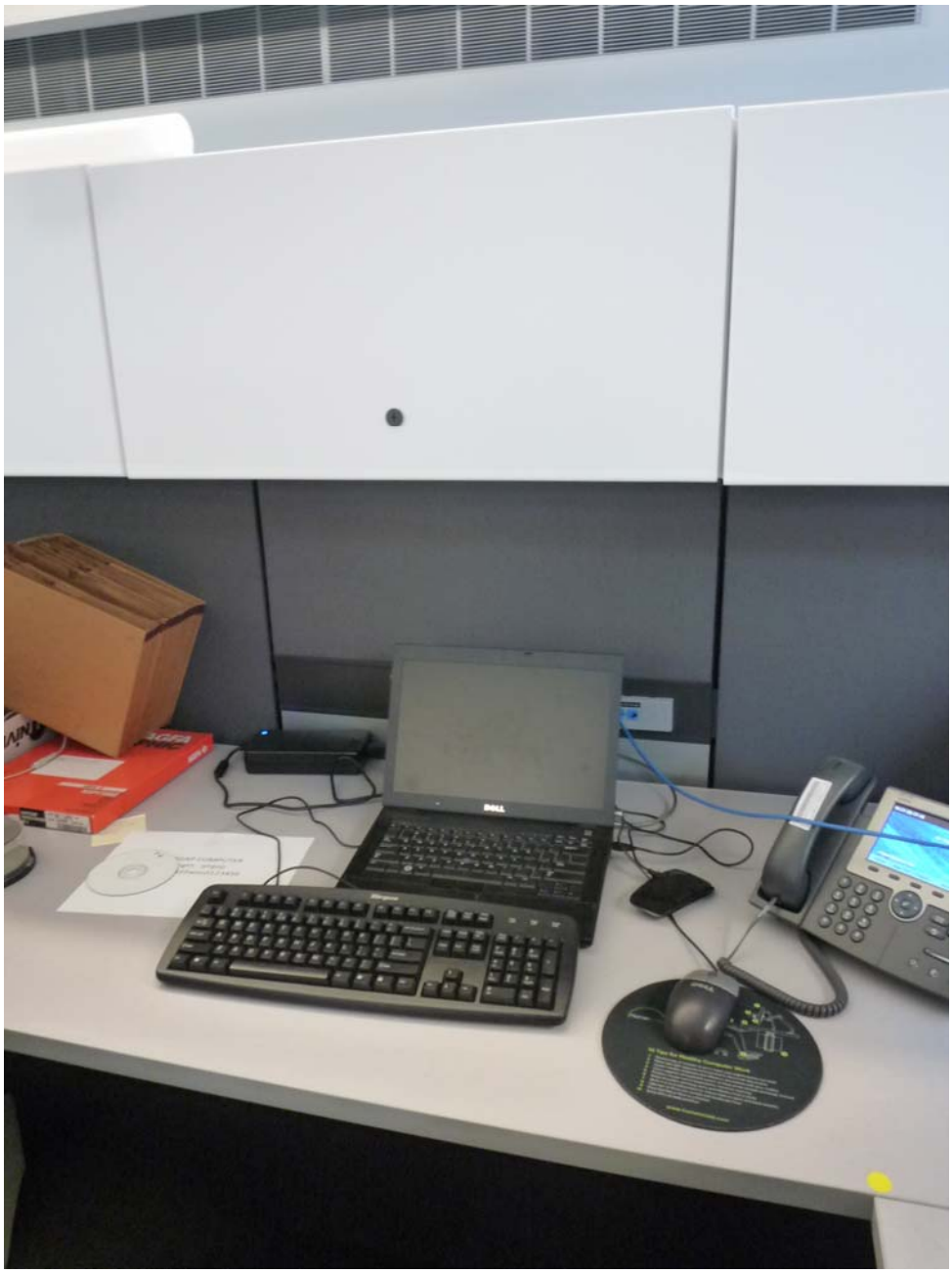

Vertical Illuminance Measurements
at EYE near Desk 162-167 (1st FL South)
Illuminance (lux)
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)


Window Luminance Measurements
on Desk 162-167 (1st FL South)
Luminance (cd/m2)
8000
7000
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)

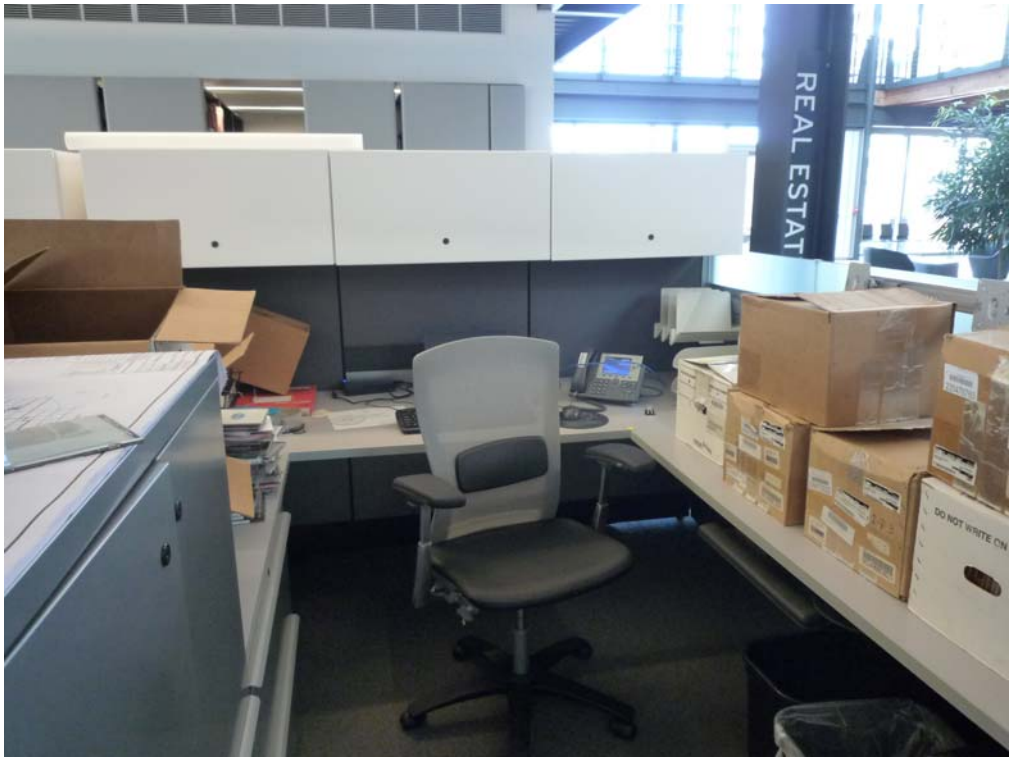

Desk Luminance Measurements
on Desk 162-167 (1st FL South)
Luminance (cd/m2)
100
80
60
40
20
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)


Screen Luminance Measurements
on Desk 162-167 (1st FL South)
Luminance (cd/m2)
20
10
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk162 (1st FL,South, closest to window)
Desk163 (1st FL,South)
Desk164 (1st FL,South)
Desk165 (1st FL,South)
Desk166 (1st FL,South)
Desk167 (1st FL,South, close to atrium)

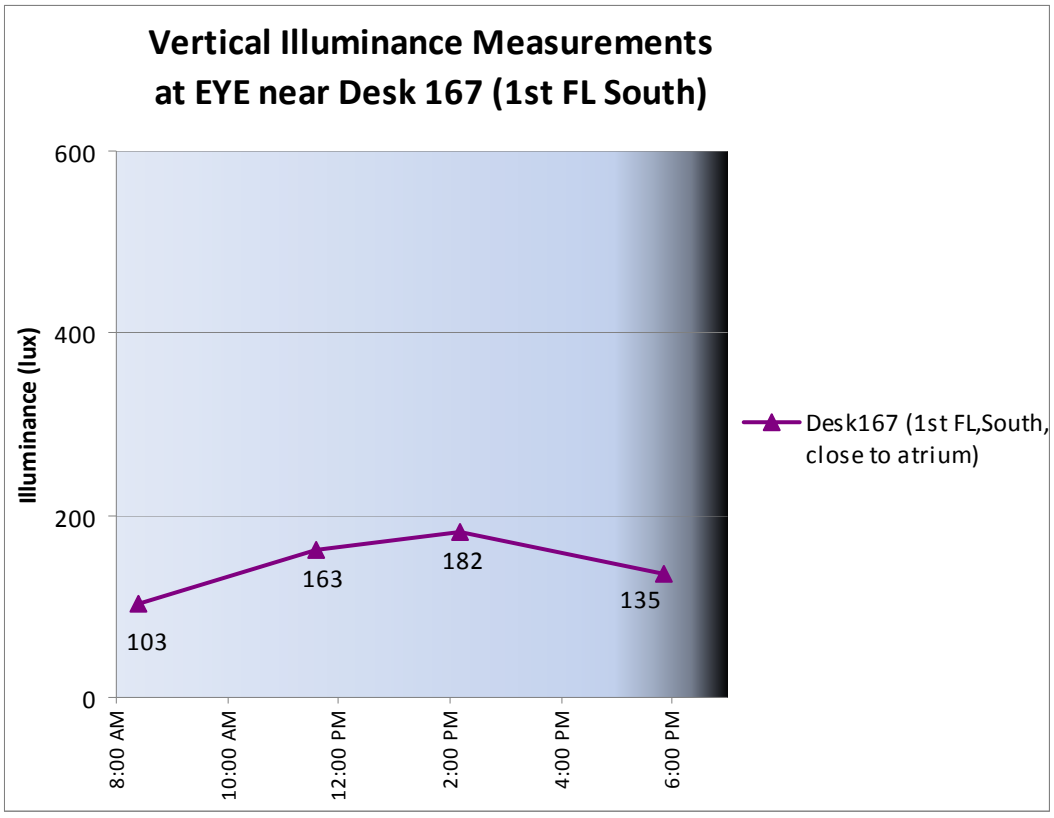
DESK 167



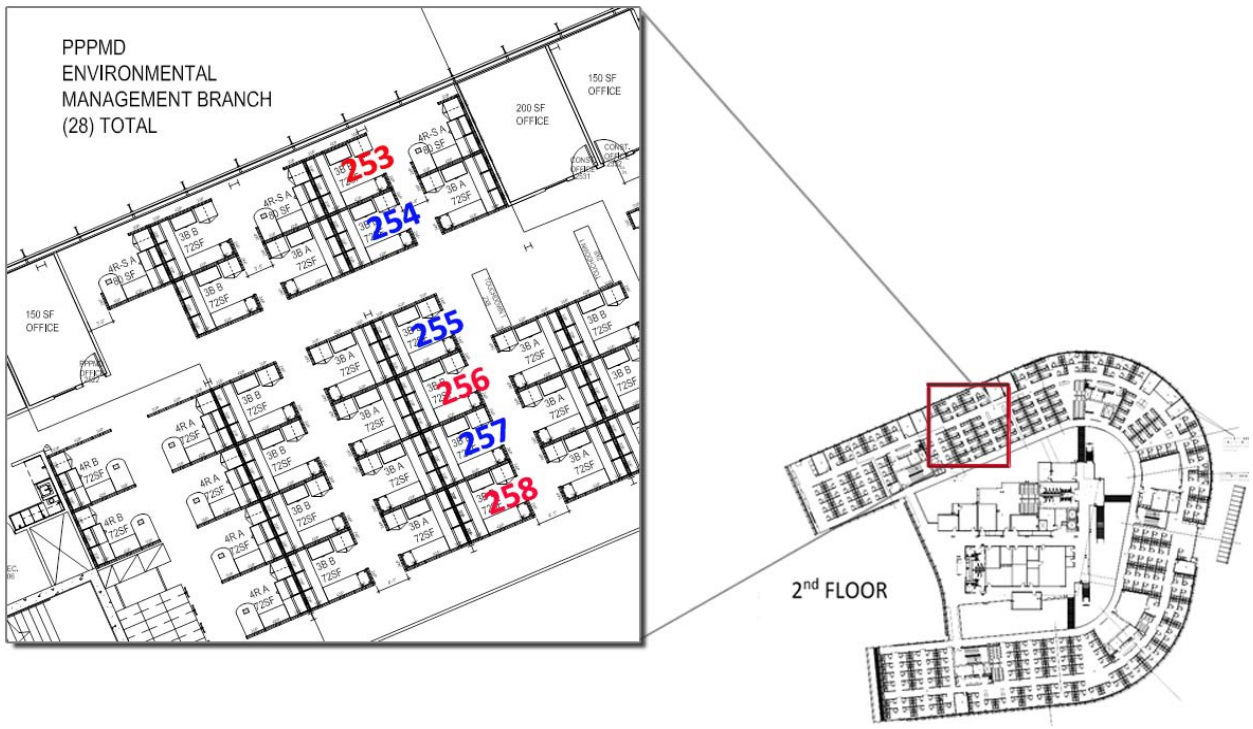
14:30, Desk 167, Desk measurement location shown with yellow dot



14:30, Desk 167, Looking West

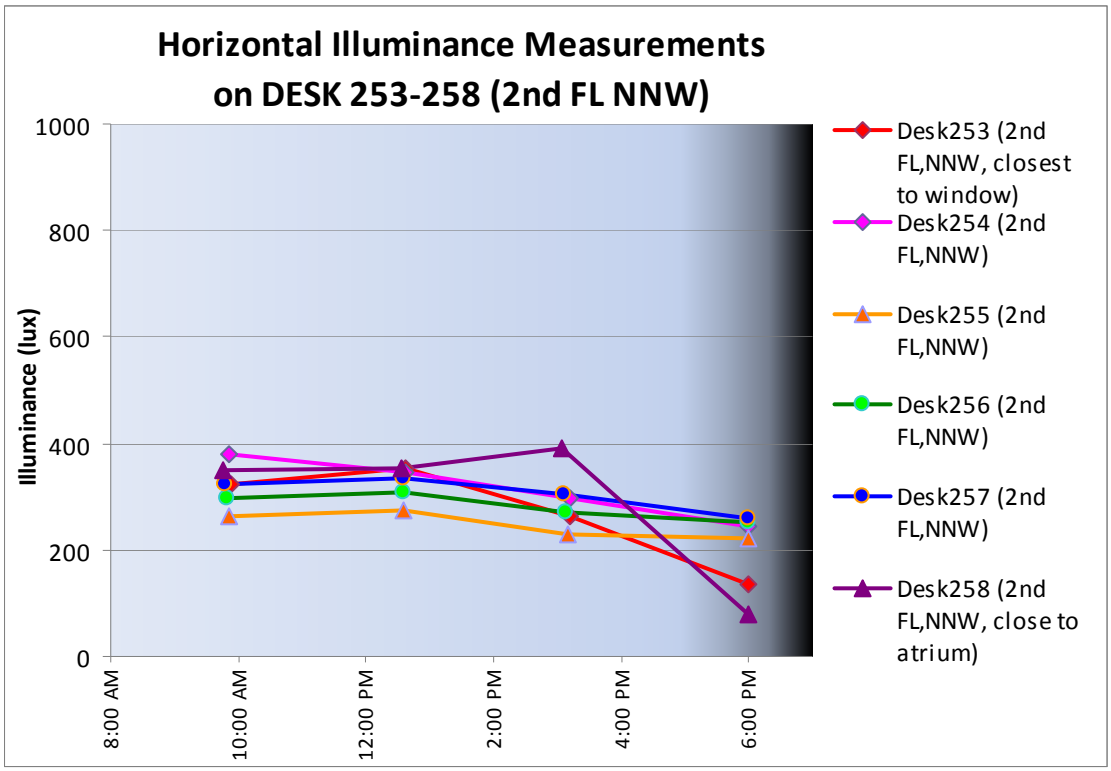


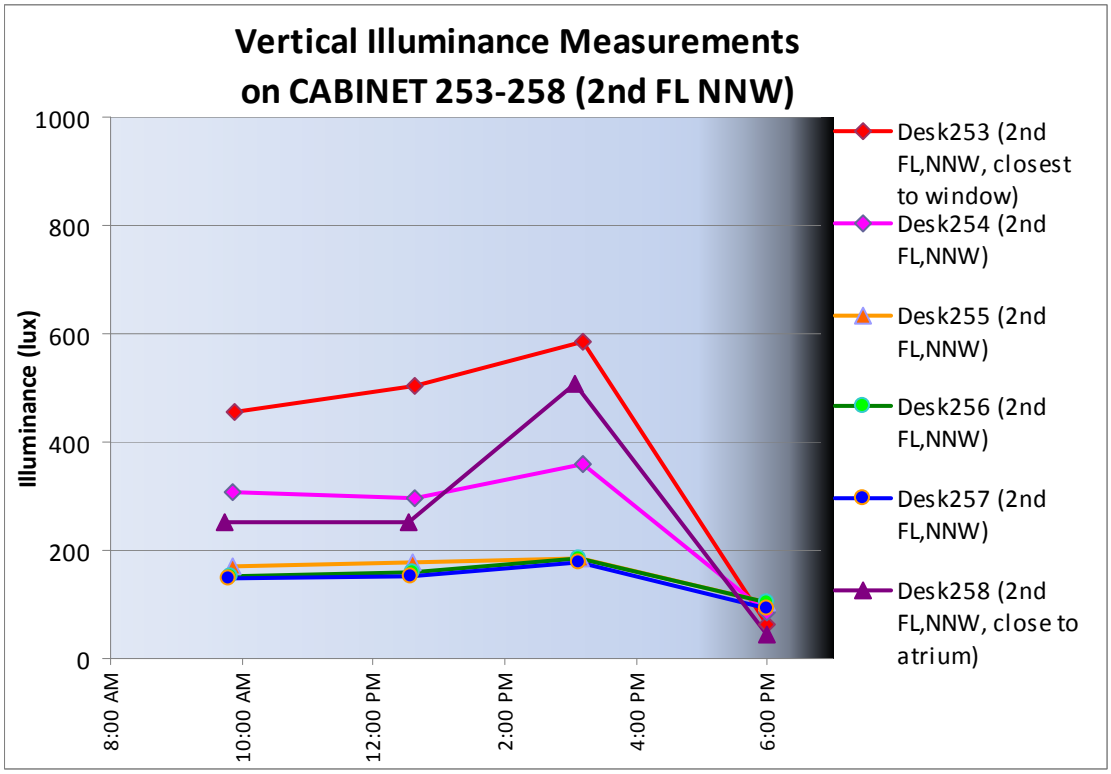
APPENDIX C: PHOTOMETRIC DATA FOR DESKS 253-258

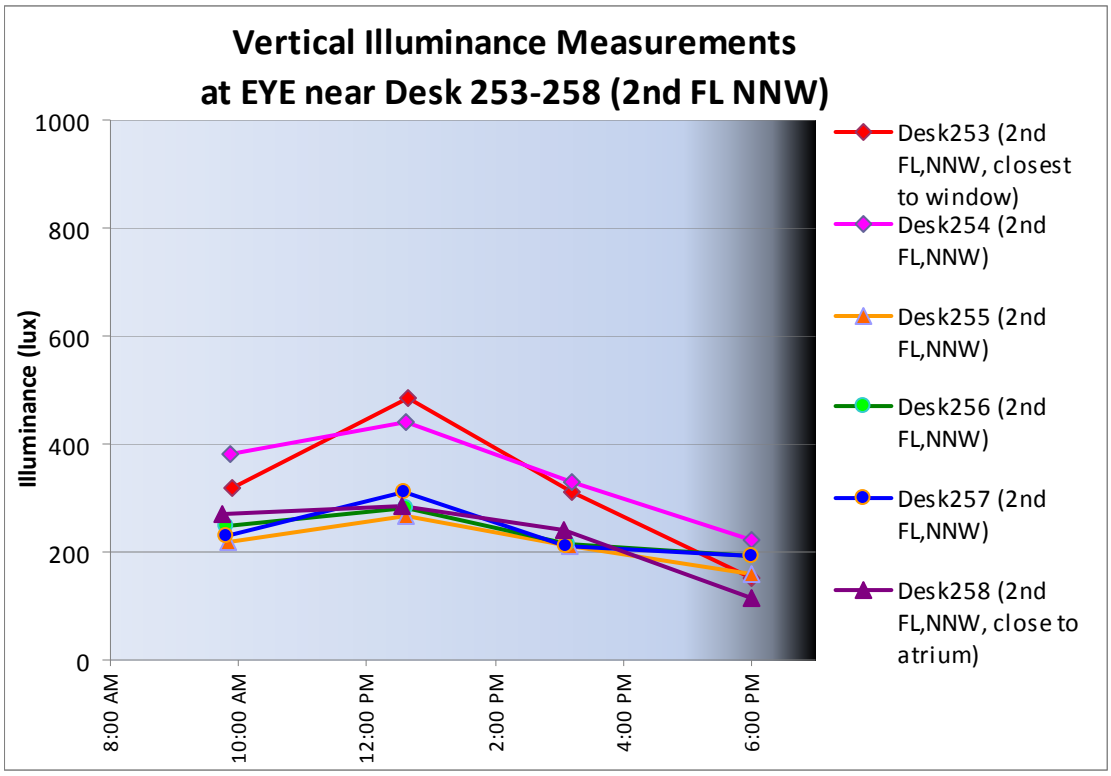


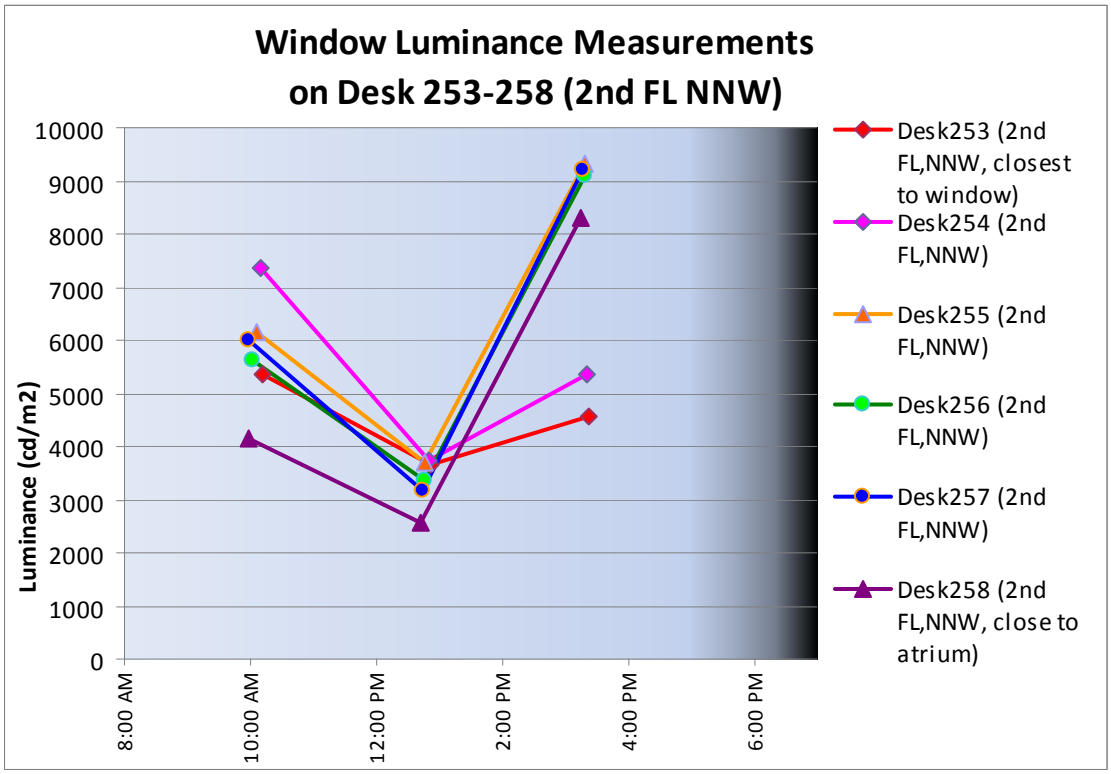
Desk with illuminance measures

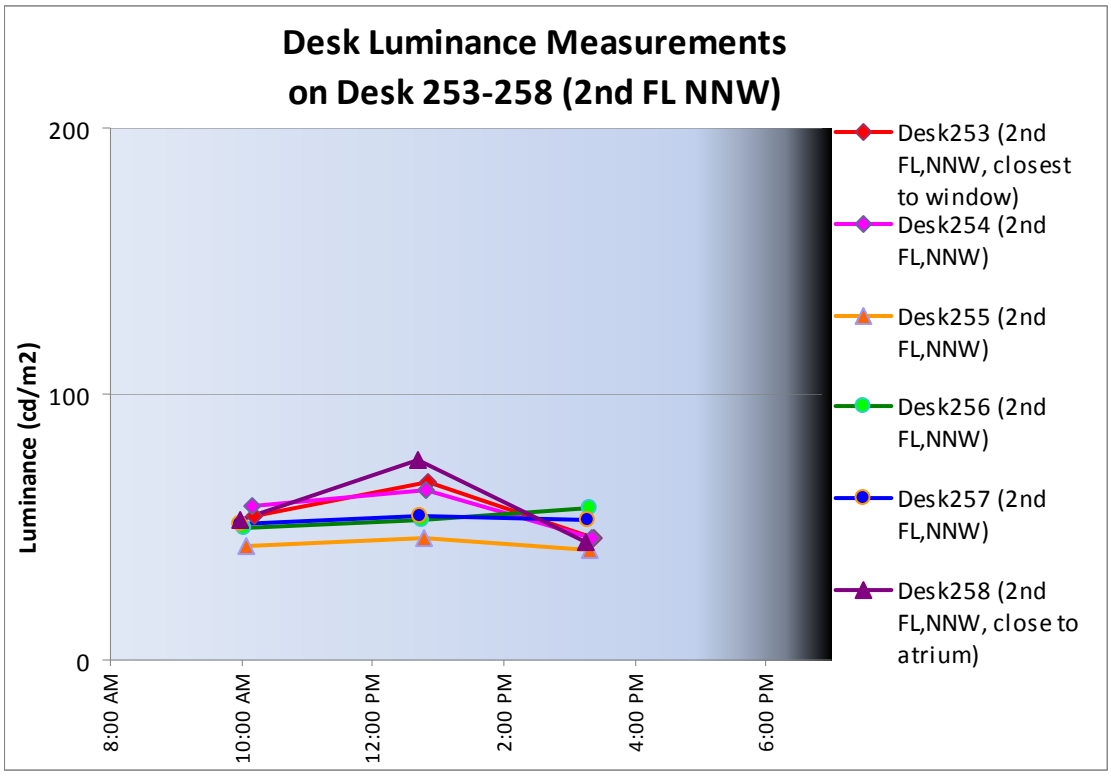
Desk with illuminance + SPD measures

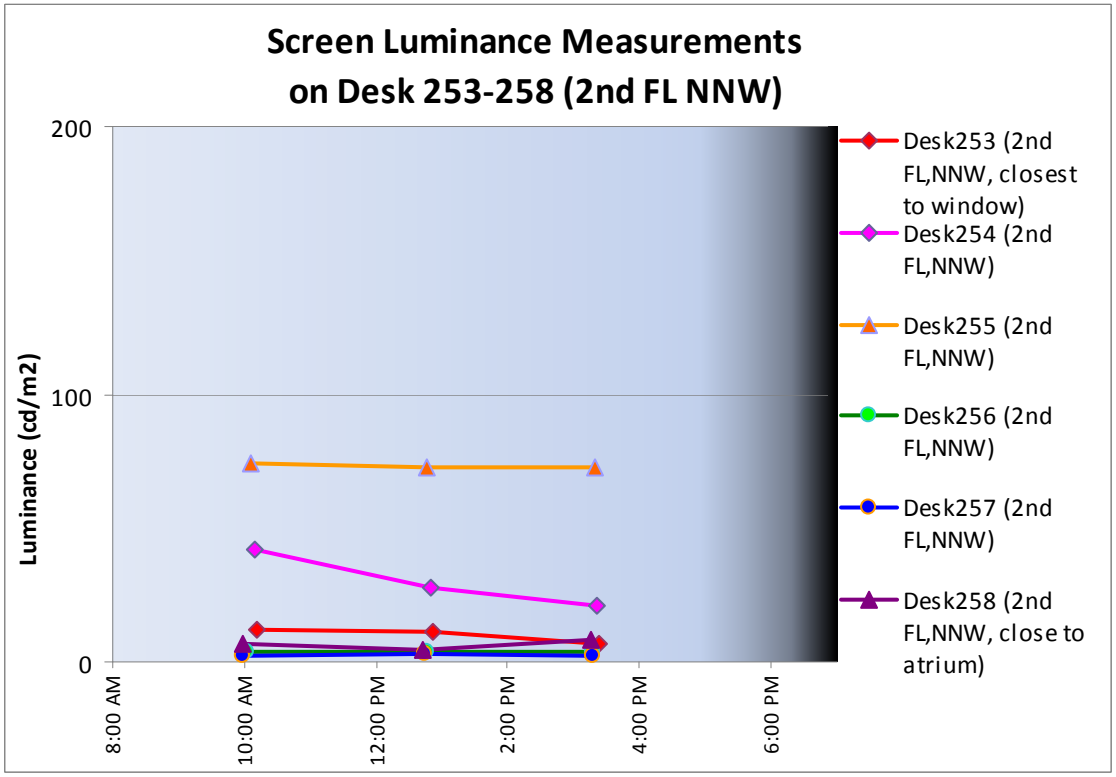

Horizontal Illuminance Measurements
on DESK 253-258 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)


Vertical Illuminance Measurements
on CABINET 253-258 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)

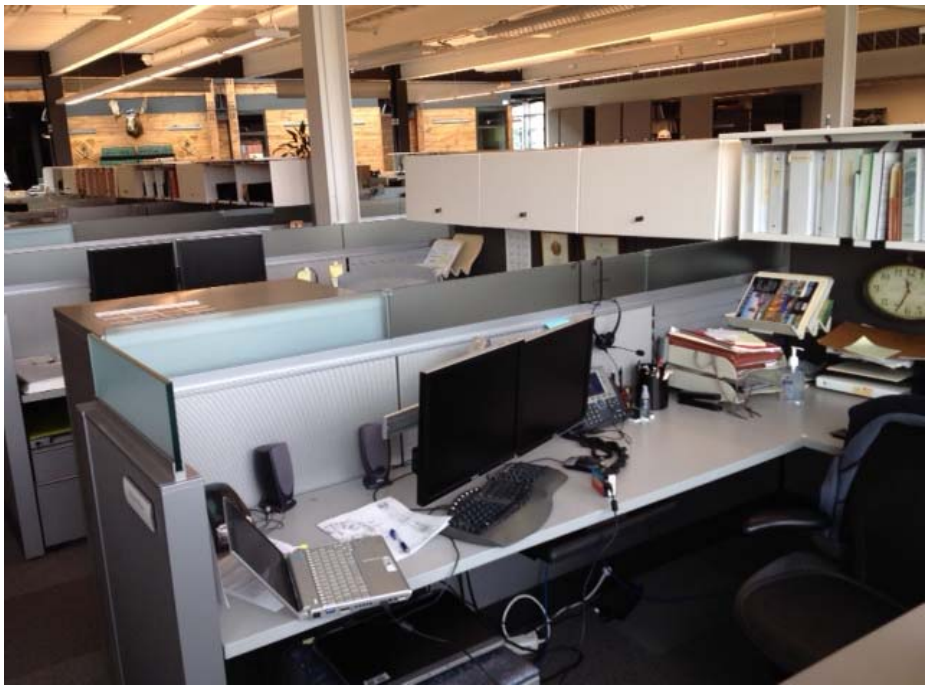

Vertical Illuminance Measurements
at EYE near Desk 253-258 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)


Window Luminance Measurements
on Desk 253-258 (2nd FL NNW)
Luminance (cd/m2)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)

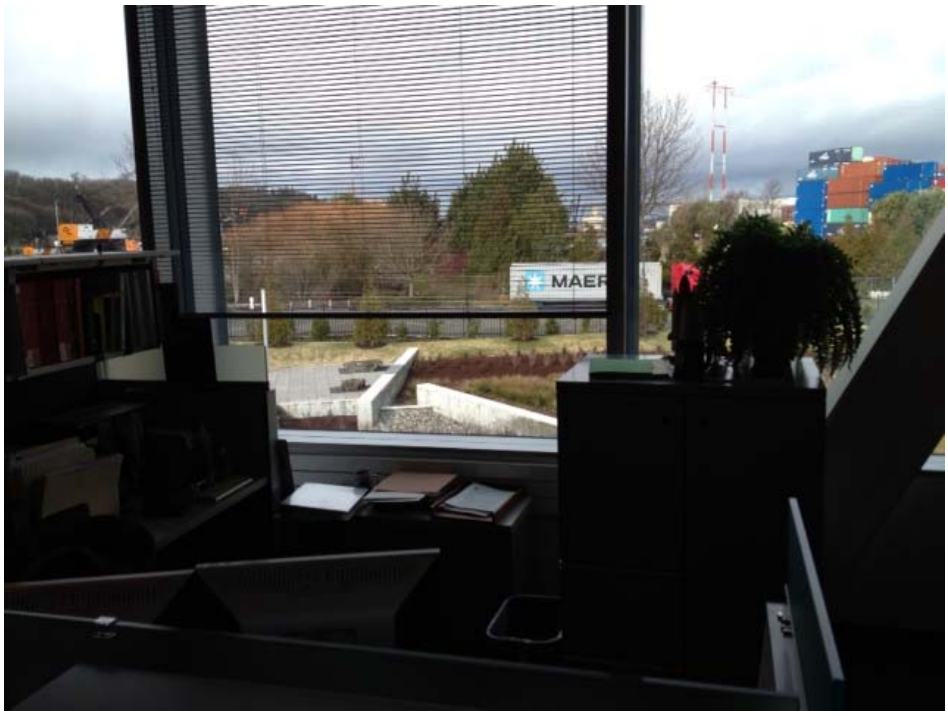

Desk Luminance Measurements
on Desk 253-258 (2nd FL NNW)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)


Screen Luminance Measurements
on Desk 253-258 (2nd FL NNW)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)
Desk254 (2nd FL,NNW)
Desk255 (2nd FL,NNW)
Desk256 (2nd FL,NNW)
Desk257 (2nd FL,NNW)
Desk258 (2nd FL,NNW, close to atrium)

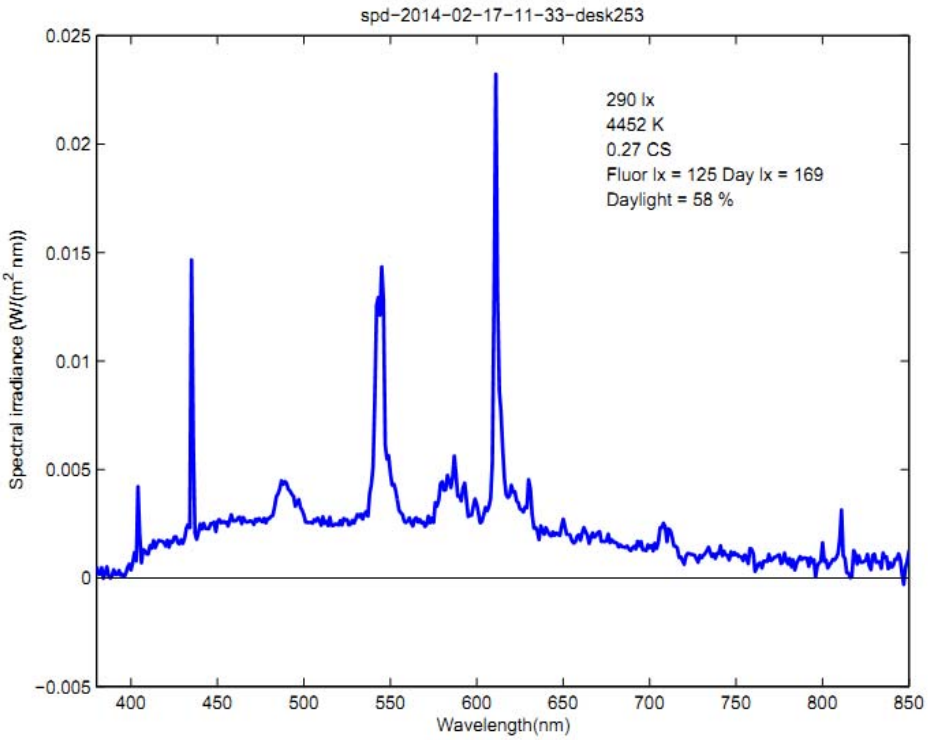
DESK 253

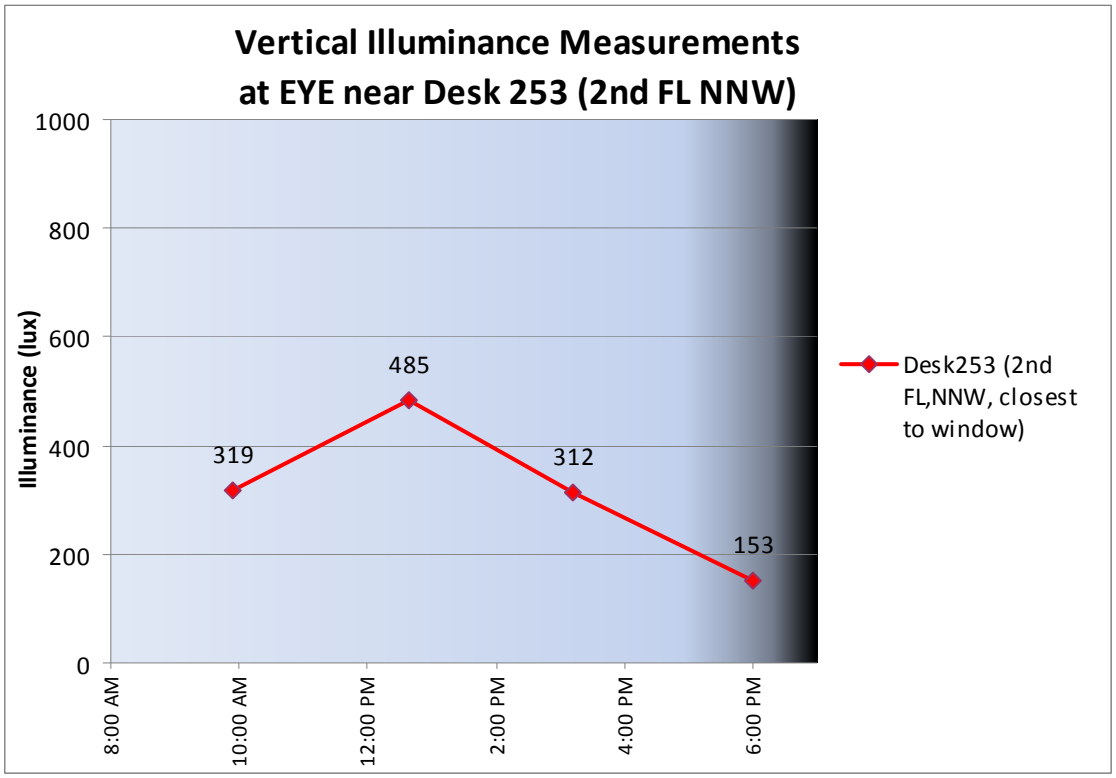


11:34, Desk 253

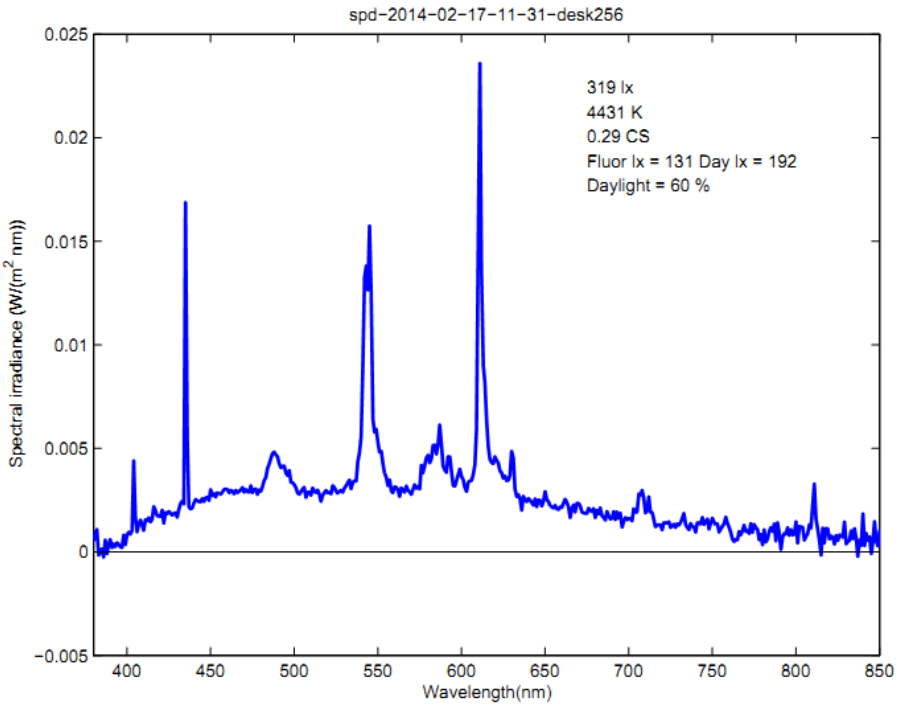


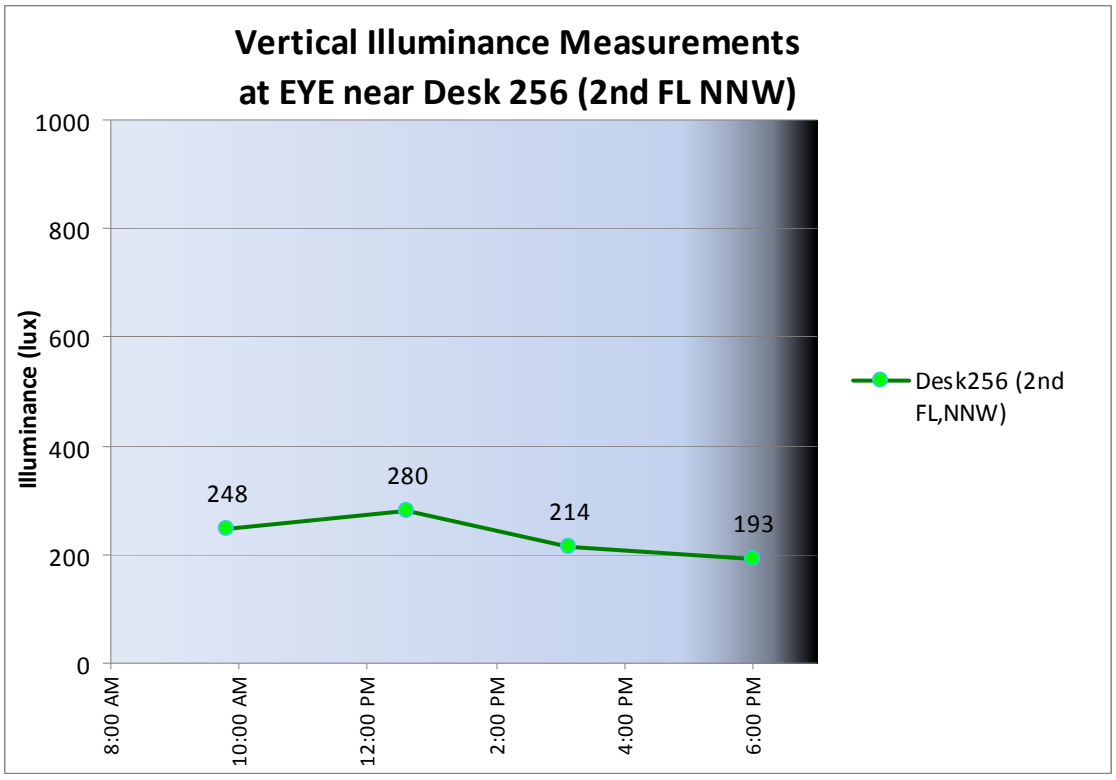
11:34, Desk 253, Looking North


spd-2014-02-17-11-33-desk253
290 lx
4452 K
0.27 CS
Fluor lx = 125 Day lx = 169
Daylight = 58 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

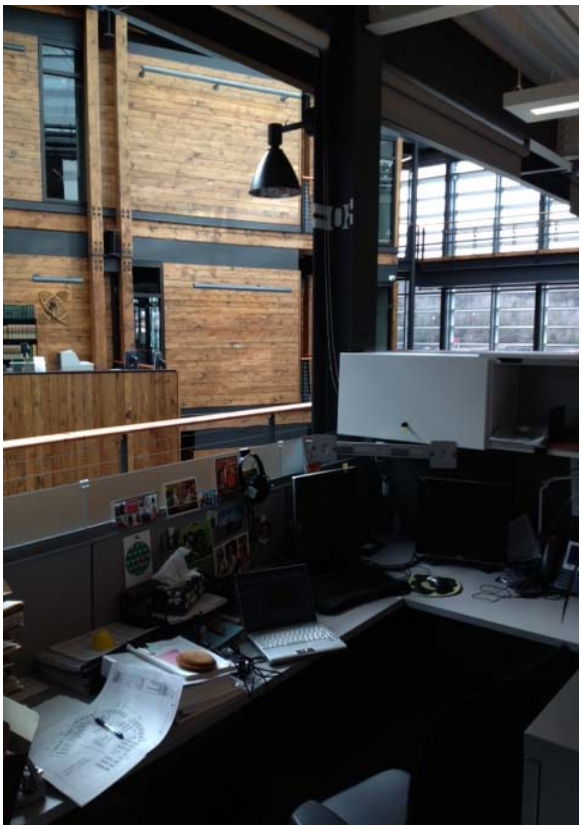

Vertical Illuminance Measurements
at EYE near Desk 253 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
485
319
312
153
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk253 (2nd FL,NNW, closest to window)

DESK 256

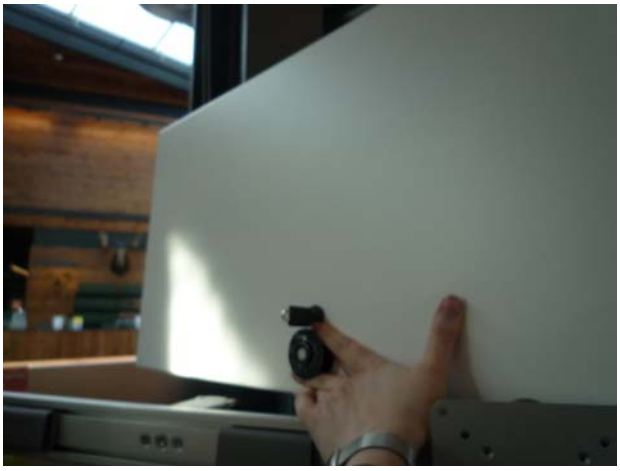

spd-2014-02-17-11-31-desk256
319 lx
4431 K
0.29 CS
Fluor lx = 131 Day lx = 192
Daylight = 60 %
Spectral irradiance (W/(m2 nm))
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850
Wavelength(nm)


Vertical Illuminance Measurements
at EYE near Desk 256 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
248
280
214
193
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk256 (2nd FL,NNW)

DESK 258



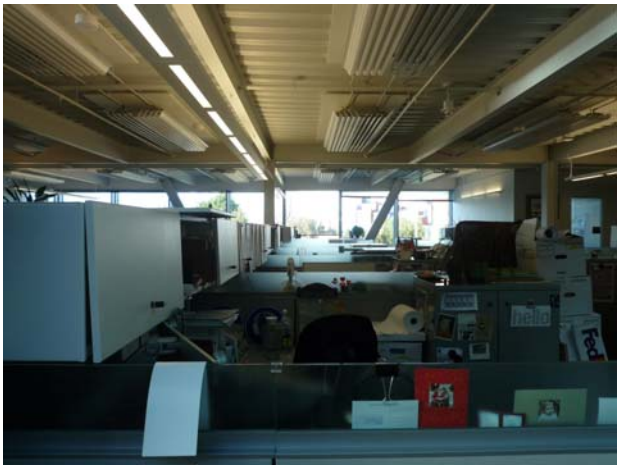
11:27, Desk 258



15:05, Desk 258, Measurement on cabinet near shaft of sun

15:26, Desk 258, Looking North

15:26, Desk 258, Looking West

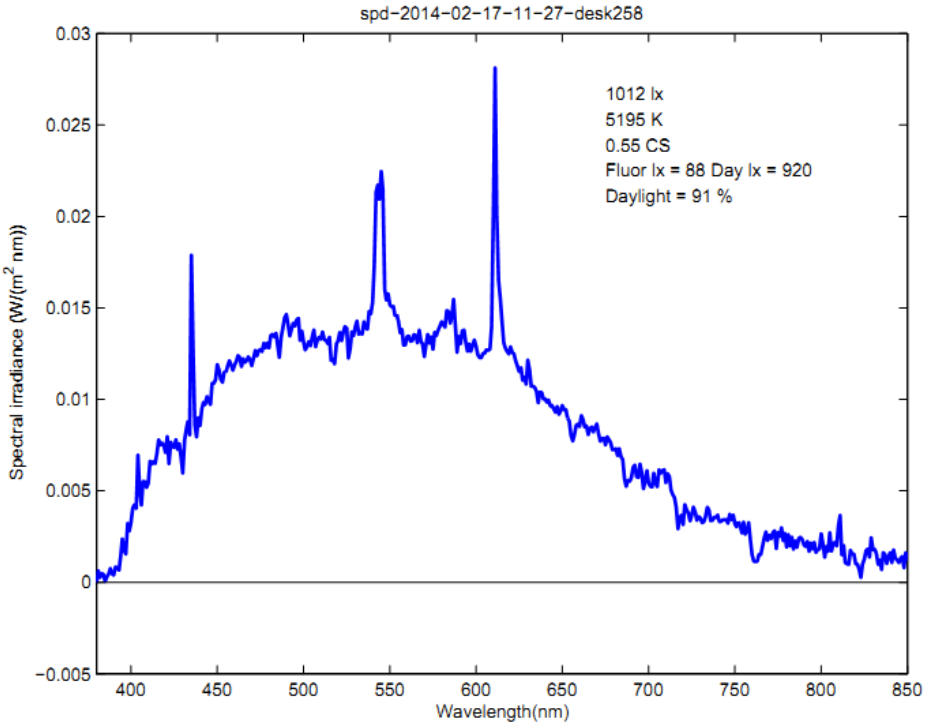


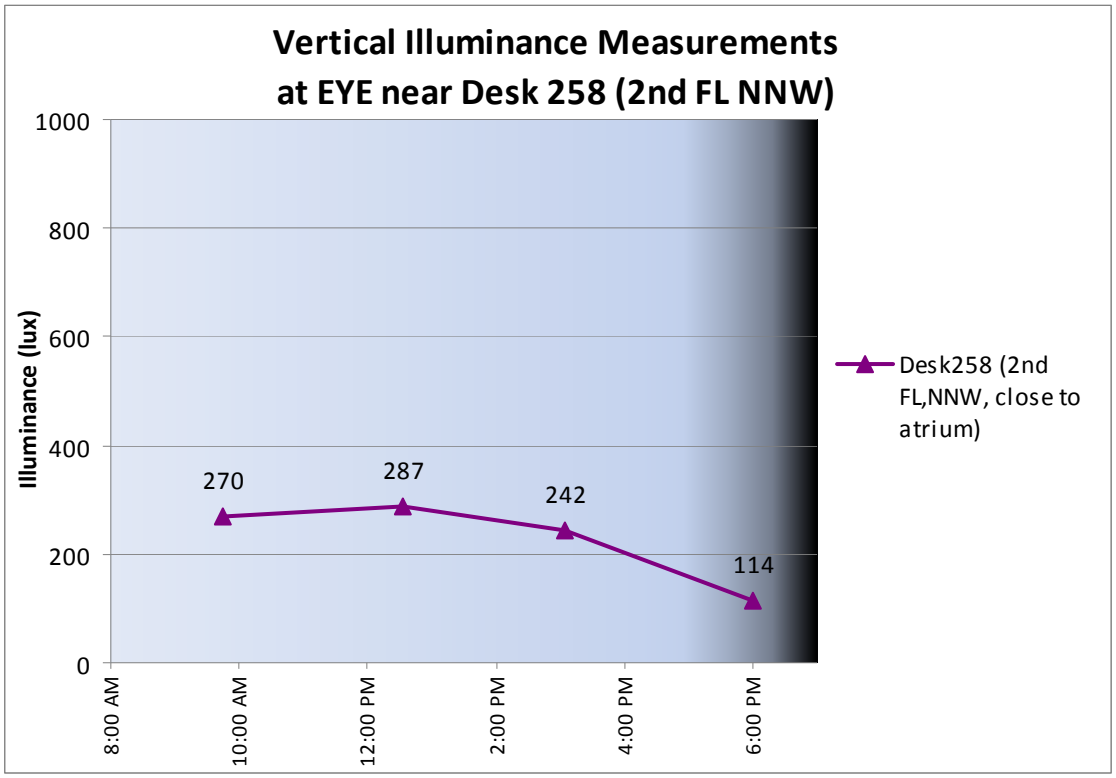
15:26, Desk 258, Looking North

15:26, Desk 258, Looking North

15:27, Desk 258, Looking North

15:27, Desk 258, Looking North

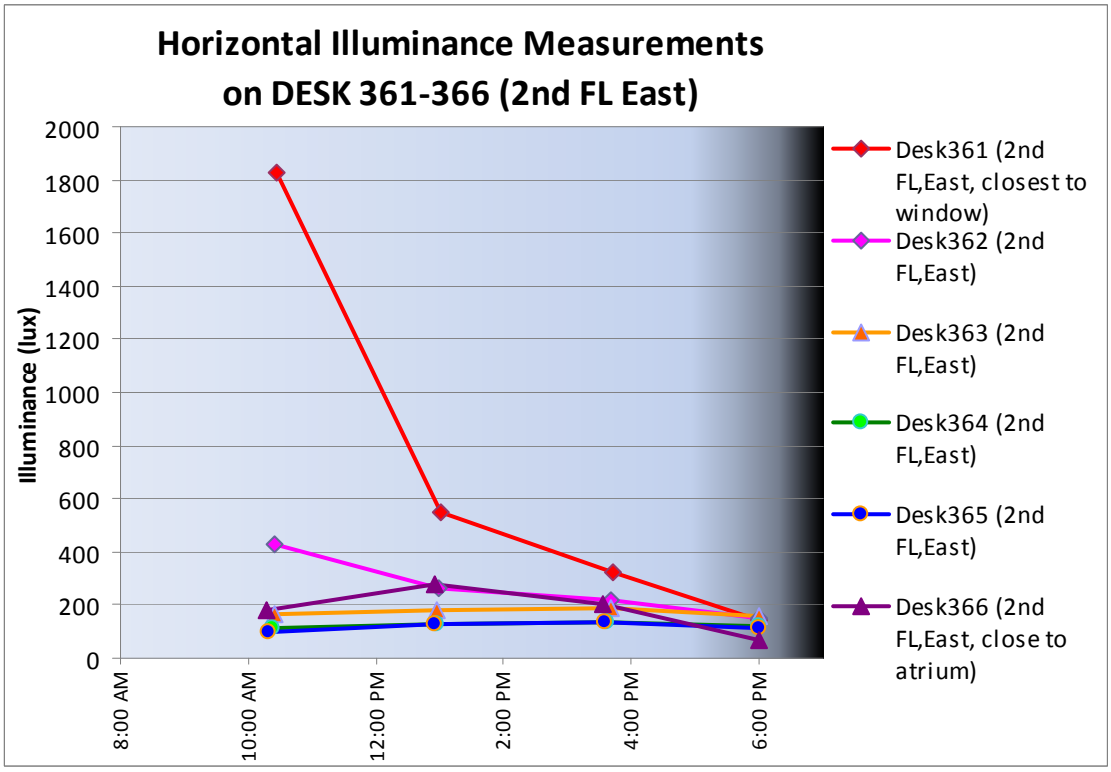

spd−2014−02−17−11−27−desk258
1012 lx
5195 K
0.55 CS
Fluor lx = 88 Day lx = 920
Daylight = 91 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
−0.005
400
450
500
550
600
650
700
750
800
850

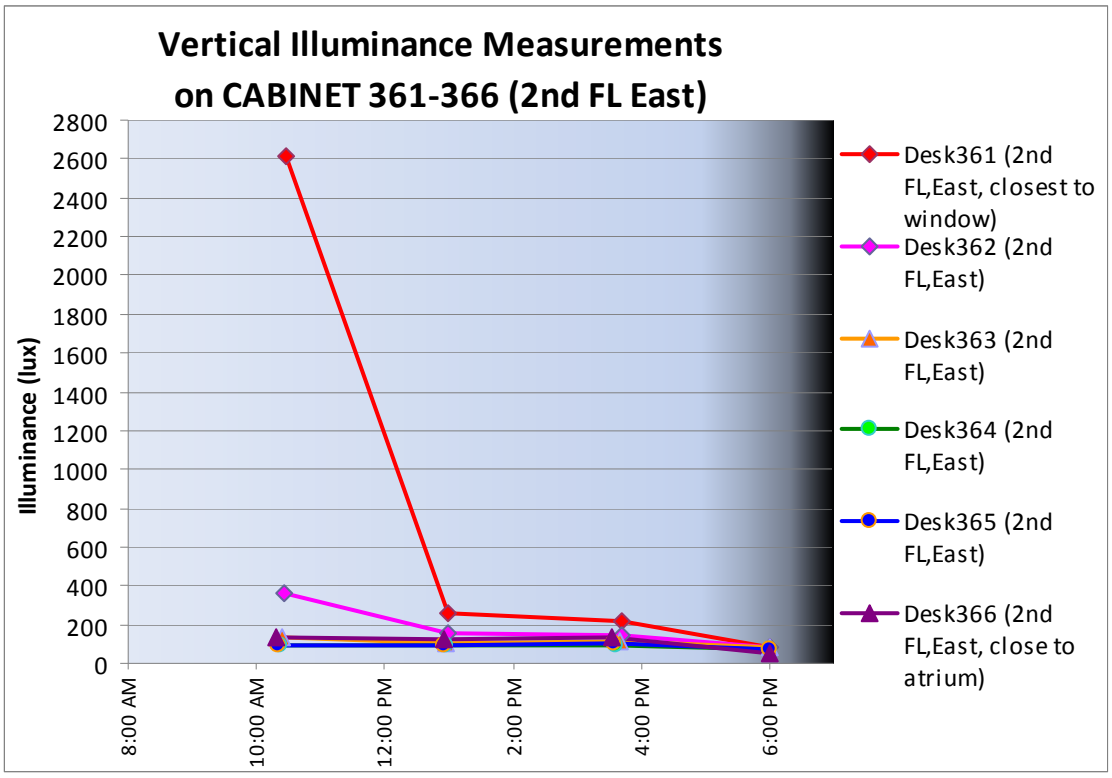

Vertical Illuminance Measurements
at EYE near Desk 258 (2nd FL NNW)
Illuminance (lux)
1000
800
600
400
200
0
270
287
242
114
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk258 (2nd FL,NNW, close to atrium)

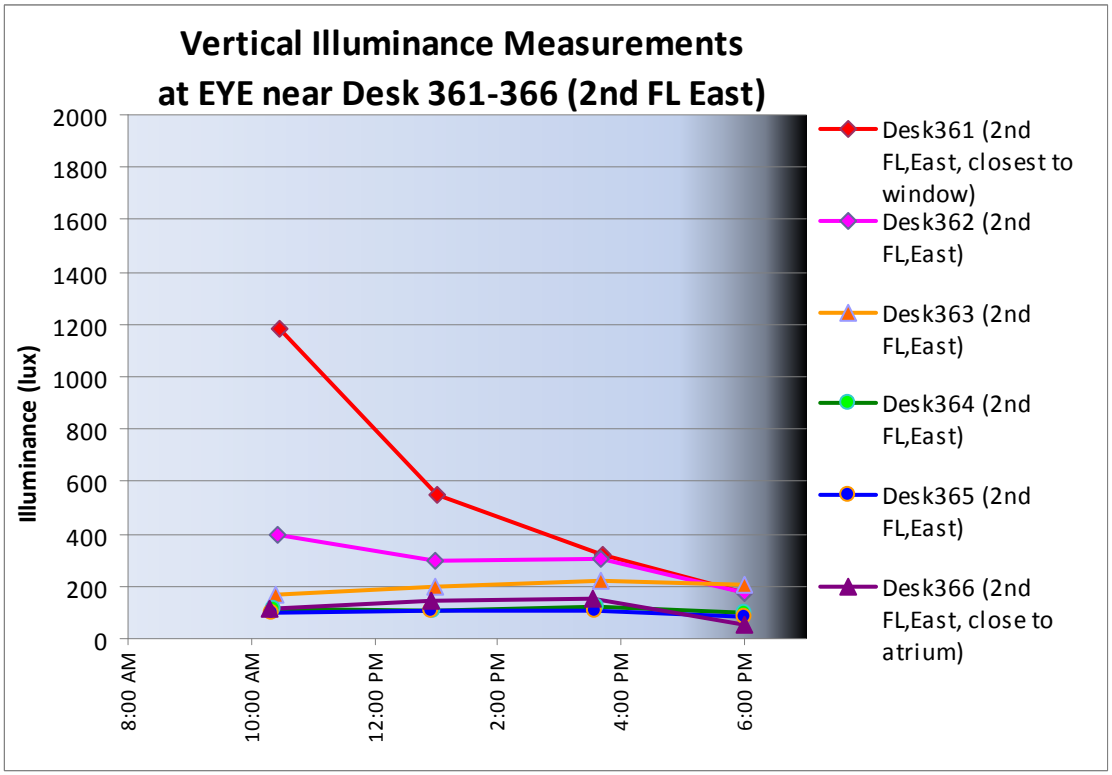
APPENDIX D: PHOTOMETRIC DATA FOR DESKS 361-366

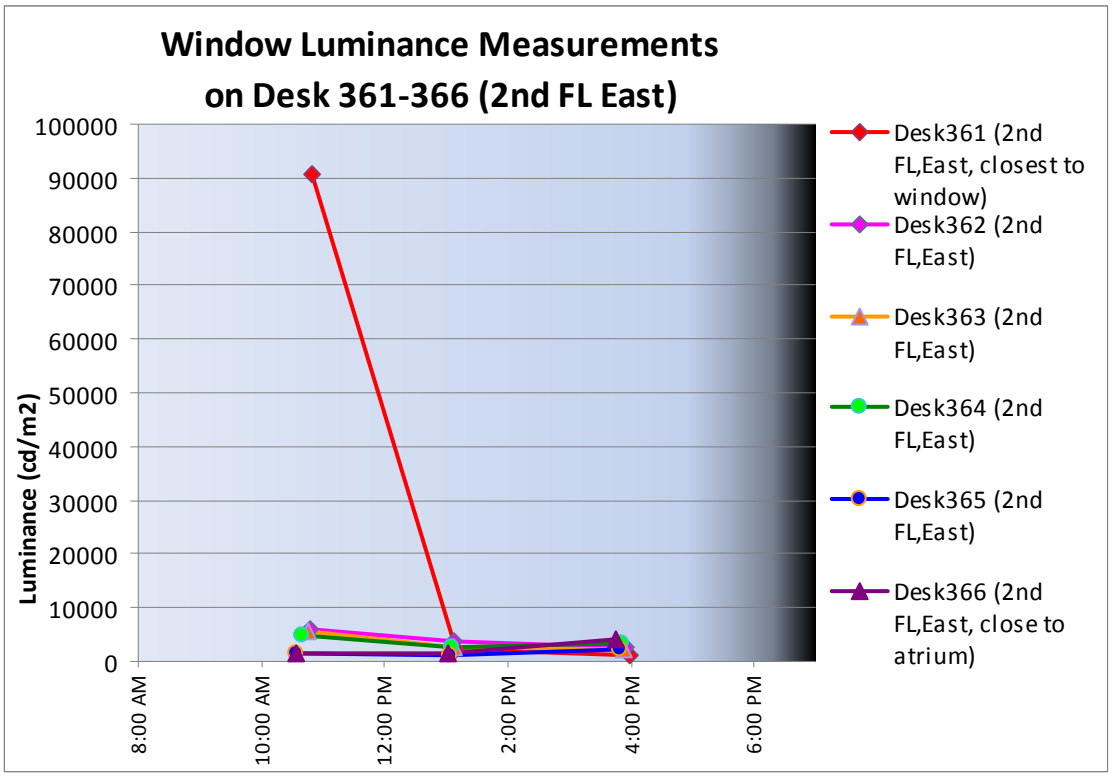
Desk with illuminance measures

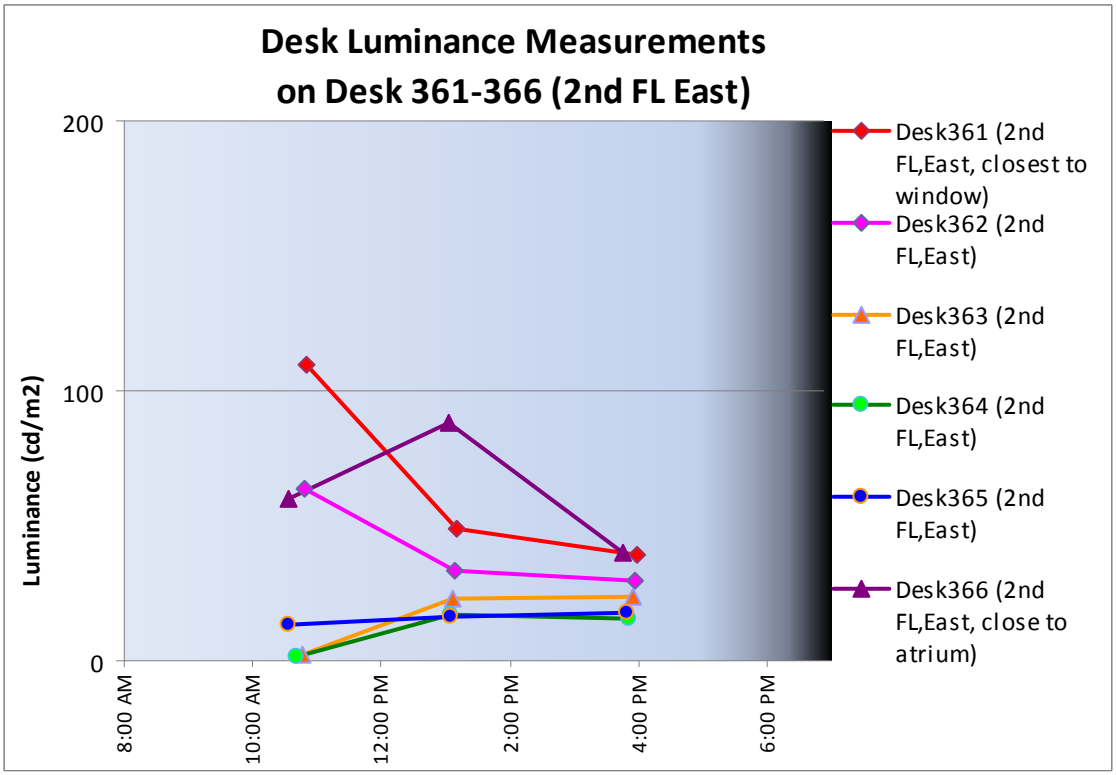
Desk with illuminance + SPD measures

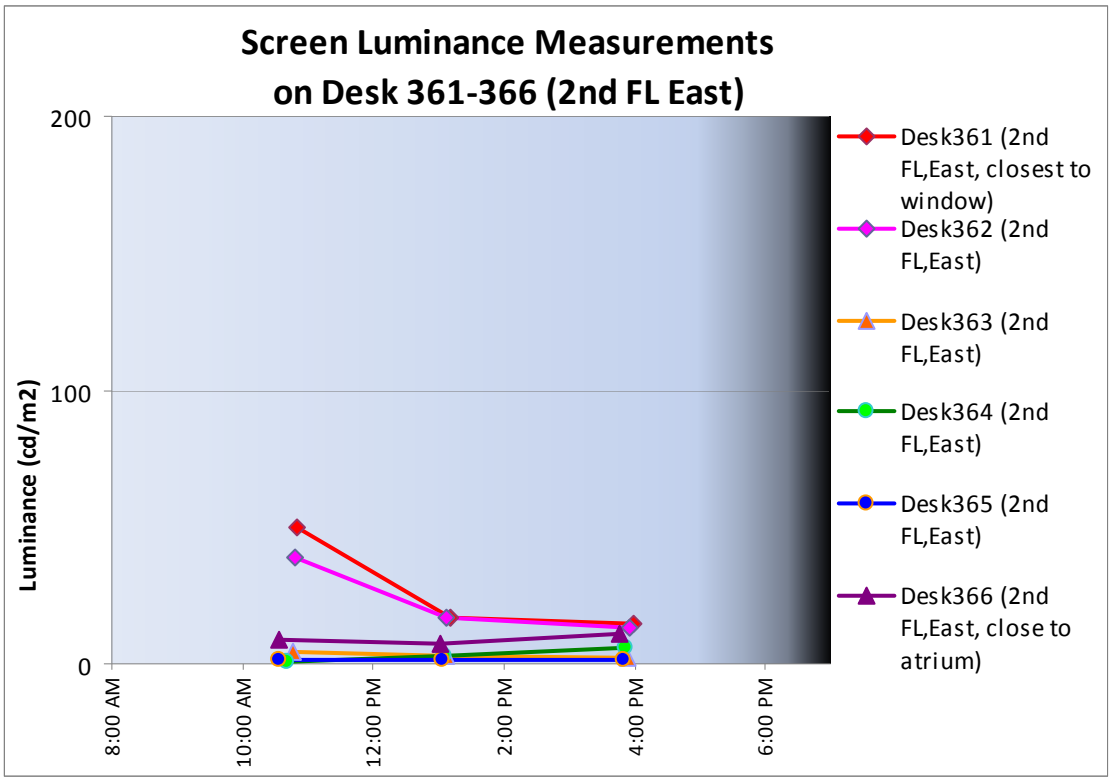



Vertical Illuminance Measurements
on CABINET 361-366 (2nd FL East)
Illuminance (lux)
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)
Desk362 (2nd FL,East)
Desk363 (2nd FL,East)
Desk364 (2nd FL,East)
Desk365 (2nd FL,East)
Desk366 (2nd FL,East, close to atrium)

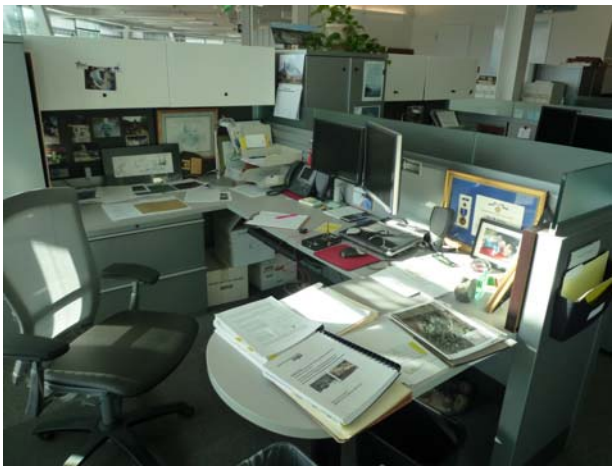

Vertical Illuminance Measurements
at EYE near Desk 361-366 (2nd FL East)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)
Desk362 (2nd FL,East)
Desk363 (2nd FL,East)
Desk364 (2nd FL,East)
Desk365 (2nd FL,East)
Desk366 (2nd FL,East, close to atrium)


Window Luminance Measurements
on Desk 361-366 (2nd FL East)
Luminance (cd/m2)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)
Desk362 (2nd FL,East)
Desk363 (2nd FL,East)
Desk364 (2nd FL,East)
Desk365 (2nd FL,East)
Desk366 (2nd FL,East, close to atrium)


Desk Luminance Measurements
on Desk 361-366 (2nd FL East)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)
Desk362 (2nd FL,East)
Desk363 (2nd FL,East)
Desk364 (2nd FL,East)
Desk365 (2nd FL,East)
Desk366 (2nd FL,East, close to atrium)

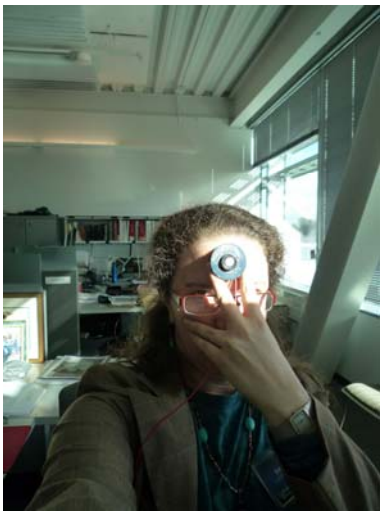

Screen Luminance Measurements
on Desk 361-366 (2nd FL East)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)
Desk362 (2nd FL,East)
Desk363 (2nd FL,East)
Desk364 (2nd FL,East)
Desk365 (2nd FL,East)
Desk366 (2nd FL,East, close to atrium)

DESK 361



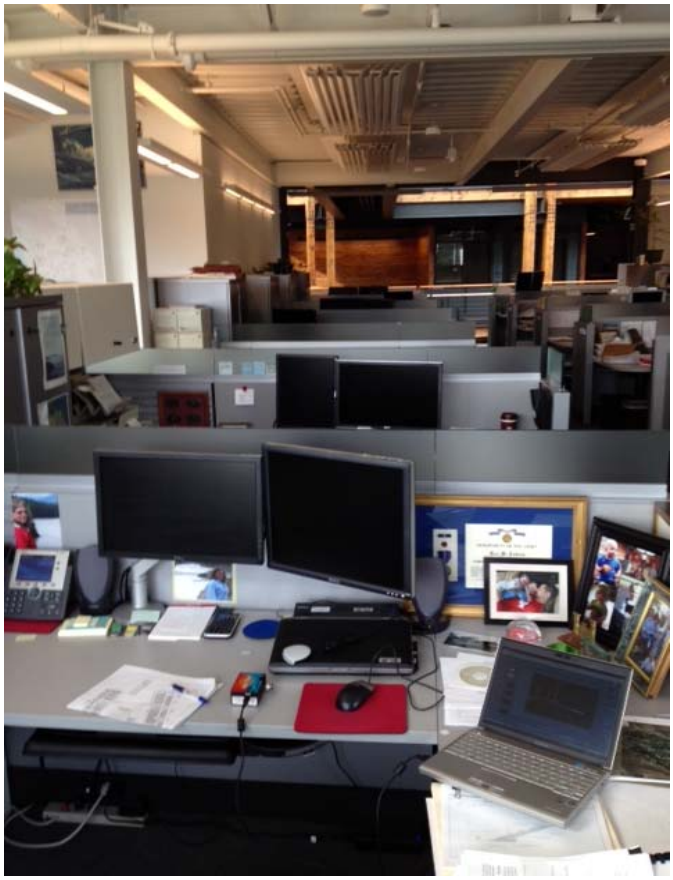
10:27, Desk 361, Shafts of sun

10:30, Desk 361, Illuminance measurement on desk near shaft of sun



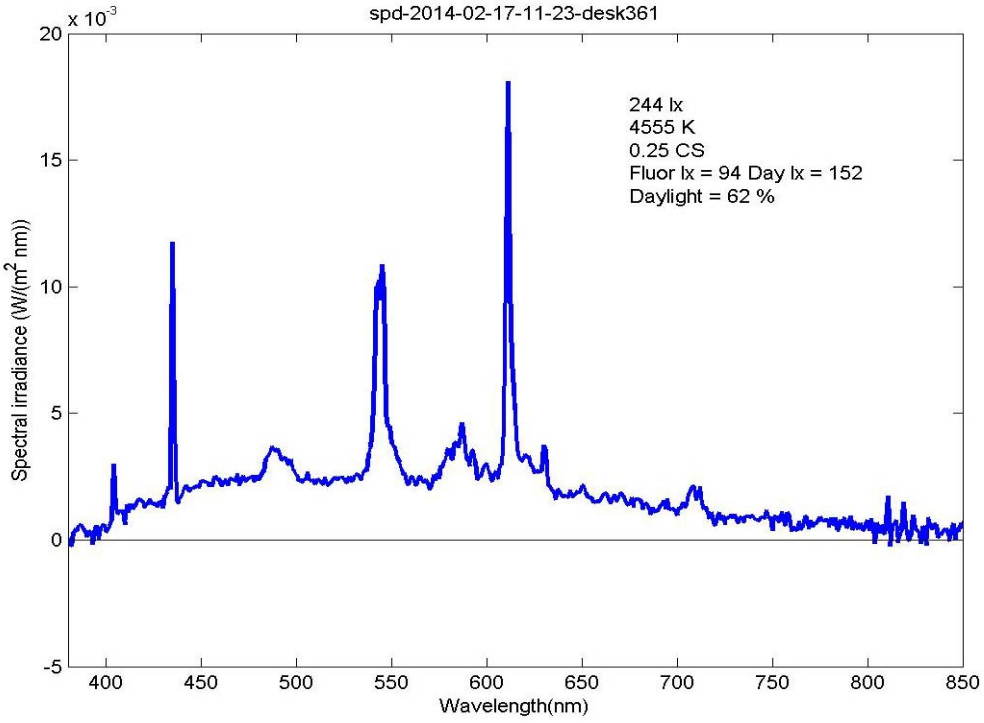
10:30, Desk 361, Measuring vertical illuminance at eye

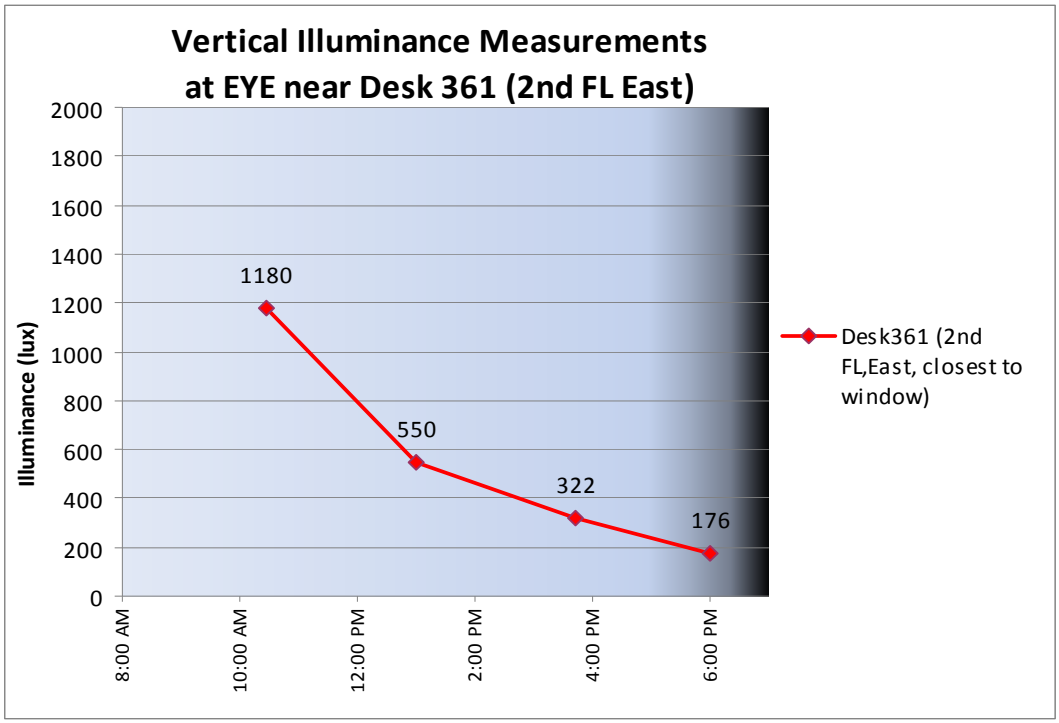
10:31, Desk 361, Shafts of sun



11:23, Desk 361, Looking South towards atrium

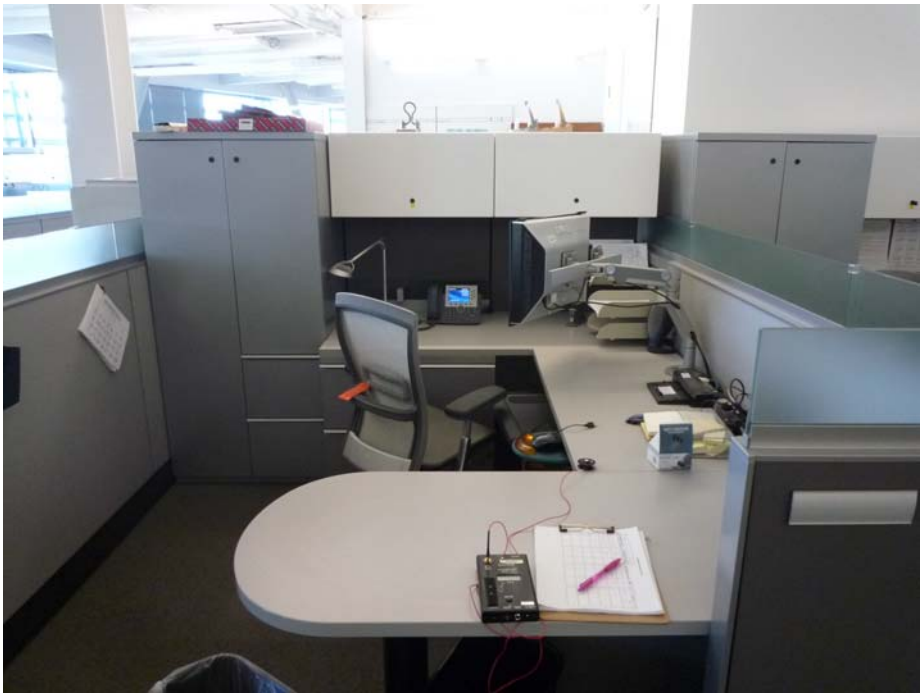
11:23, Desk 361, Looking East




Vertical Illuminance Measurements
at EYE near Desk 361 (2nd FL East)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1180
550
322
176
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk361 (2nd FL,East, closest to window)

DESK 363

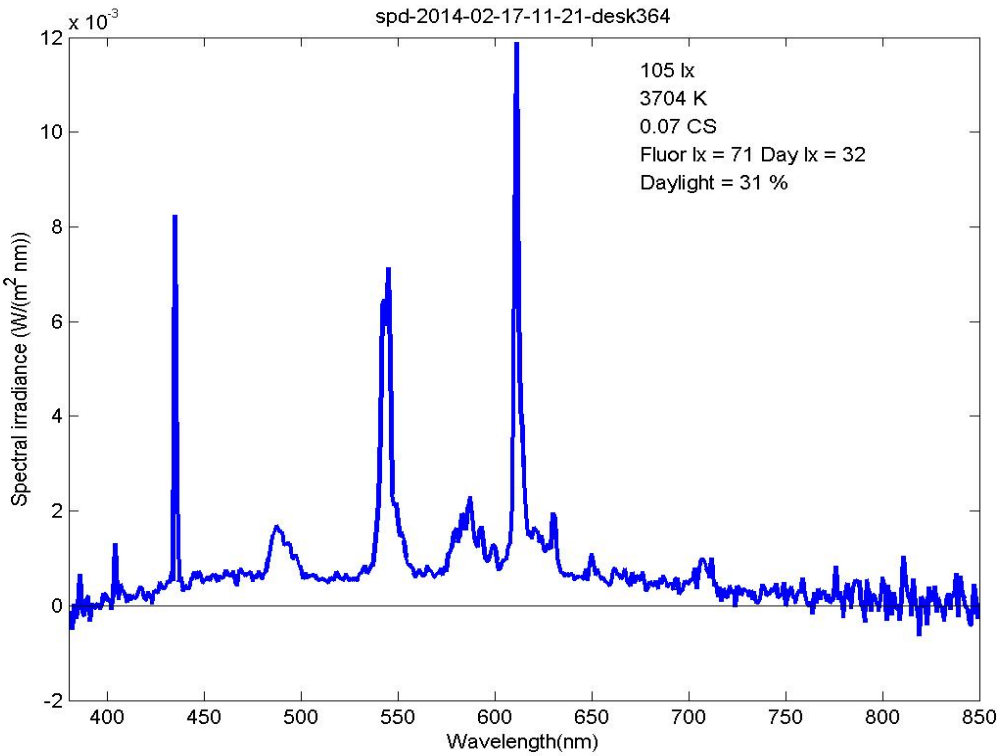
15:38, Desk 363, Looking Southwest

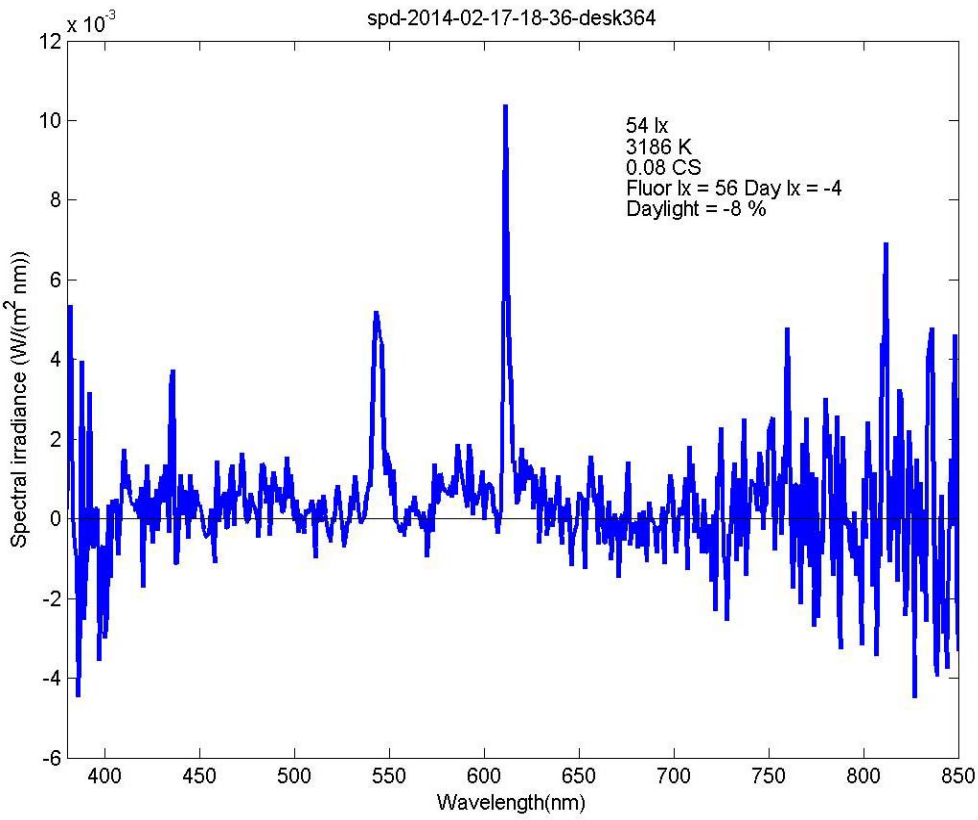


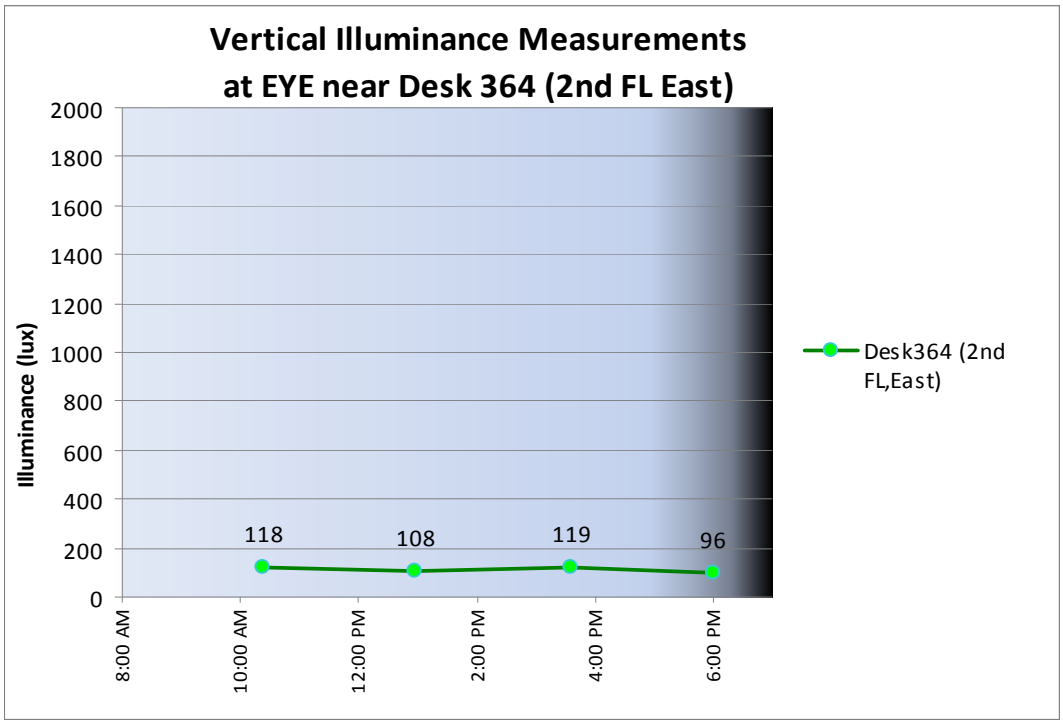
15:38, Desk 363, Looking South, Illuminance measurement on desk

DESK 364

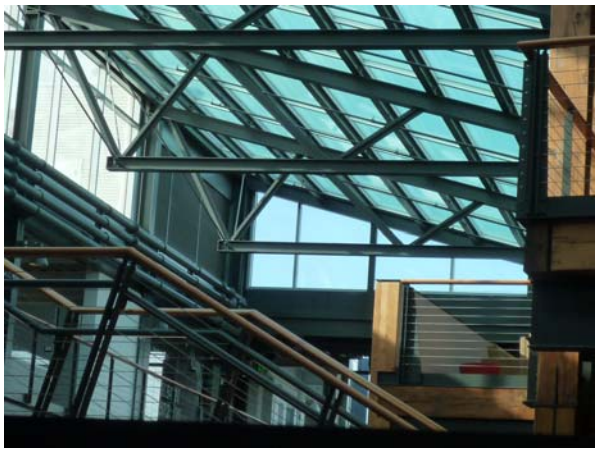
11:21, Desk 364, Looking West



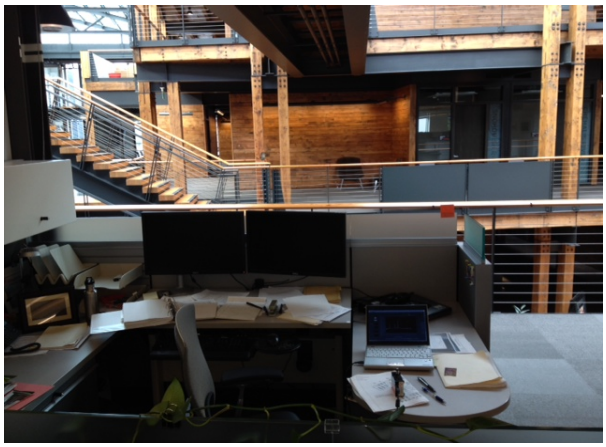

spd-2014-02-17-18-36-desk364
x 10-3
54 lx
3186 K
0.08 CS
Fluor lx = 56 Day lx = -4
Daylight = -8 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)


Vertical Illuminance Measurements
at EYE near Desk 364 (2nd FL East)
Illuminance (lux)
118
108
119
96
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk364 (2nd FL,East)

DESK 366



10:34, Desk 366, Looking West



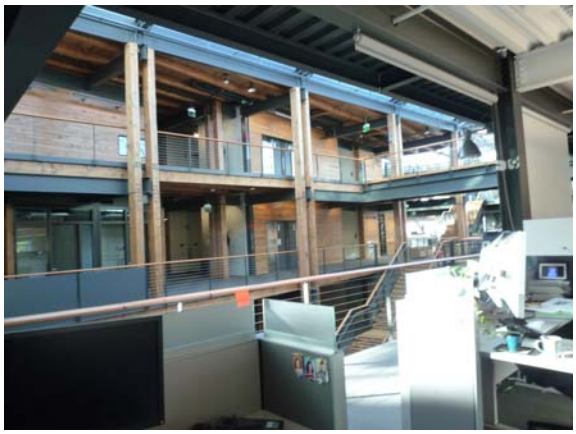
11:16, Desk 366, Looking West

15:28, Desk 366, Looking South

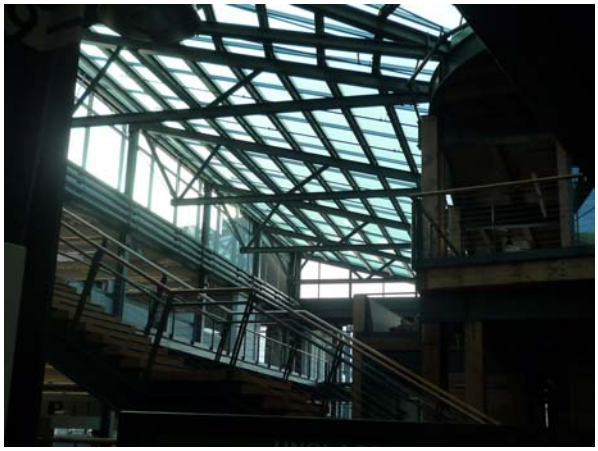
15:28, Desk 366, Looking South

15:28, Desk 366, Looking East

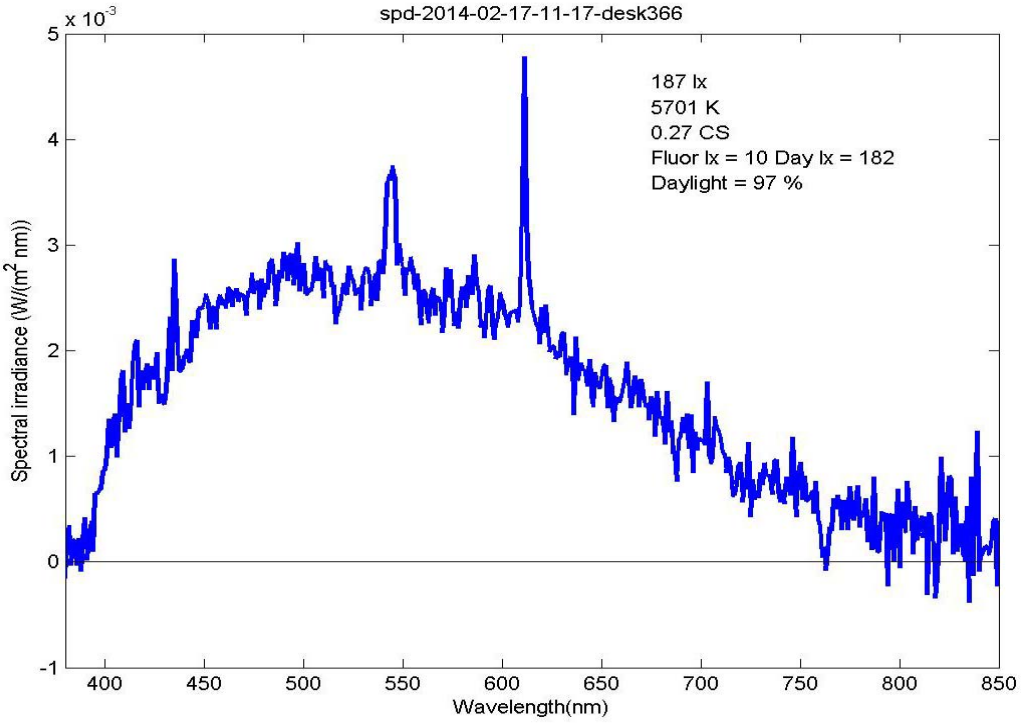
15:29, Desk 366, Looking East

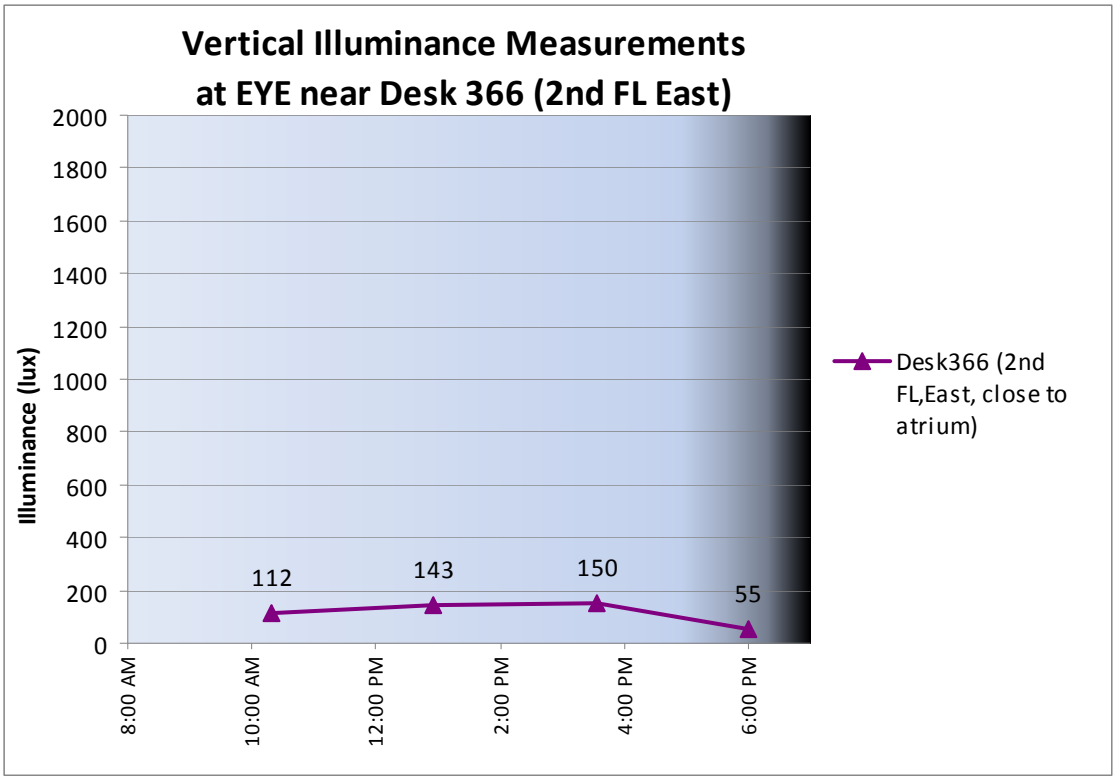


15:29, Desk 366, Looking West

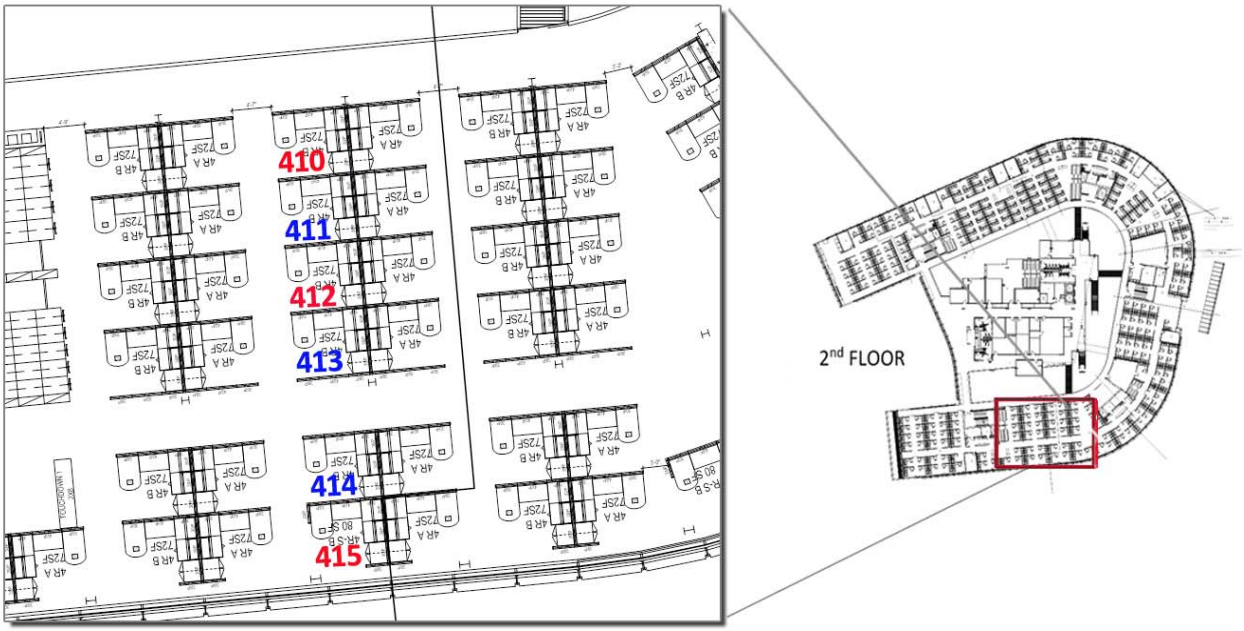


15:46, Desk 366, Looking West


spd-2014-02-17-11-17-desk366
x 10-3
187 lx
5701 K
0.27 CS
Fluor lx = 10 Day lx = 182
Daylight = 97 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

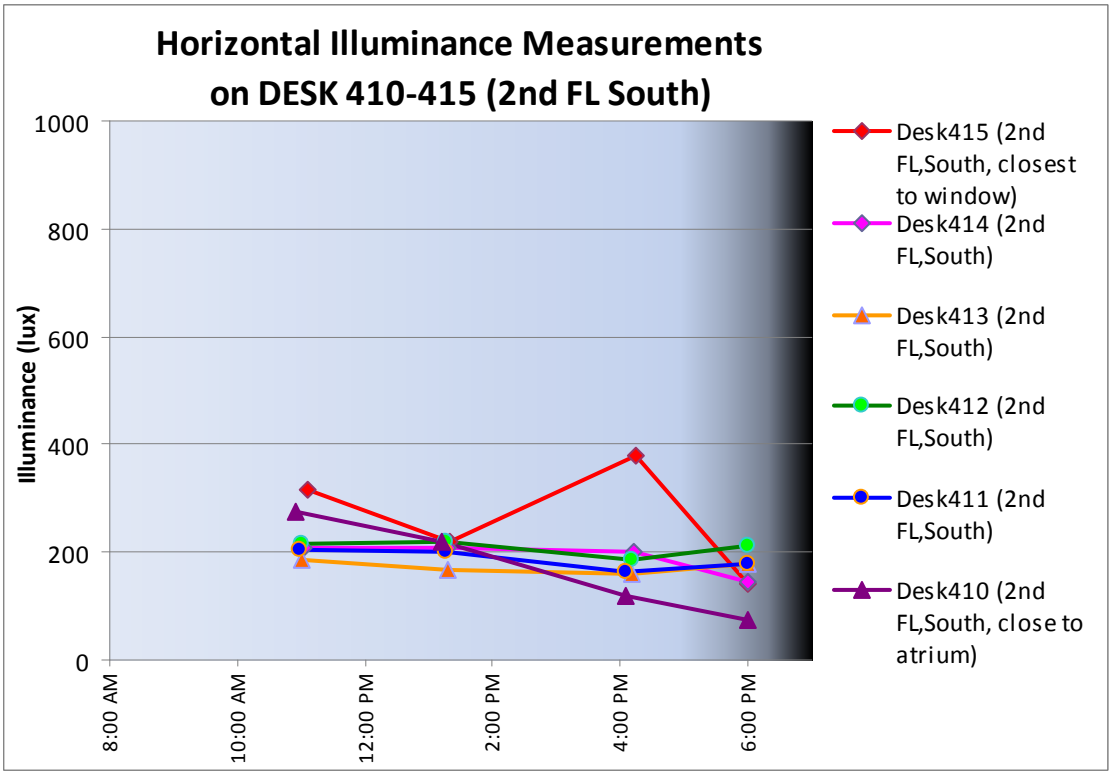

Vertical Illuminance Measurements
at EYE near Desk 366 (2nd FL East)
Illuminance (lux)
112
143
150
55
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk366 (2nd FL,East, close to atrium)

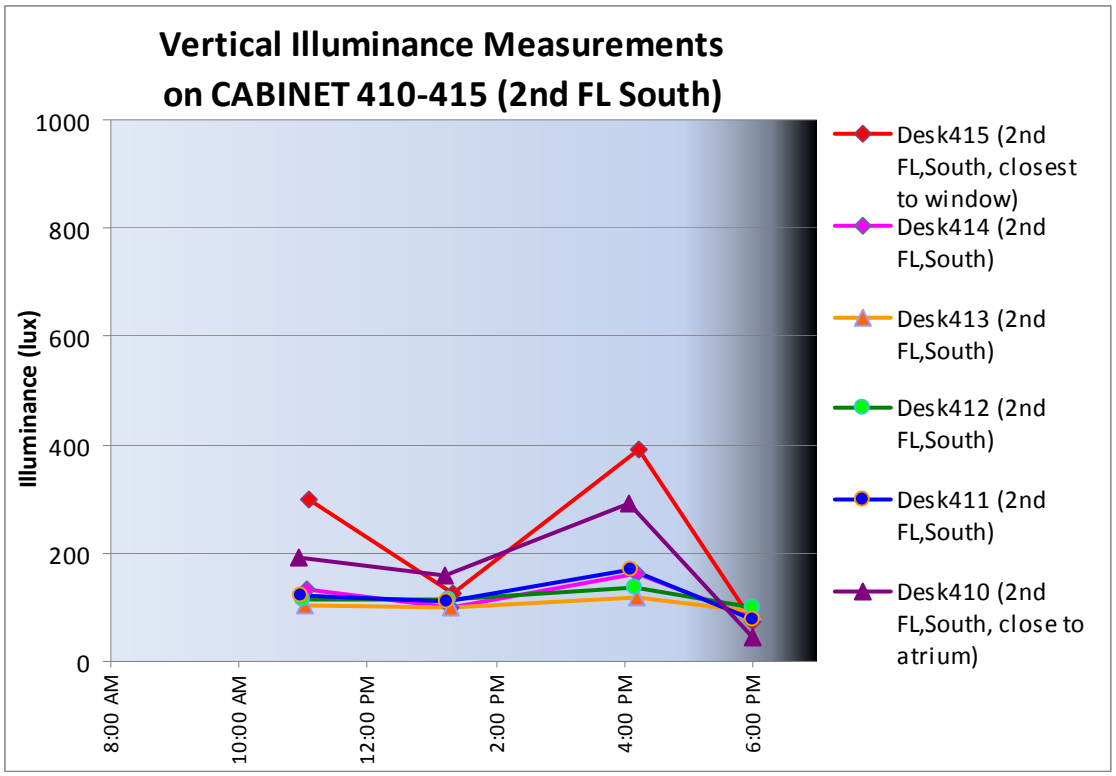
APPENDIX E: PHOTOMETRIC DATA FOR DESKS 410-415

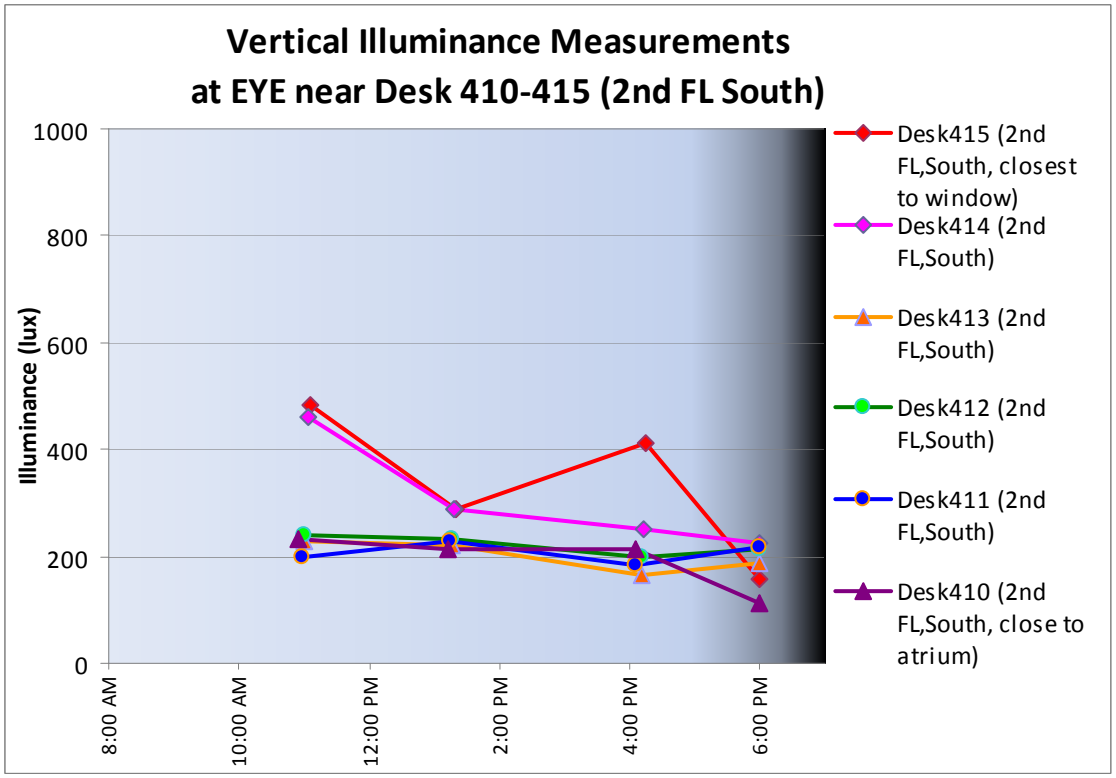


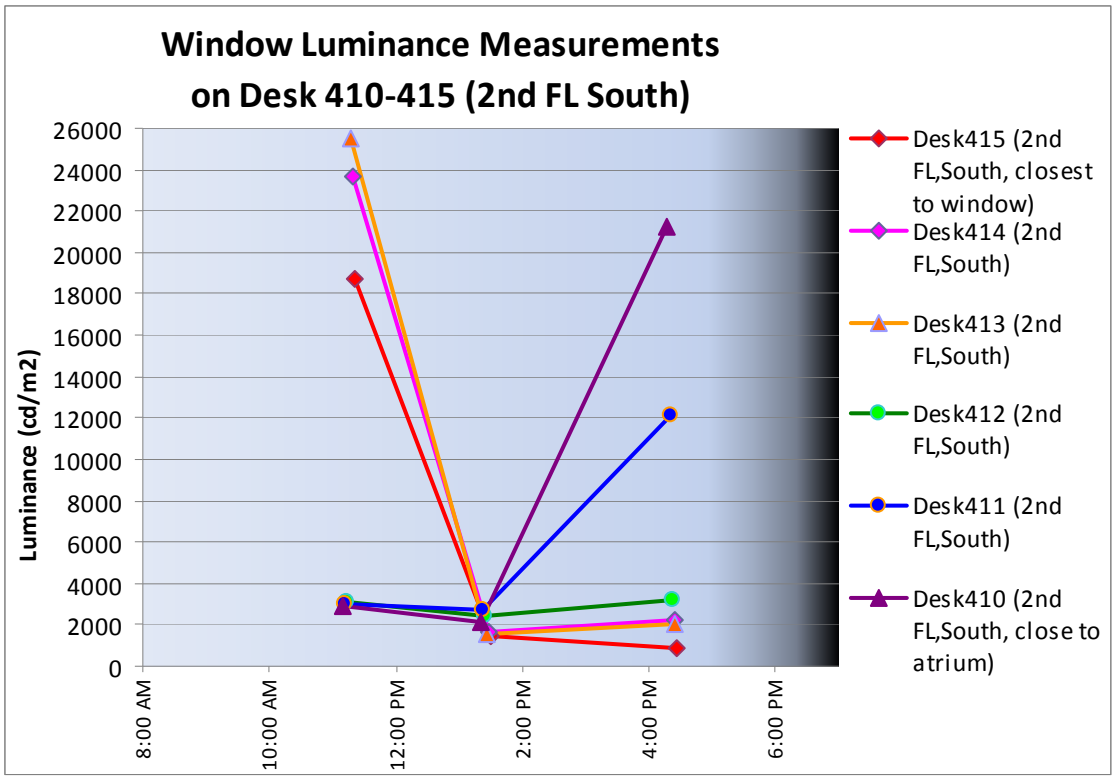
Desk with illuminance measures

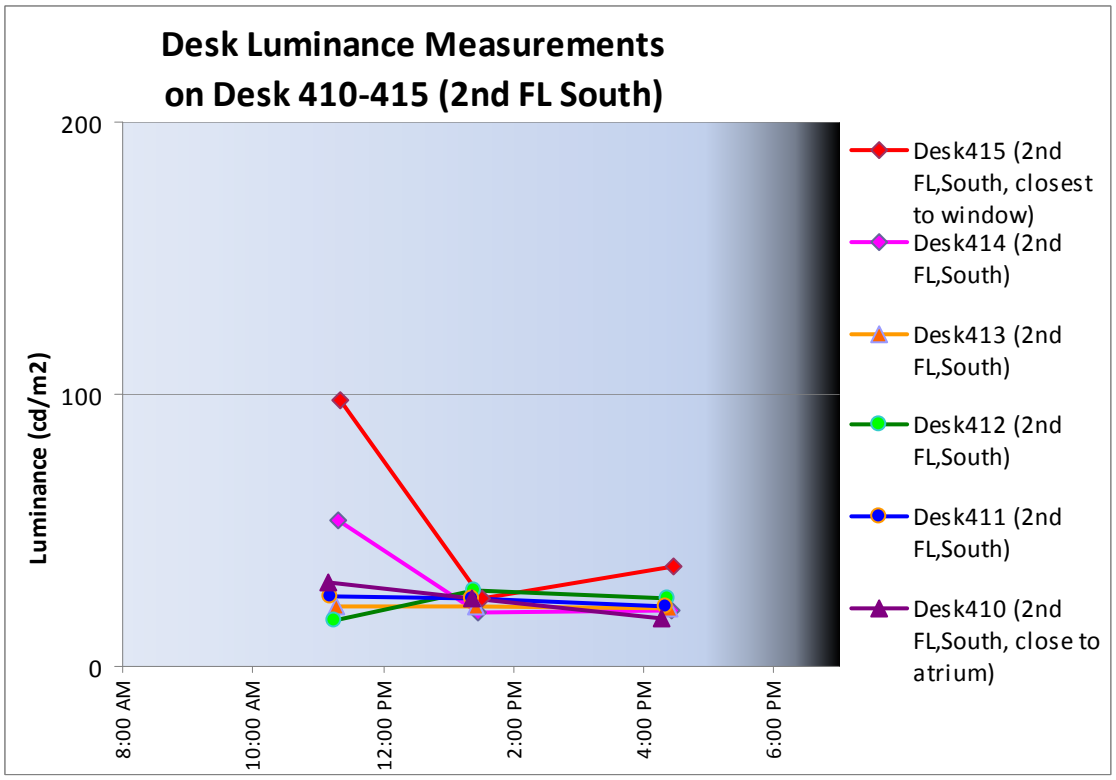
Desk with illuminance + SPD measures

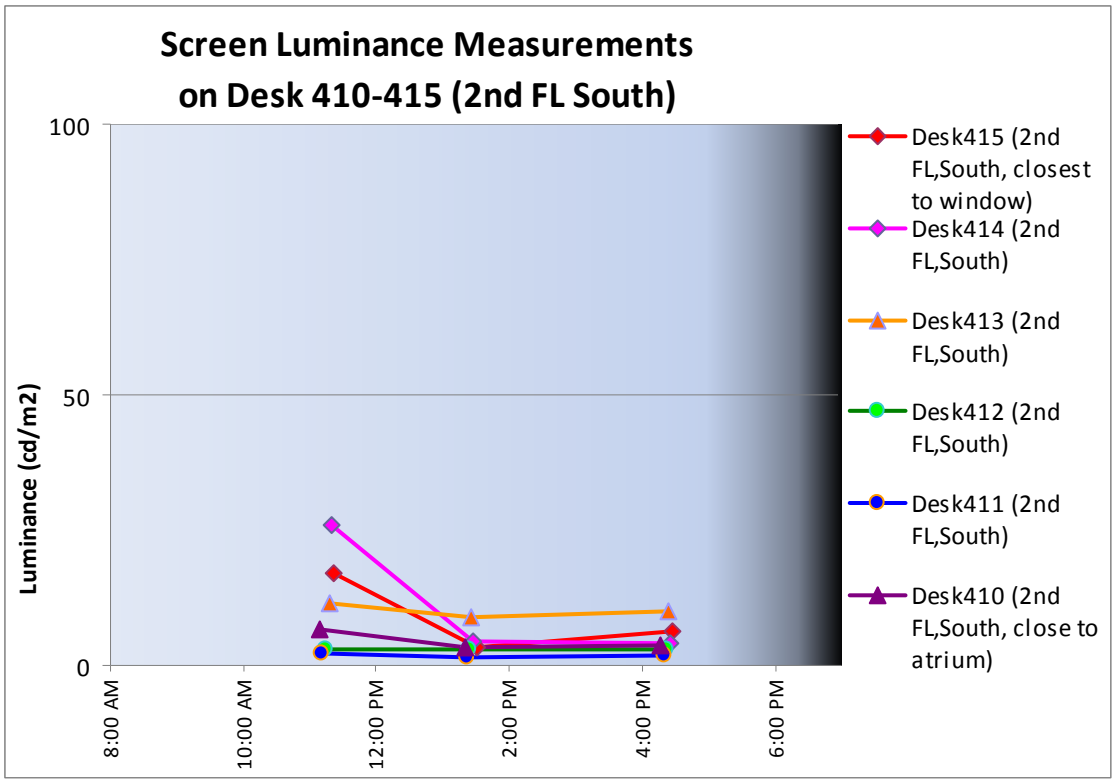



Vertical Illuminance Measurements
on CABINET 410-415 (2nd FL South)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)
Desk414 (2nd FL,South)
Desk413 (2nd FL,South)
Desk412 (2nd FL,South)
Desk411 (2nd FL,South)
Desk410 (2nd FL,South, close to atrium)


Vertical Illuminance Measurements
at EYE near Desk 410-415 (2nd FL South)
Illuminance (lux)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)
Desk414 (2nd FL,South)
Desk413 (2nd FL,South)
Desk412 (2nd FL,South)
Desk411 (2nd FL,South)
Desk410 (2nd FL,South, close to atrium)


Window Luminance Measurements
on Desk 410-415 (2nd FL South)
Luminance (cd/m2)
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)
Desk414 (2nd FL,South)
Desk413 (2nd FL,South)
Desk412 (2nd FL,South)
Desk411 (2nd FL,South)
Desk410 (2nd FL,South, close to atrium)

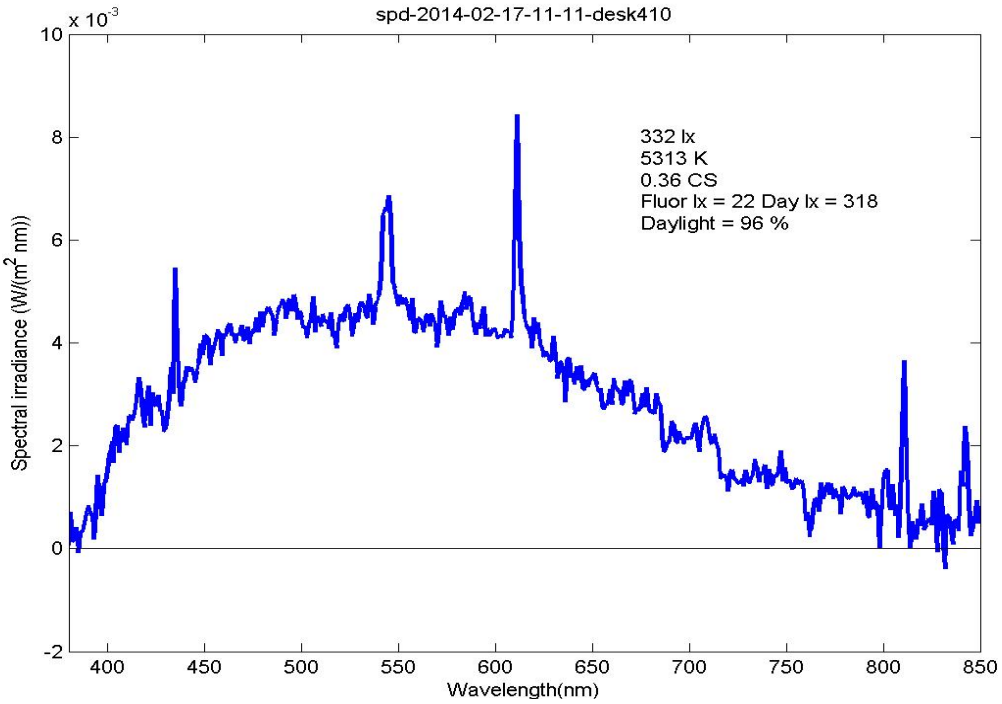

Desk Luminance Measurements
on Desk 410-415 (2nd FL South)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)
Desk414 (2nd FL,South)
Desk413 (2nd FL,South)
Desk412 (2nd FL,South)
Desk411 (2nd FL,South)
Desk410 (2nd FL,South, close to atrium)

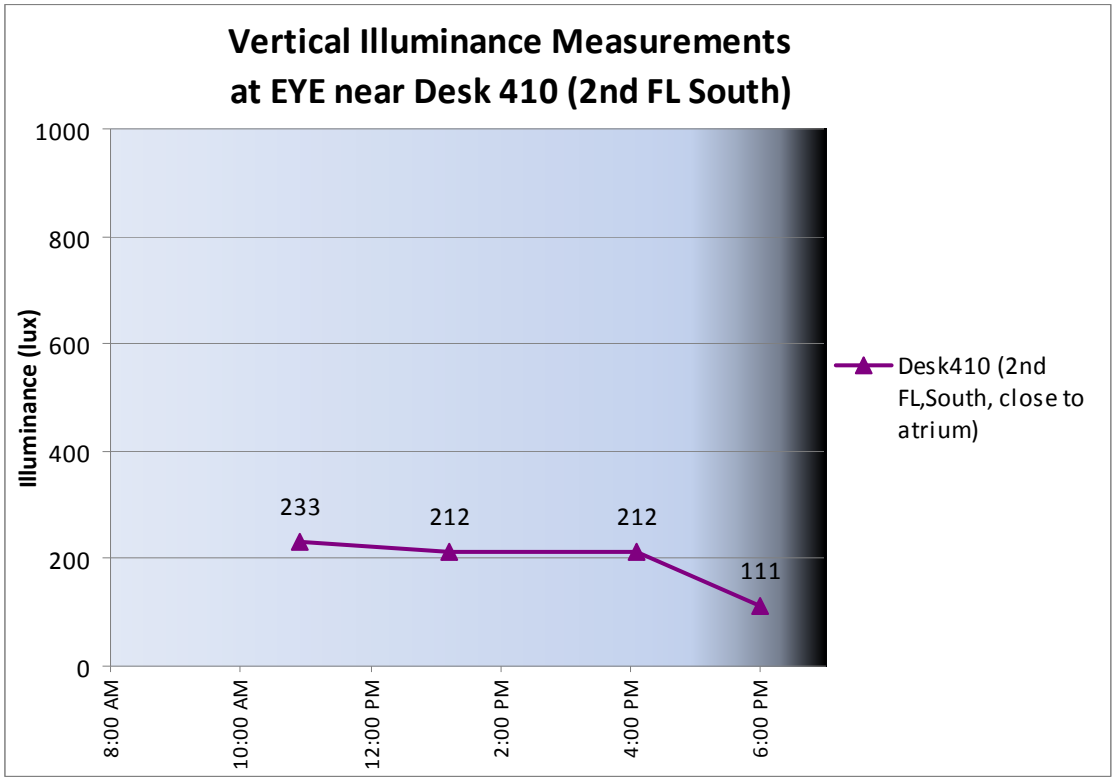

Screen Luminance Measurements on Desk 410-415 (2nd FL South)
Luminance (cd/m2)
100
50
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)
Desk414 (2nd FL,South)
Desk413 (2nd FL,South)
Desk412 (2nd FL,South)
Desk411 (2nd FL,South)
Desk410 (2nd FL,South, close to atrium)

DESK 410

11:12, Desk 410, Looking North to atrium

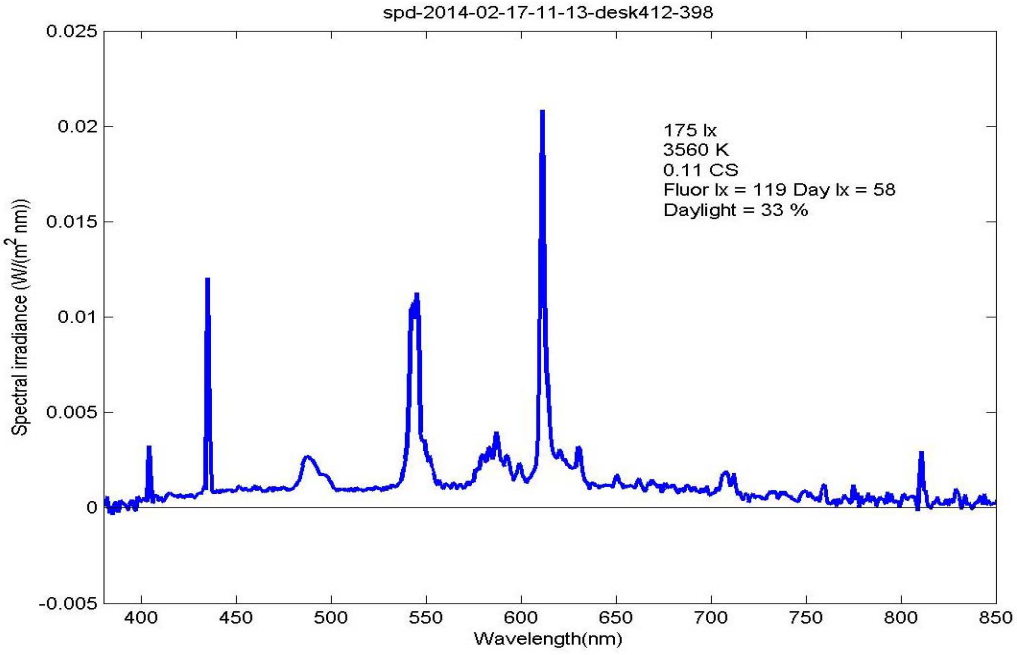
16:17, Desk 410, Looking West

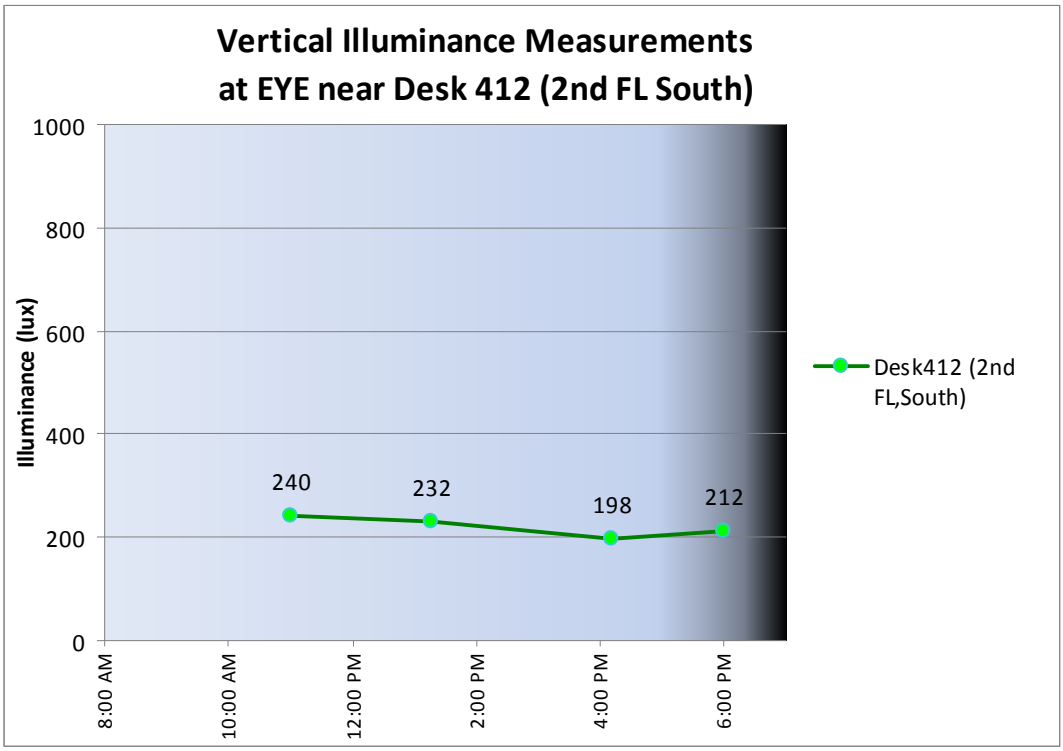

spd-2014-02-17-11-11-desk410
x 10^-3
Spectral irradiance (W/(m^2 nm))
Wavelength(nm)
332 lx
5313 K
0.36 CS
Fluor lx = 22 Day lx = 318
Daylight = 96 %


Vertical Illuminance Measurements
at EYE near Desk 410 (2nd FL South)
Illuminance (lux)
233
212
212
111
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk410 (2nd FL,South, close to atrium)

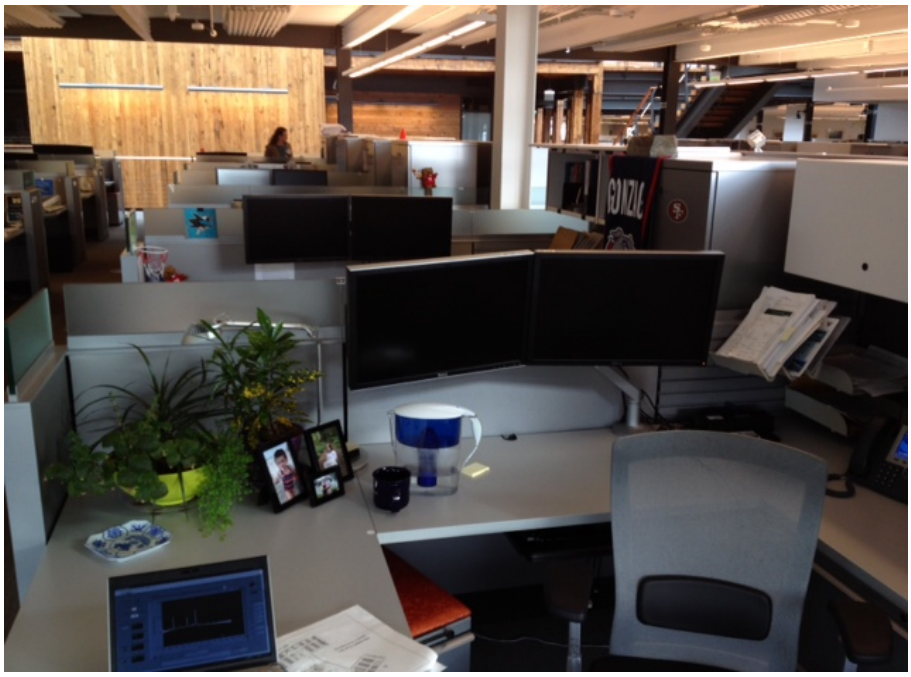
DESK 412-398

11:14, Desk 412, Looking North



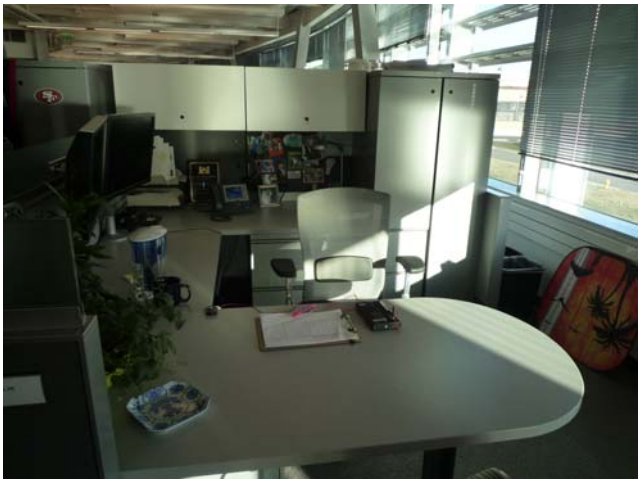

Vertical Illuminance Measurements
at EYE near Desk 412 (2nd FL South)
Illuminance (lux)
1000
800
600
400
200
0
240
232
198
212
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk412 (2nd FL,South)

DESK 415



11:09, Desk 415, Looking North

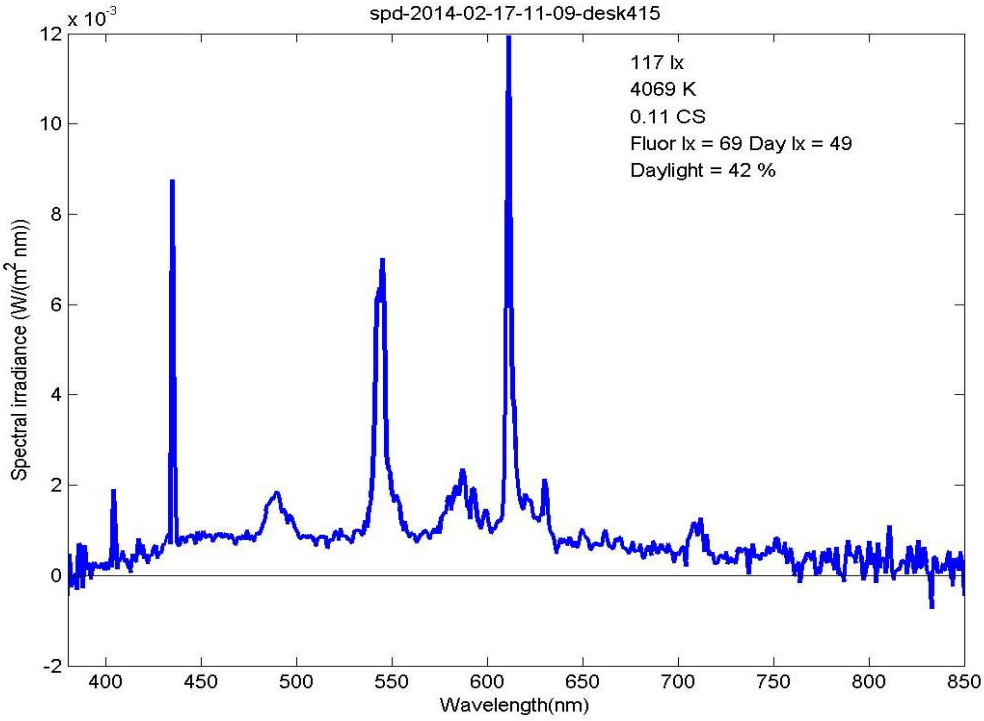
11:09, Desk 415, Looking South

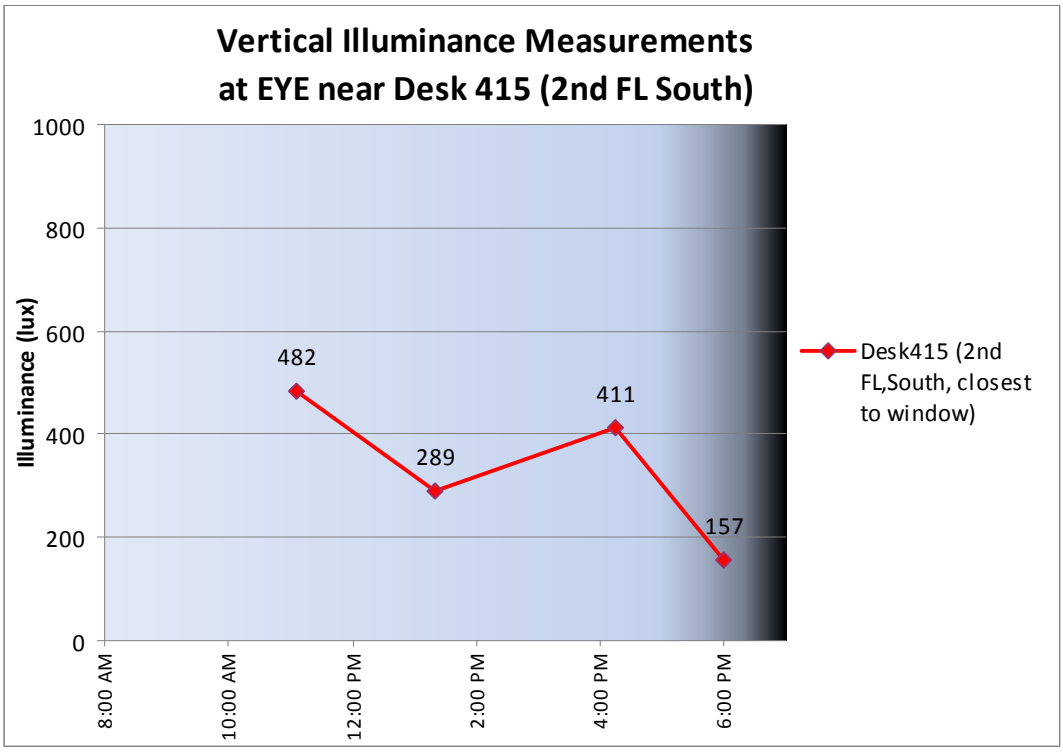


16:14, Desk 415, Looking East

16:14, Desk 415, Looking Southeast

16:14, Desk 415, Looking Southwest


spd-2014-02-17-11-09-desk415
x 10^-3
117 lx
4069 K
0.11 CS
Fluor lx = 69 Day lx = 49
Daylight = 42 %
Spectral irradiance (W/(m^2 nm))
Wavelength(nm)

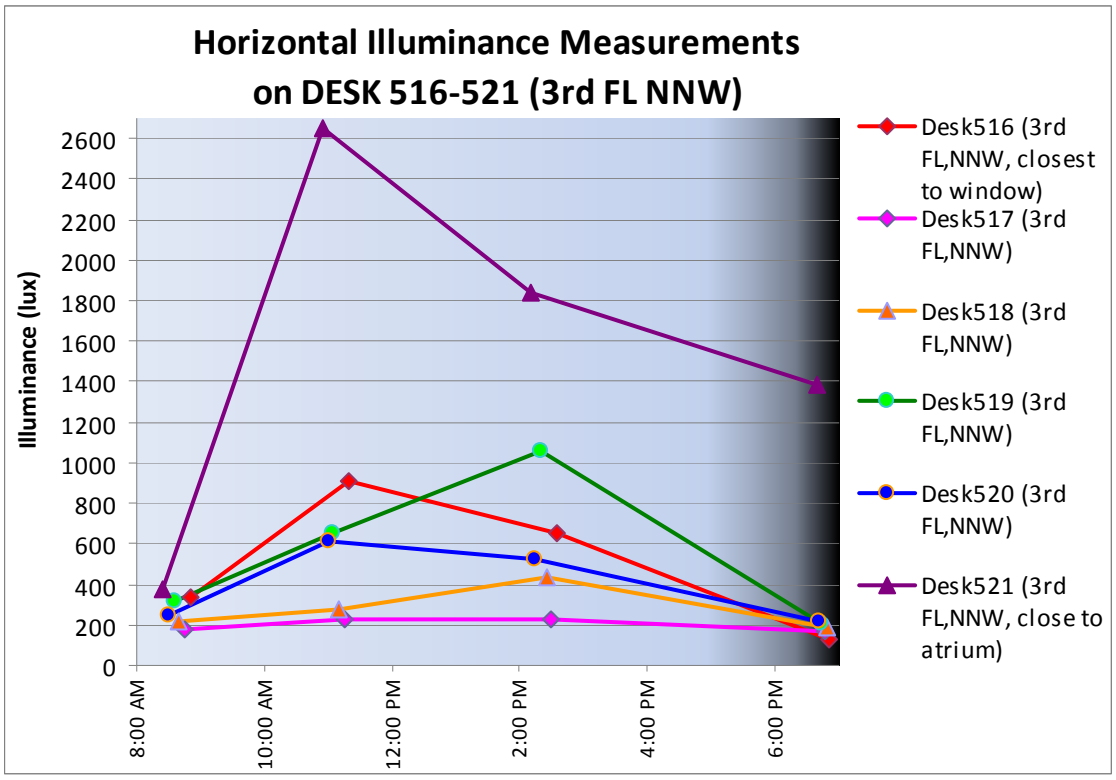

Vertical Illuminance Measurements
at EYE near Desk 415 (2nd FL South)
Illuminance (lux)
482
289
411
157
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk415 (2nd FL,South, closest to window)

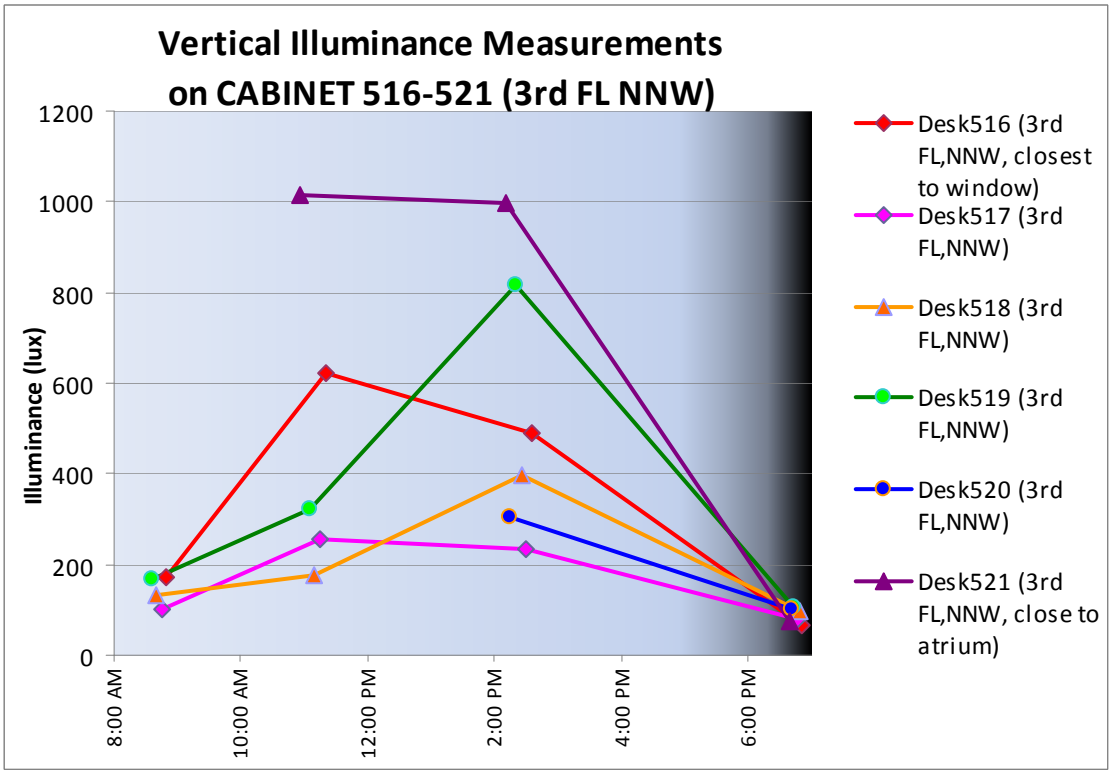
APPENDIX F: PHOTOMETRIC DATA FOR DESKS 516-521, AND 498, 501, 511, 515

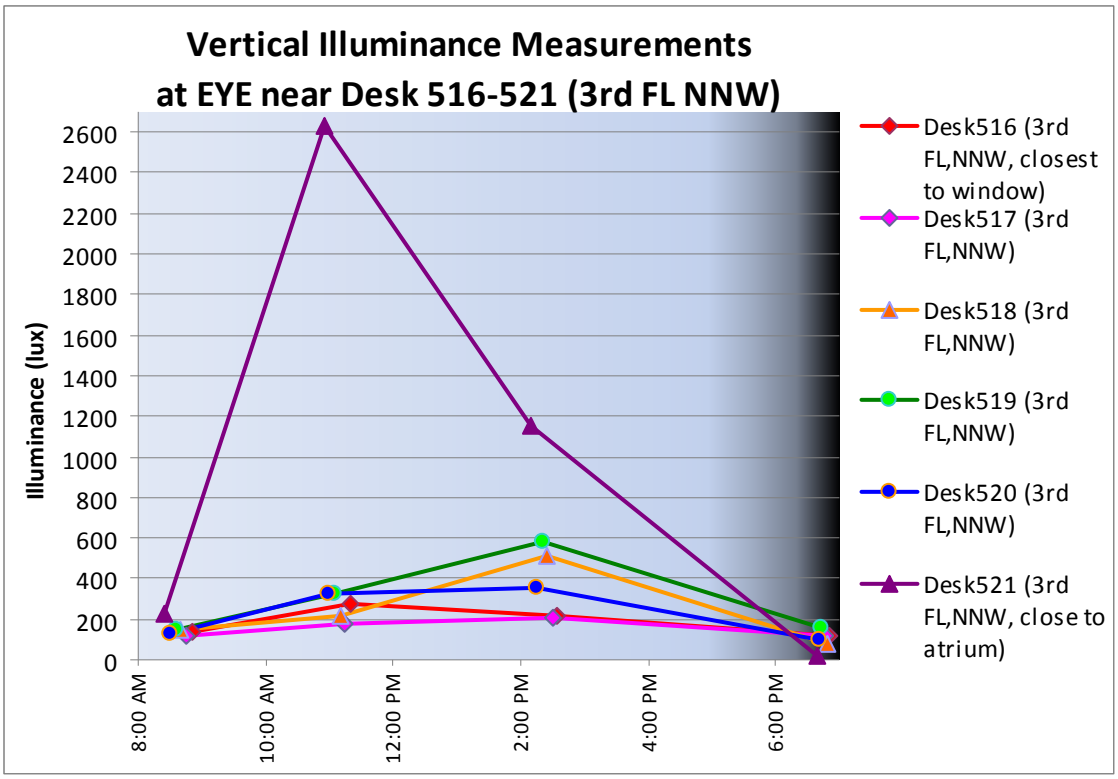
Desk with illuminance measures

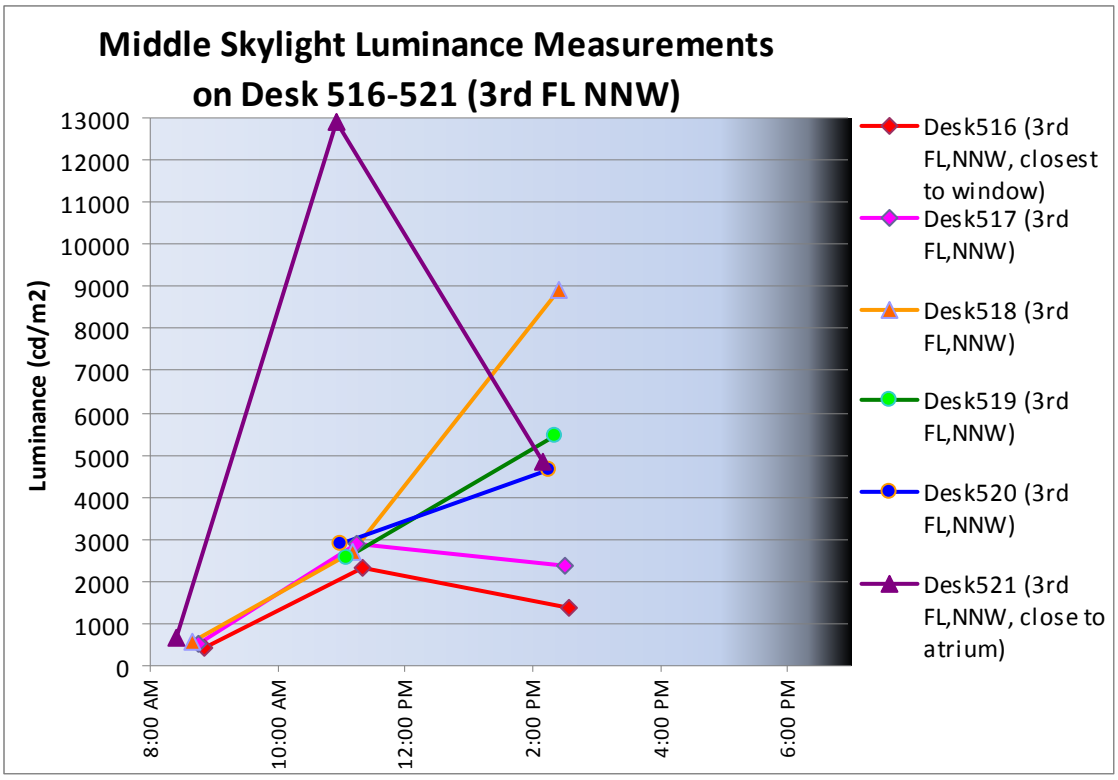
Desk with illuminance + SPD measures

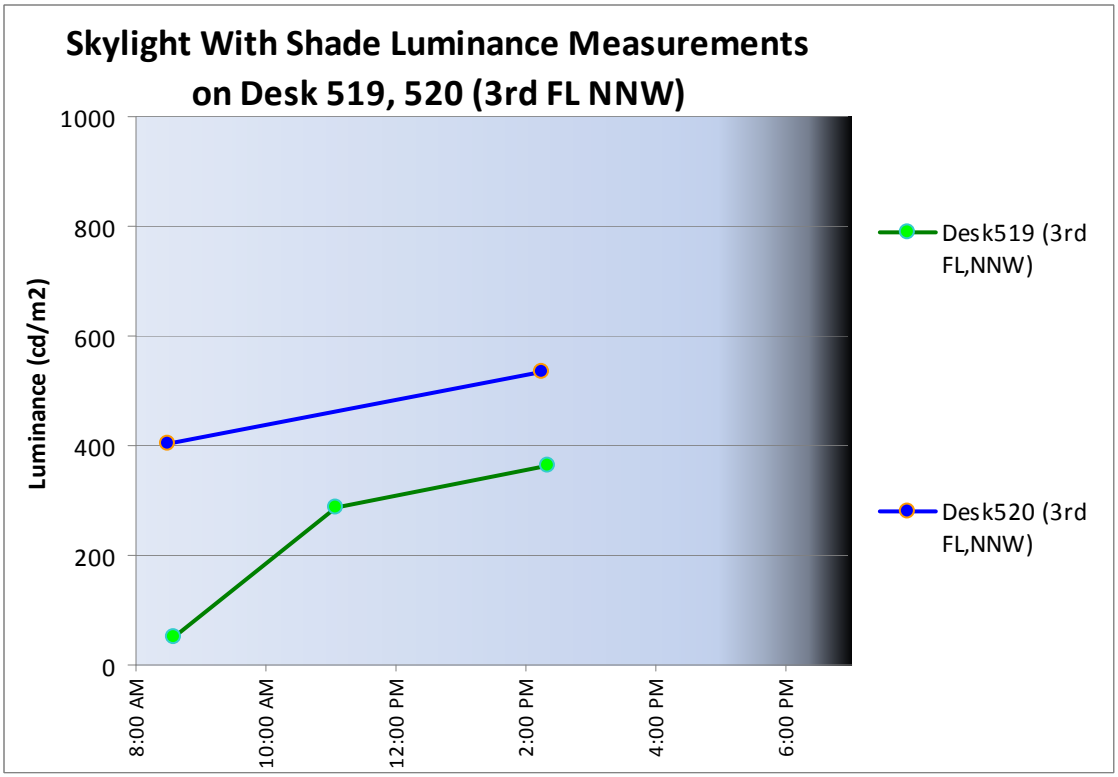
Desk with just SPD

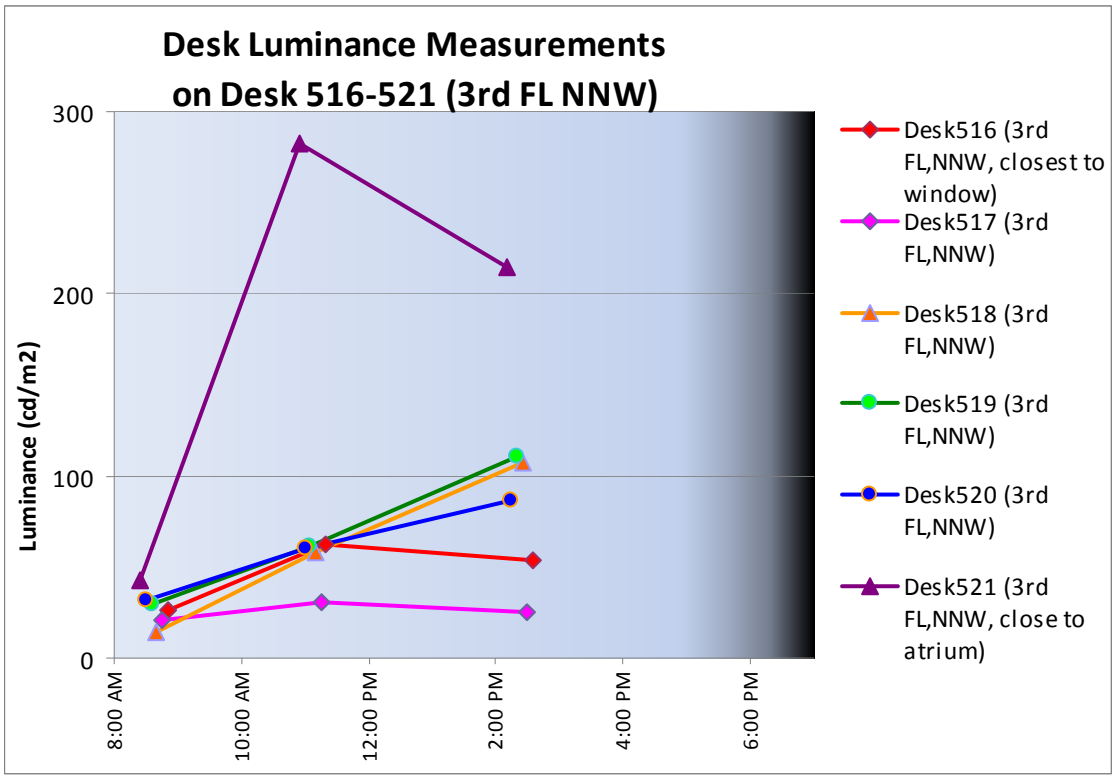

Horizontal Illuminance Measurements
on DESK 516-521 (3rd FL NNW)
Illuminance (lux)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)

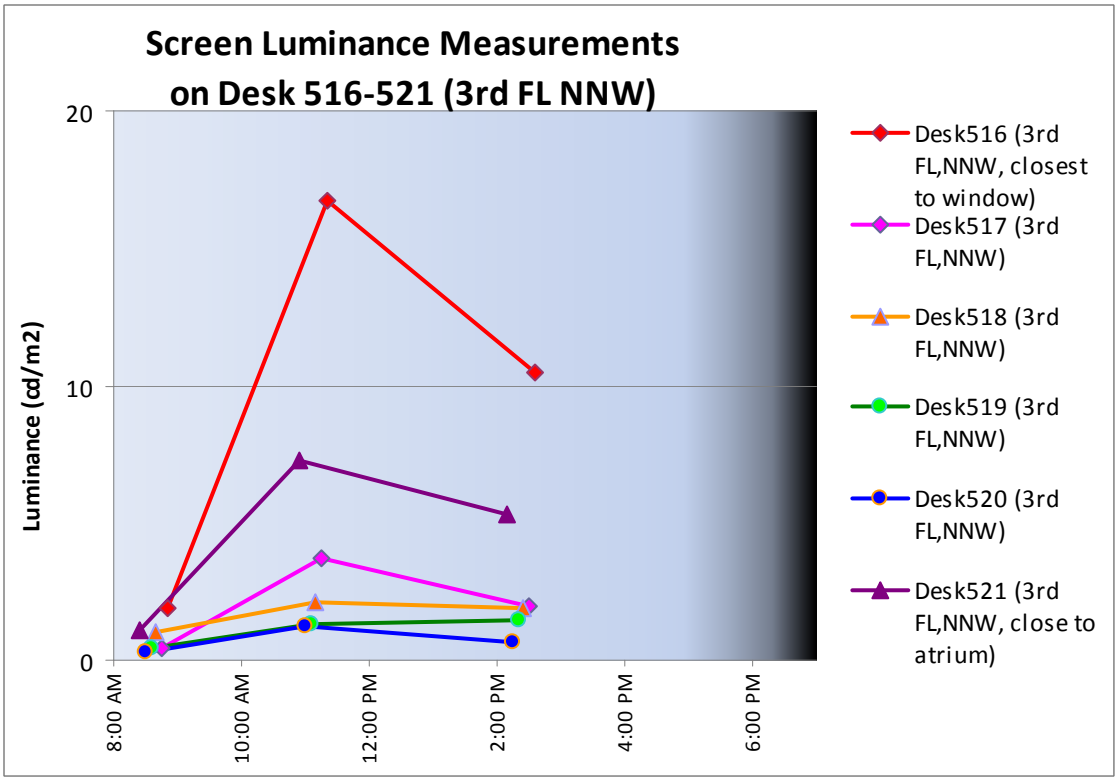

Vertical Illuminance Measurements
on CABINET 516-521 (3rd FL NNW)
Illuminance (lux)
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)


Vertical Illuminance Measurements
at EYE near Desk 516-521 (3rd FL NNW)
Illuminance (lux)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)

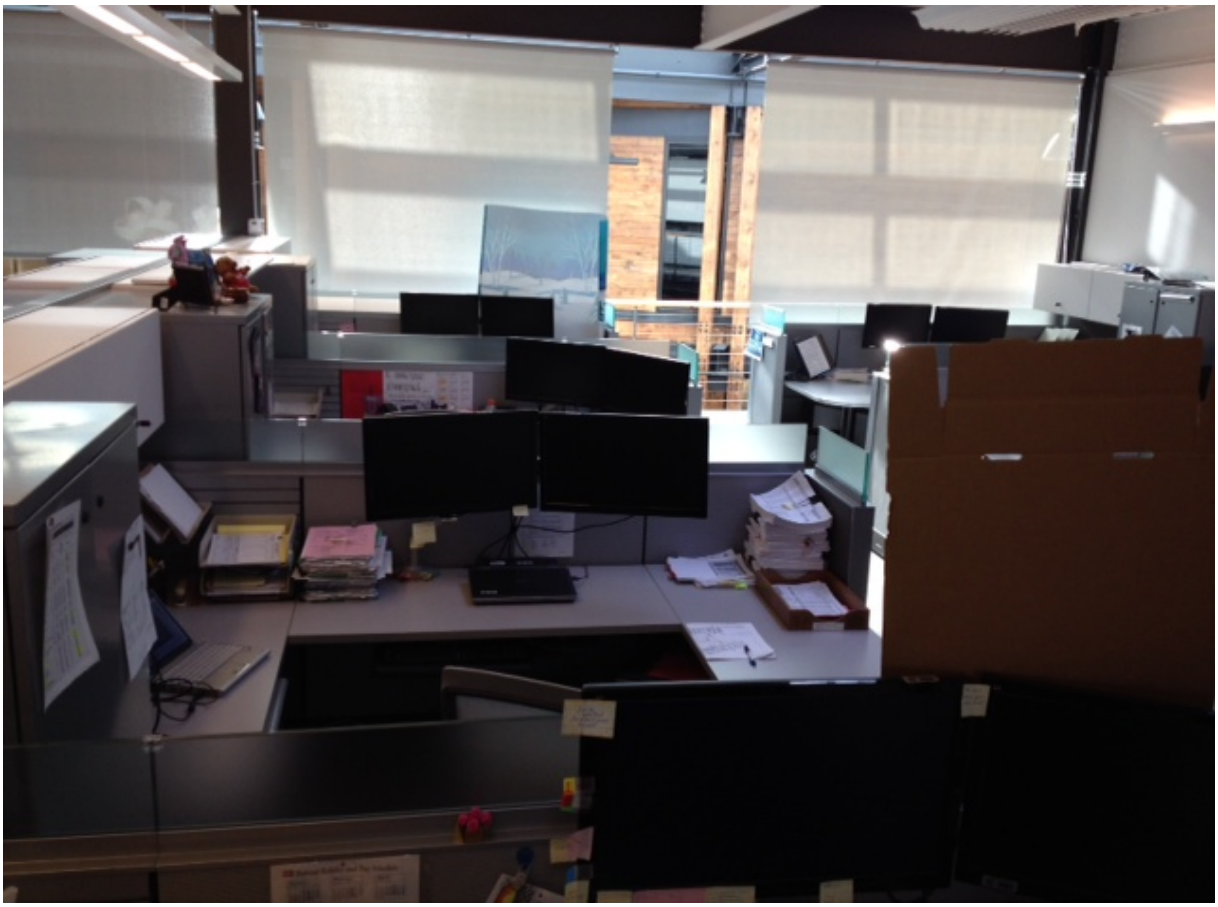

Middle Skylight Luminance Measurements
on Desk 516-521 (3rd FL NNW)
Luminance (cd/m2)
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)


Skylight With Shade Luminance Measurements
on Desk 519, 520 (3rd FL NNW)
Luminance (cd/m2)
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)

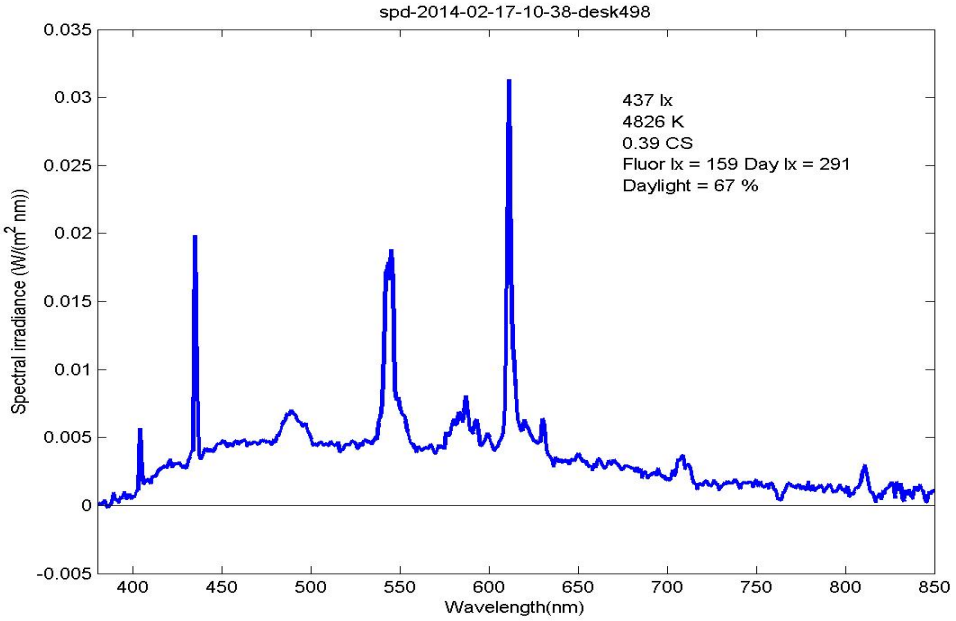

Desk Luminance Measurements
on Desk 516-521 (3rd FL NNW)
Luminance (cd/m2)
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)

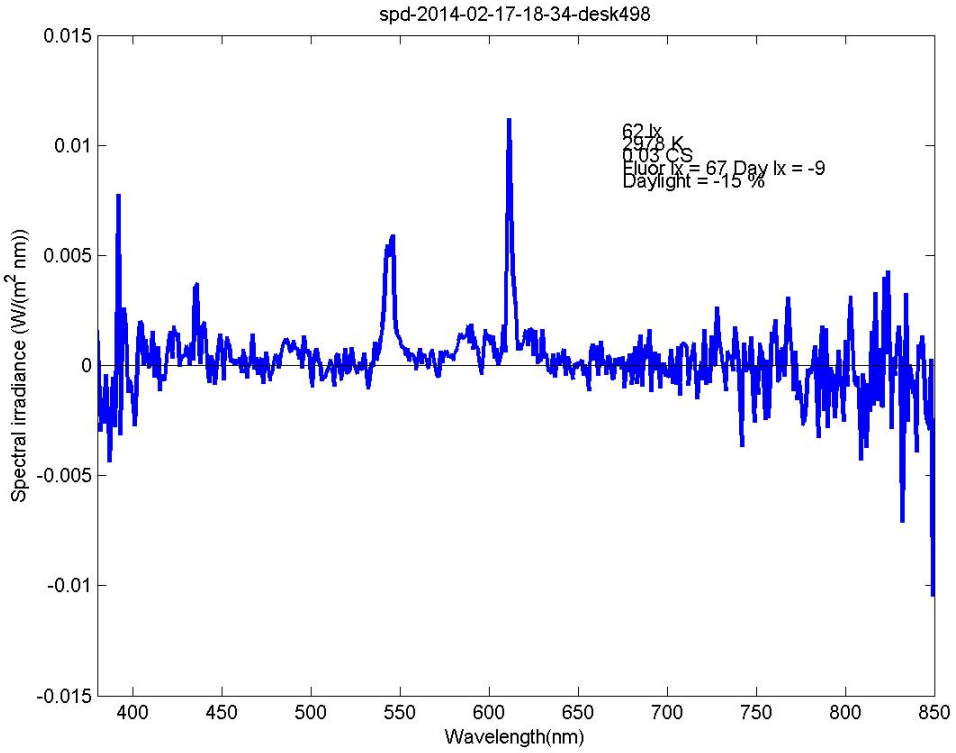

Screen Luminance Measurements
on Desk 516-521 (3rd FL NNW)
Luminance (cd/m2)
20
10
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk516 (3rd FL,NNW, closest to window)
Desk517 (3rd FL,NNW)
Desk518 (3rd FL,NNW)
Desk519 (3rd FL,NNW)
Desk520 (3rd FL,NNW)
Desk521 (3rd FL,NNW, close to atrium)

DESK 498



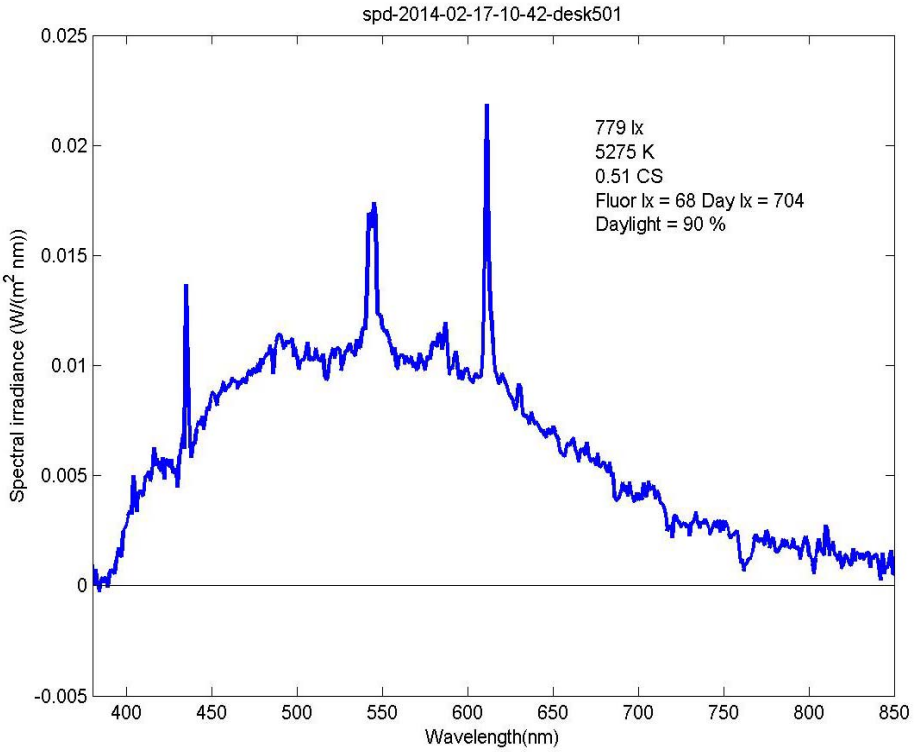
10:39, Desk 498, Looking South

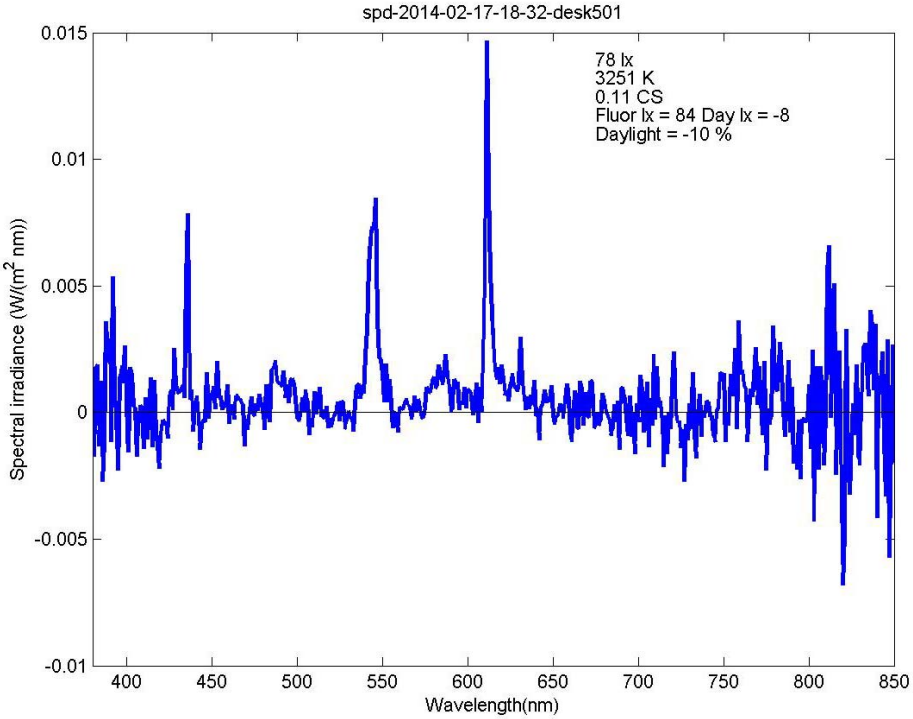

spd-2014-02-17-10-38-desk498
437 lx
4826 K
0.39 CS
Fluor lx = 159 Day lx = 291
Daylight = 67 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)


spd-2014-02-17-18-34-desk498
62 lx
2978 K
0.03 CS
Fluor lx = 67 Day lx = -9
Daylight = -15 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

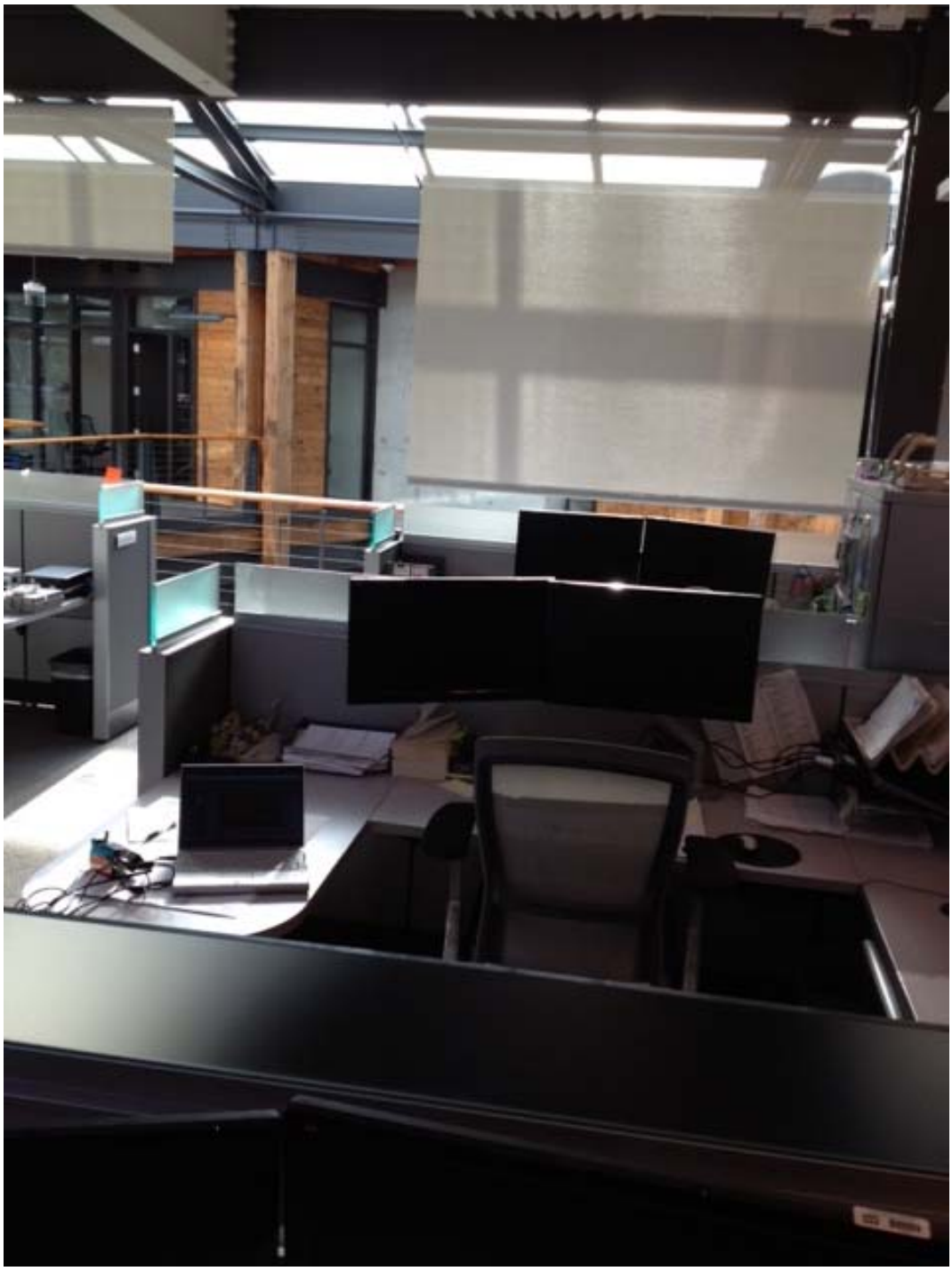
DESK 501

10:41, Desk 501, Looking South

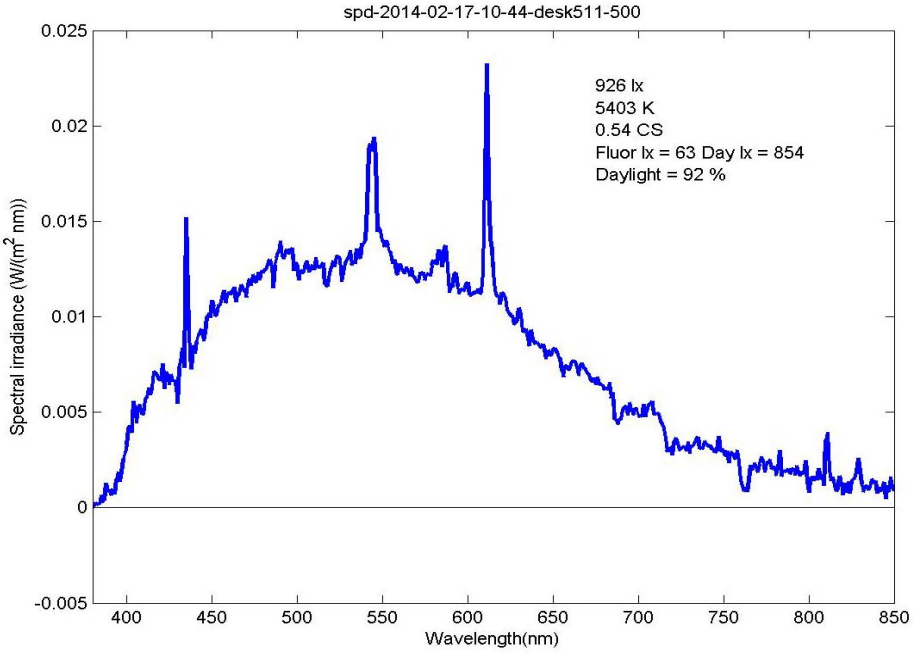

spd-2014-02-17-10-42-desk501
779 lx
5275 K
0.51 CS
Fluor lx = 68 Day lx = 704
Daylight = 90 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

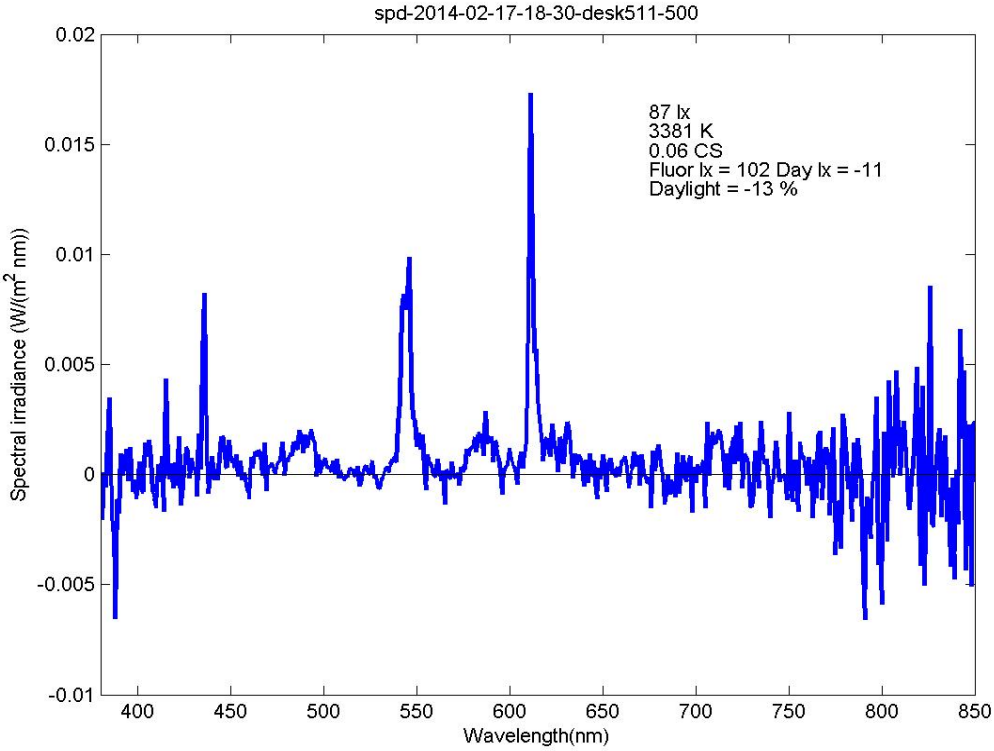

spd-2014-02-17-18-32-desk501
78 lx
3251 K
0.11 CS
Fluor lx = 84 Day lx = -8
Daylight = -10 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.015
0.01
0.005
0
-0.005
-0.01
400
450
500
550
600
650
700
750
800
850

DESK 511

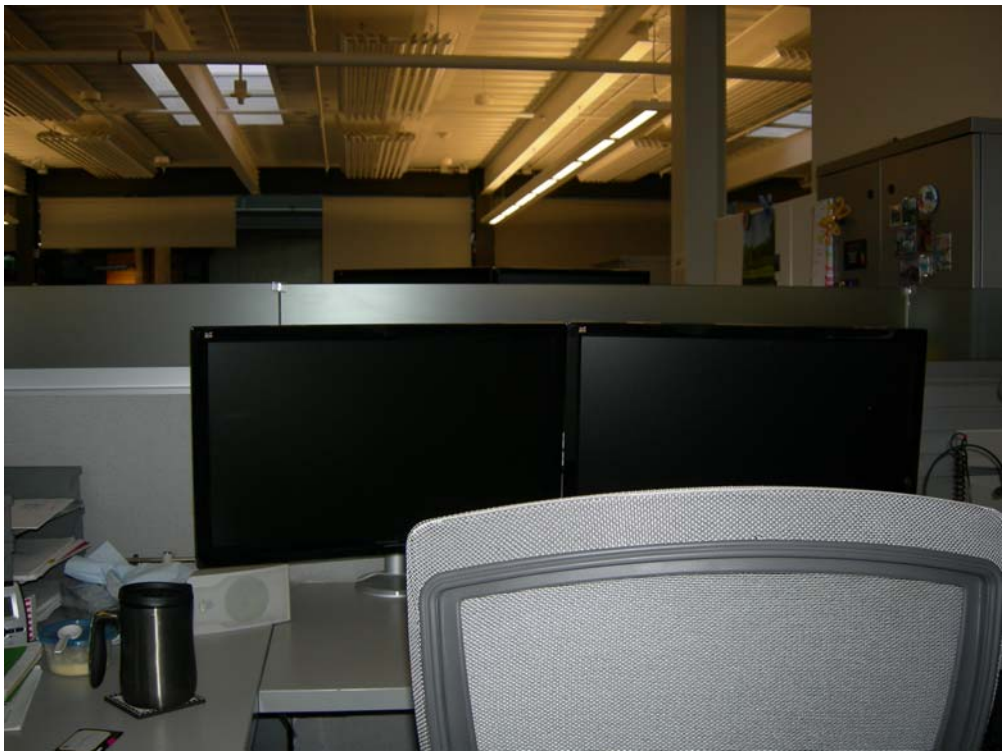


10:43, Desk 511, Looking South


spd-2014-02-17-10-44-desk511-500
926 lx
5403 K
0.54 CS
Fluor lx = 63 Day lx = 854
Daylight = 92 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

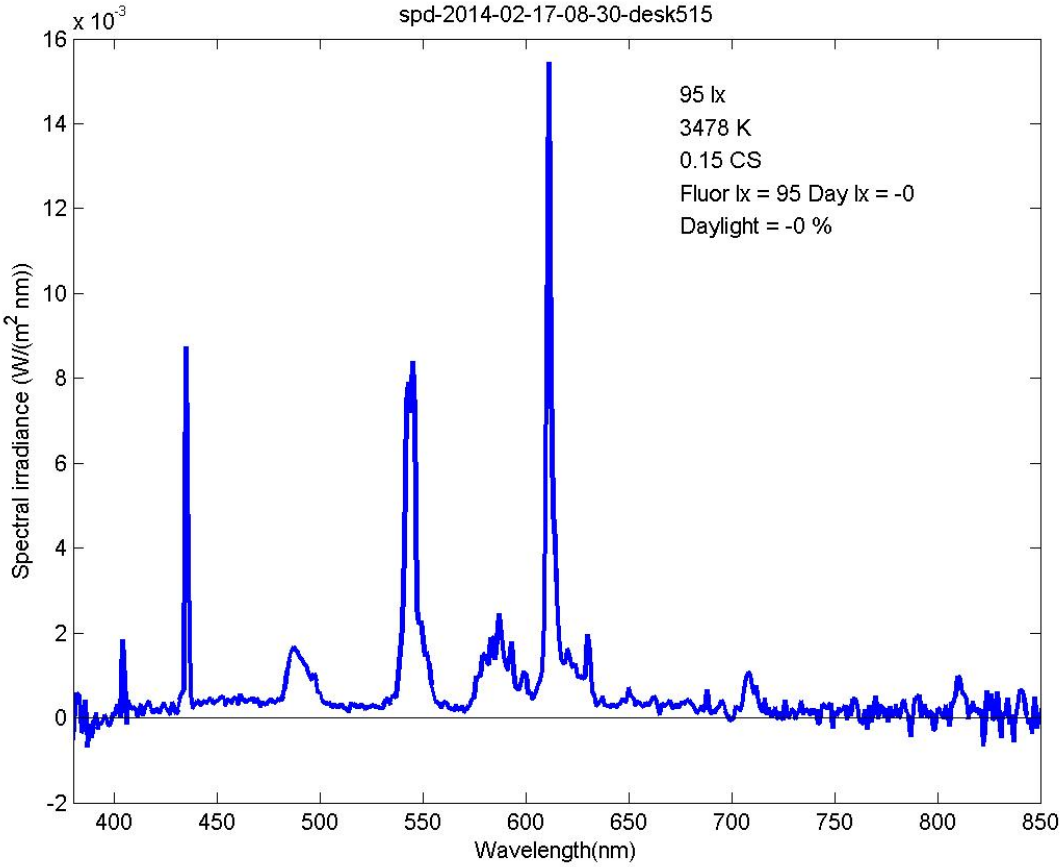

spd-2014-02-17-18-30-desk511-500
87 lx
3381 K
0.06 CS
Fluor lx = 102 Day lx = -11
Daylight = -13 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.02
0.015
0.01
0.005
0
-0.005
-0.01
400
450
500
550
600
650
700
750
800
850

DESK 515



13:05, Desk 515, Looking South, Skylight visible

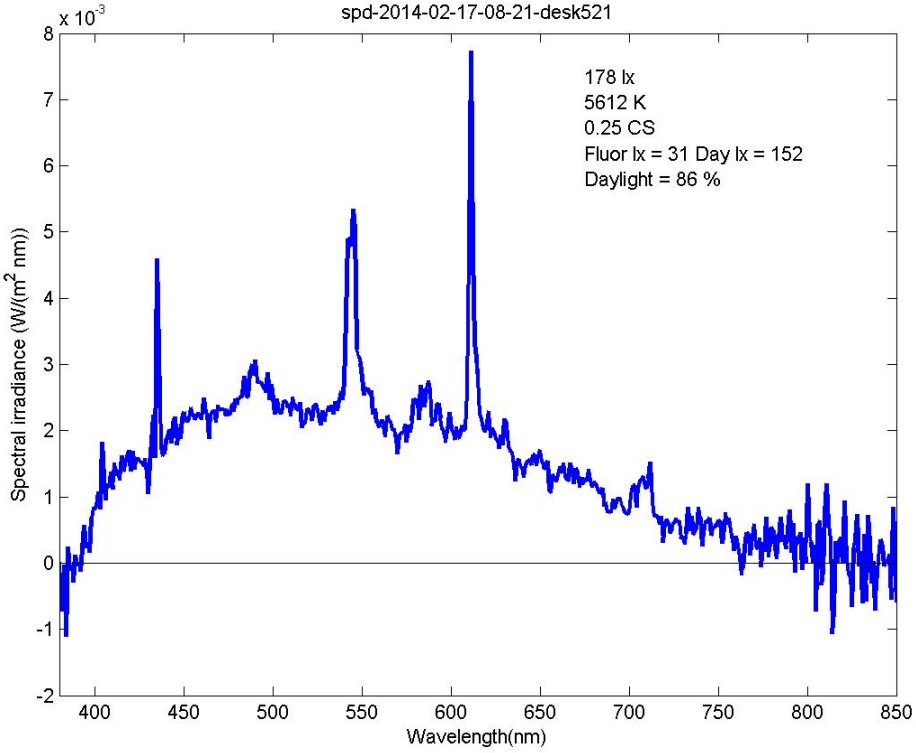
13:06, Desk 515, Looking North

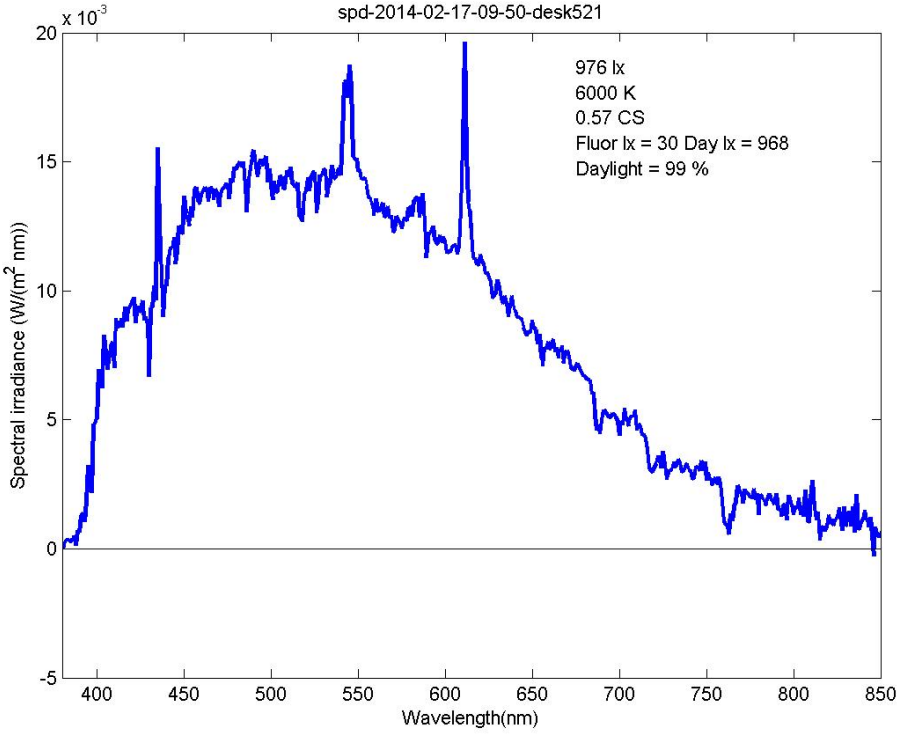

spd-2014-02-17-08-30-desk515
x 10-3
95 lx
3478 K
0.15 CS
Fluor lx = 95 Day lx = -0
Daylight = -0 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
16
14
12
10
8
6
4
2
0
-2
400
450
500
550
600
650
700
750
800
850

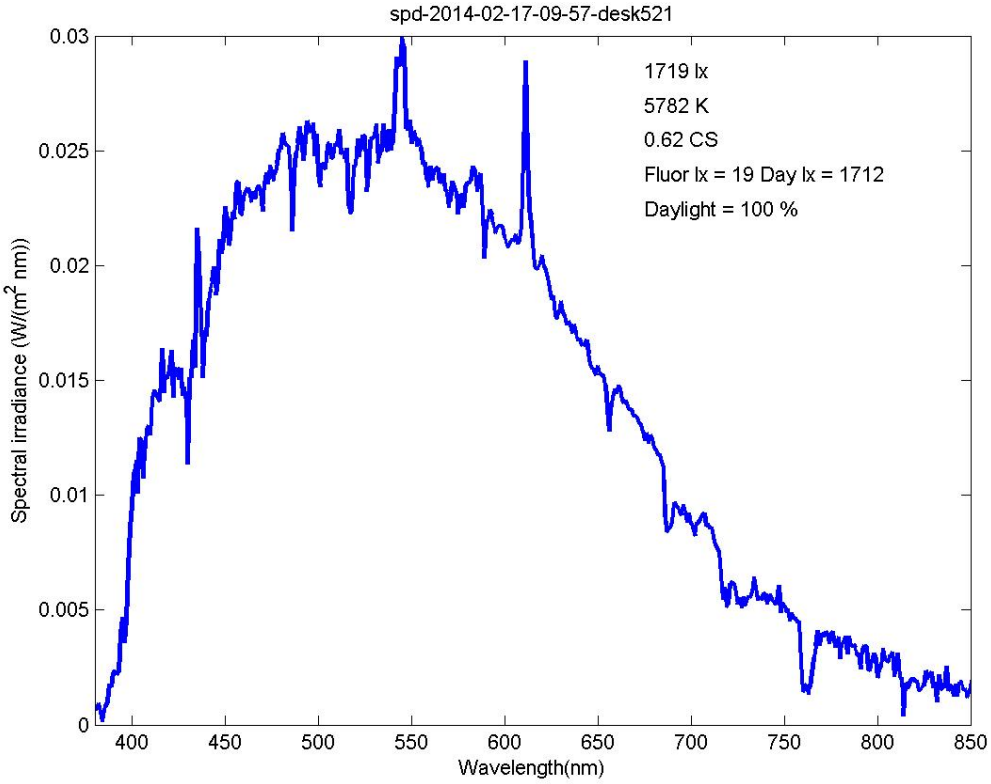
DESK 521

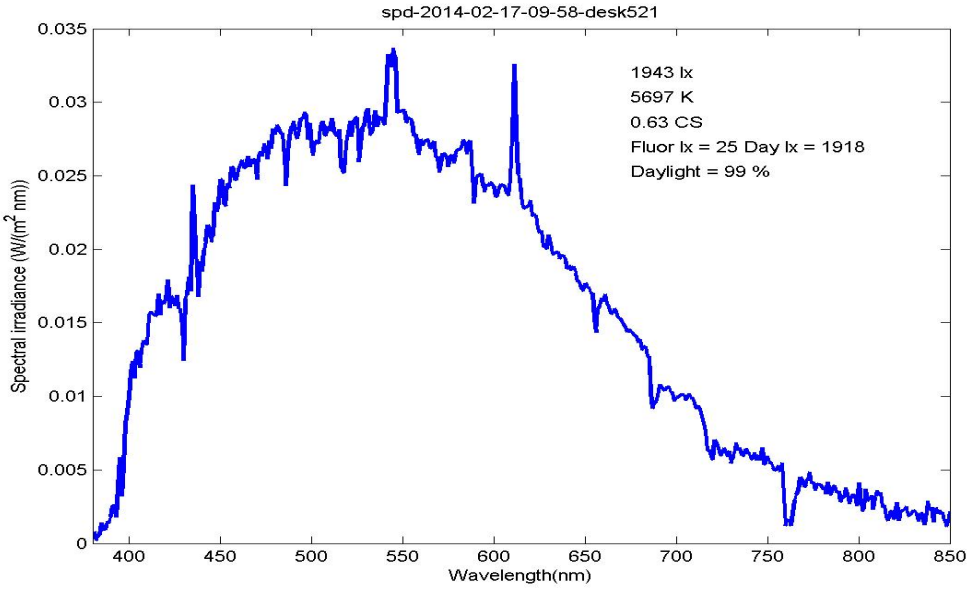
12:58, Desk 512, Looking Southwest

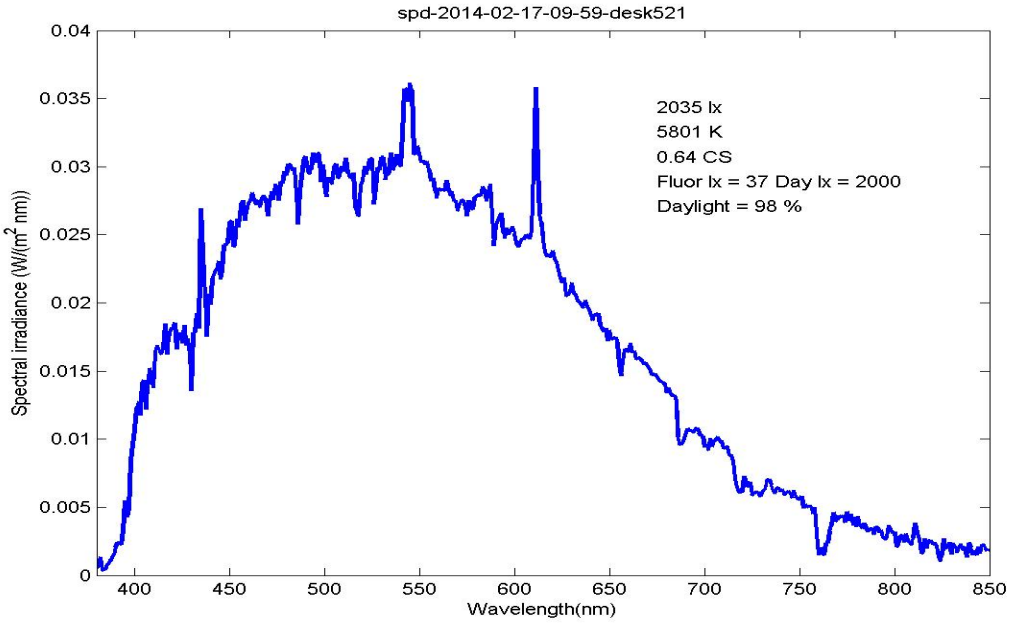
12:58, Desk 512, Dr. Mariana Figueiro collecting illuminance data

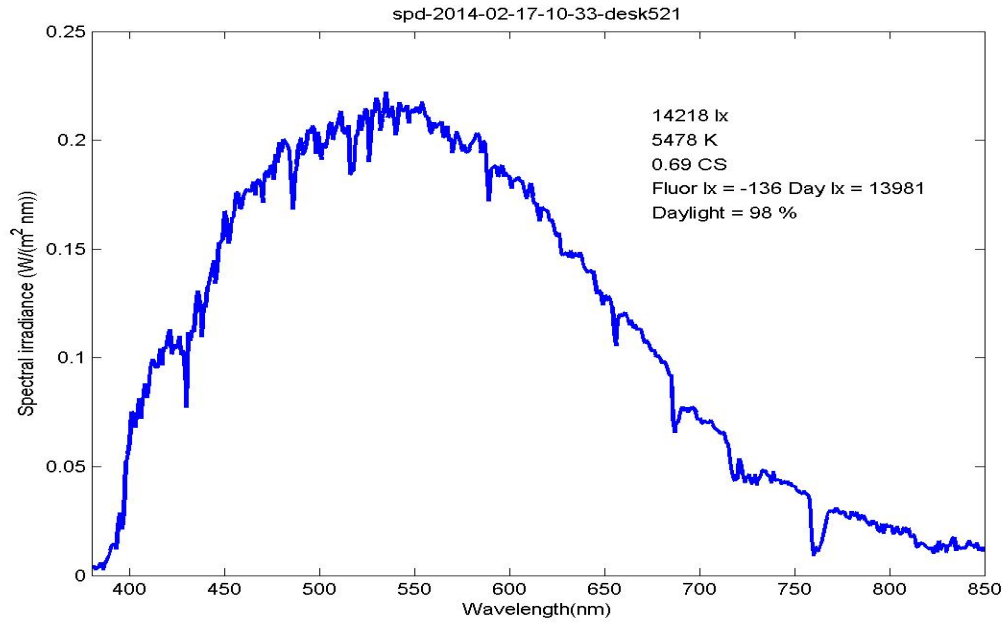

spd-2014-02-17-08-21-desk521
x 10-3
178 lx
5612 K
0.25 CS
Fluor lx = 31 Day lx = 152
Daylight = 86 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

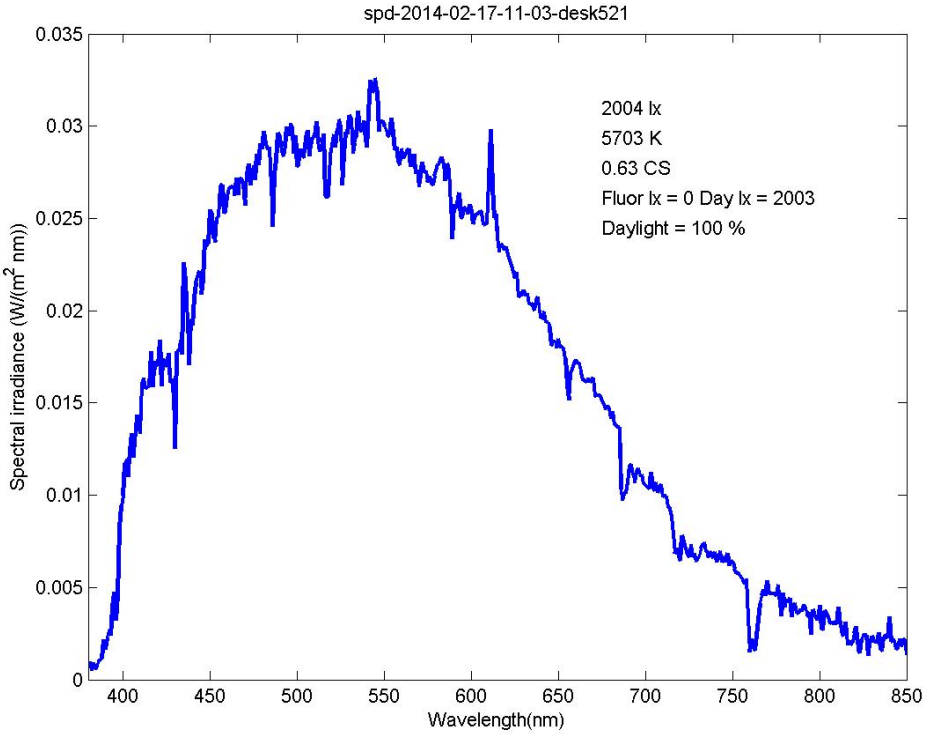

spd-2014-02-17-09-50-desk521
x 10-3
976 lx
6000 K
0.57 CS
Fluor lx = 30 Day lx = 968
Daylight = 99 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

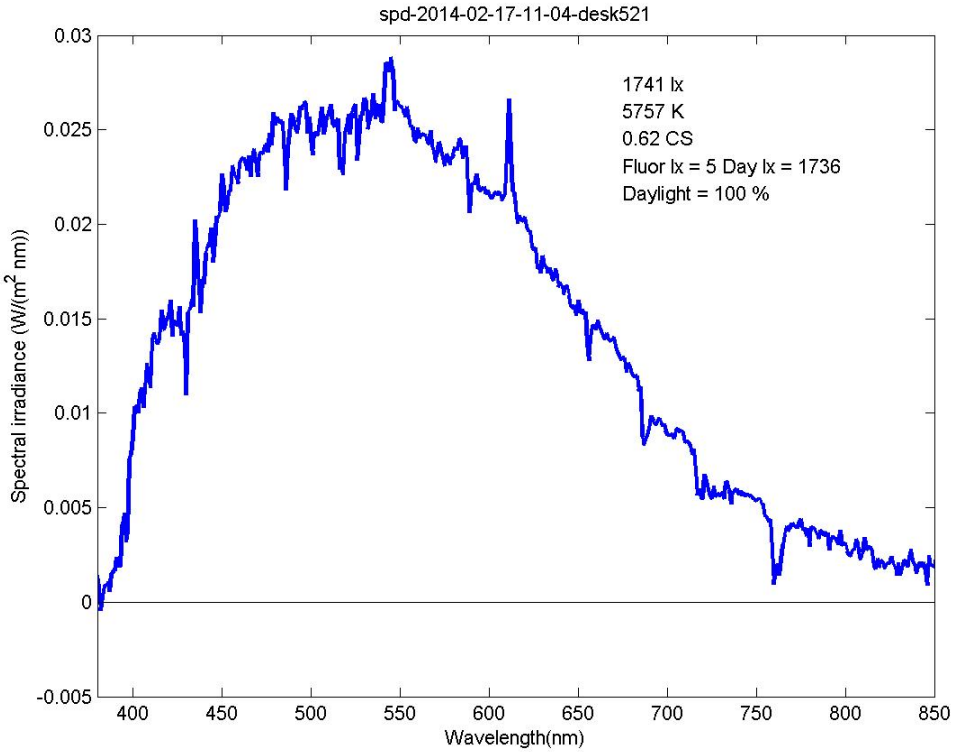

spd-2014-02-17-09-57-desk521
1719 lx
5782 K
0.62 CS
Fluor lx = 19 Day lx = 1712
Daylight = 100 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
400
450
500
550
600
650
700
750
800
850

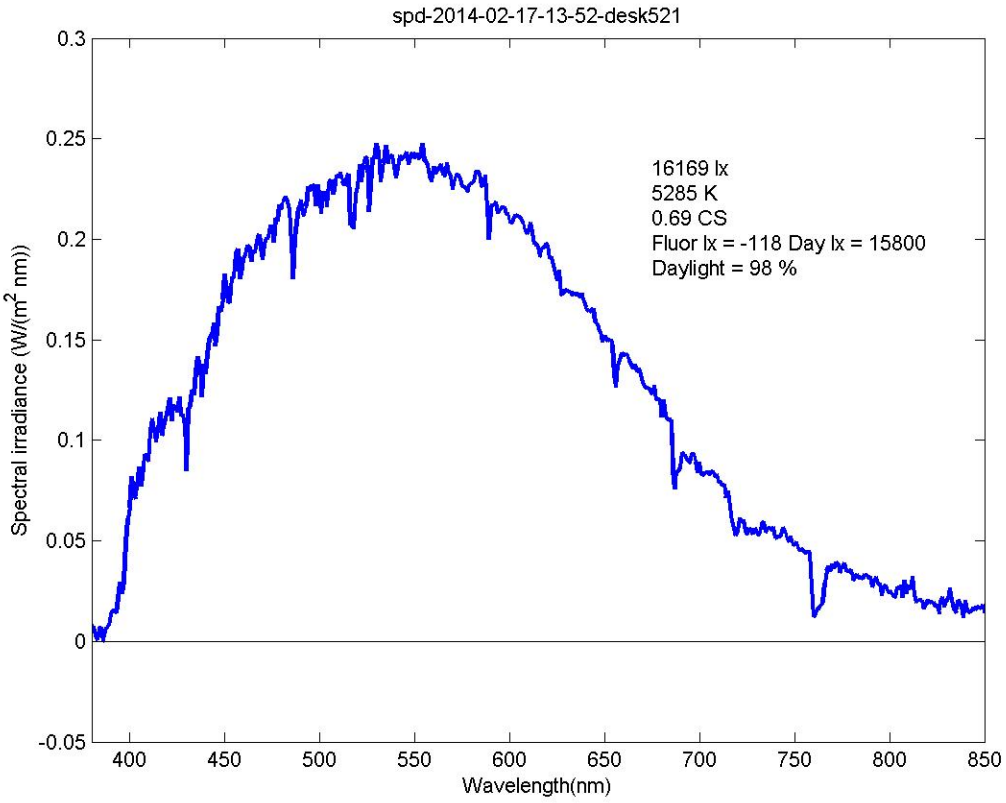

spd-2014-02-17-09-58-desk521
1943 lx
5697 K
0.63 CS
Fluor lx = 25 Day lx = 1918
Daylight = 99 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
400
450
500
550
600
650
700
750
800
850

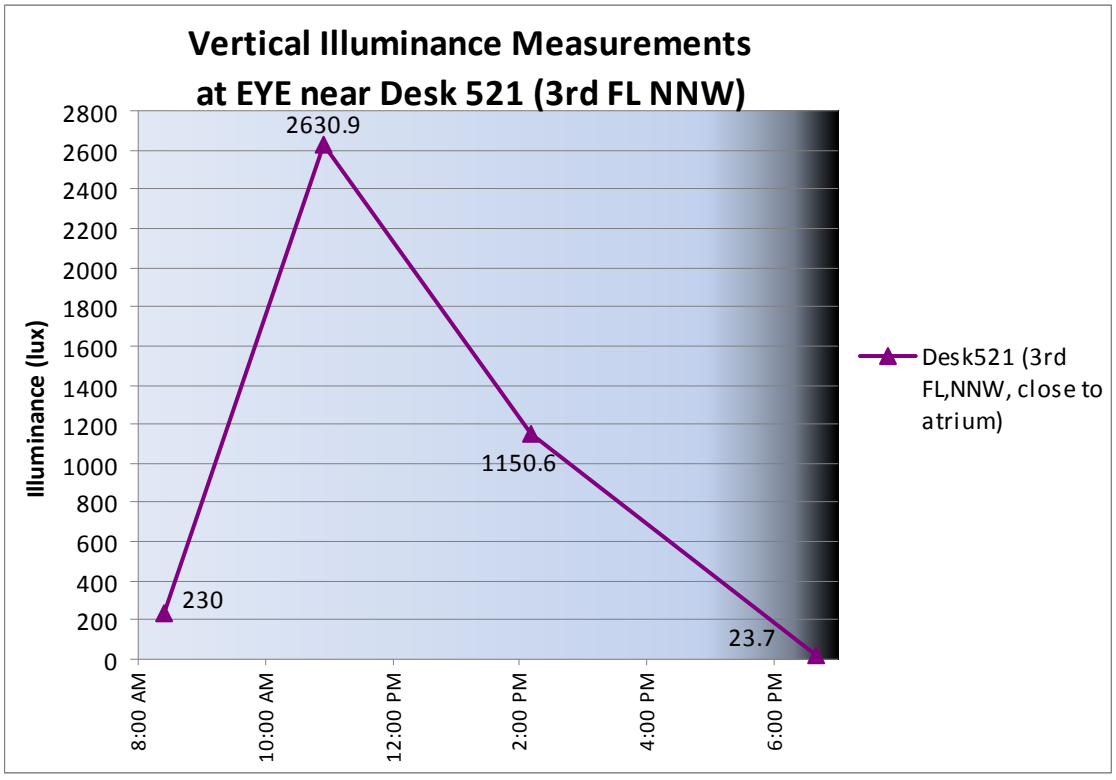

spd-2014-02-17-09-59-desk521
2035 lx
5801 K
0.64 CS
Fluor lx = 37 Day lx = 2000
Daylight = 98 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
400
450
500
550
600
650
700
750
800
850


spd-2014-02-17-10-33-desk521
14218 lx
5478 K
0.69 CS
Fluor lx = -136 Day lx = 13981
Daylight = 98 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.25
0.2
0.15
0.1
0.05
0
400
450
500
550
600
650
700
750
800
850

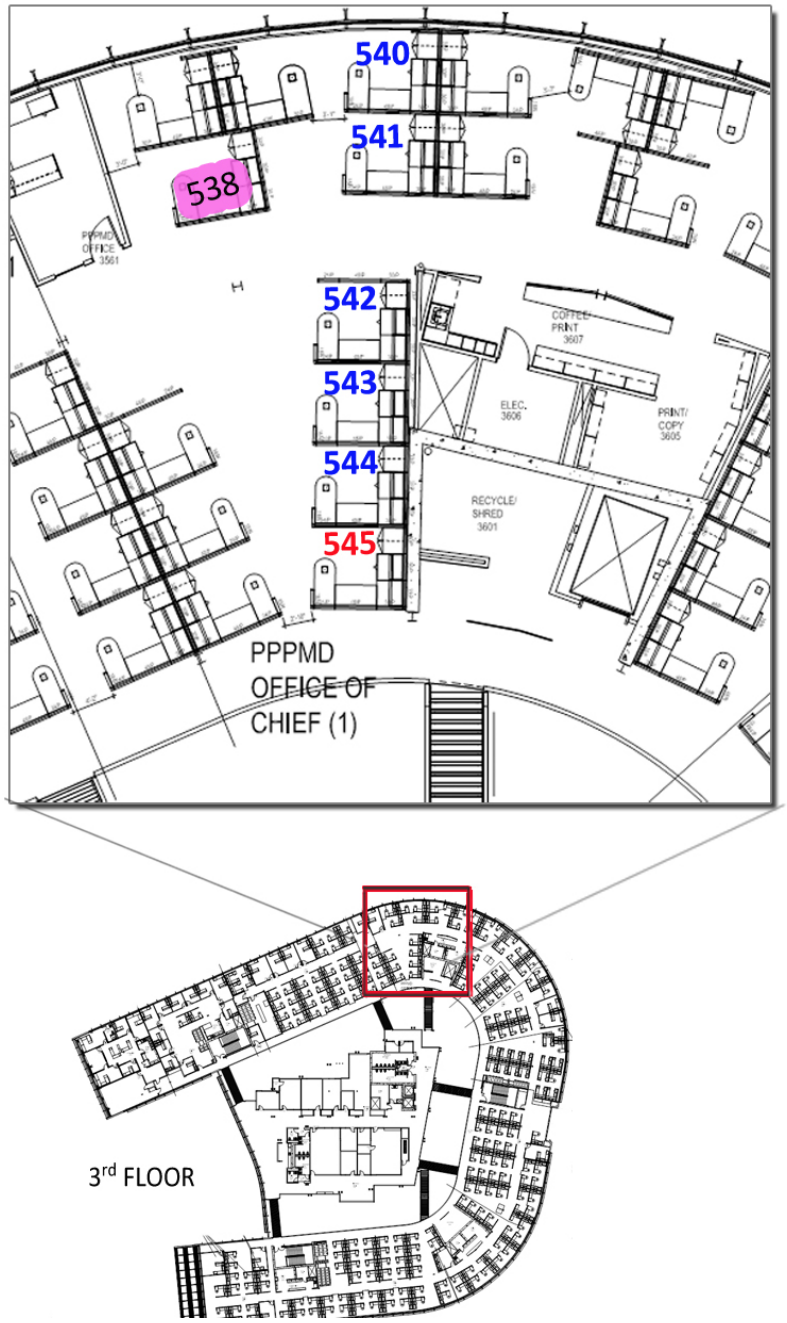

spd-2014-02-17-11-03-desk521
2004 lx
5703 K
0.63 CS
Fluor lx = 0 Day lx = 2003
Daylight = 100 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
400
450
500
550
600
650
700
750
800
850


spd-2014-02-17-11-04-desk521
1741 lx
5757 K
0.62 CS
Fluor lx = 5 Day lx = 1736
Daylight = 100 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850


spd-2014-02-17-13-52-desk521
16169 lx
5285 K
0.69 CS
Fluor lx = -118 Day lx = 15800
Daylight = 98 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
400
450
500
550
600
650
700
750
800
850


Vertical Illuminance Measurements
at EYE near Desk 521 (3rd FL NNW)
Illuminance (lux)
2630.9
1150.6
230
23.7
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk521 (3rd FL,NNW, close to atrium)

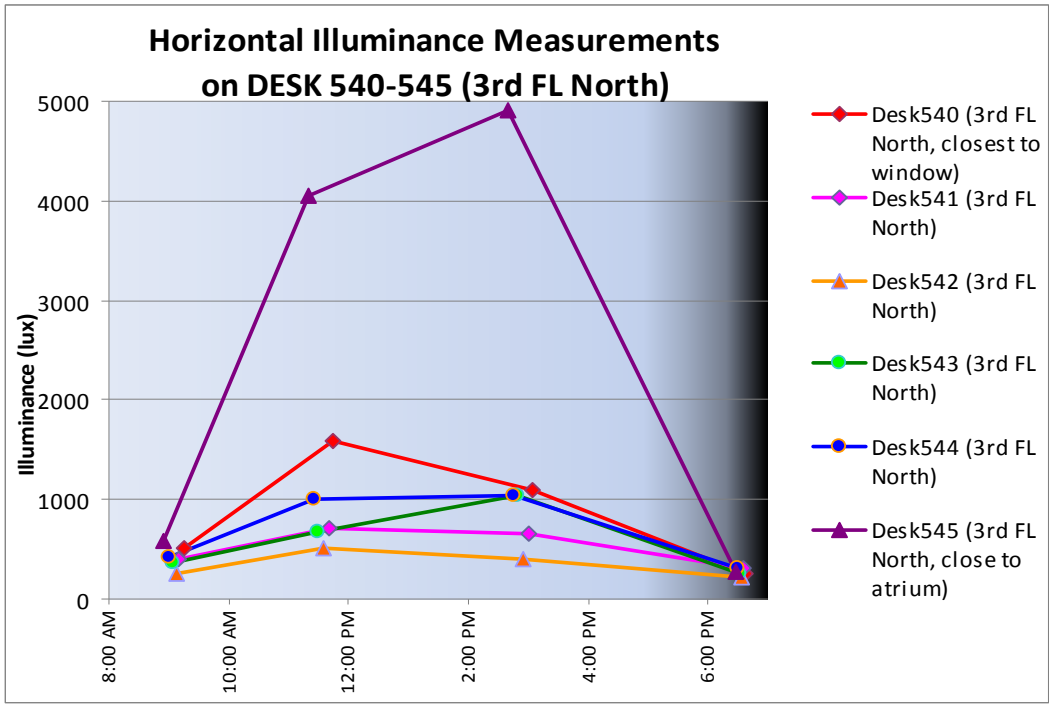
APPENDIX G: PHOTOMETRIC DATA FOR DESKS 540-545, AND 538

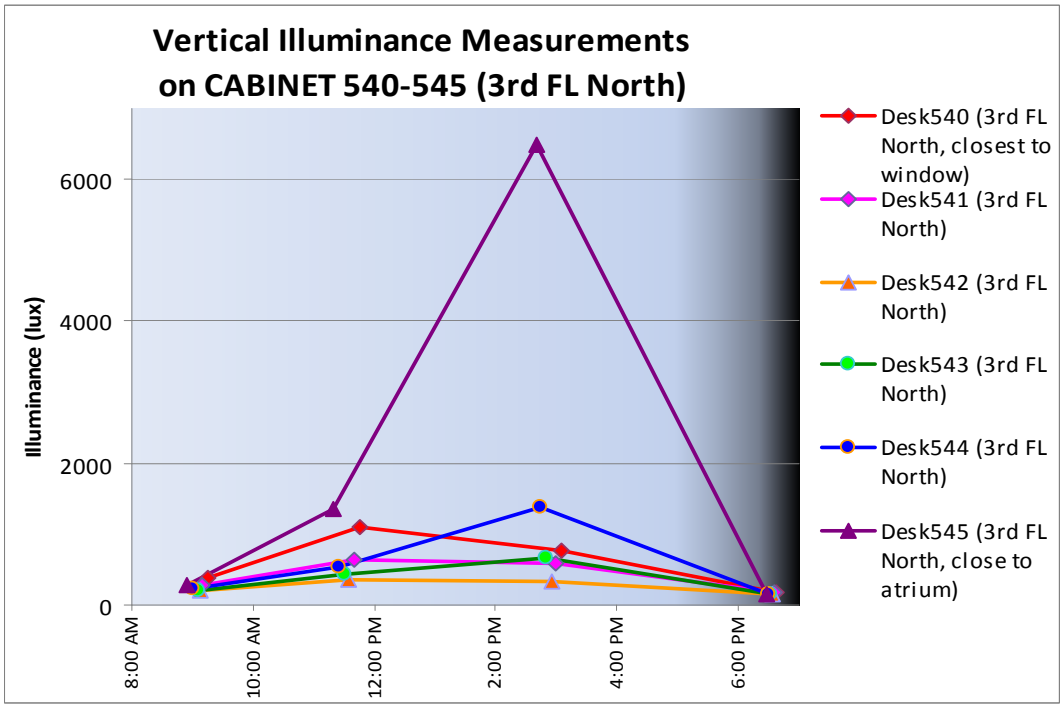


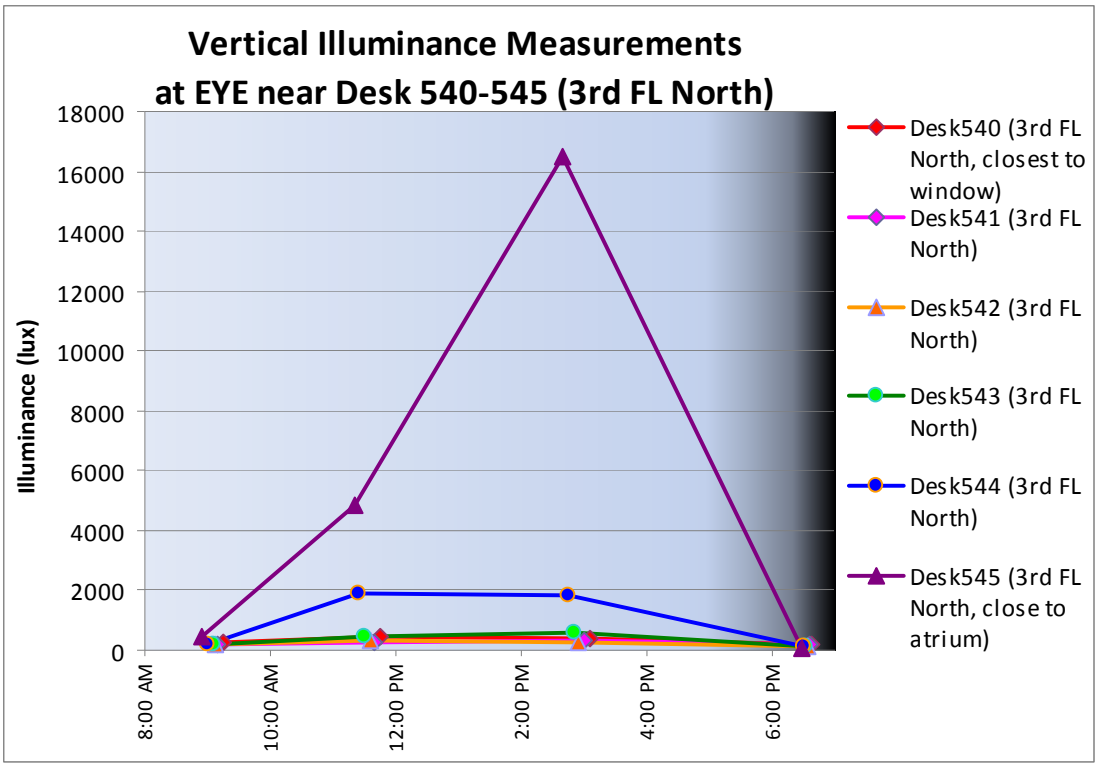
Desk with illuminance measures

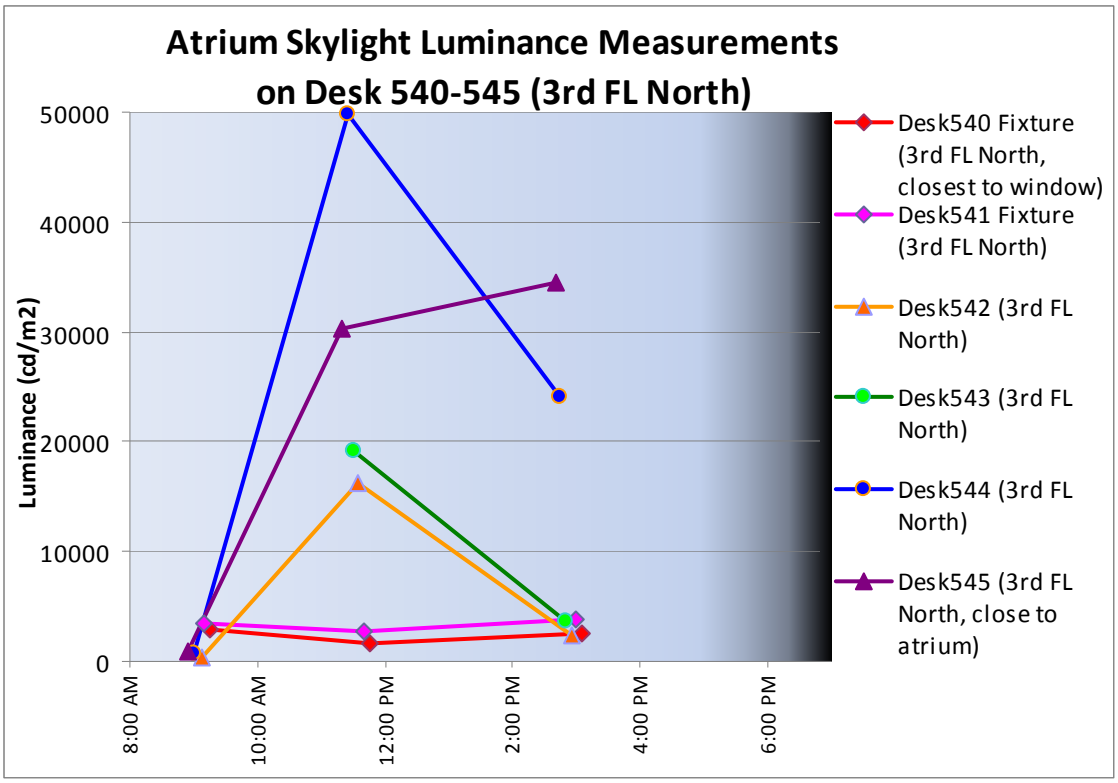
Desk with illuminance + SPD measures

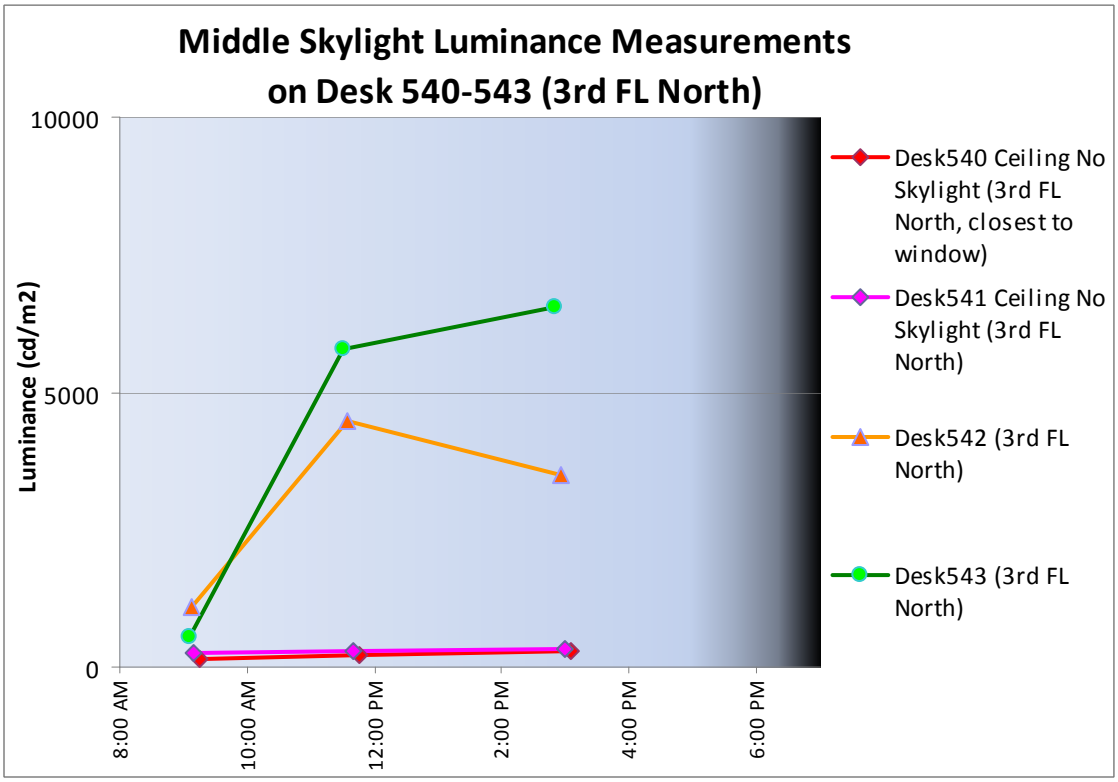
Desk with just SPD

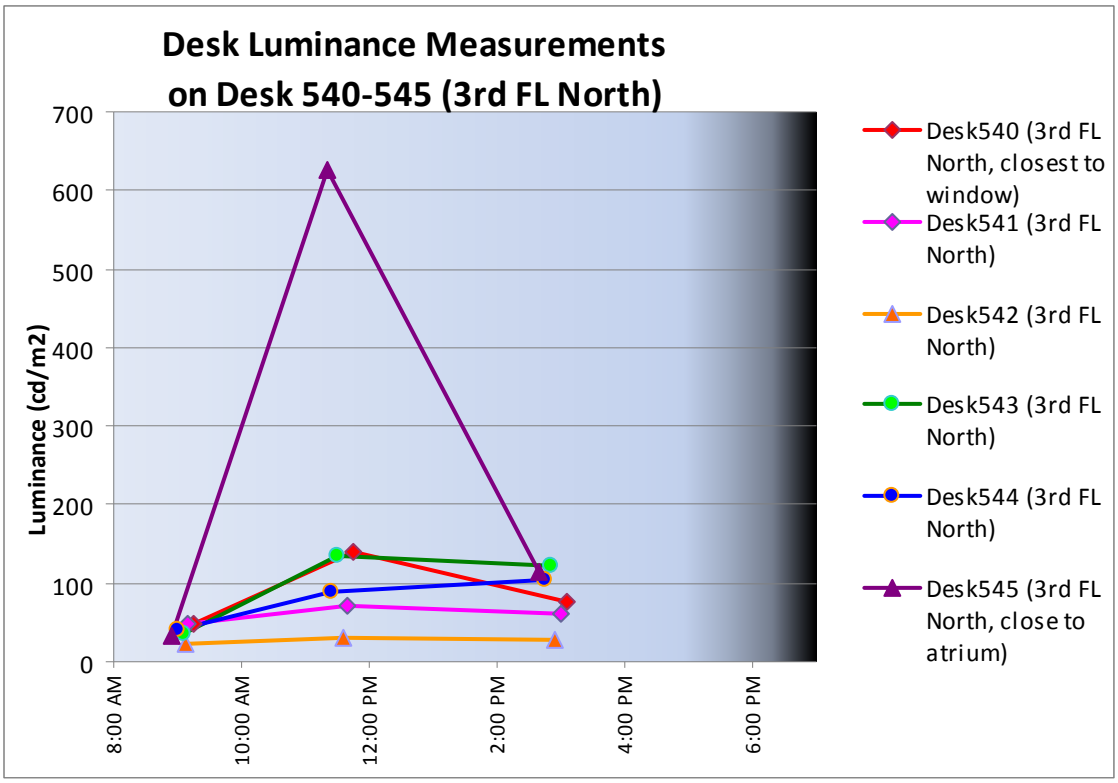

Horizontal Illuminance Measurements on DESK 540-545 (3rd FL North)
Illuminance (lux)
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 (3rd FL North, closest to window)
Desk541 (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)

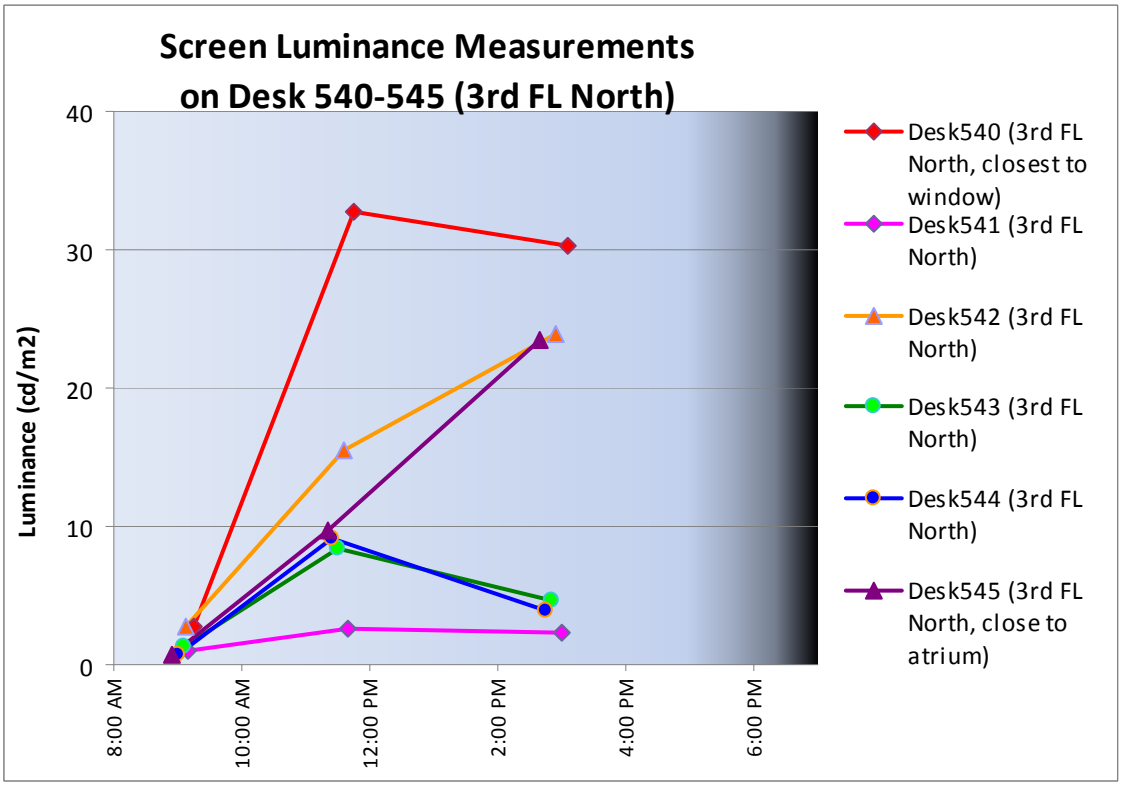

Vertical Illuminance Measurements on CABINET 540-545 (3rd FL North)
Illuminance (lux)
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 (3rd FL North, closest to window)
Desk541 (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)


Vertical Illuminance Measurements
at EYE near Desk 540-545 (3rd FL North)
Illuminance (lux)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 (3rd FL North, closest to window)
Desk541 (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)


Atrium Skylight Luminance Measurements on Desk 540-545 (3rd FL North)
Luminance (cd/m2)
50000
40000
30000
20000
10000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 Fixture (3rd FL North, closest to window)
Desk541 Fixture (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)


Middle Skylight Luminance Measurements on Desk 540-543 (3rd FL North)
Luminance (cd/m2)
10000
5000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 Ceiling No Skylight (3rd FL North, closest to window)
Desk541 Ceiling No Skylight (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)

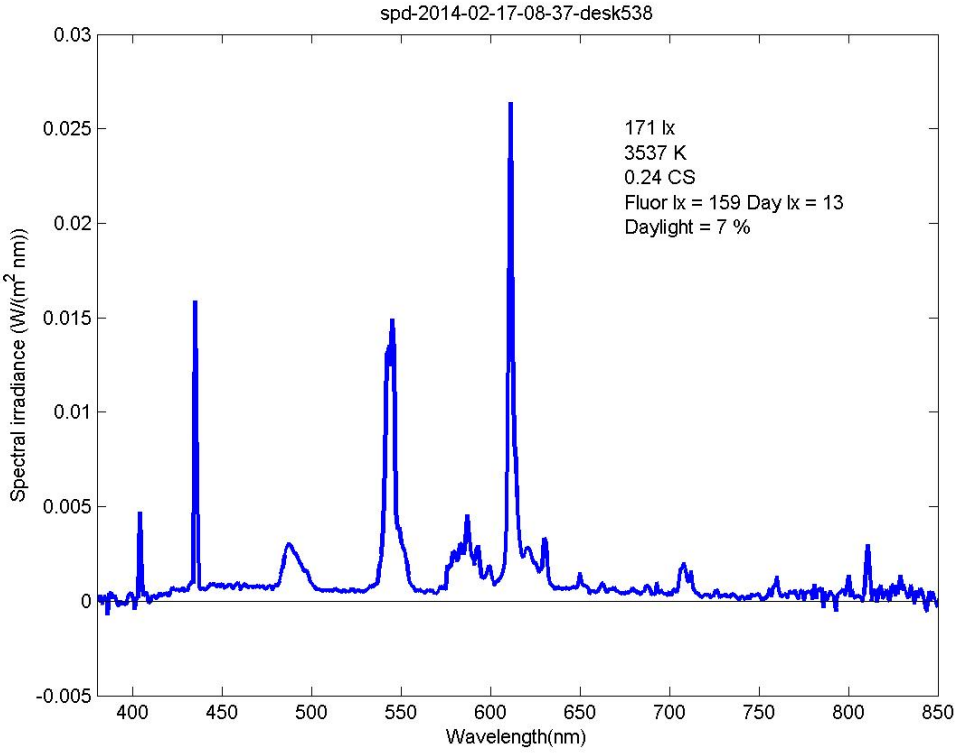

Desk Luminance Measurements on Desk 540-545 (3rd FL North)
Luminance (cd/m2)
700
600
500
400
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 (3rd FL North, closest to window)
Desk541 (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)

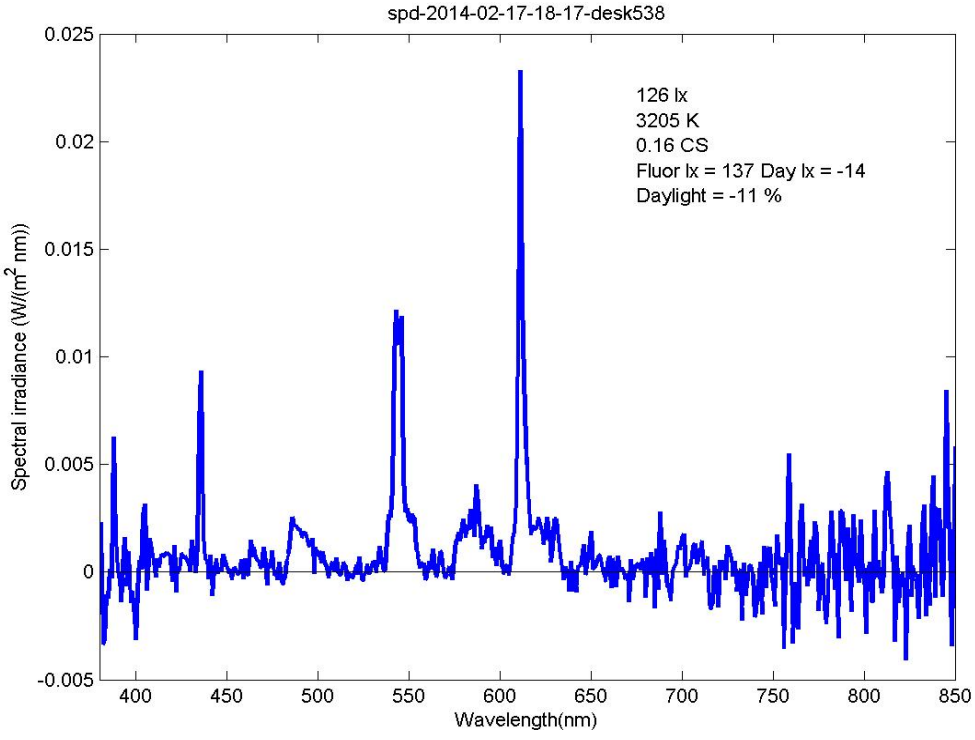

Screen Luminance Measurements on Desk 540-545 (3rd FL North)
Luminance (cd/m2)
40
30
20
10
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk540 (3rd FL North, closest to window)
Desk541 (3rd FL North)
Desk542 (3rd FL North)
Desk543 (3rd FL North)
Desk544 (3rd FL North)
Desk545 (3rd FL North, close to atrium)

DESK 538

13:12, Desk 538, Looking at monitor bezel

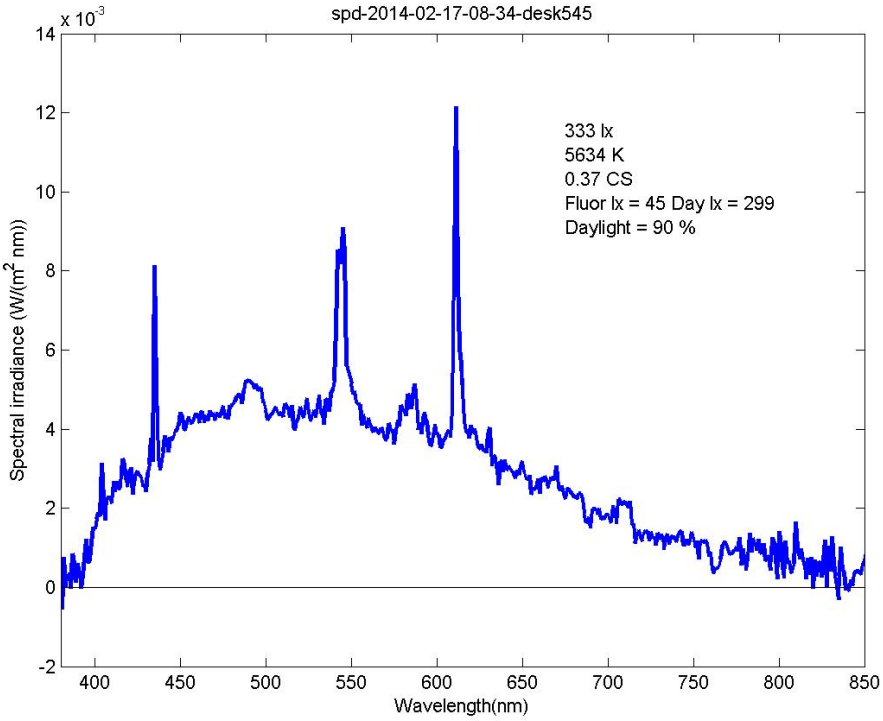
13:12, Desk 538, Looking North

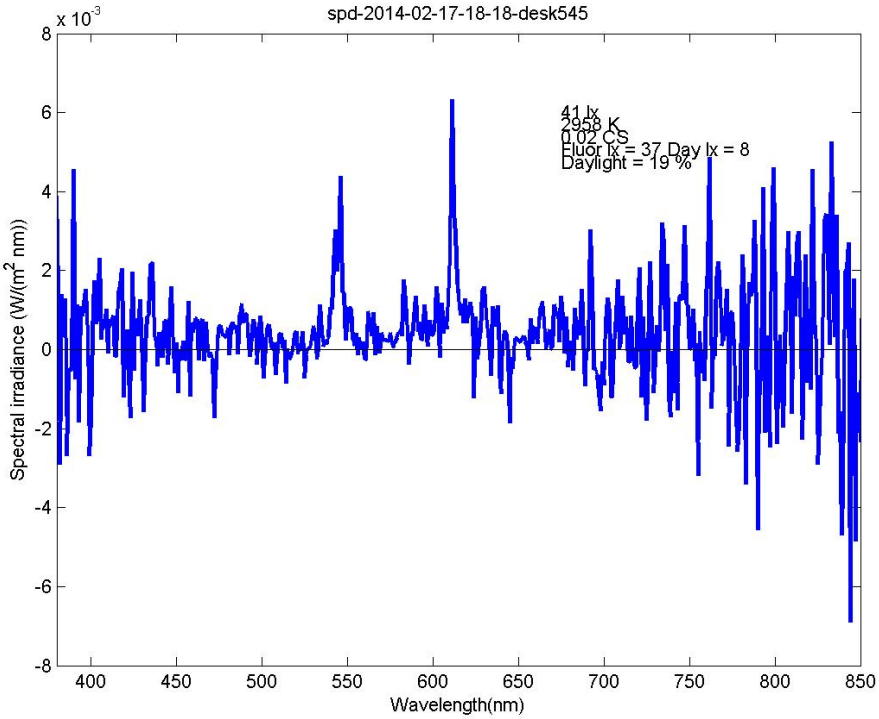

spd-2014-02-17-08-37-desk538
171 lx
3537 K
0.24 CS
Fluor lx = 159 Day lx = 13
Daylight = 7 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

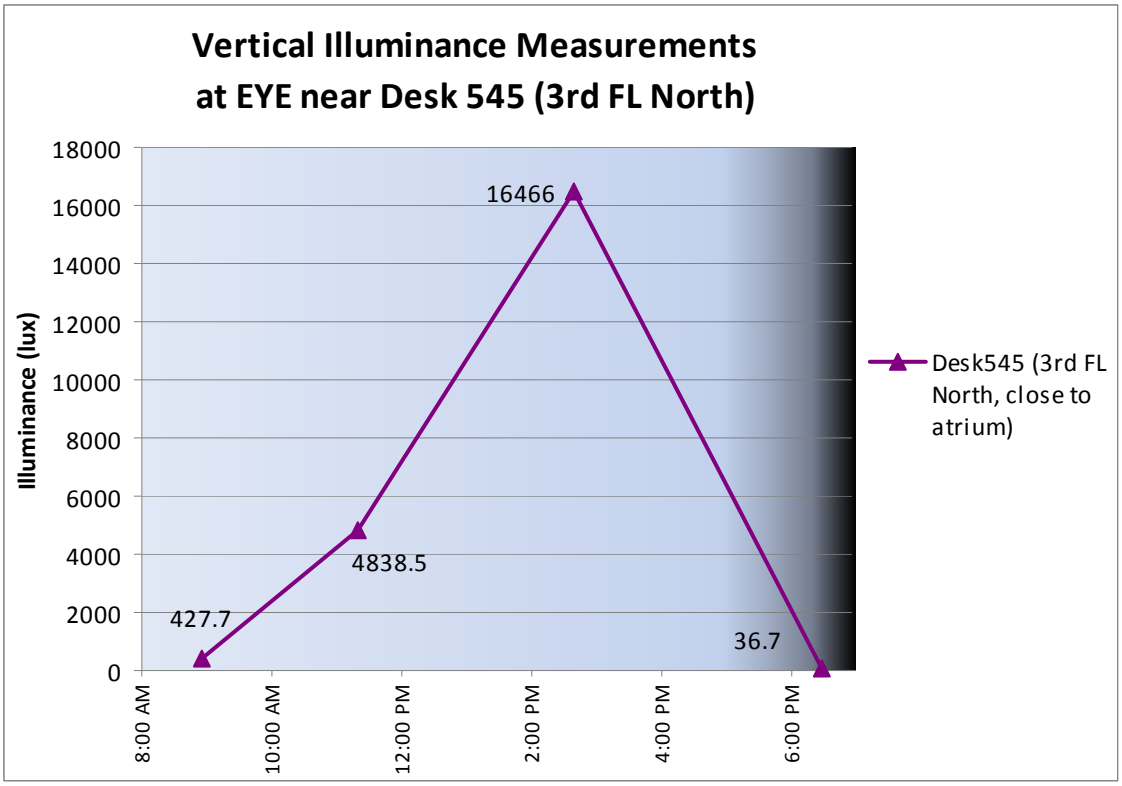

spd-2014-02-17-18-17-desk538
126 lx
3205 K
0.16 CS
Fluor lx = 137 Day lx = -14
Daylight = -11 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

DESK 545

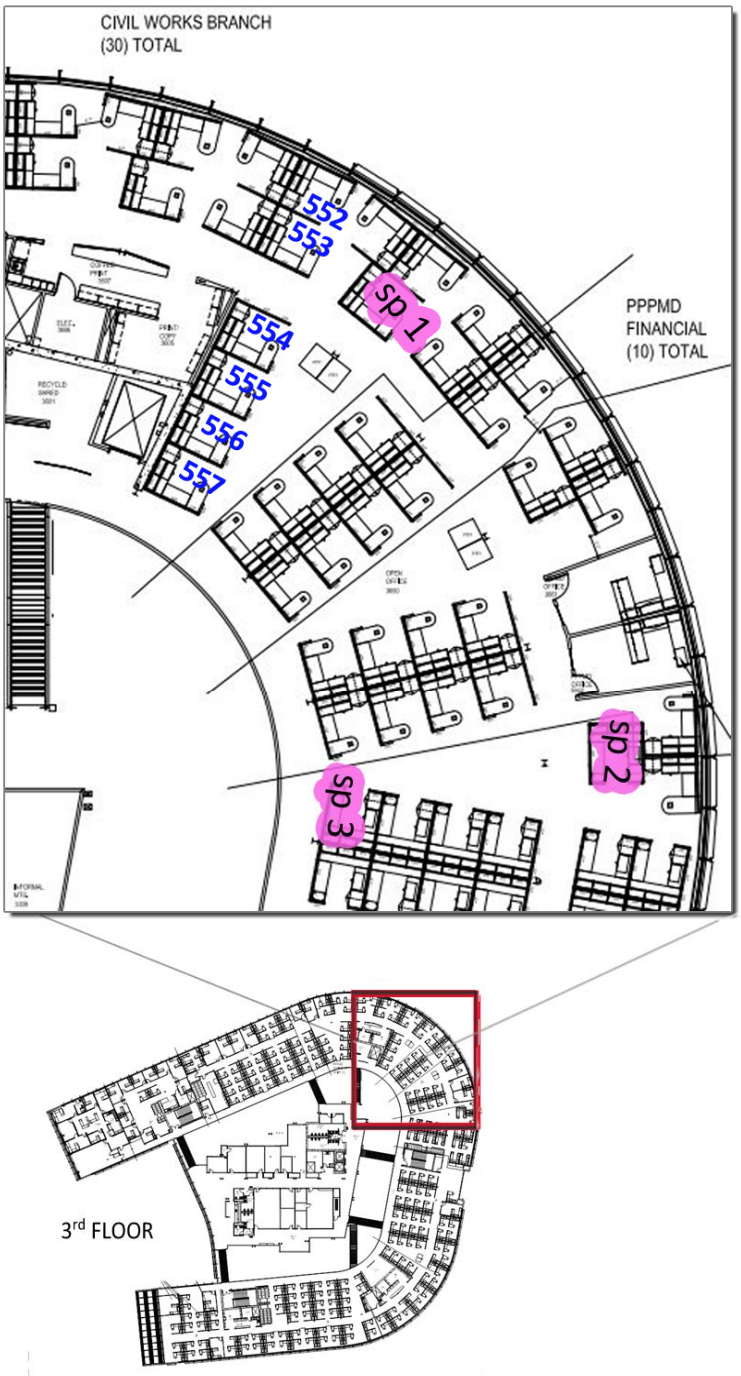
13:09, Desk 545, monitor bezel, looking South towards atrium




spd-2014-02-17-18-18-desk545
x 10-3
41 lx
2958 K
0.02 CS
Fluor lx = 37 Day lx = 8
Daylight = 19 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
8
6
4
2
0
-2
-4
-6
-8
400
450
500
550
600
650
700
750
800
850


Vertical Illuminance Measurements
at EYE near Desk 545 (3rd FL North)
Illuminance (lux)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
16466
4838.5
427.7
36.7
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk545 (3rd FL North, close to atrium)

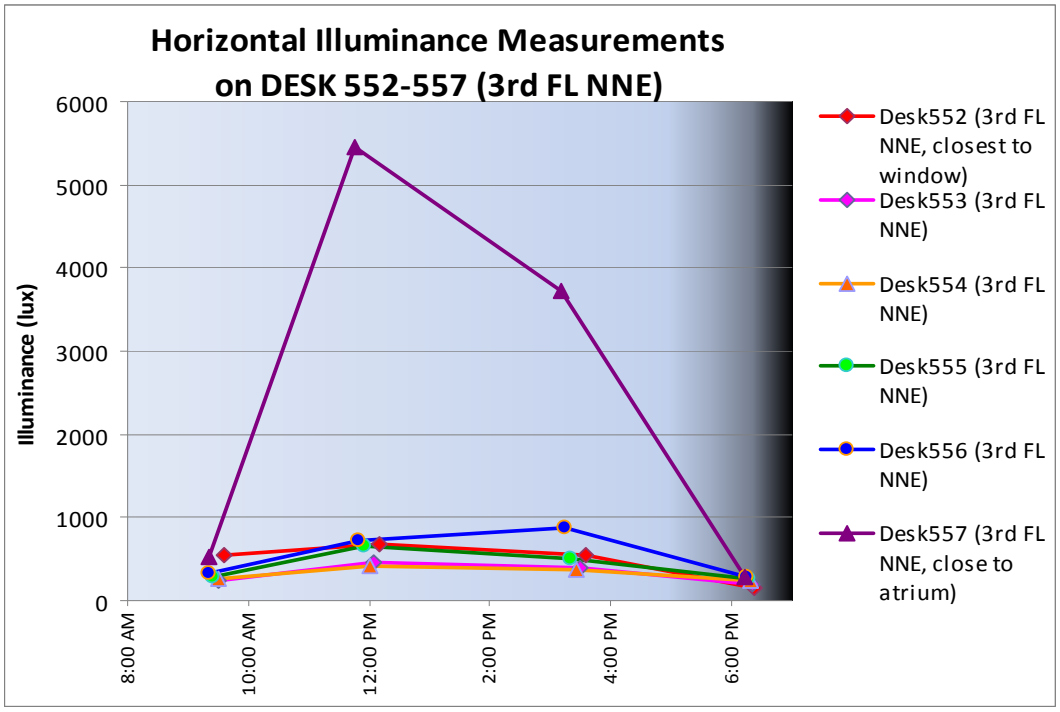
APPENDIX H: PHOTOMETRIC DATA FOR DESKS 552-557 AND SPACES 1, 2, 3

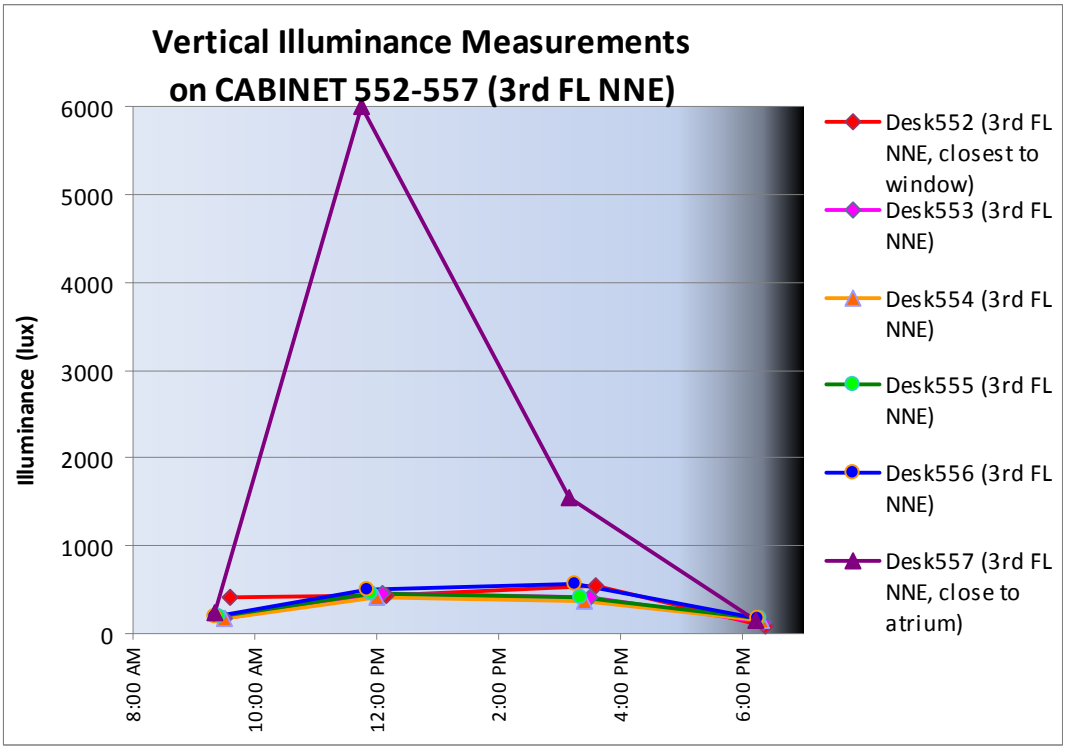


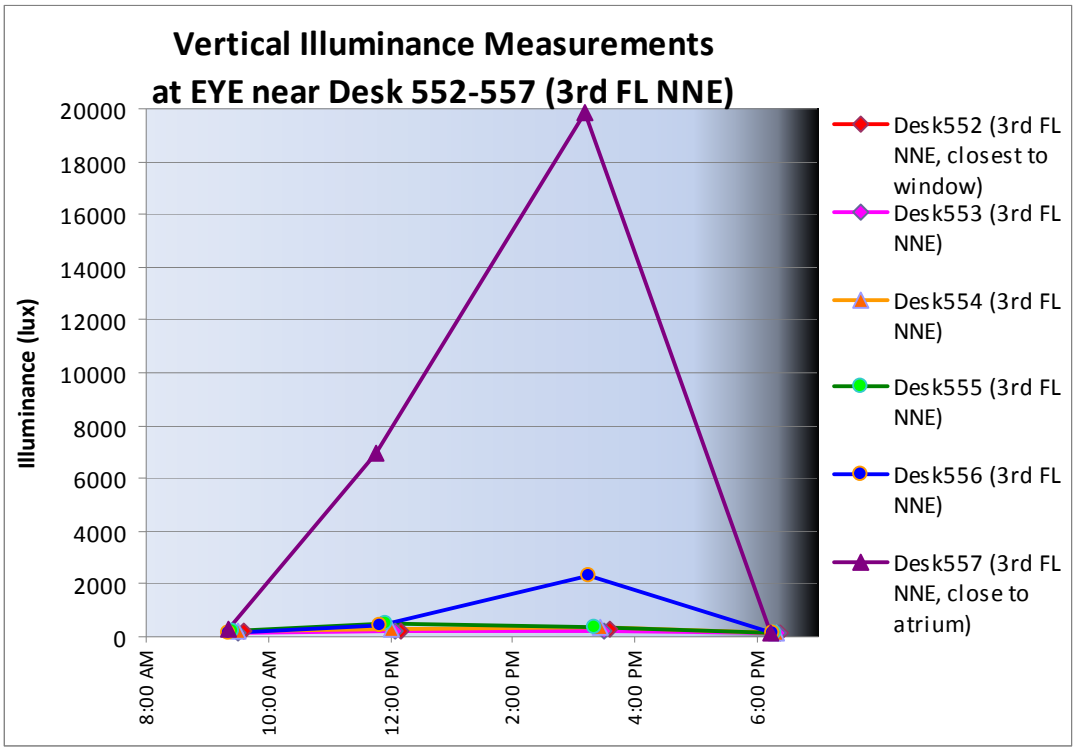
Desk with illuminance measures

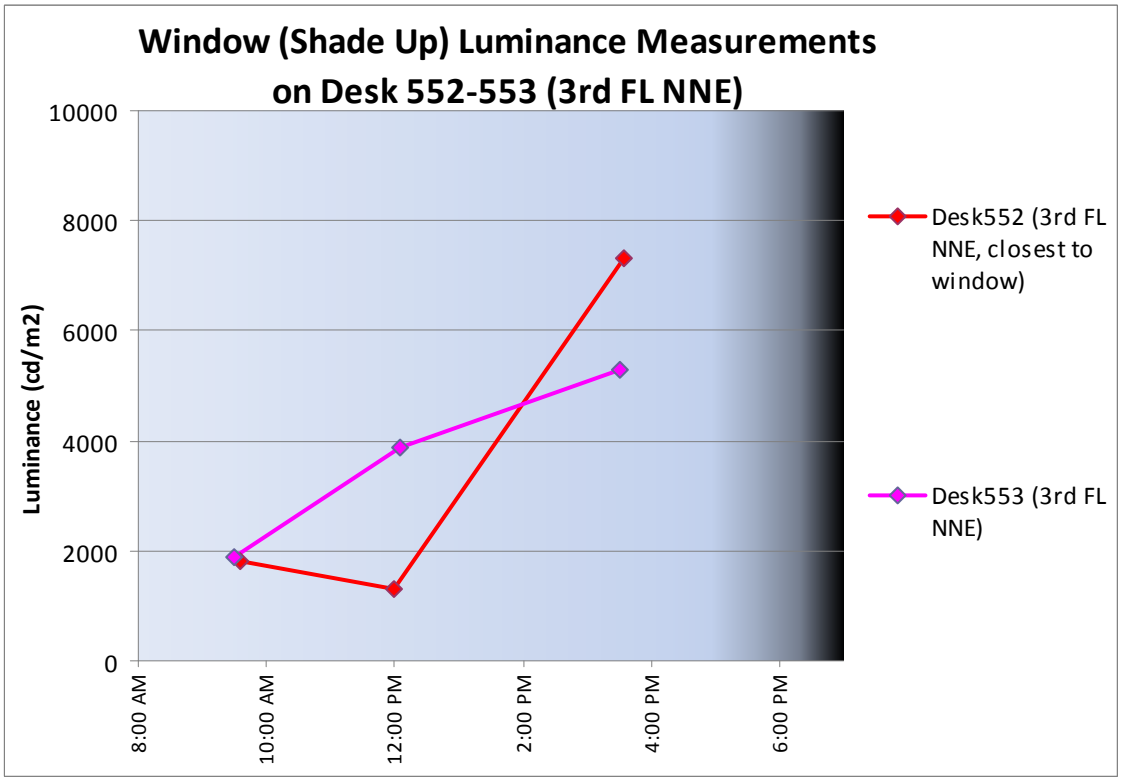
Desk with illuminance + SPD measures

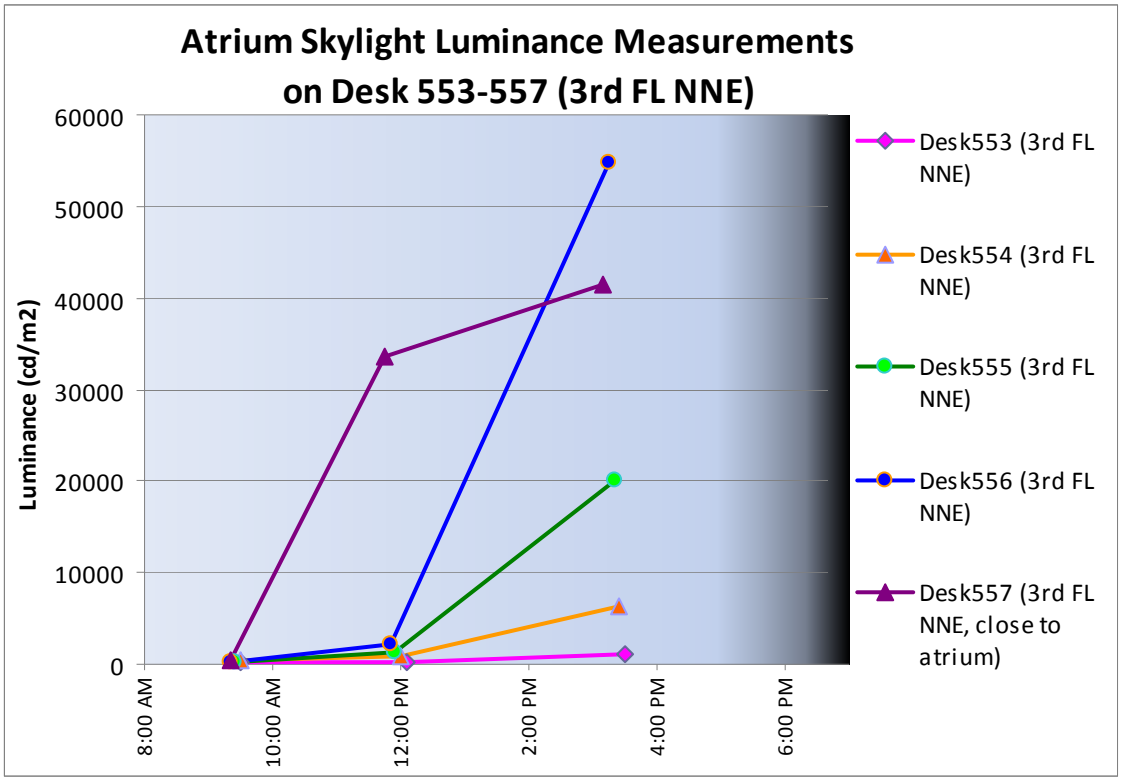
Desk with just SPD

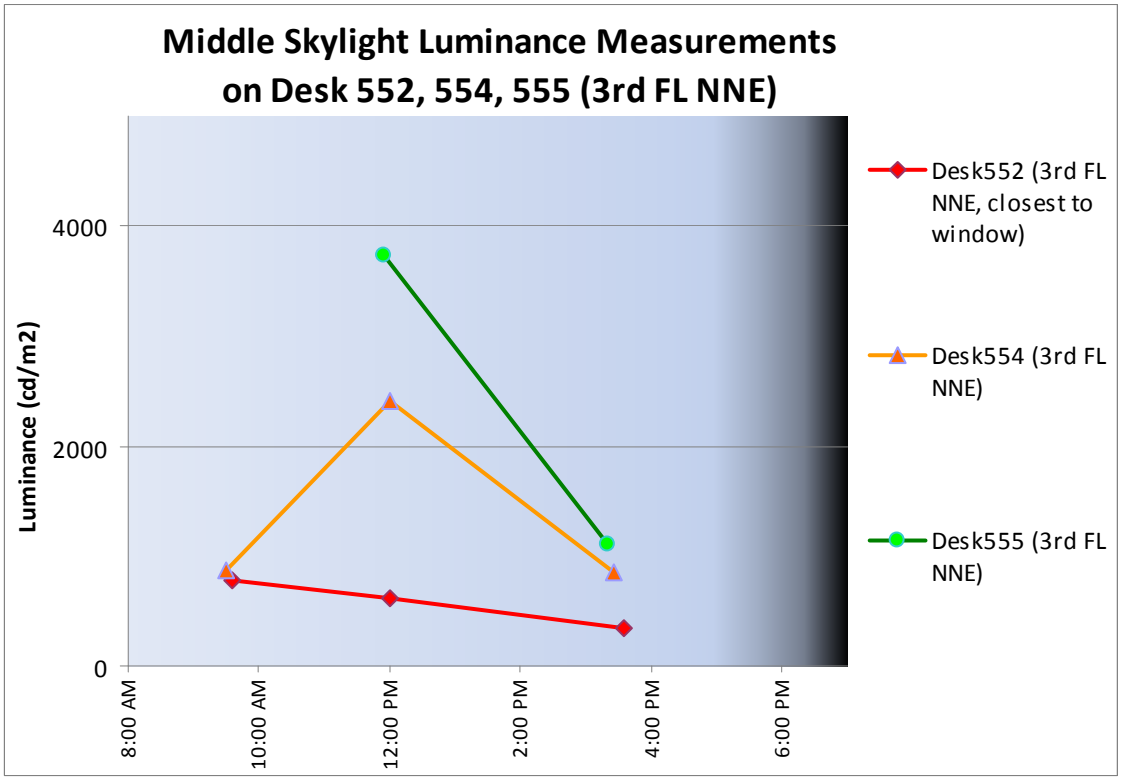

Horizontal Illuminance Measurements on DESK 552-557 (3rd FL NNE)
Illuminance (lux)
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)

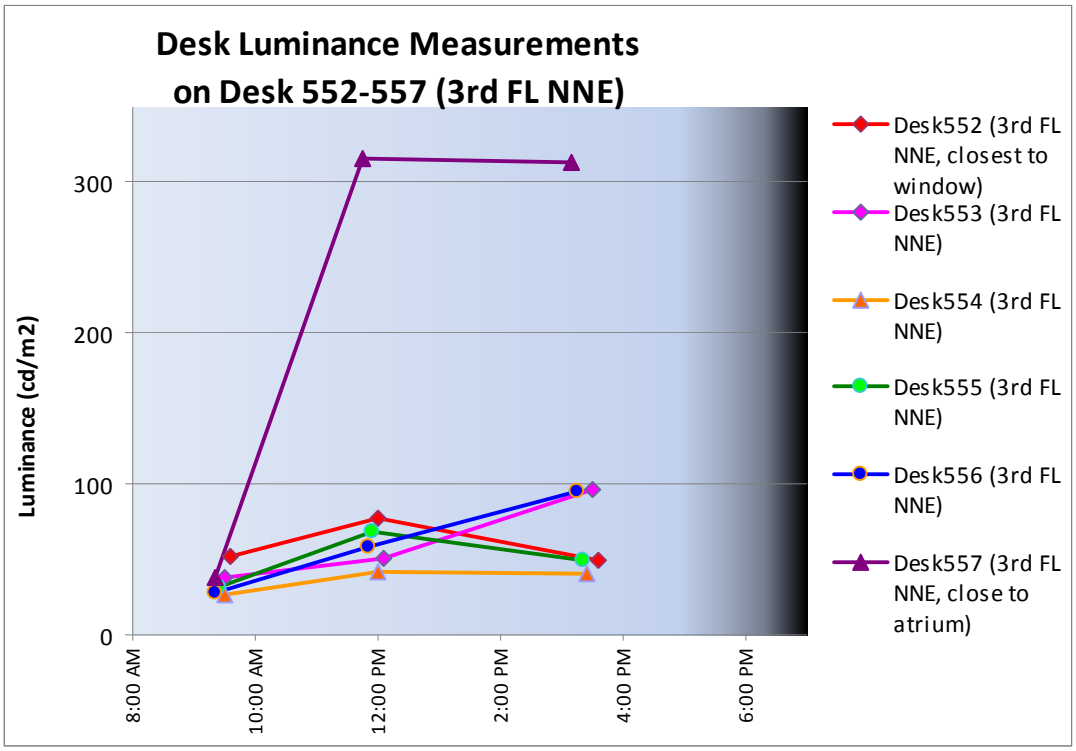

Vertical Illuminance Measurements on CABINET 552-557 (3rd FL NNE)
Illuminance (lux)
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)

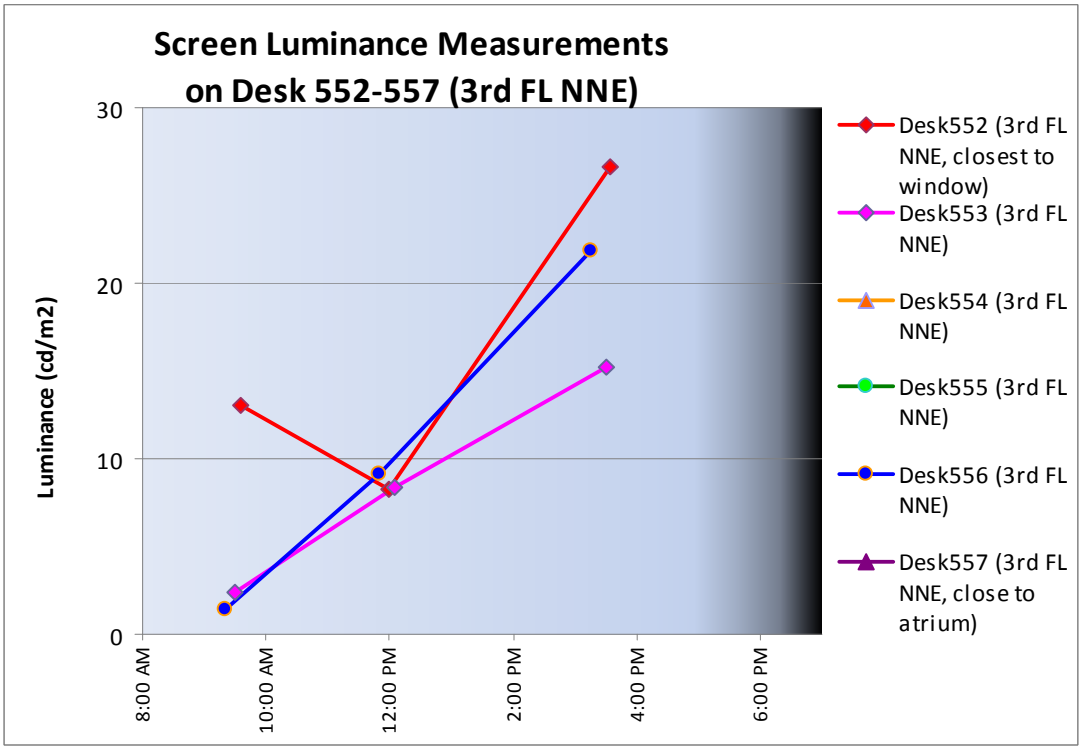

Vertical Illuminance Measurements
at EYE near Desk 552-557 (3rd FL NNE)
Illuminance (lux)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)


Window (Shade Up) Luminance Measurements
on Desk 552-553 (3rd FL NNE)
Luminance (cd/m2)
10000
8000
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)

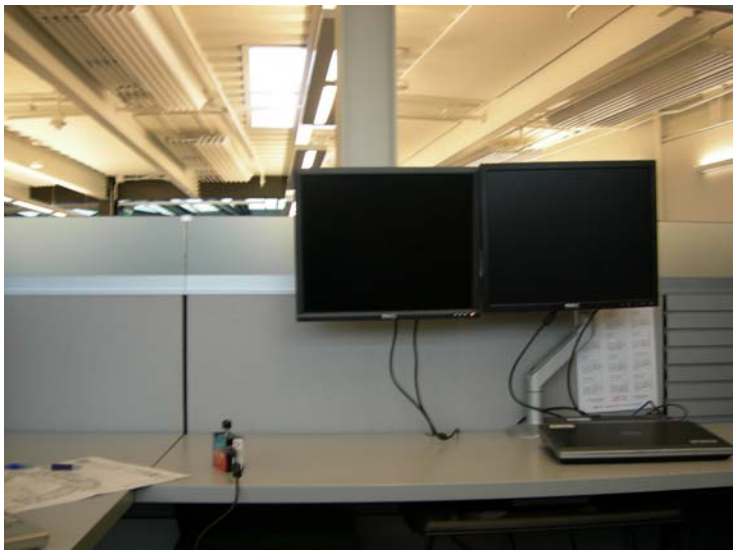

Atrium Skylight Luminance Measurements
on Desk 553-557 (3rd FL NNE)
Luminance (cd/m2)
60000
50000
40000
30000
20000
10000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)


Middle Skylight Luminance Measurements
on Desk 552, 554, 555 (3rd FL NNE)
Luminance (cd/m2)
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)


Desk Luminance Measurements on Desk 552-557 (3rd FL NNE)
Luminance (cd/m2)
0
100
200
300
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)

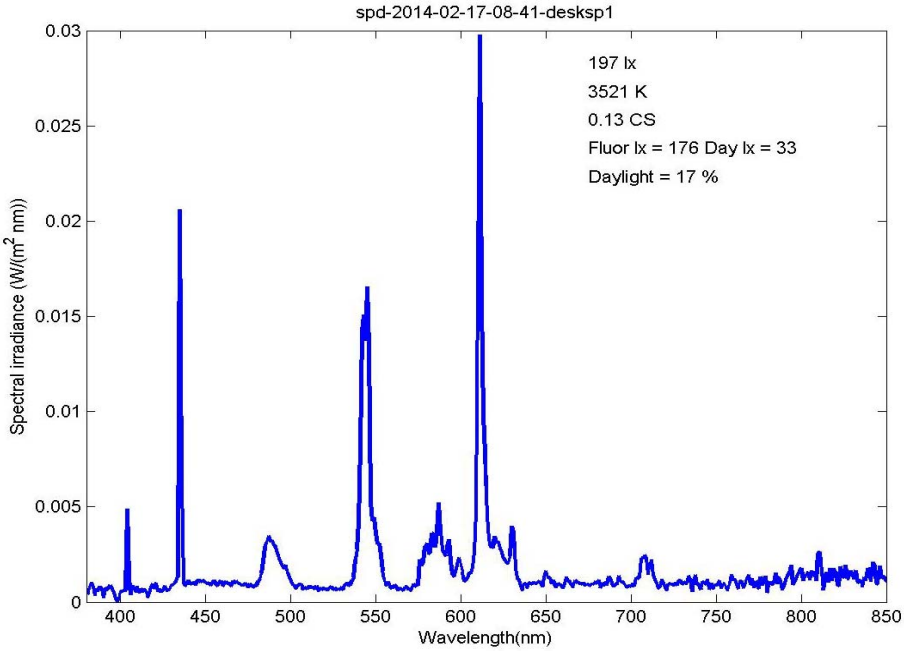

Screen Luminance Measurements on Desk 552-557 (3rd FL NNE)
Luminance (cd/m2)
0
10
20
30
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk552 (3rd FL NNE, closest to window)
Desk553 (3rd FL NNE)
Desk554 (3rd FL NNE)
Desk555 (3rd FL NNE)
Desk556 (3rd FL NNE)
Desk557 (3rd FL NNE, close to atrium)

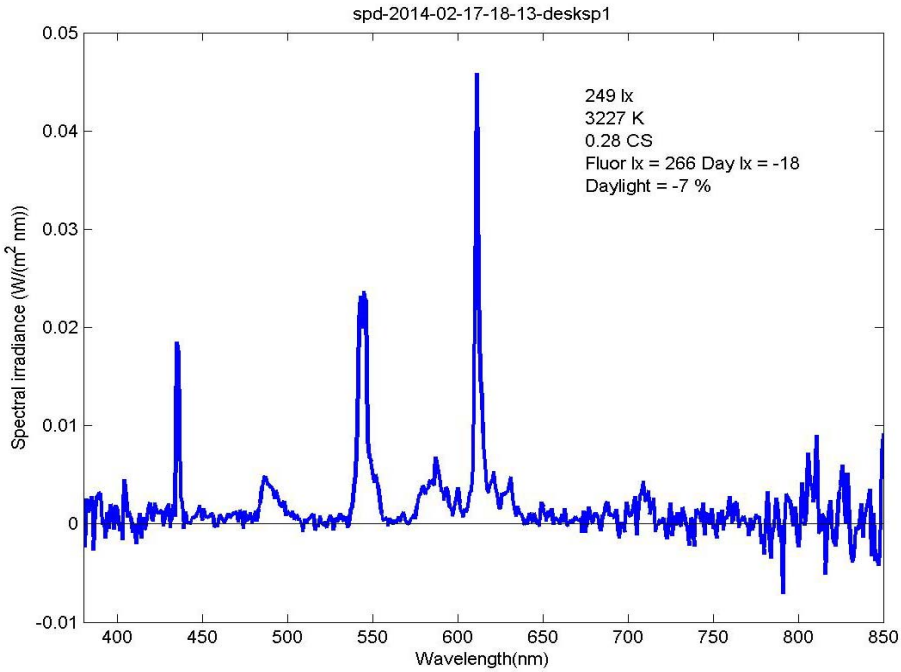
SPACE 1 (UNKNOWN DESK NUMBER)



13:16, Space 1, looking Southwest; note skylight luminance

13:17, Space 1, looking Northwest, behind desk

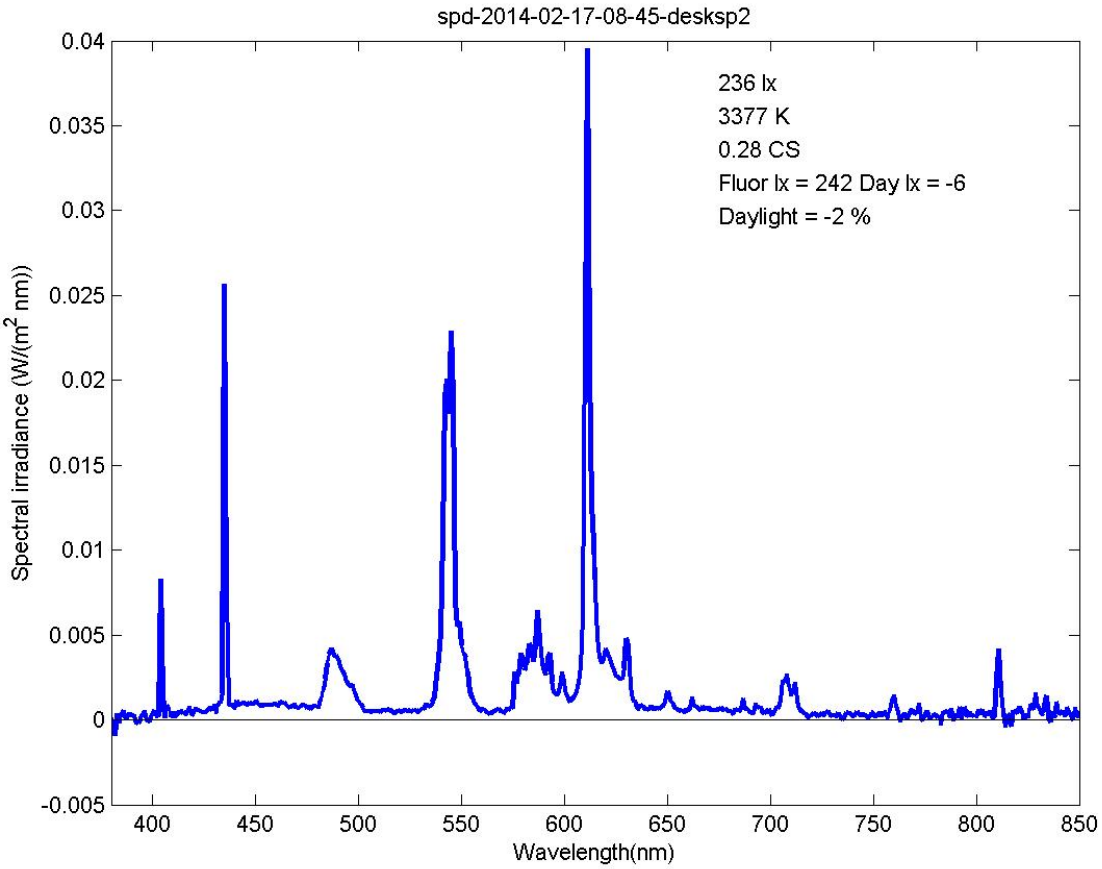

spd-2014-02-17-08-41-desksp1
197 lx
3521 K
0.13 CS
Fluor lx = 176 Day lx = 33
Daylight = 17 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
400
450
500
550
600
650
700
750
800
850


spd-2014-02-17-18-13-desksp1
249 lx
3227 K
0.28 CS
Fluor lx = 266 Day lx = -18
Daylight = -7 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.05
0.04
0.03
0.02
0.01
0
-0.01
400
450
500
550
600
650
700
750
800
850

SPACE 2 (UNKNOWN DESK NUMBER)

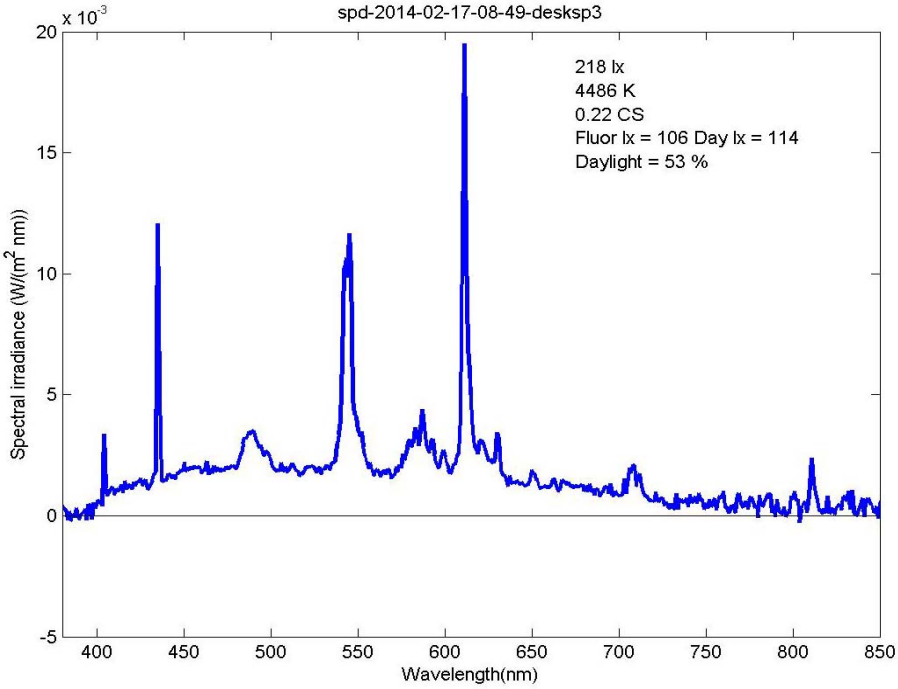
13:21, Space 2, looking West; note skylight

13:21, looking towards Space 2


spd-2014-02-17-08-45-desksp2
236 lx
3377 K
0.28 CS
Fluor lx = 242 Day lx = -6
Daylight = -2 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

SPACE 3 (UNKNOWN DESK NUMBER)

13:25, Space 3, looking West; note sunshades

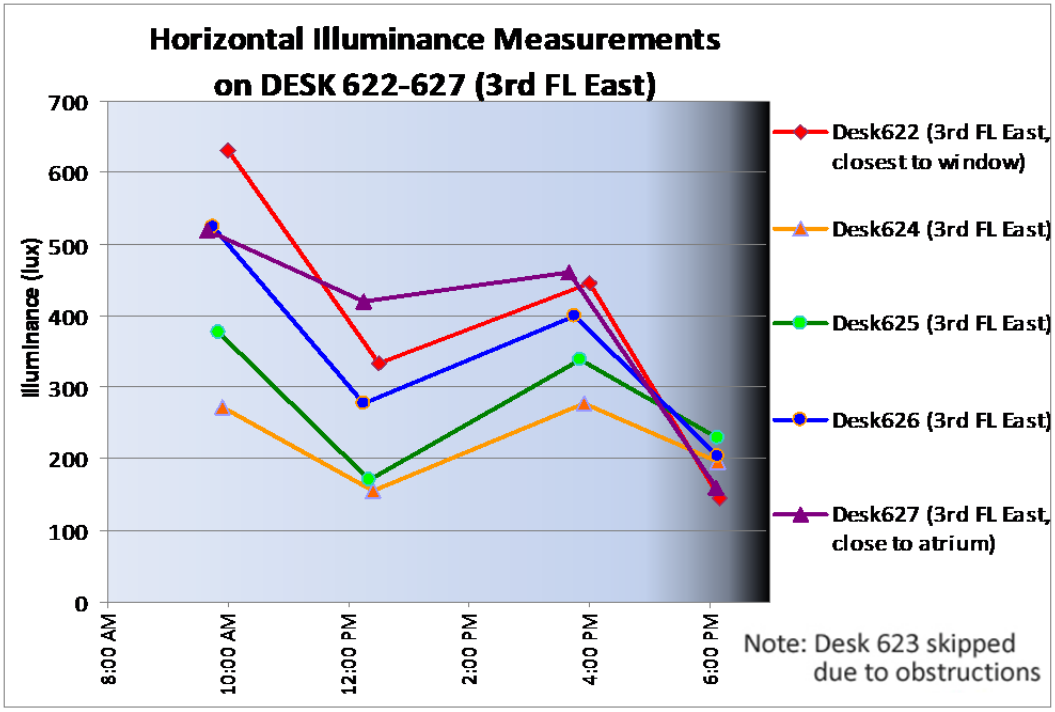


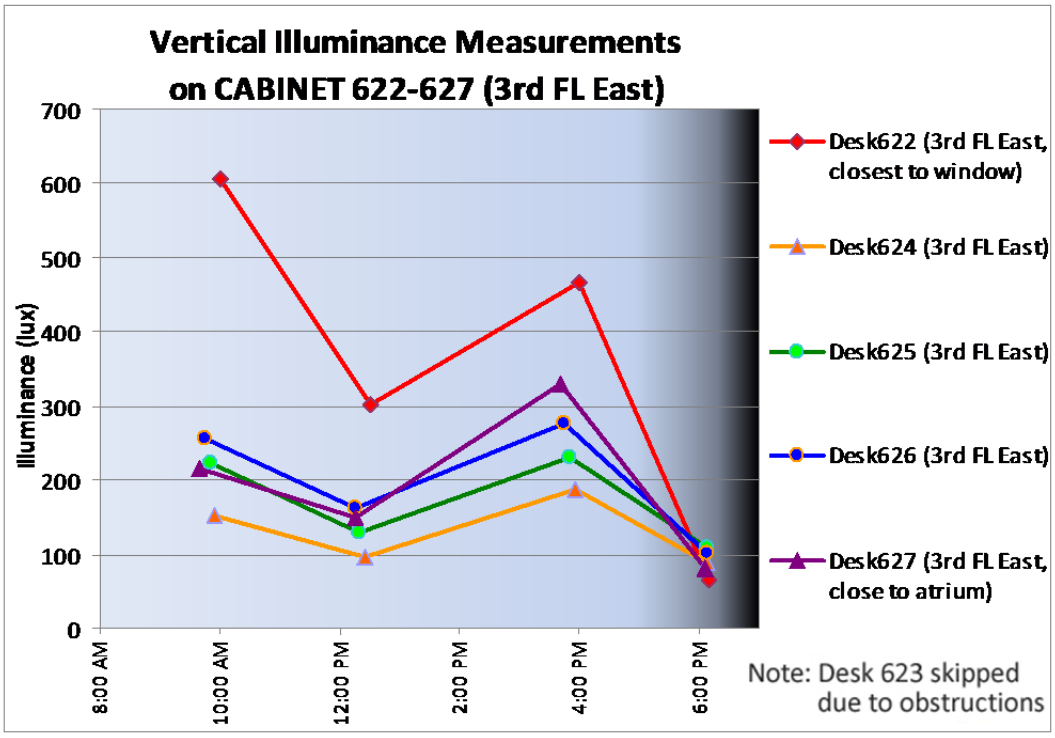
APPENDIX I: PHOTOMETRIC DATA FOR DESKS 622-627, 616, 639, 644 AND SPACE 6

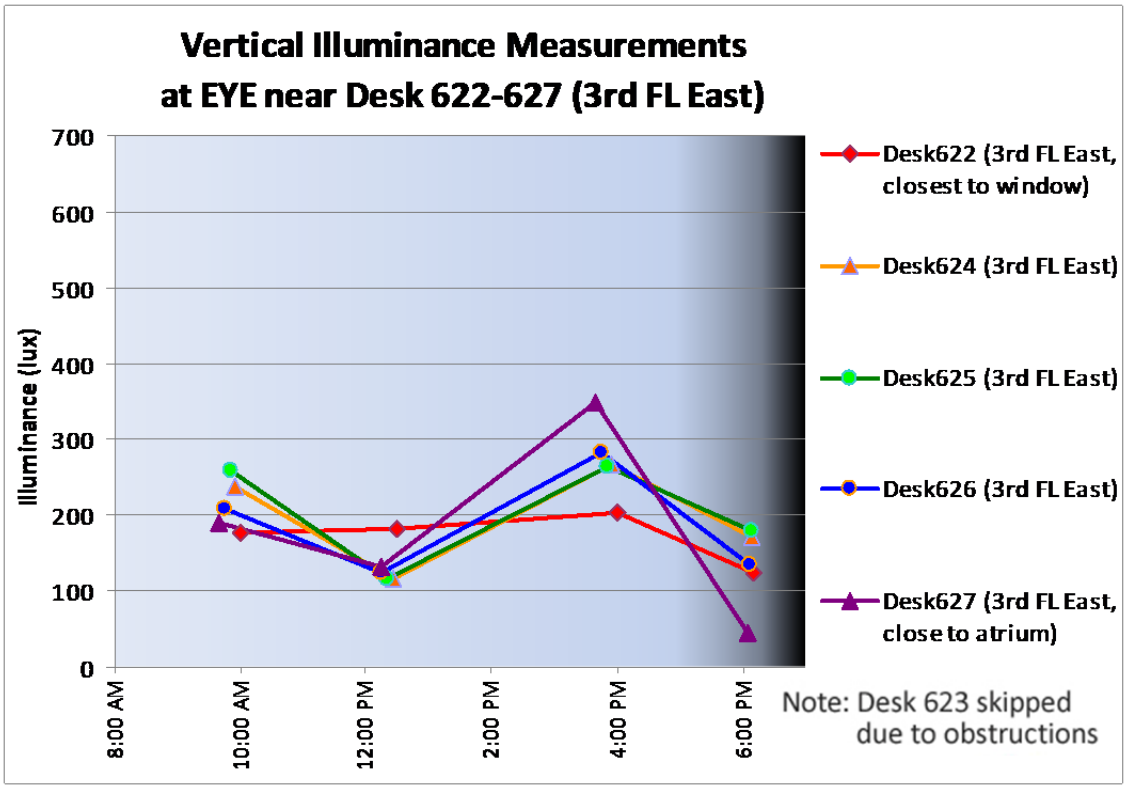
Desk with illuminance measures

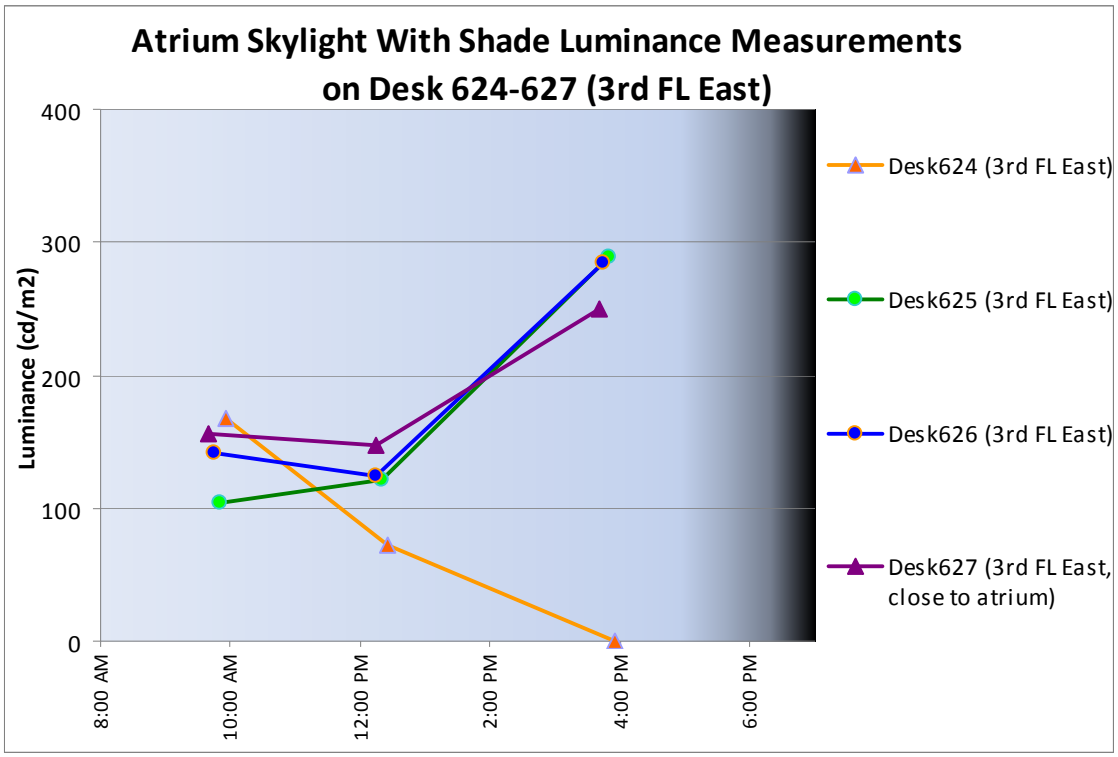
Desk with illuminance + SPD measures

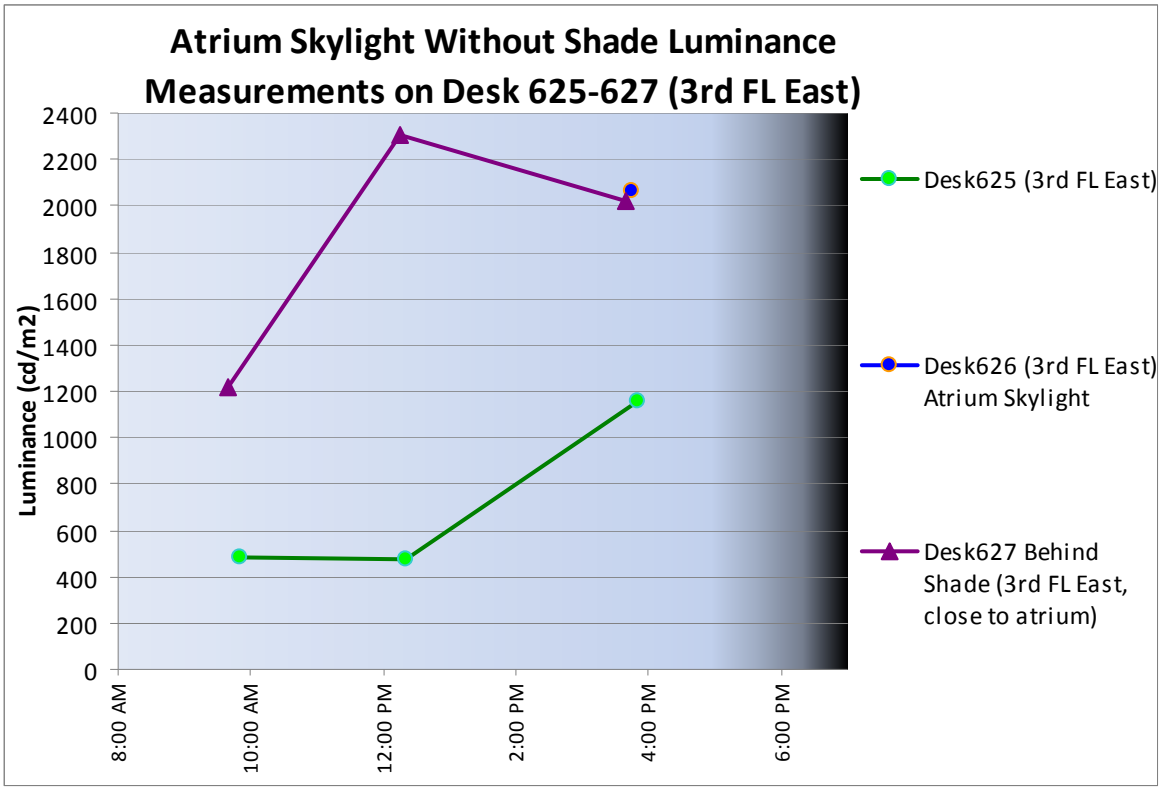
Desk with just SPD

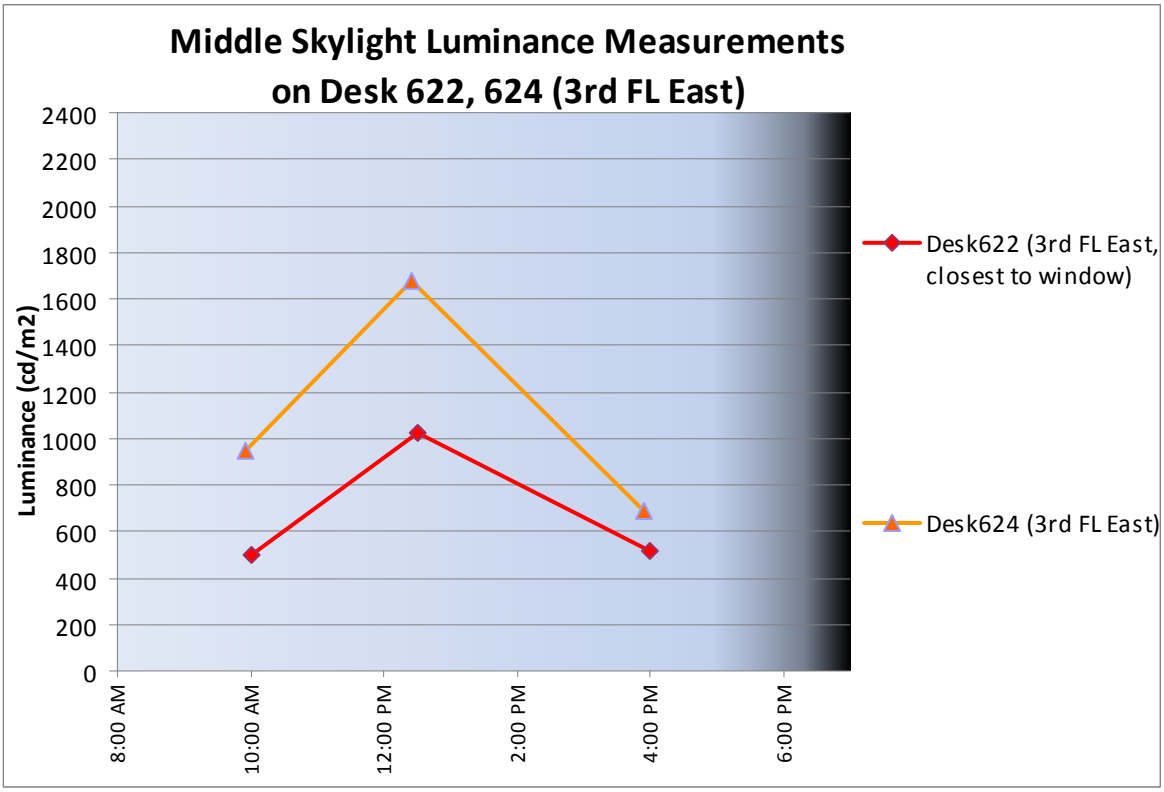

Horizontal Illuminance Measurements
on DESK 622-627 (3rd FL East)
Illuminance (lux)
700
600
500
400
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk624 (3rd FL East)
Desk625 (3rd FL East)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)
Note: Desk 623 skipped due to obstructions

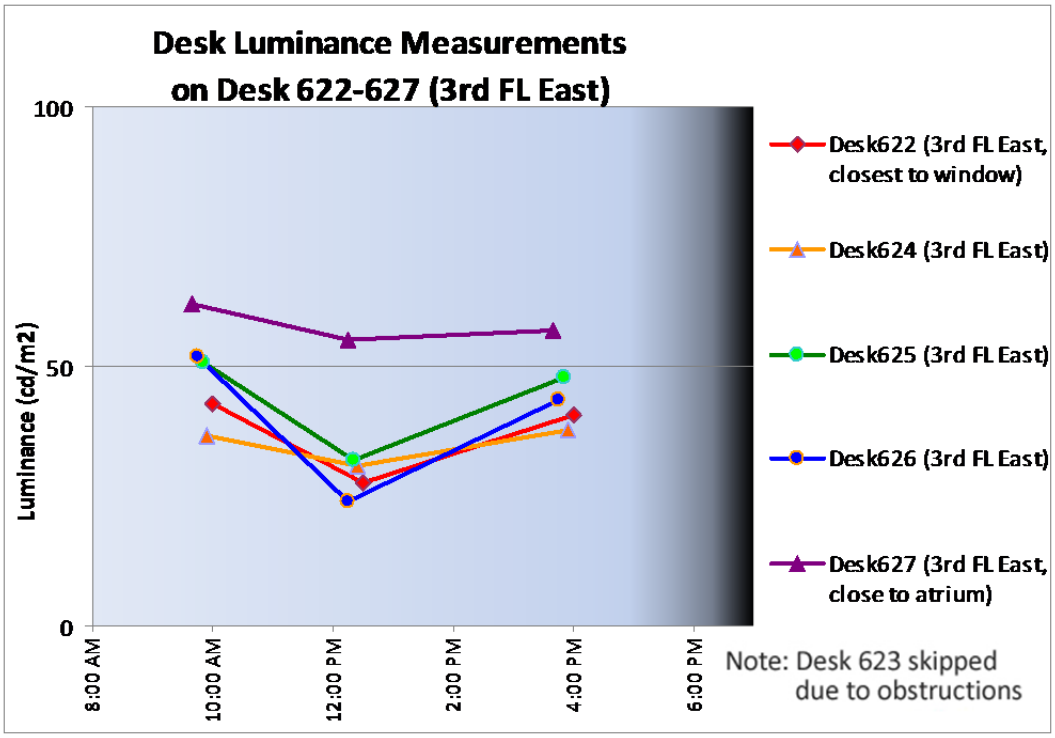

Vertical Illuminance Measurements
on CABINET 622-627 (3rd FL East)
Illuminance (lux)
700
600
500
400
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk624 (3rd FL East)
Desk625 (3rd FL East)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)
Note: Desk 623 skipped due to obstructions

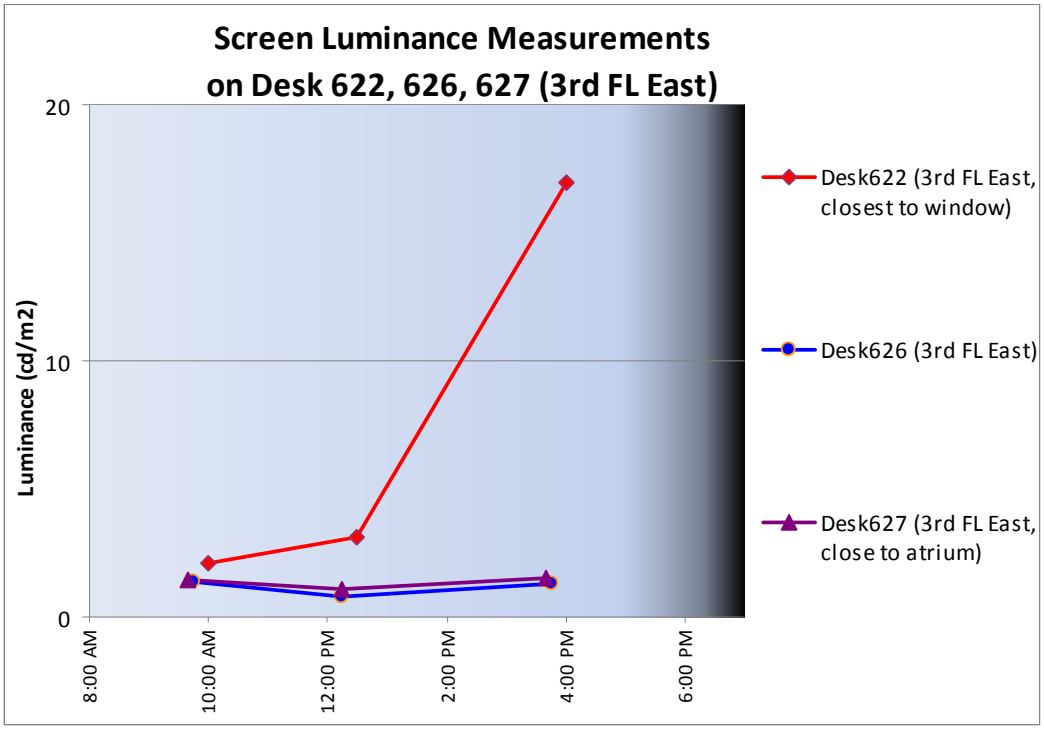

Vertical Illuminance Measurements
at EYE near Desk 622-627 (3rd FL East)
Illuminance (lux)
700
600
500
400
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk624 (3rd FL East)
Desk625 (3rd FL East)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)
Note: Desk 623 skipped due to obstructions


Atrium Skylight With Shade Luminance Measurements
on Desk 624-627 (3rd FL East)
Luminance (cd/m2)
400
300
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk624 (3rd FL East)
Desk625 (3rd FL East)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)


Atrium Skylight Without Shade Luminance Measurements on Desk 625-627 (3rd FL East)
Luminance (cd/m2)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk625 (3rd FL East)
Desk626 (3rd FL East) Atrium Skylight
Desk627 Behind Shade (3rd FL East, close to atrium)

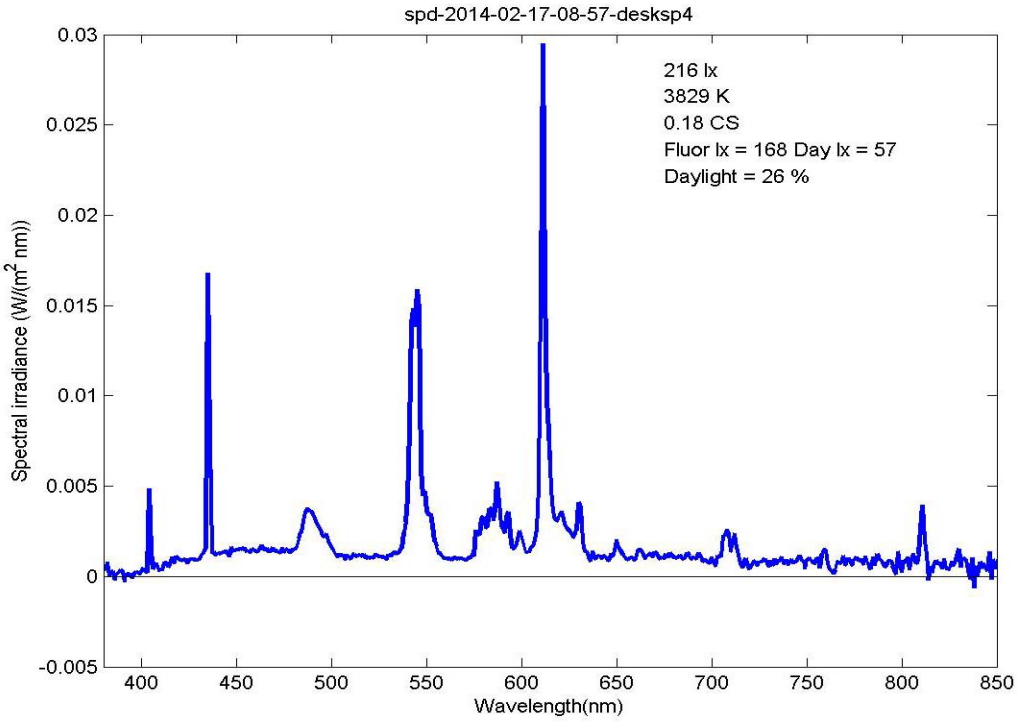

Middle Skylight Luminance Measurements on Desk 622, 624 (3rd FL East)
Luminance (cd/m2)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk624 (3rd FL East)

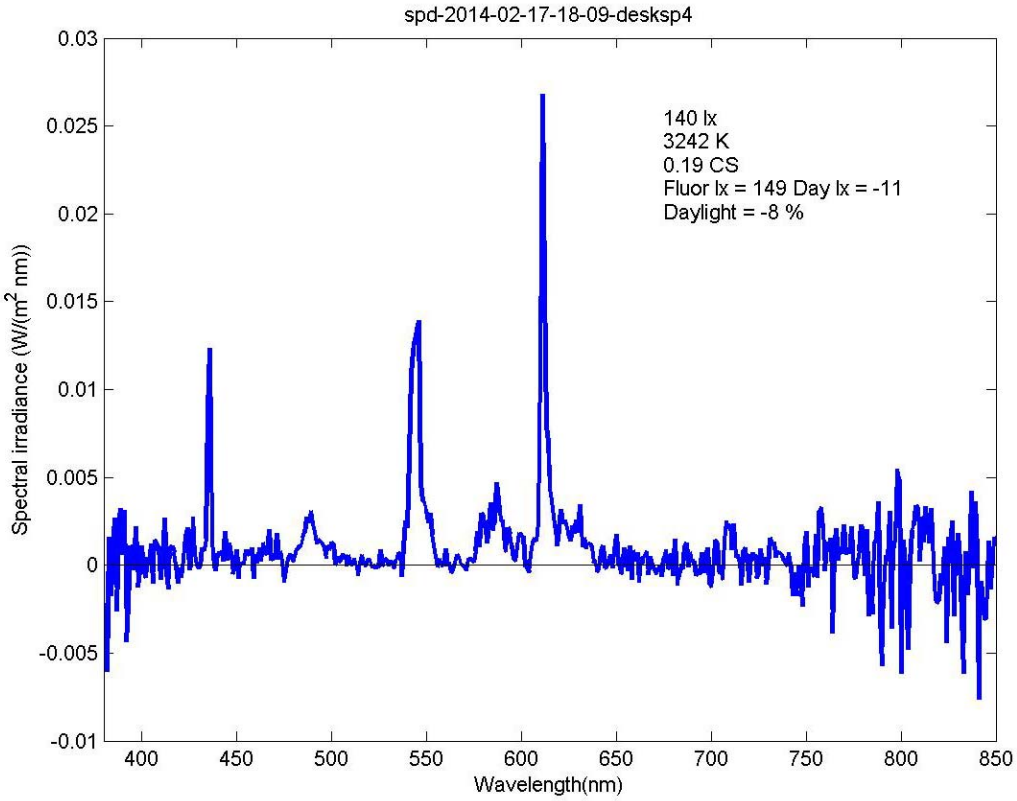

Desk Luminance Measurements
on Desk 622-627 (3rd FL East)
100
50
0
Luminance (cd/m2)
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk624 (3rd FL East)
Desk625 (3rd FL East)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)
Note: Desk 623 skipped due to obstructions


Screen Luminance Measurements
on Desk 622, 626, 627 (3rd FL East)
20
10
0
Luminance (cd/m2)
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk622 (3rd FL East, closest to window)
Desk626 (3rd FL East)
Desk627 (3rd FL East, close to atrium)

DESK 625 (SPACE 4)

13:33, Desk 625, note spectroradiometer equipment in use; see resulting data below

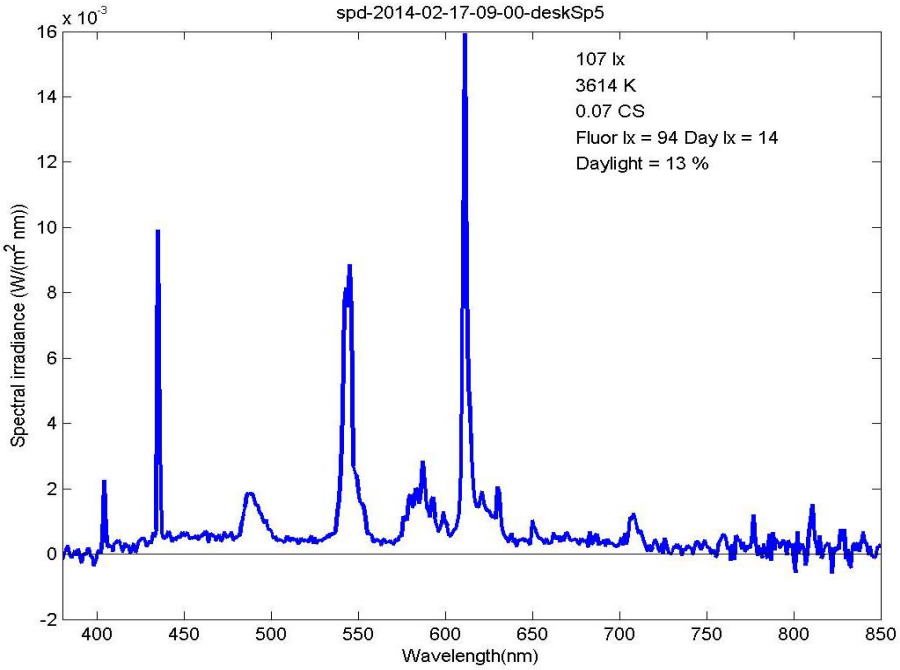


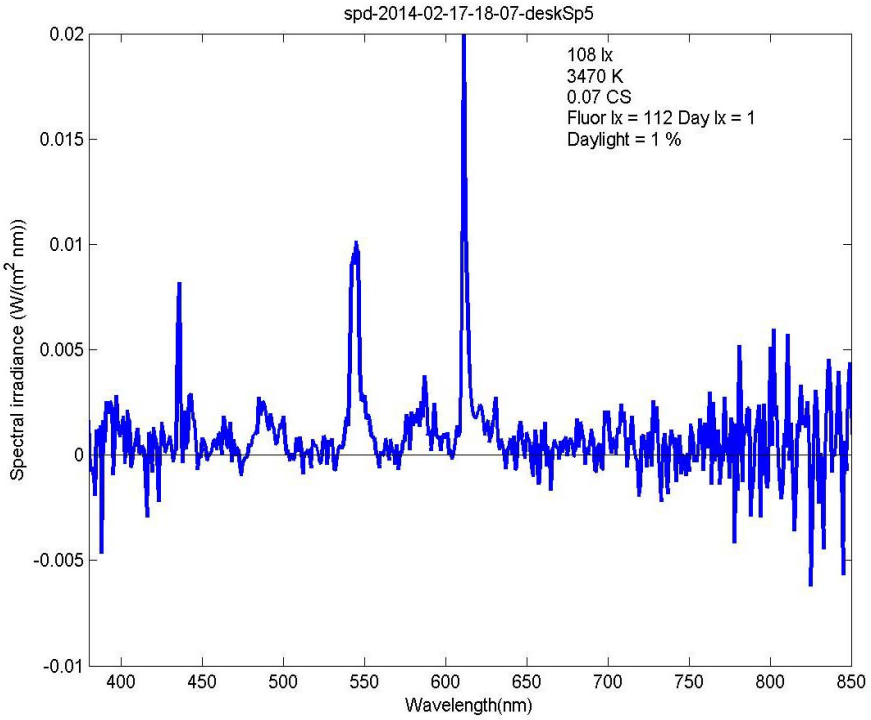

spd-2014-02-17-18-09-desksp4
140 lx
3242 K
0.19 CS
Fluor lx = 149 Day lx = -11
Daylight = -8 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
400
450
500
550
600
650
700
750
800
850

DESK 623 (SPACE 5)

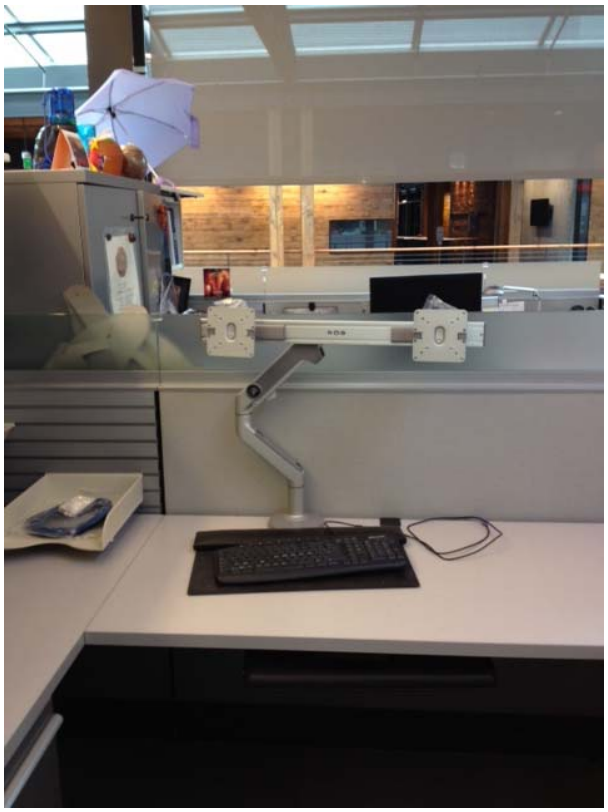
9:02, Desk 623, looking West; note shades and umbrella in the distance

9:04, Desk 623, looking East; blinds down and open

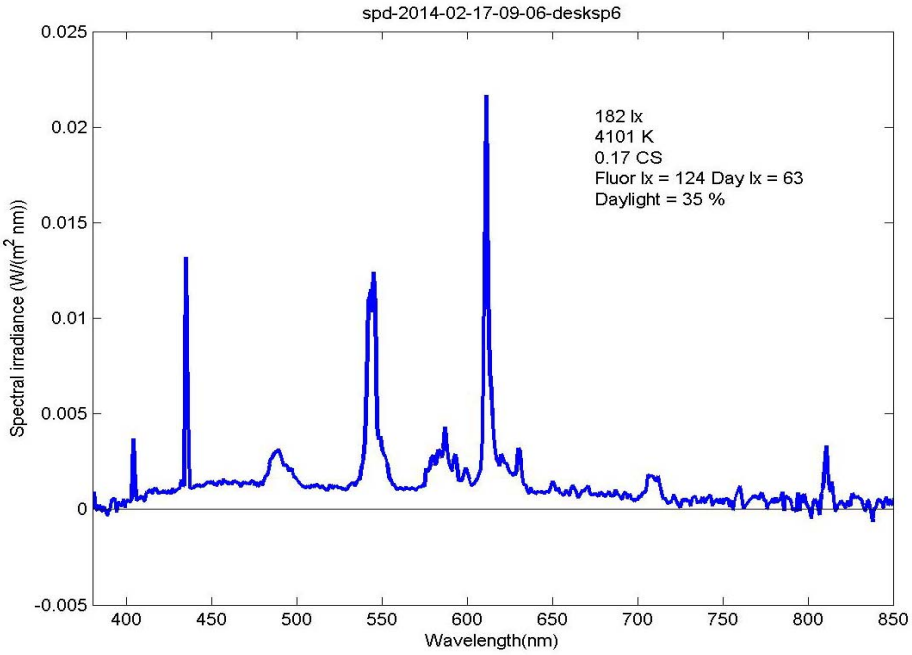

spd-2014-02-17-09-00-deskSp5
x 10^-3
107 lx
3614 K
0.07 CS
Fluor lx = 94 Day lx = 14
Daylight = 13 %
Spectral irradiance (W/(m^2 nm))
Wavelength(nm)


spd-2014-02-17-18-07-deskSp5
108 lx
3470 K
0.07 CS
Fluor lx = 112 Day lx = 1
Daylight = 1 %
Spectral irradiance (W/(m^2 nm))
Wavelength(nm)

SPACE 6



9:06, Space 6, looking West; note shades down and umbrella

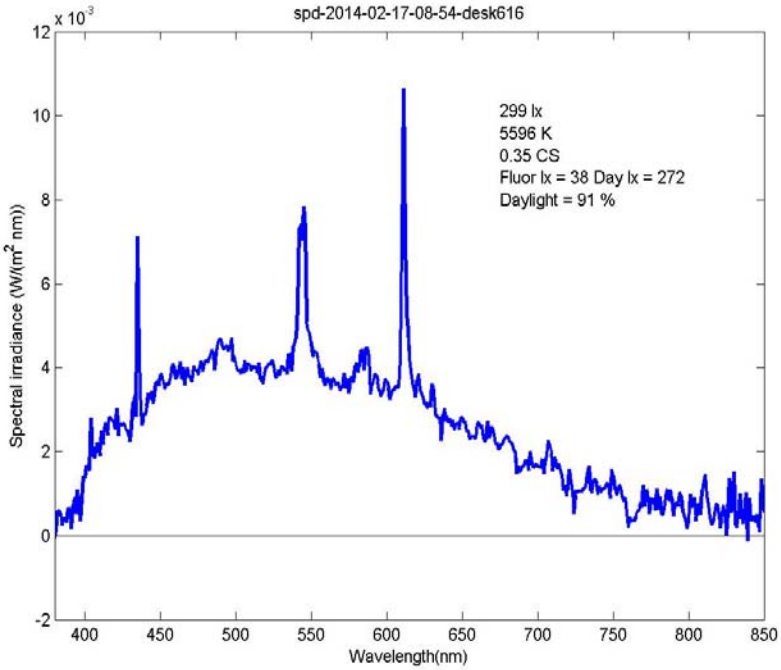


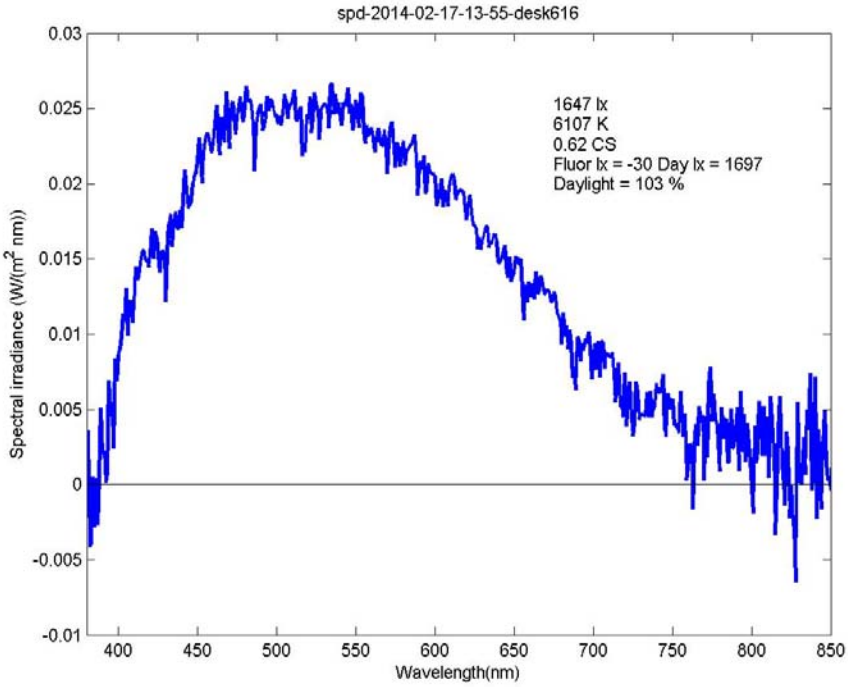
DESK 616

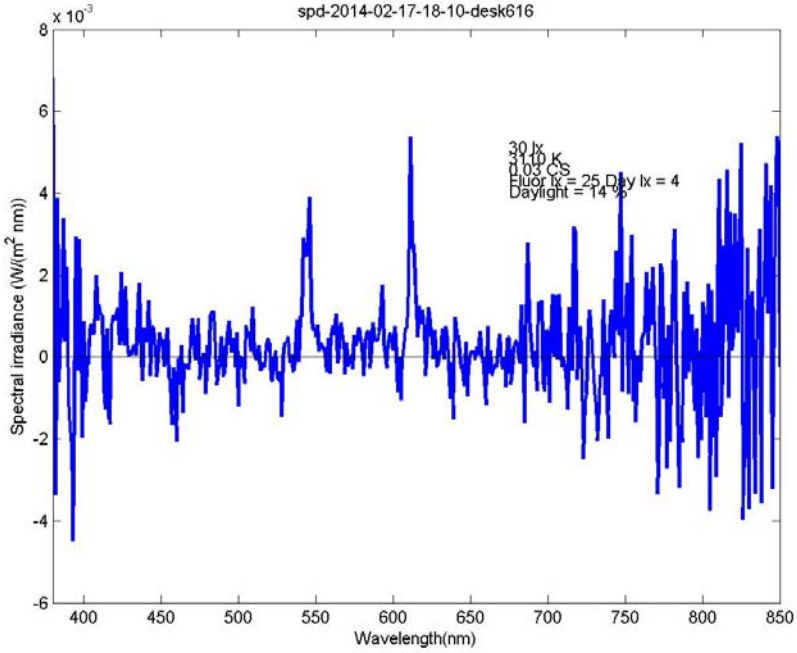
13:29, Desk 616, looking West. Note umbrella and visible skylight. Laptop and Red/Blue device is Spectroradiometer.

13:29, Desk 616, looking West. Note umbrella

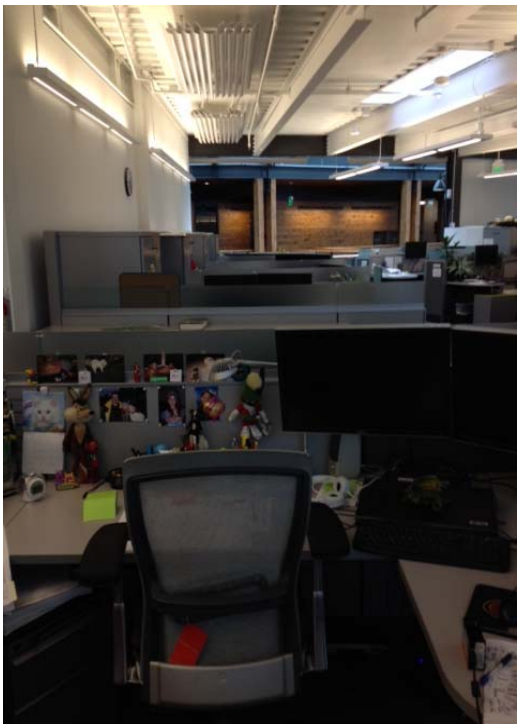
13:56, Desk 616, looking West. Note large umbrella and shafts of sun



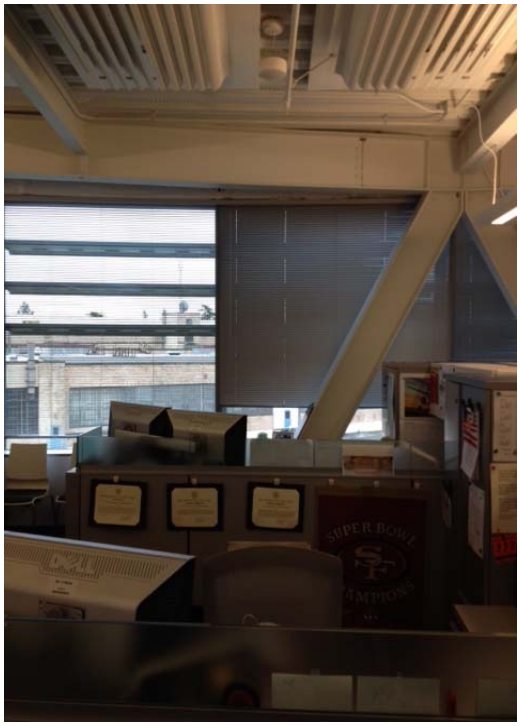

spd-2014-02-17-13-55-desk616
1647 lx
6107 K
0.62 CS
Fluor lx = -30 Day lx = 1697
Daylight = 103 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)


spd-2014-02-17-18-10-desk616
x 10-3
30 lx
3110 K
0.03 CS
Fluor lx = 25 Day lx = 4
Daylight = 14 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

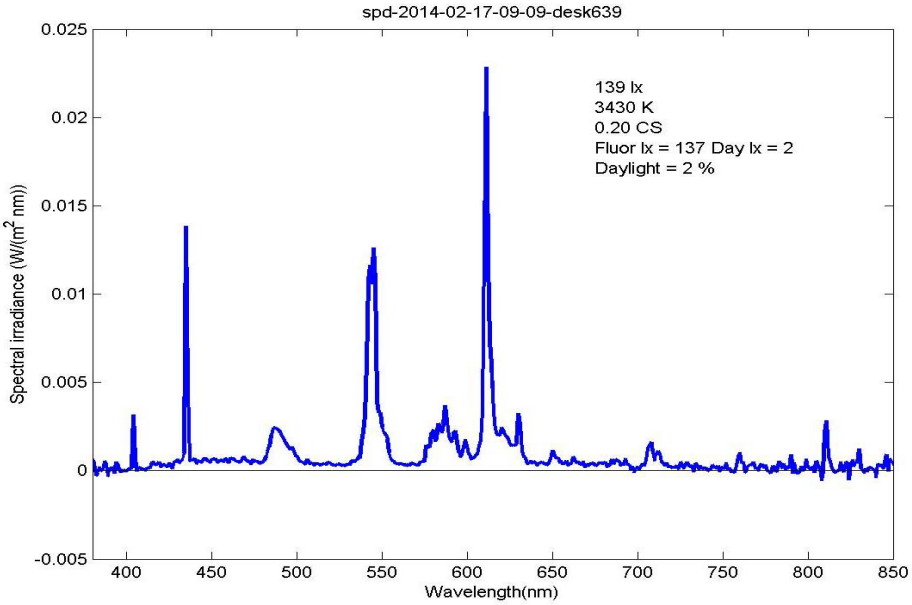
DESK 639



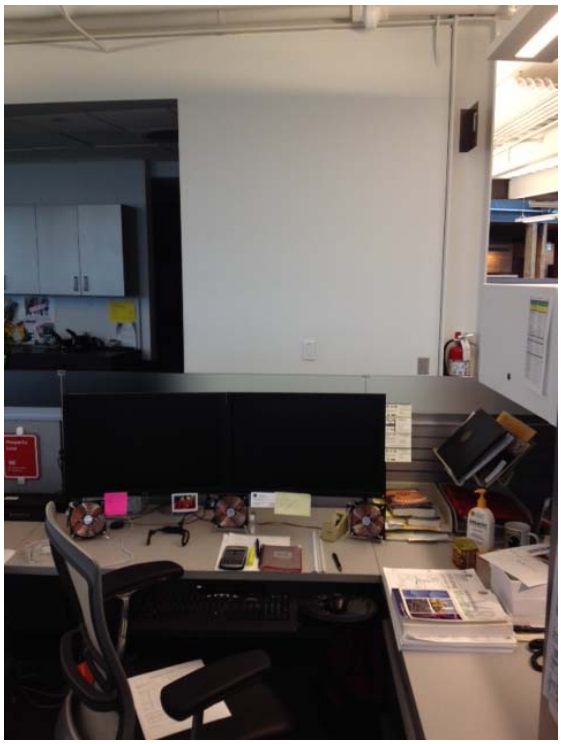
9:10, Desk 639 facing northwest towards atrium



9:10, Desk 639, looking southeast

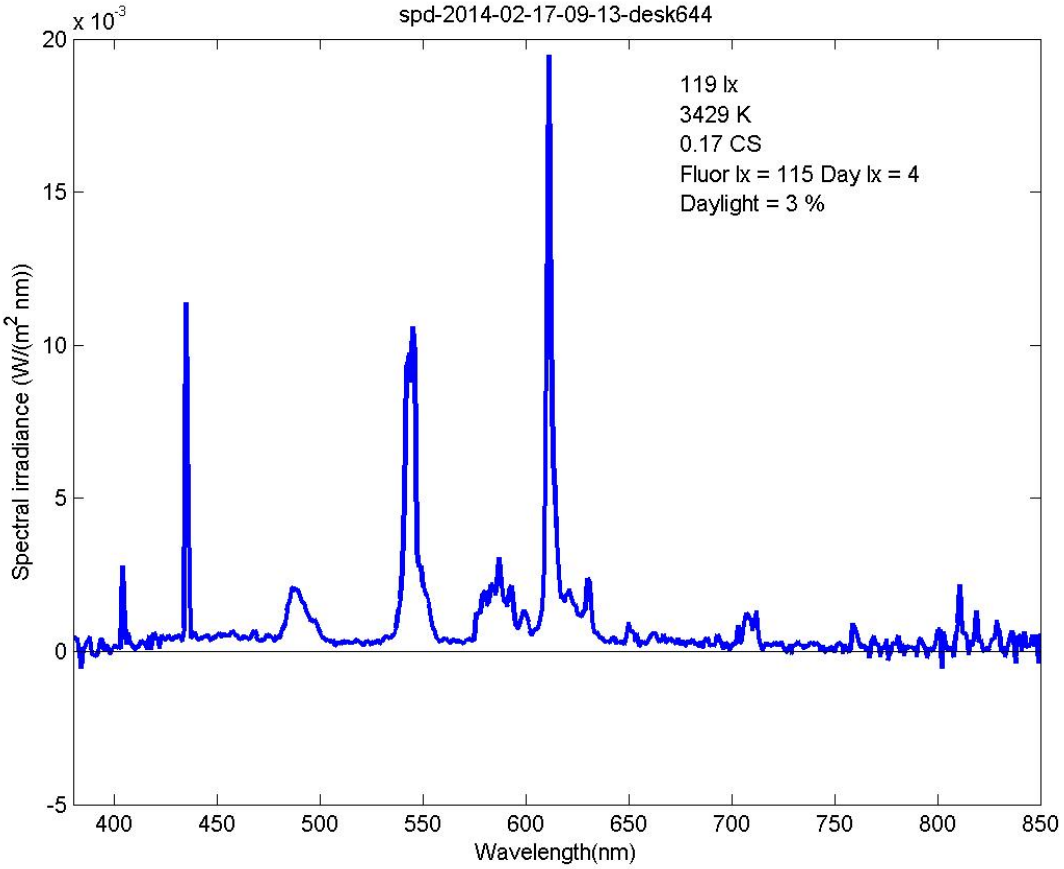

spd-2014-02-17-09-09-desk639
139 lx
3430 K
0.20 CS
Fluor lx = 137 Day lx = 2
Daylight = 2 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

DESK 644



9:13, Desk 644

9:14, Desk 644, looking southeast

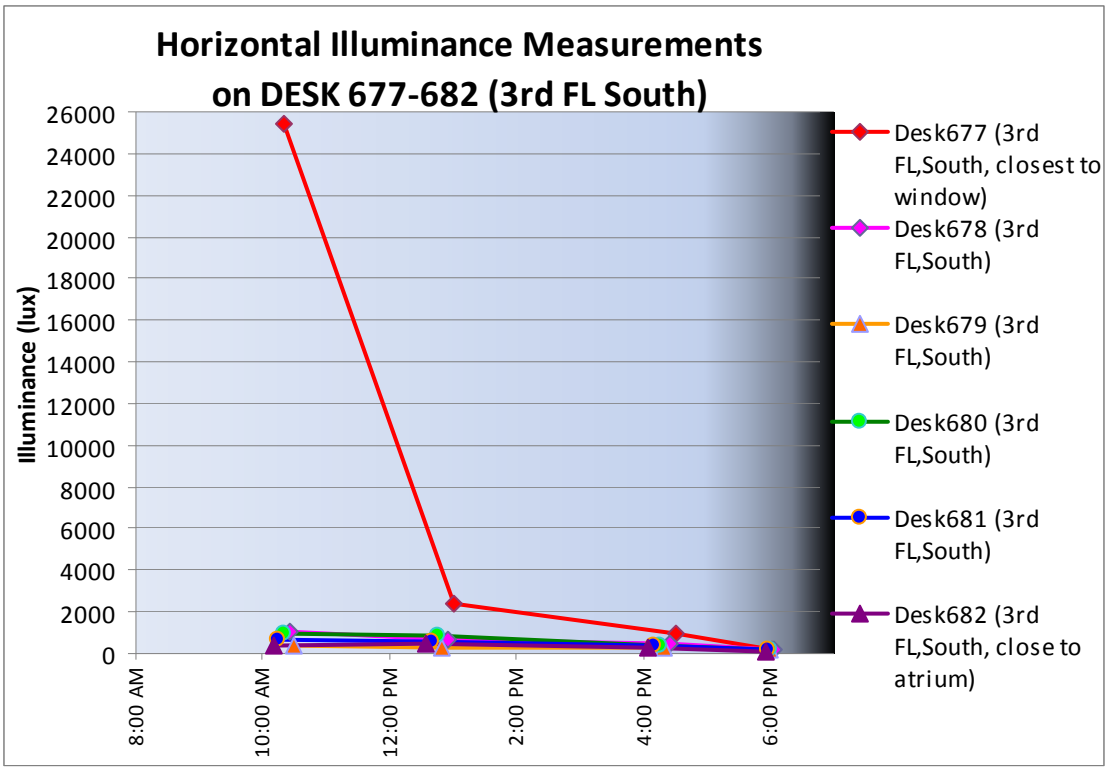

spd-2014-02-17-09-13-desk644
x 10-3
119 lx
3429 K
0.17 CS
Fluor lx = 115 Day lx = 4
Daylight = 3 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
20
15
10
5
0
-5
400
450
500
550
600
650
700
750
800
850

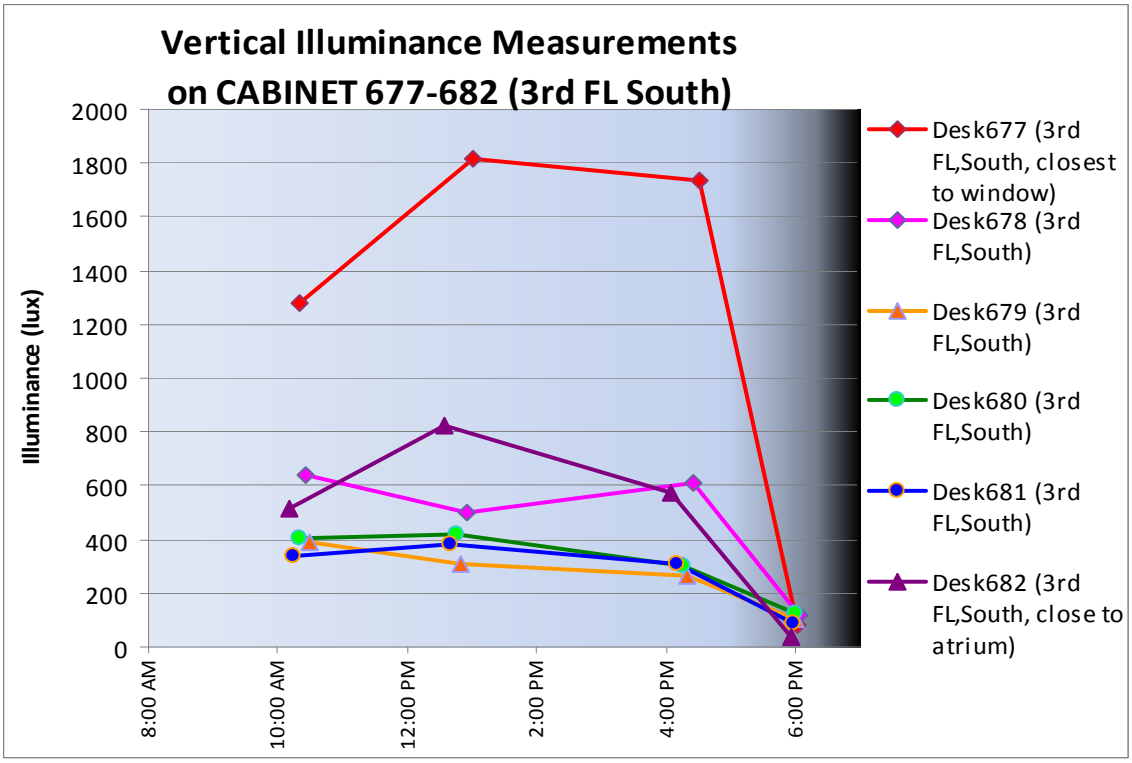
APPENDIX J: PHOTOMETRIC DATA FOR DESKS 677-682, AND 658, 708, AND 710

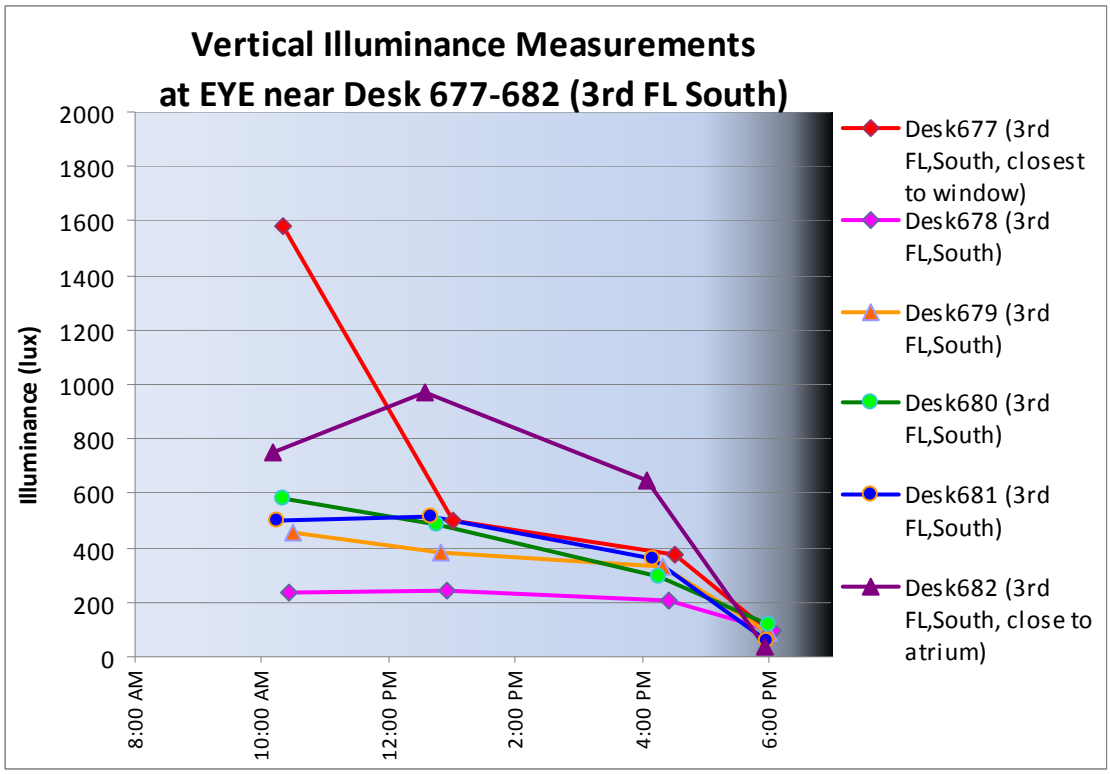
Desk with illuminance measures

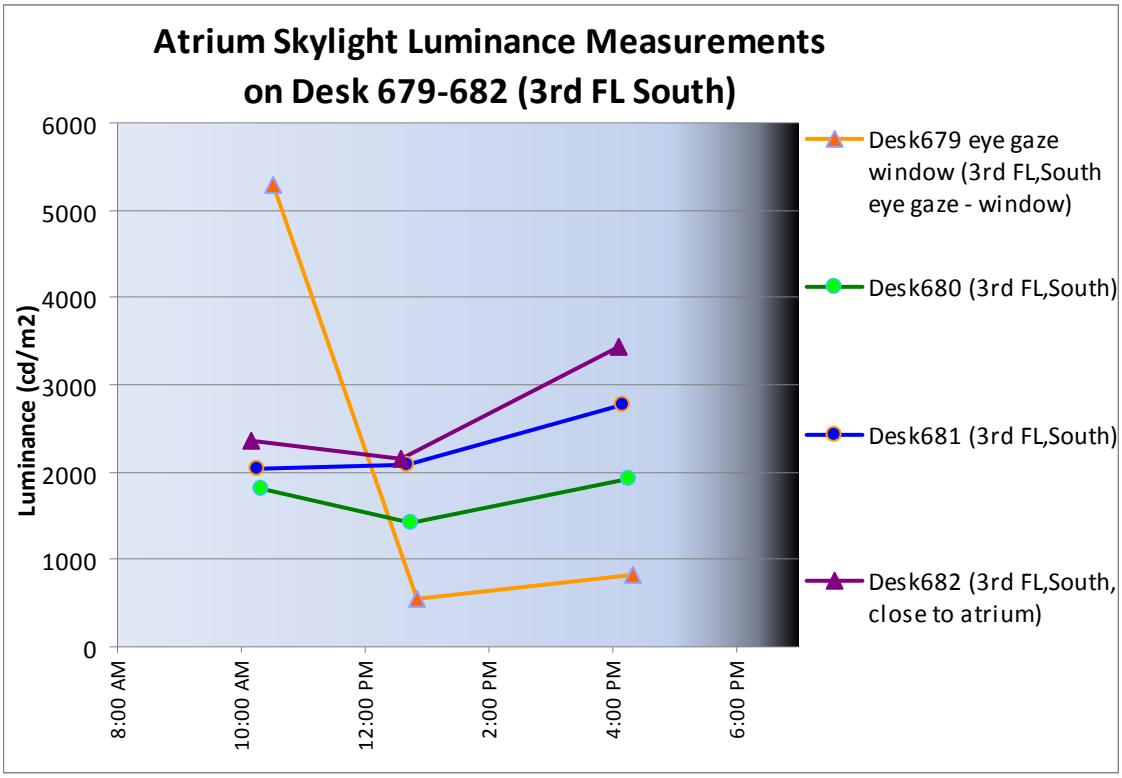
Desk with illuminance + SPD measures

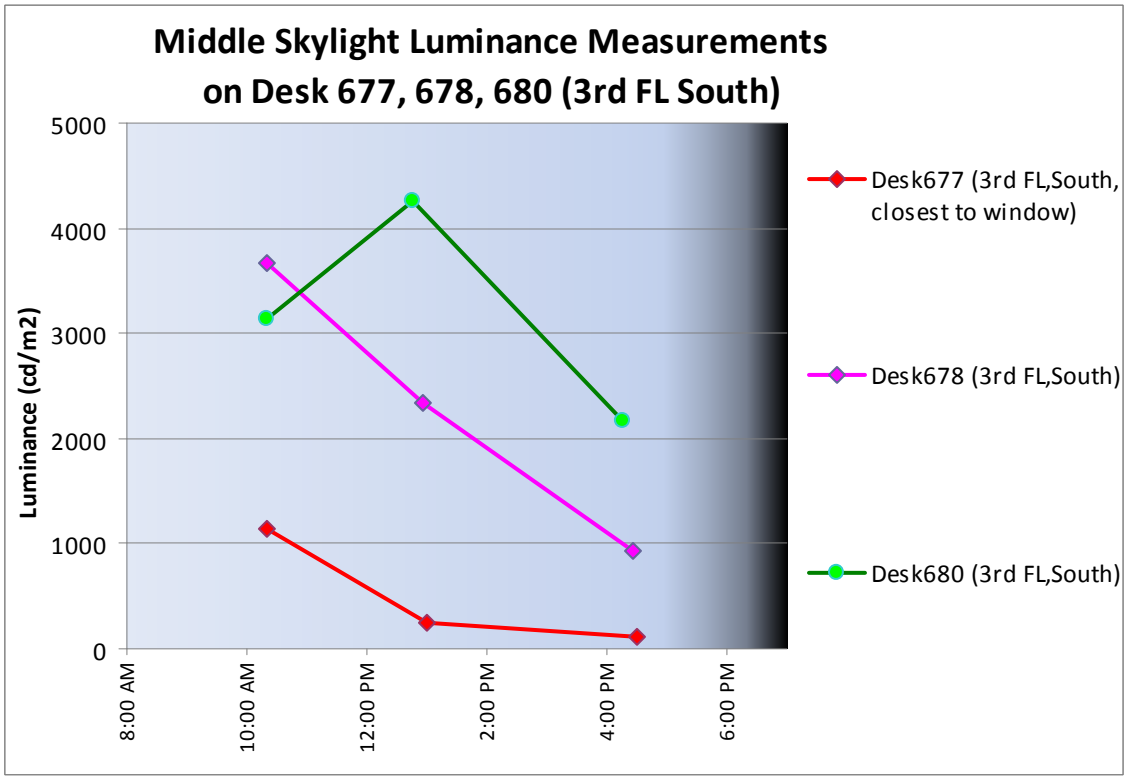
Desk with just SPD

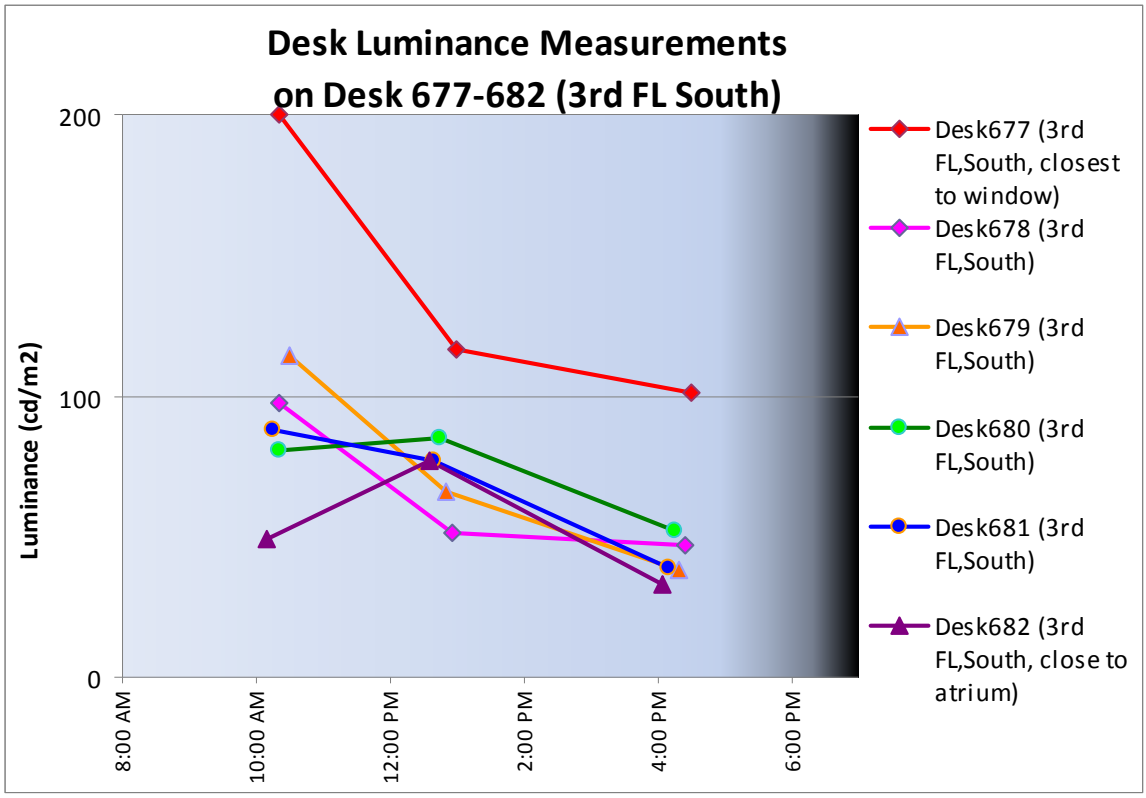

Horizontal Illuminance Measurements
on DESK 677-682 (3rd FL South)
Illuminance (lux)
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk679 (3rd FL,South)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)

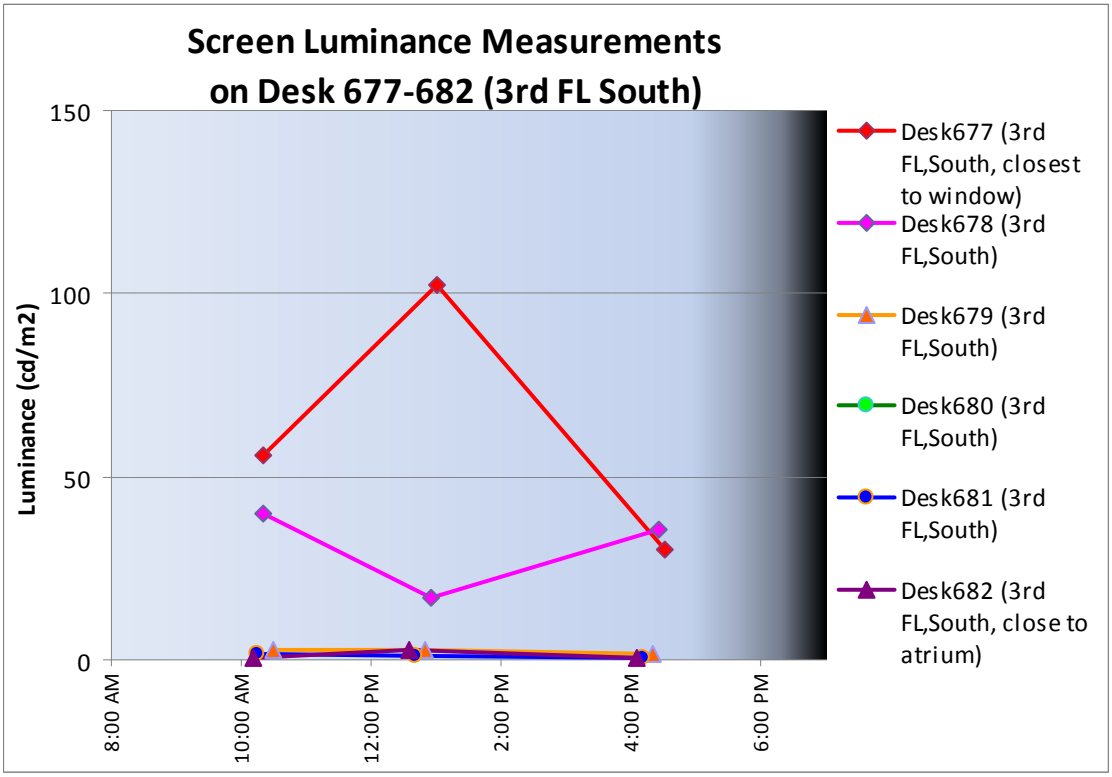

Vertical Illuminance Measurements
on CABINET 677-682 (3rd FL South)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk679 (3rd FL,South)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)


Vertical Illuminance Measurements
at EYE near Desk 677-682 (3rd FL South)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk679 (3rd FL,South)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)


Atrium Skylight Luminance Measurements
on Desk 679-682 (3rd FL South)
Luminance (cd/m2)
6000
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk679 eye gaze window (3rd FL,South eye gaze - window)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)


Middle Skylight Luminance Measurements
on Desk 677, 678, 680 (3rd FL South)
Luminance (cd/m2)
5000
4000
3000
2000
1000
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk680 (3rd FL,South)

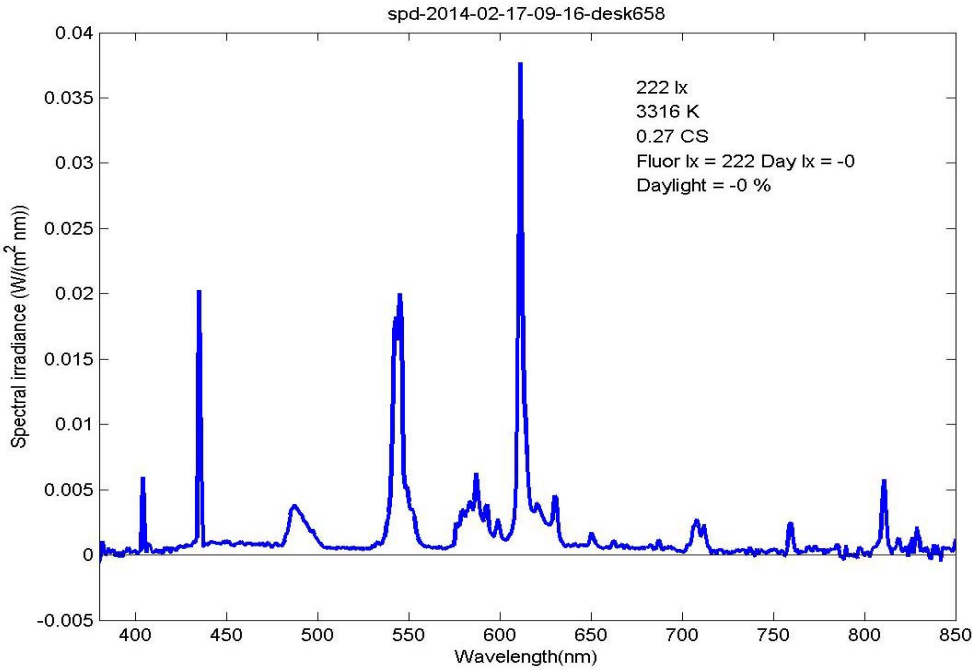

Desk Luminance Measurements
on Desk 677-682 (3rd FL South)
Luminance (cd/m2)
200
100
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk679 (3rd FL,South)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)


Screen Luminance Measurements
on Desk 677-682 (3rd FL South)
Luminance (cd/m2)
150
100
50
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk677 (3rd FL,South, closest to window)
Desk678 (3rd FL,South)
Desk679 (3rd FL,South)
Desk680 (3rd FL,South)
Desk681 (3rd FL,South)
Desk682 (3rd FL,South, close to atrium)

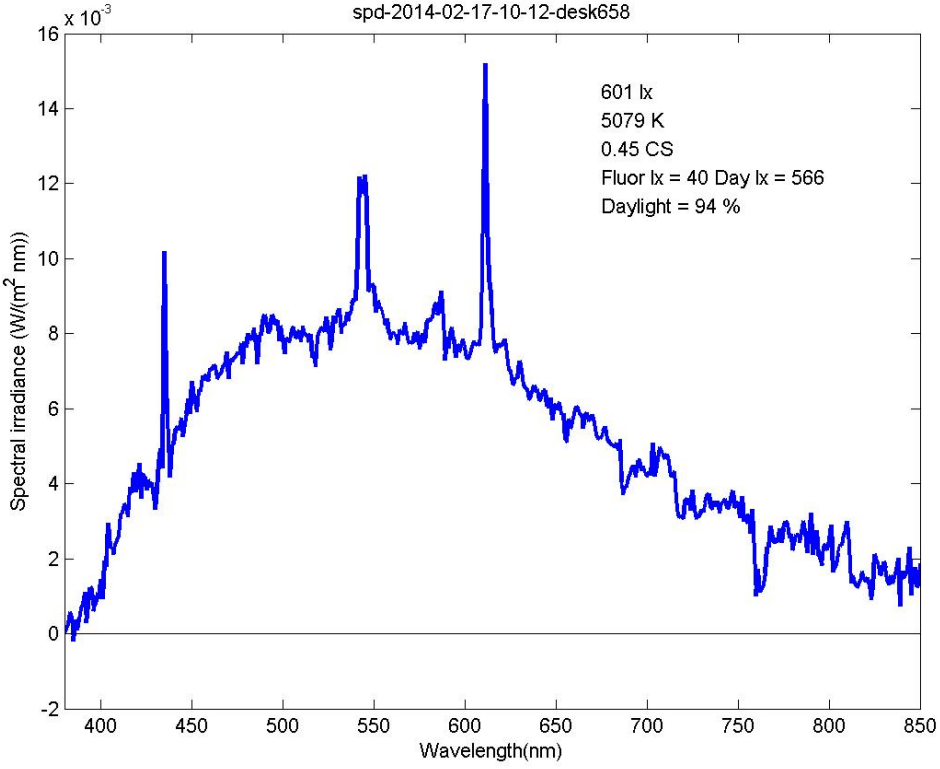
DESK 658

9:17, Desk 658, Looking South behind desk

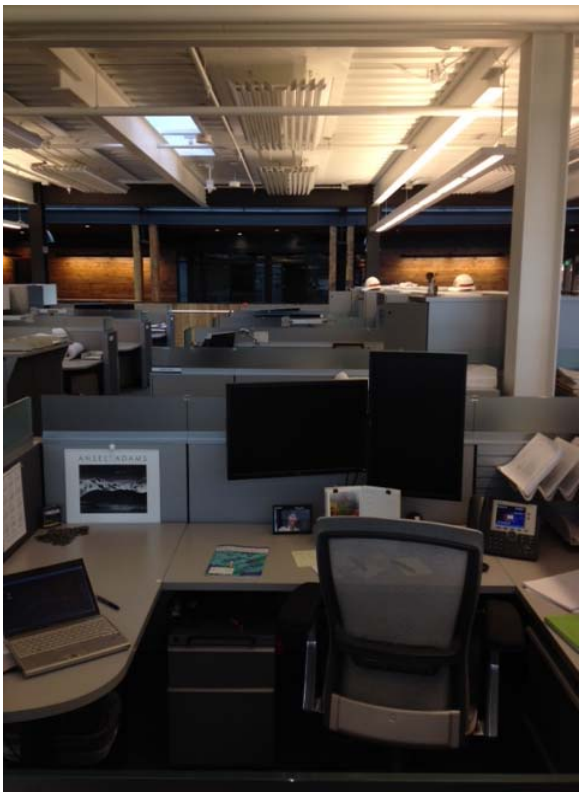
9:17, Desk 658, Looking North towards atrium



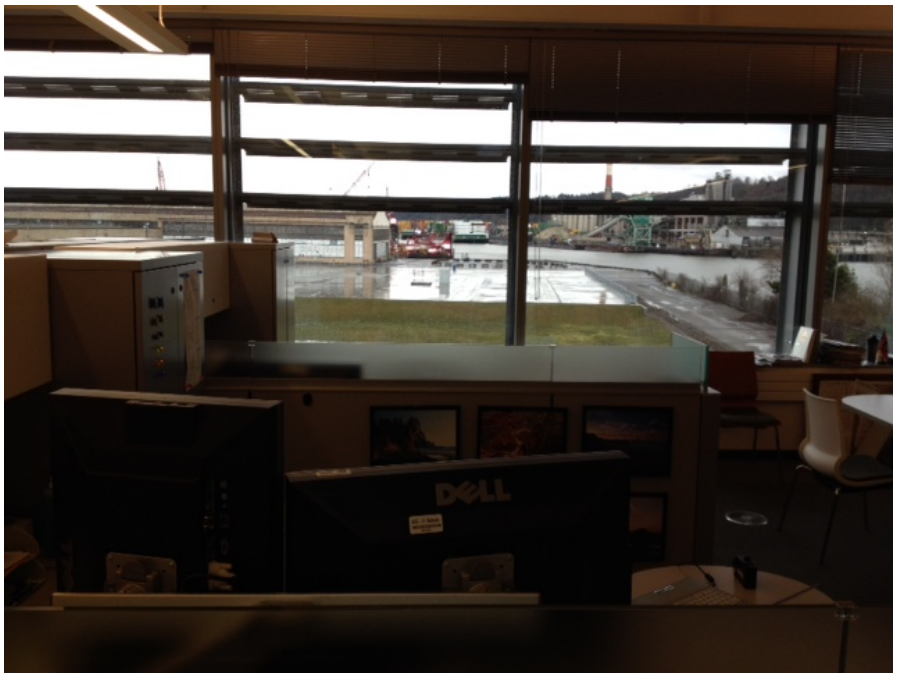
10:14, Desk 658. Note shaft of sun and resulting SPD below



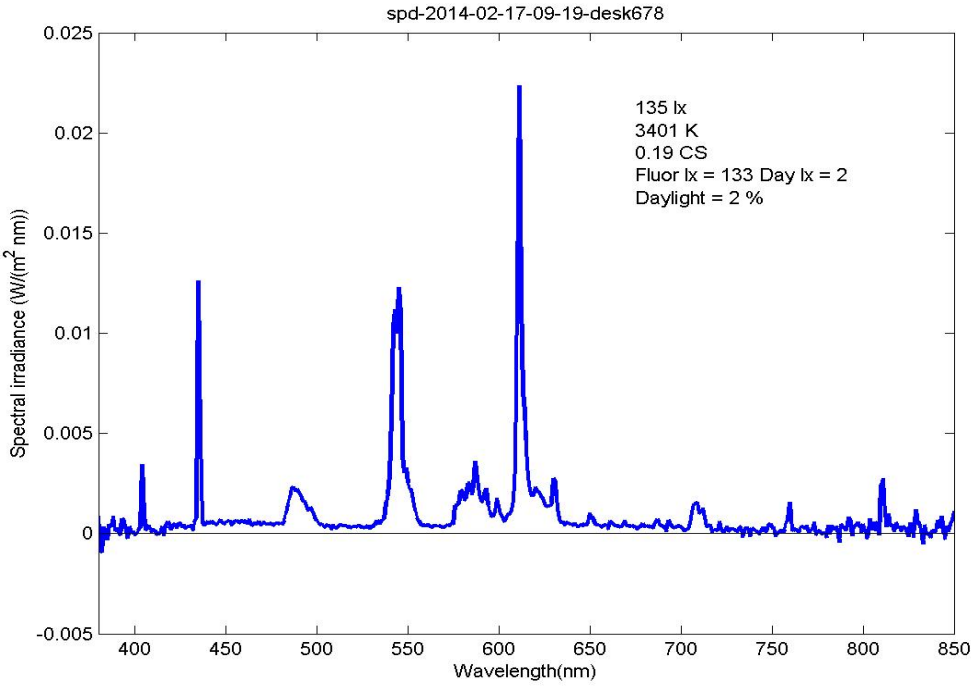
DESK 678

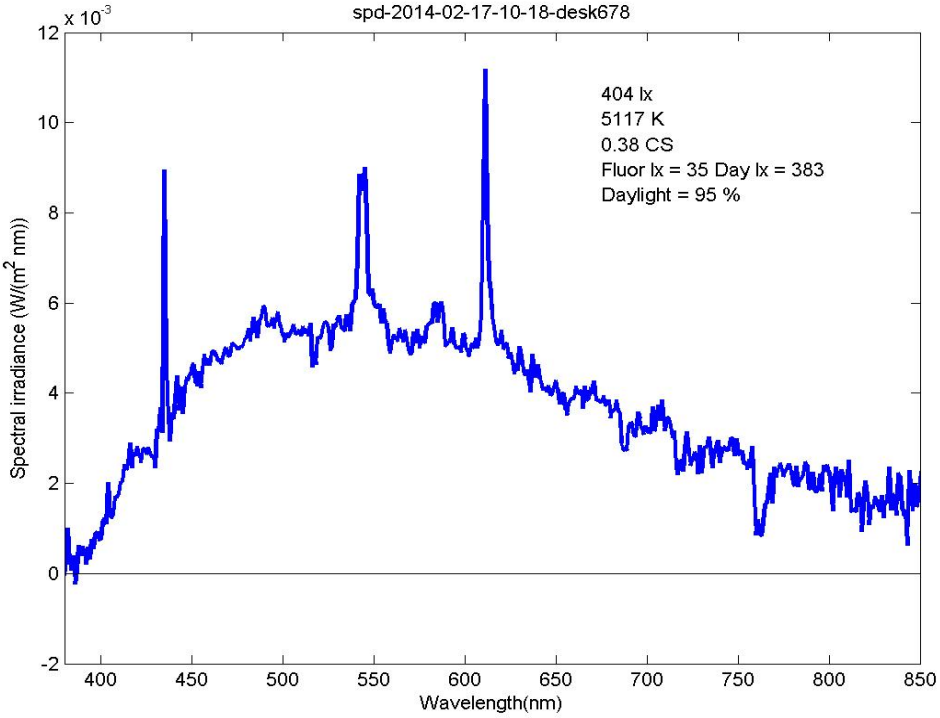


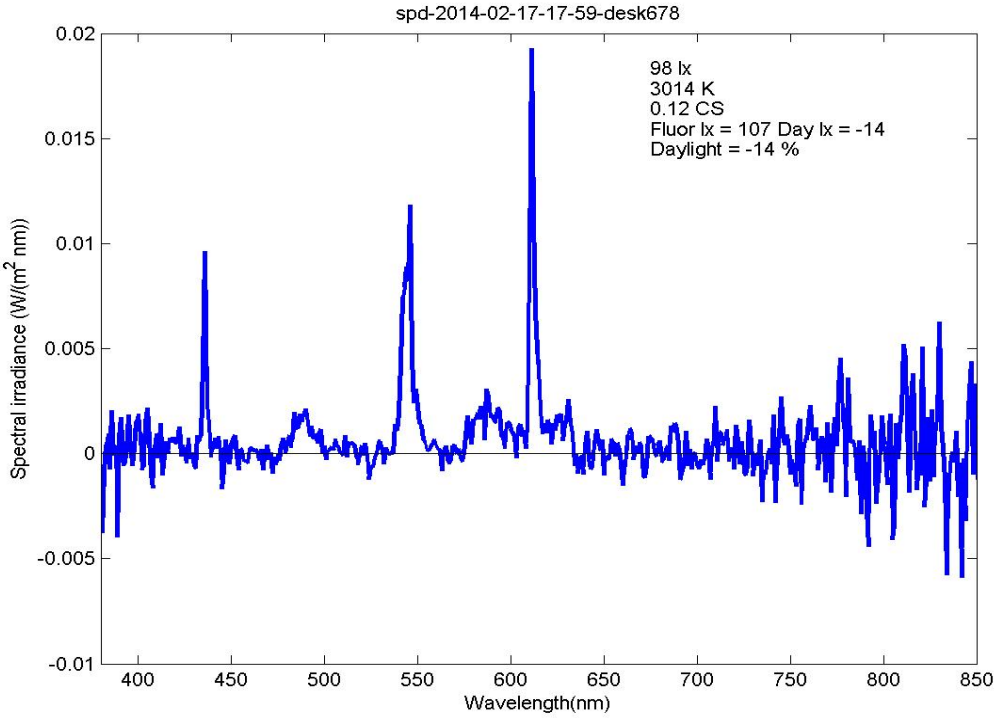
9:20, Desk 678, looking North

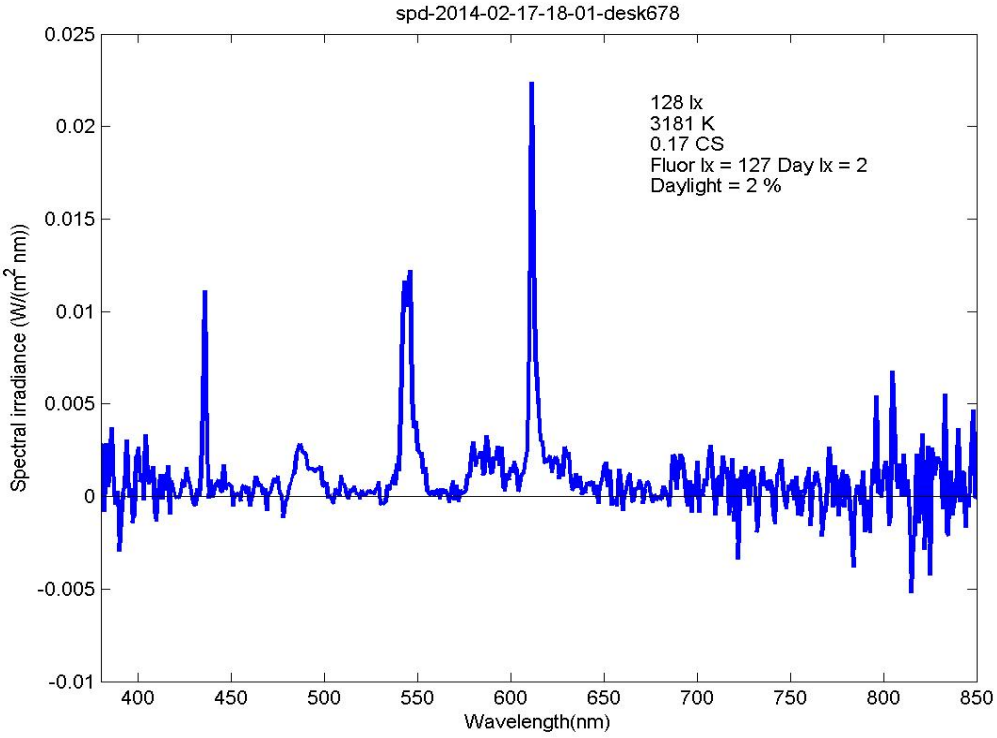


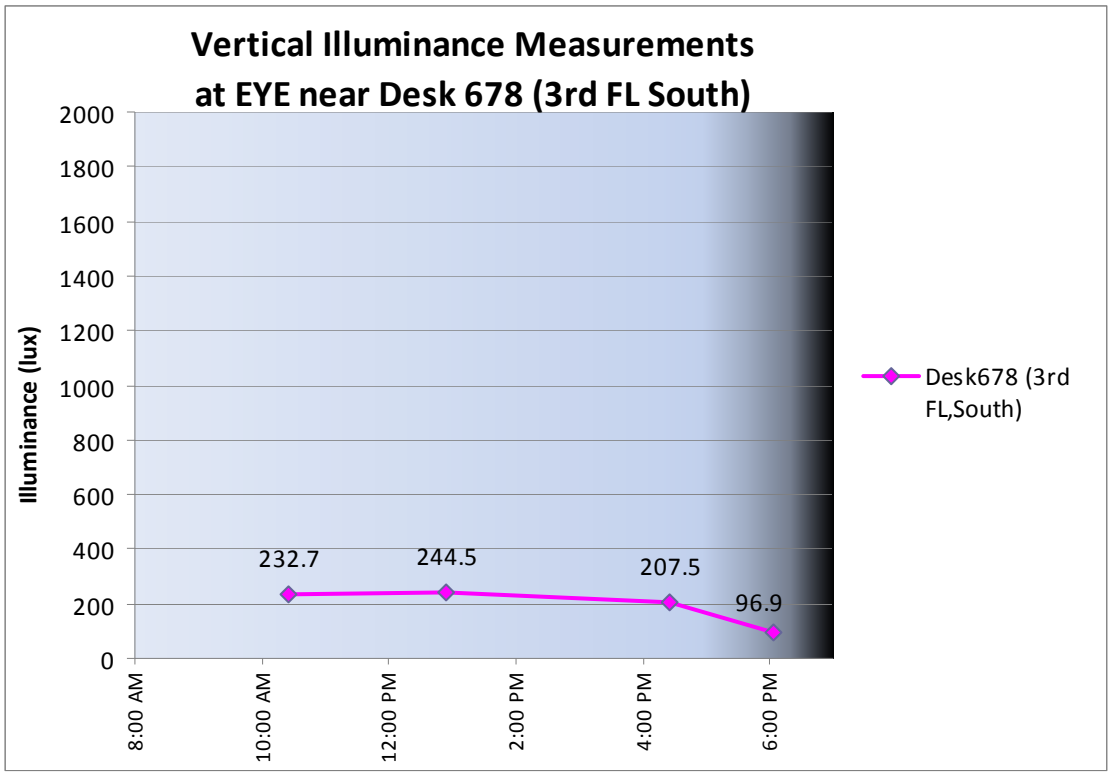
9:20, Desk 678, looking South behind desk


spd-2014-02-17-09-19-desk678
135 lx
3401 K
0.19 CS
Fluor lx = 133 Day lx = 2
Daylight = 2 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
400
450
500
550
600
650
700
750
800
850

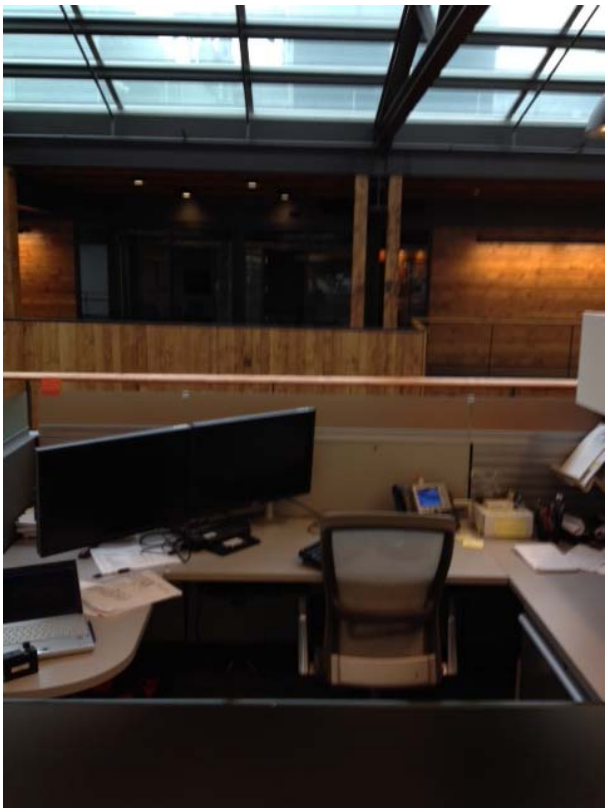

spd-2014-02-17-10-18-desk678
x 10-3
404 lx
5117 K
0.38 CS
Fluor lx = 35 Day lx = 383
Daylight = 95 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
12
10
8
6
4
2
0
-2
400
450
500
550
600
650
700
750
800
850


spd-2014-02-17-17-59-desk678
98 lx
3014 K
0.12 CS
Fluor lx = 107 Day lx = -14
Daylight = -14 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.02
0.015
0.01
0.005
0
-0.005
-0.01
400
450
500
550
600
650
700
750
800
850

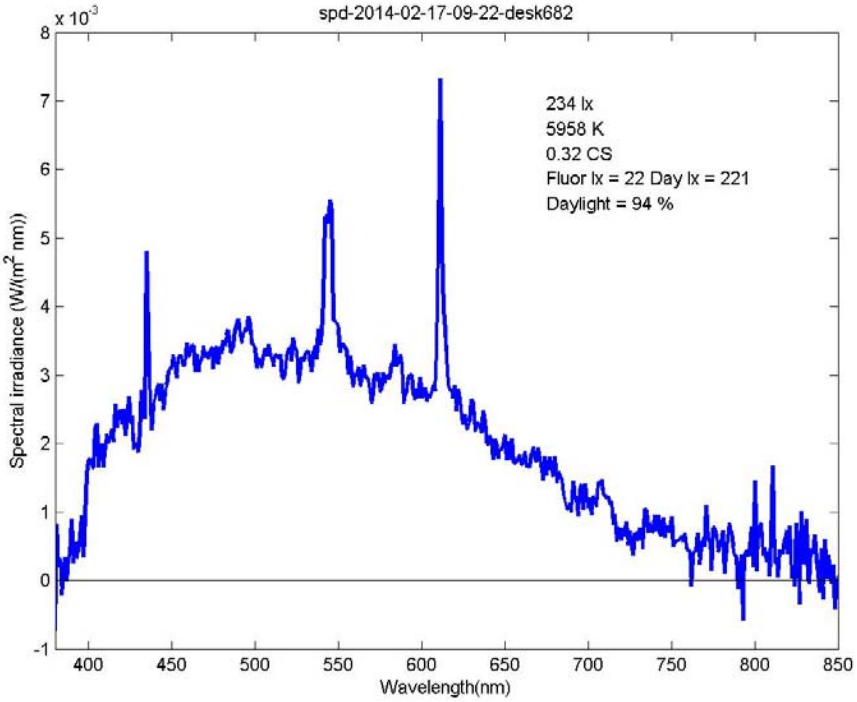

spd-2014-02-17-18-01-desk678
128 lx
3181 K
0.17 CS
Fluor lx = 127 Day lx = 2
Daylight = 2 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
400
450
500
550
600
650
700
750
800
850

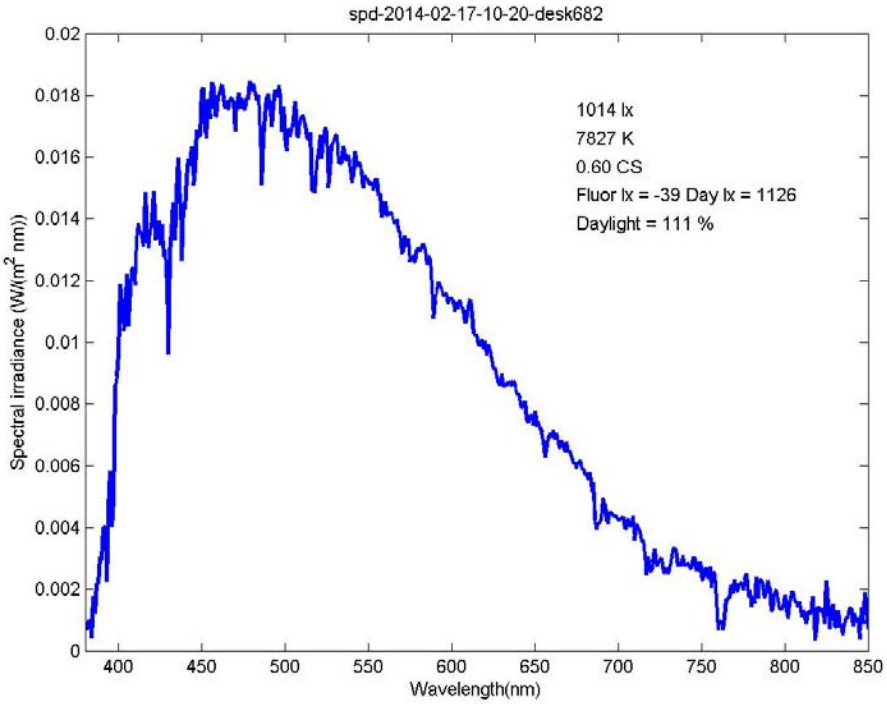

Vertical Illuminance Measurements
at EYE near Desk 678 (3rd FL South)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
232.7
244.5
207.5
96.9
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
Desk678 (3rd FL,South)

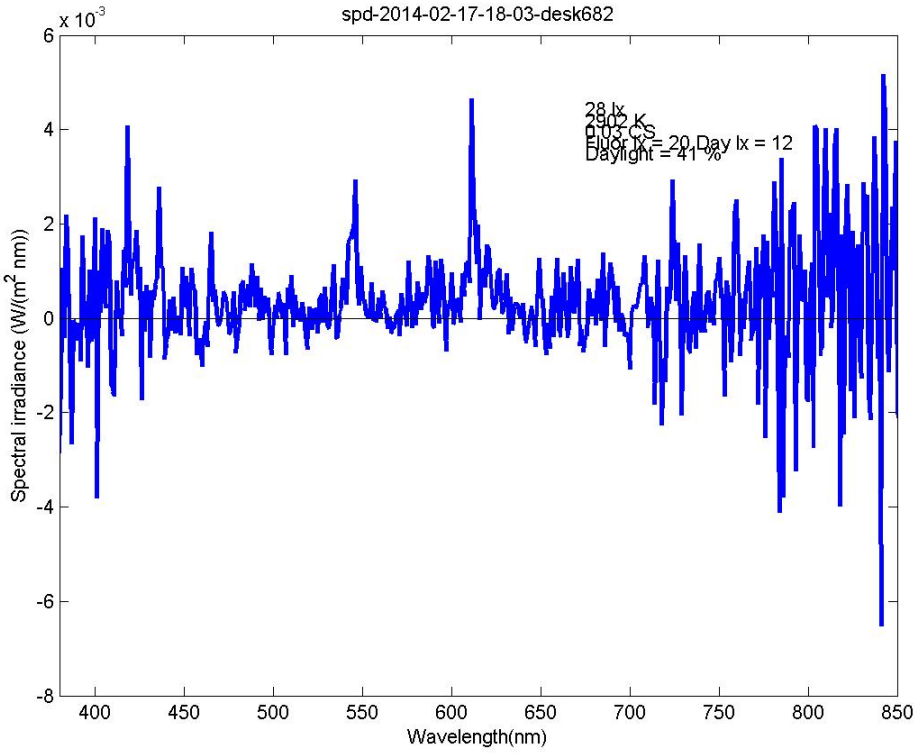
DESK 682

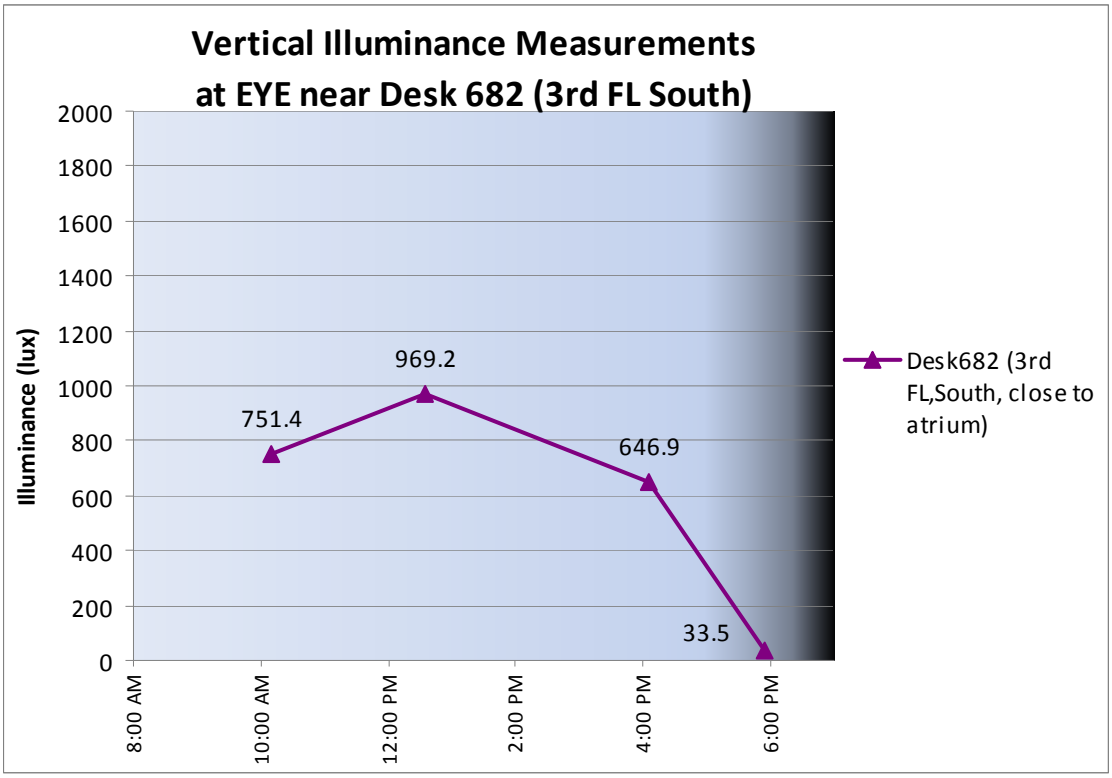


9:23, Desk 682, looking North. Note view of atrium skylight

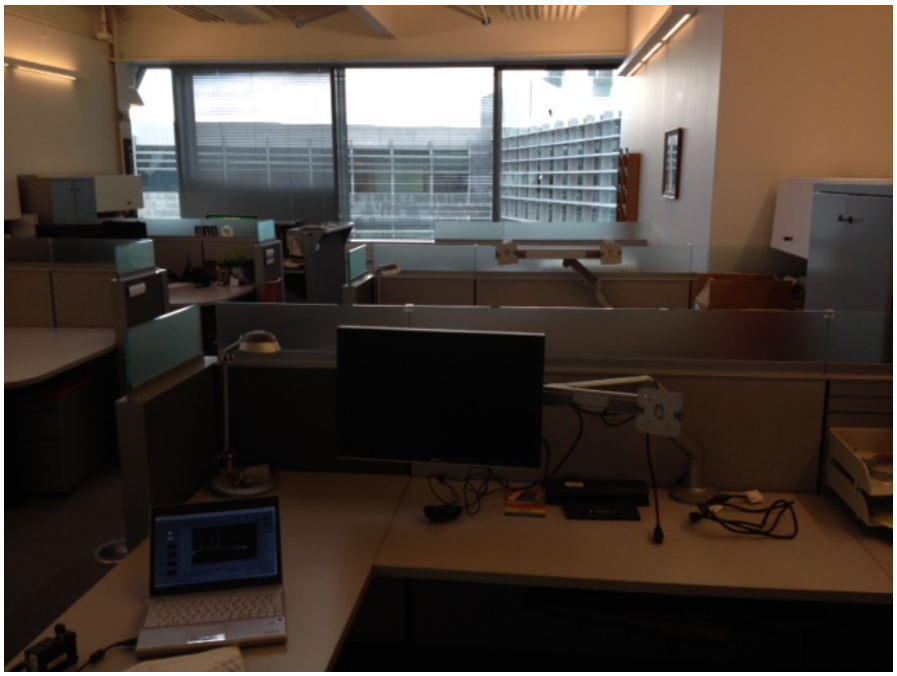



spd-2014-02-17-10-20-desk682
1014 lx
7827 K
0.60 CS
Fluor lx = -39 Day lx = 1126
Daylight = 111 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

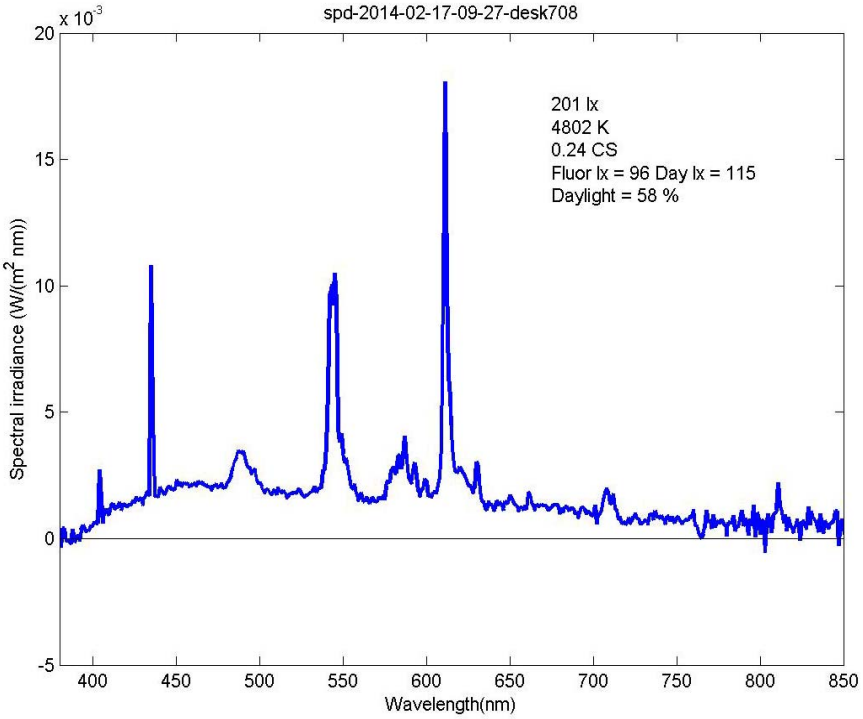

spd-2014-02-17-18-03-desk682
x 10-3
28 lx
2902 K
0.03 CS
Fluor lx = 20 Day lx = 12
Daylight = 41 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)

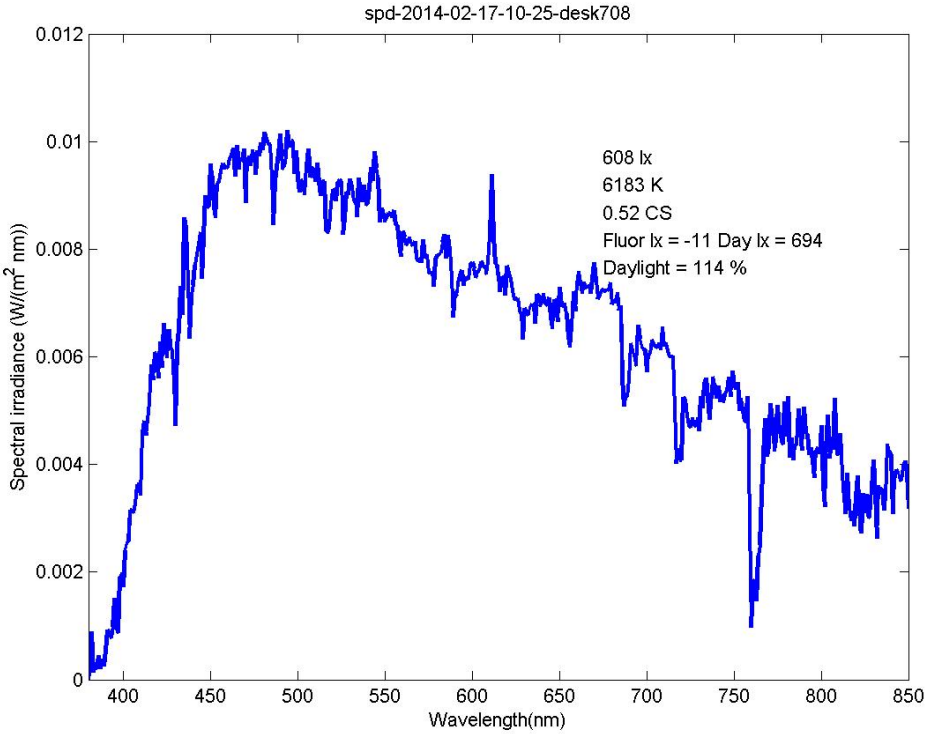

Vertical Illuminance Measurements
at EYE near Desk 682 (3rd FL South)
Illuminance (lux)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
751.4
969.2
646.9
33.5
Desk682 (3rd FL,South, close to atrium)

DESK 708



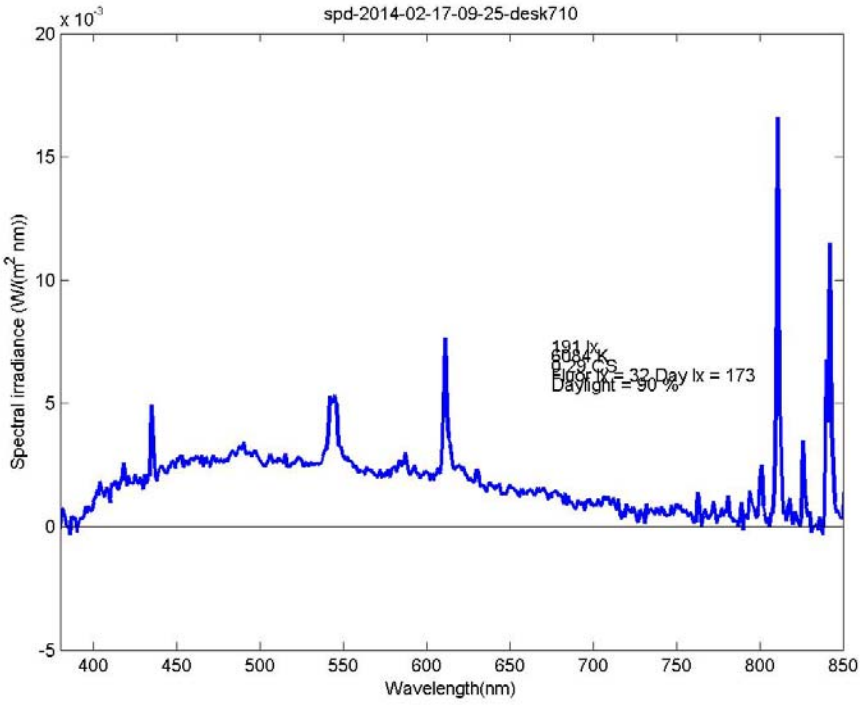
9:28, Desk 708, looking North. One shade down but open

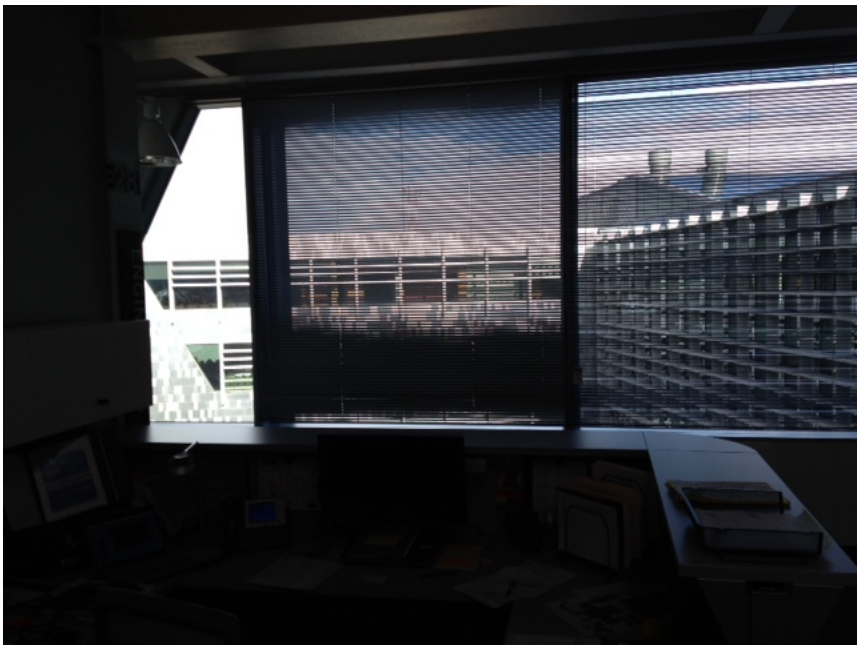



spd-2014-02-17-10-25-desk708
608 lx
6183 K
0.52 CS
Fluor lx = -11 Day lx = 694
Daylight = 114 %
Spectral irradiance (W/(m2 nm))
Wavelength(nm)
0.012
0.01
0.008
0.006
0.004
0.002
0
400
450
500
550
600
650
700
750
800
850

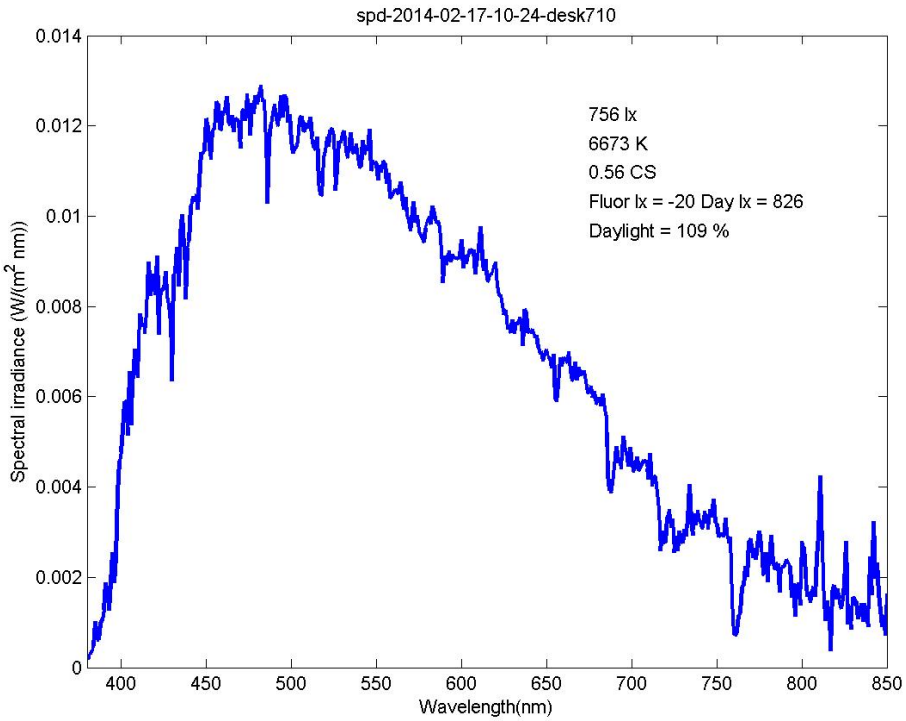
DESK 710

9:26, Desk 710. Note reflected light from shiny metal structure not apparent



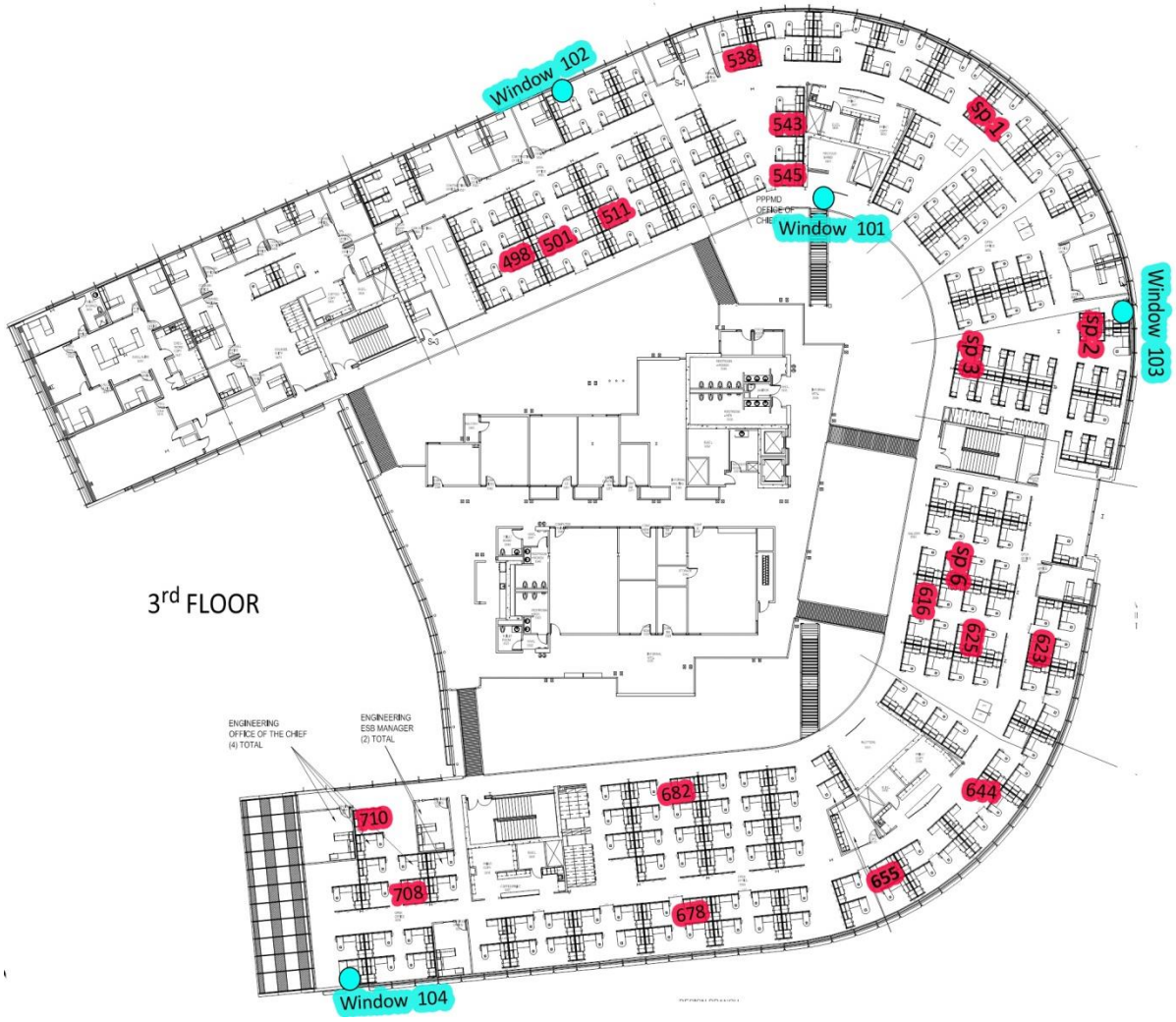


10:23, Desk 710. Note reflected light from shiny metal structure



APPENDIX K: STATIONARY DAYSIMETER RESULTS (MOUNTED ON STICKS AND AT WINDOWS)

PHOTOS, AND DAYSIMETER ILLUMINANCE AND CIRCADIAN STIMULUS (CS) RESULTS



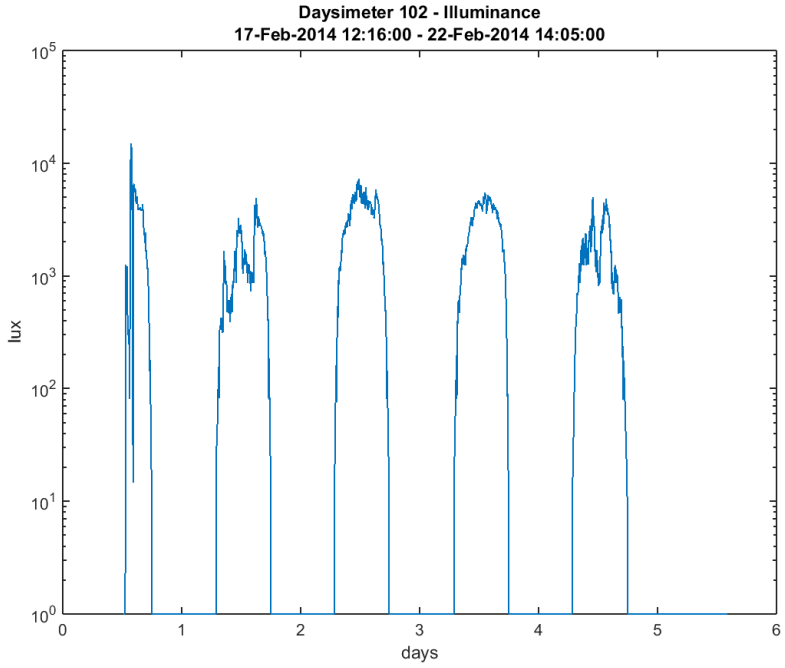
Desk with stick Daysimeter

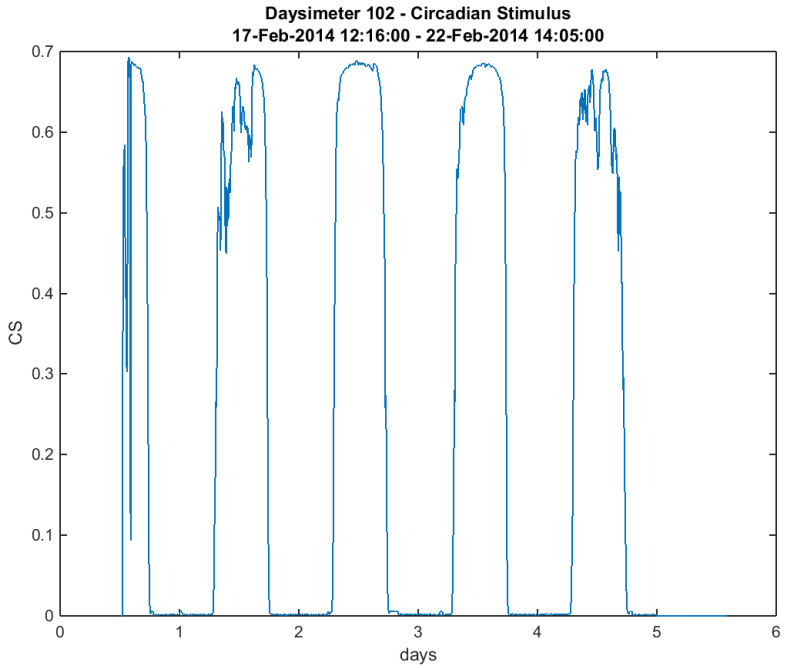
window with Daysimeter

NOTE: IN THE ORIGINAL REPORT, SOME SUNNY DAYS WERE LISTED FOR CERTAIN DEVICES. USING OUR CURRENT METHOD FOR DETERMINING SUNNY/CLOUDY DAYS THERE WERE NO SUNNY DAYS DURING THE RECORDING PERIOD.

WINDOW UNIT 102

14:32, Daysimeter unit 102, attached by suction cup to window, facing outward

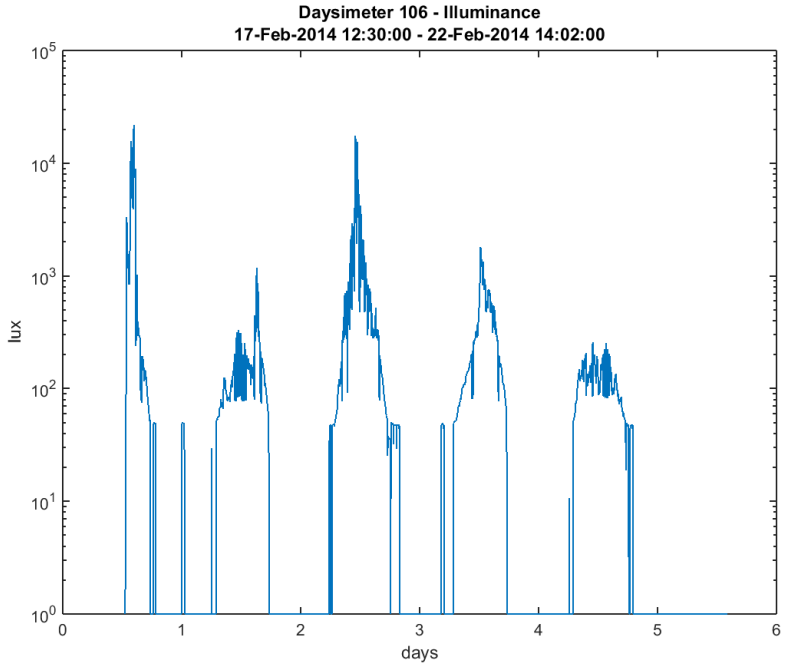


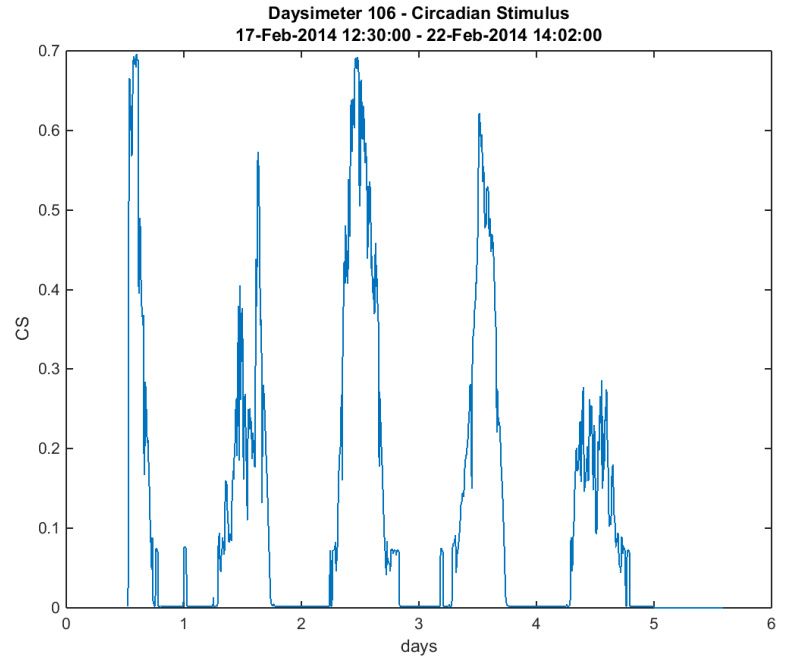


Daysimeter 102 – Northwest Façade. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 2459 ± 1127 lux on cloudy days. The mean CS value on was 0.60 ± 0.10 on cloudy days. There are no sunny days data available.

DESK 498

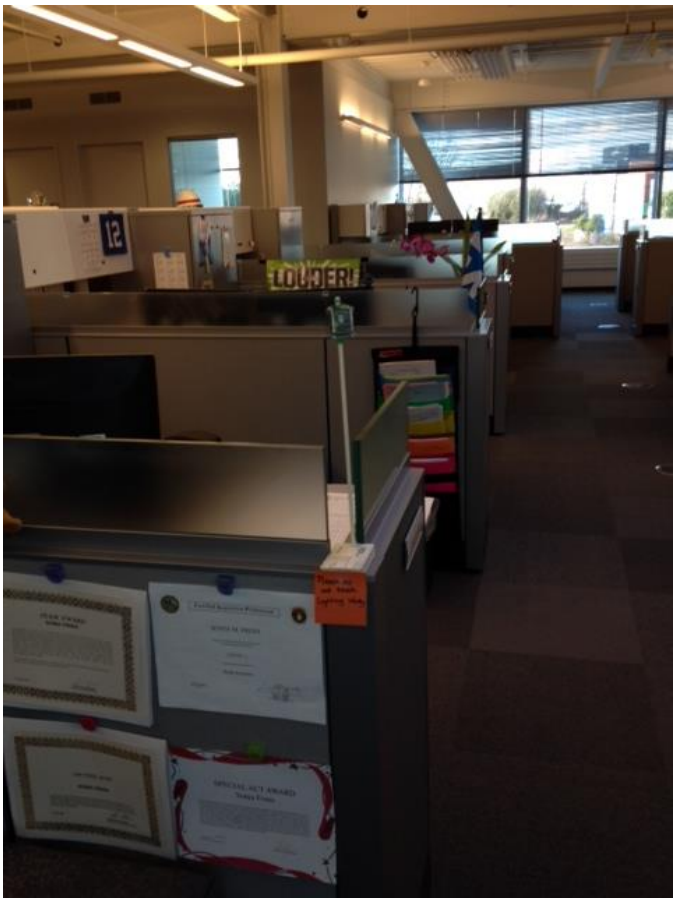
16:31, Daysimeter is mounted on a stick at Desk 498



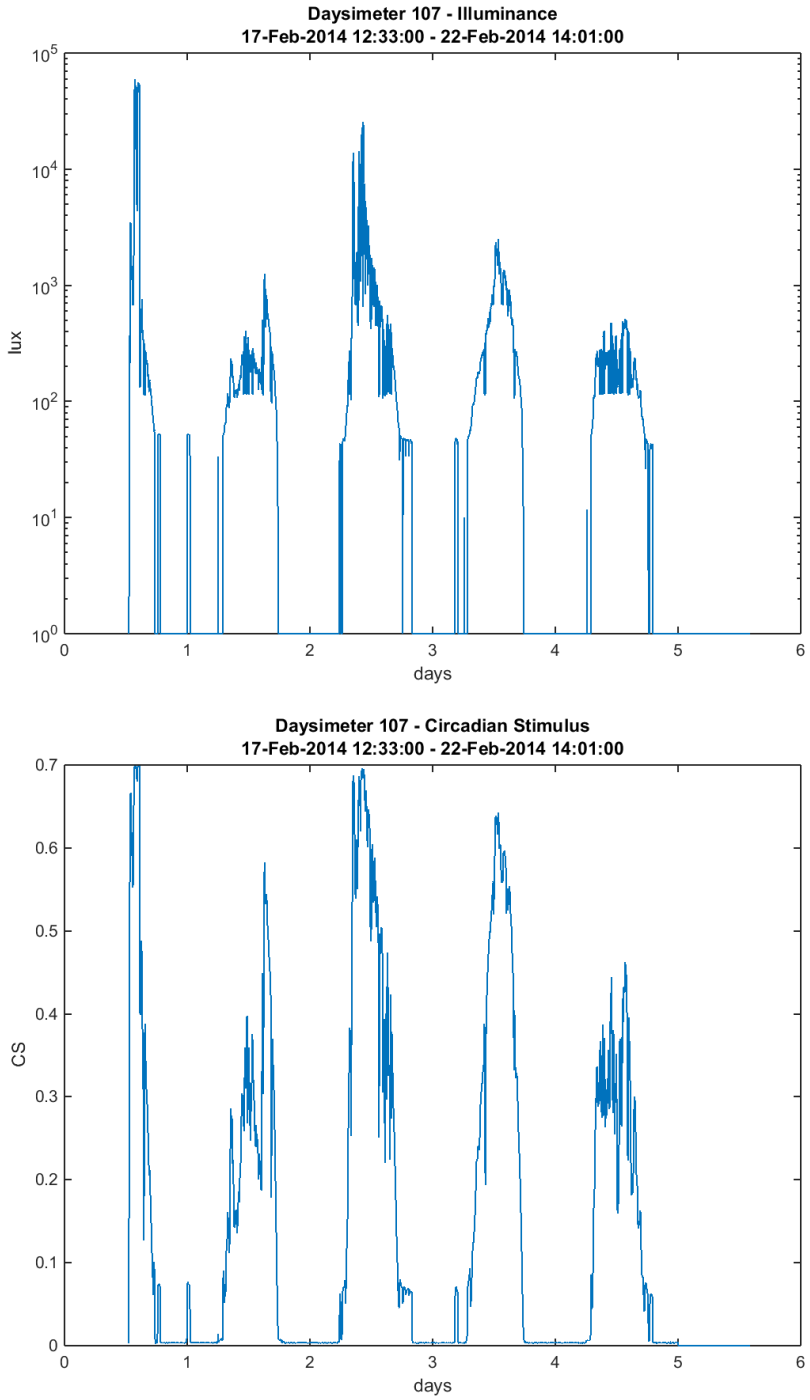


Deskspace 498 (Daysimeter 106). This Daysimeter was placed on a desk situated on the north side of the building but the deskspace was facing the atrium. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 610 ± 559 lux on cloudy days. The mean CS value on was 0.28 ± 0.12 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

Desk 501

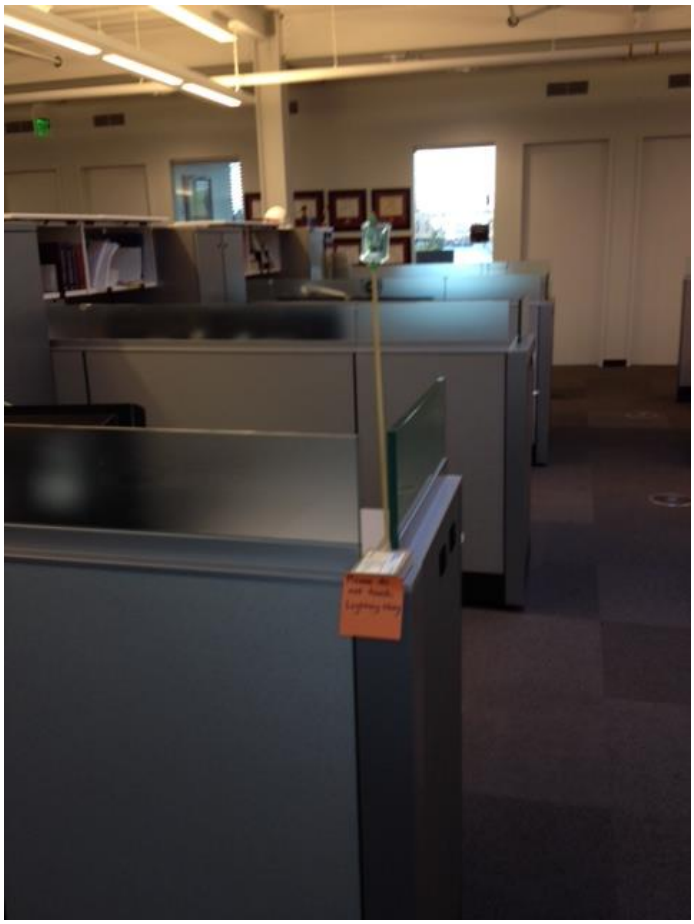


16:33, Desk 501

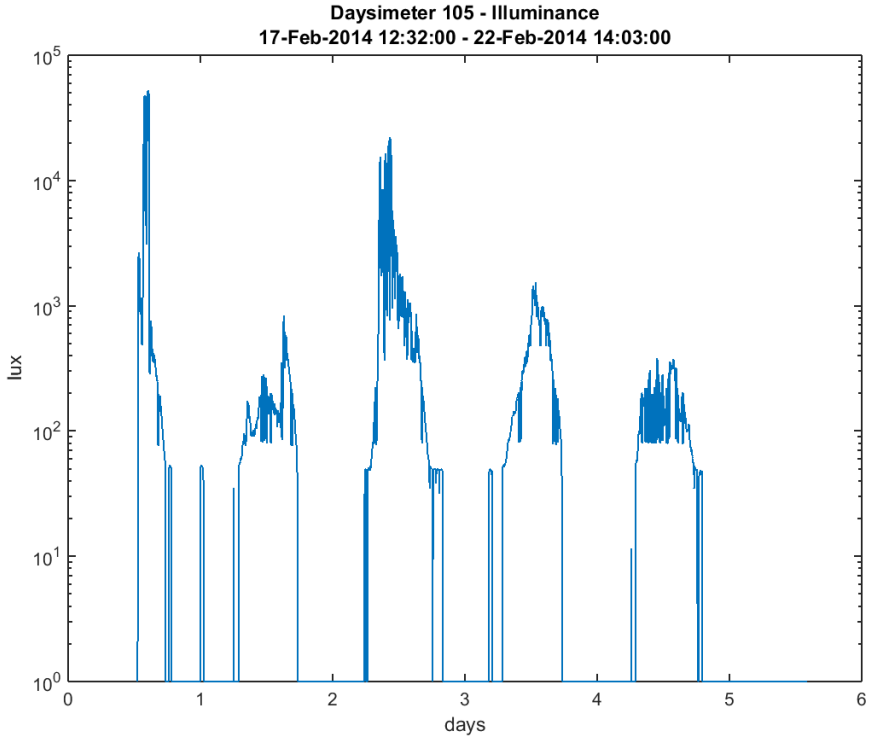


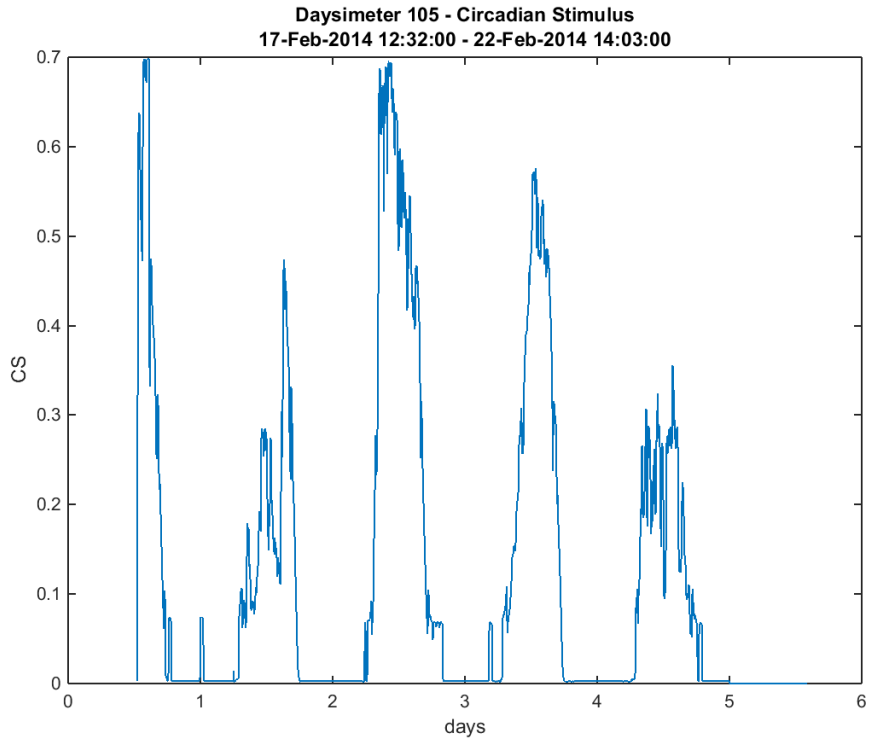
Deskspace 501 (Daysimeter 107). This Daysimeter was placed on a desk situated on the north side of the building but the deskspace was facing the atrium. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1356 ± 1532 lux on cloudy days. The mean CS value on was 0.35 ± 0.12 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 511



16:32, Desk 511

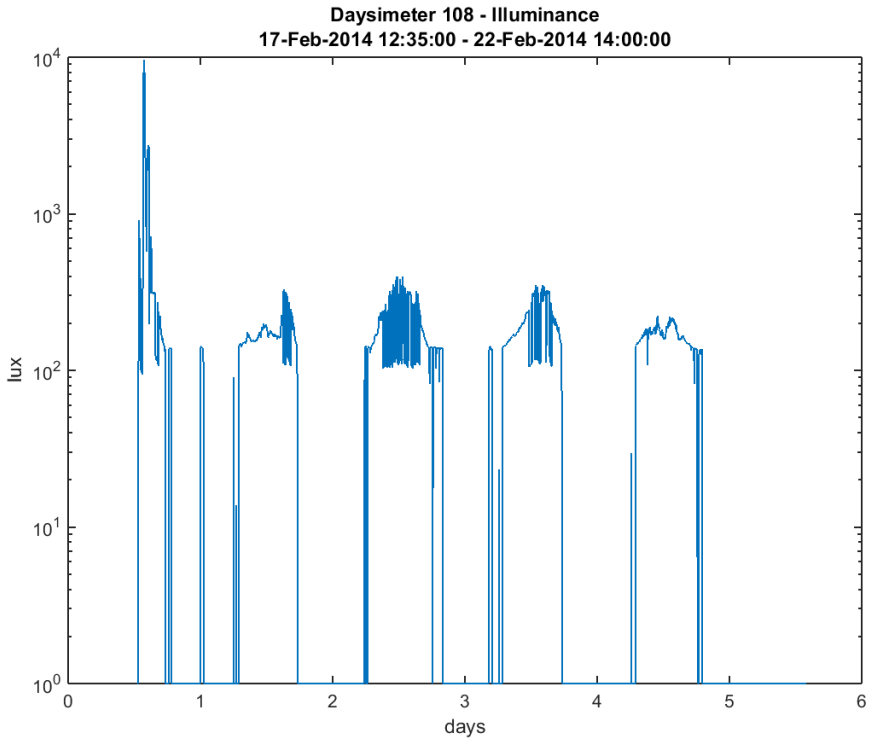


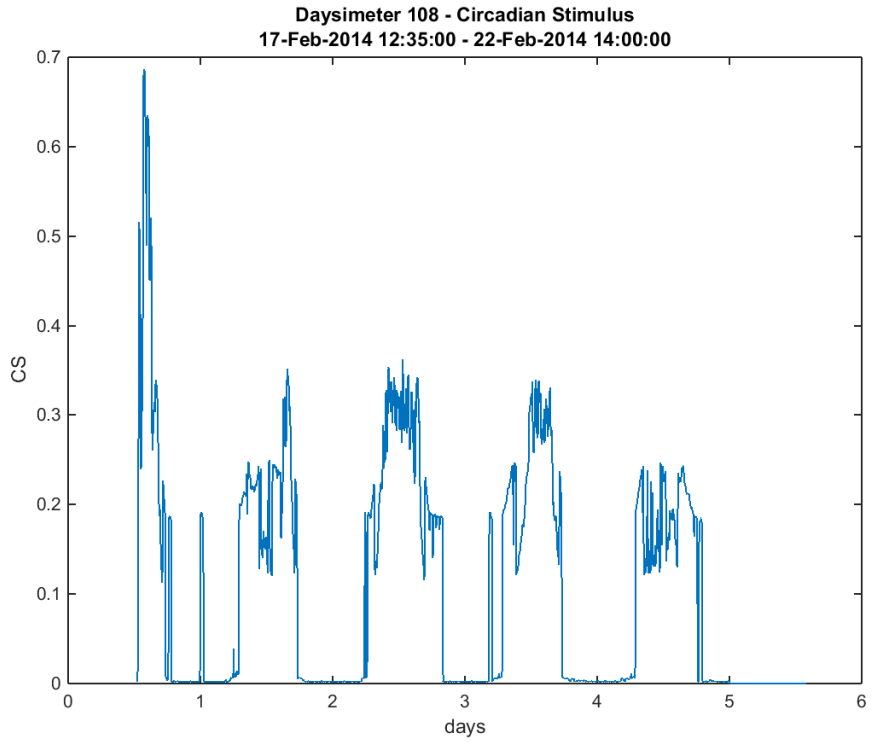


Deskspace 511 (Daysimeter 105). This Daysimeter was placed on a desk situated on the north side of the building but the deskspace was facing the atrium. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1226 ± 1286 lux on cloudy days. The mean CS value on was 0.30 ± 0.11 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 538

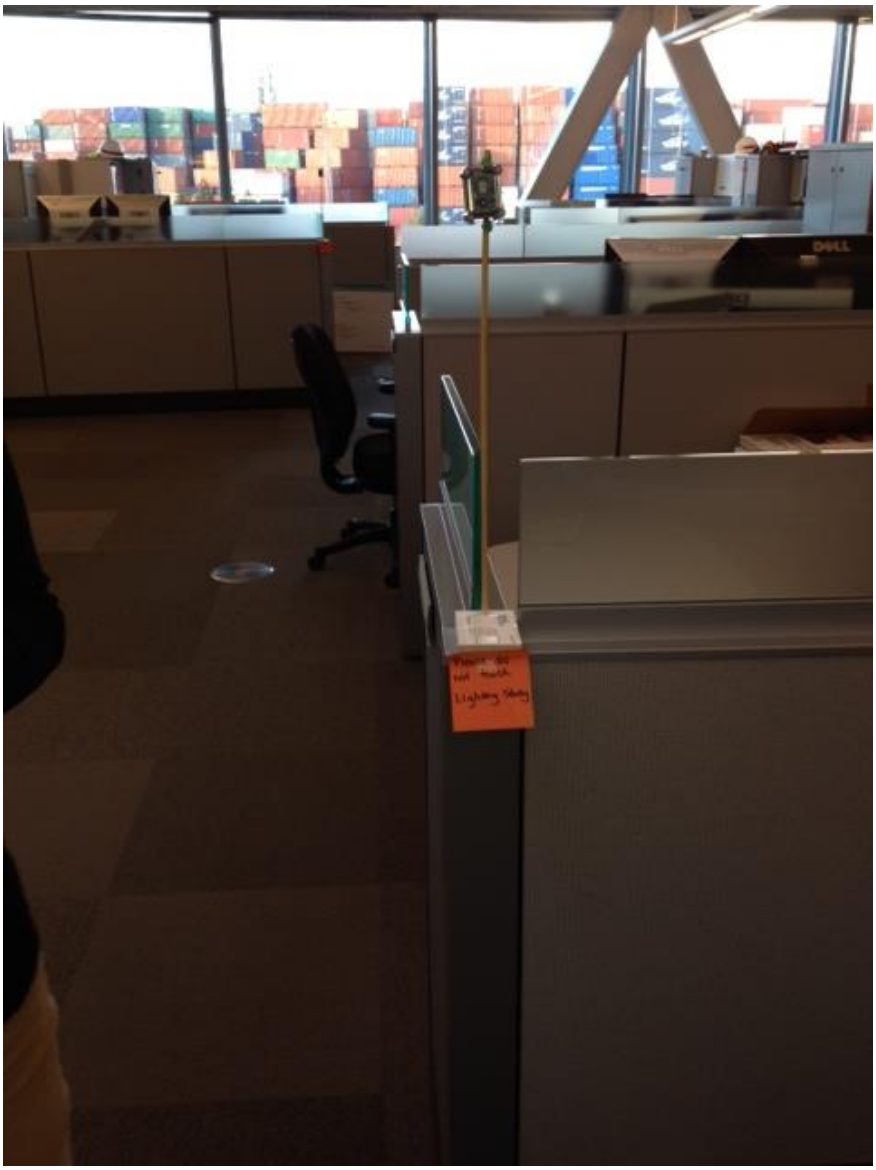
16:35, Desk 538



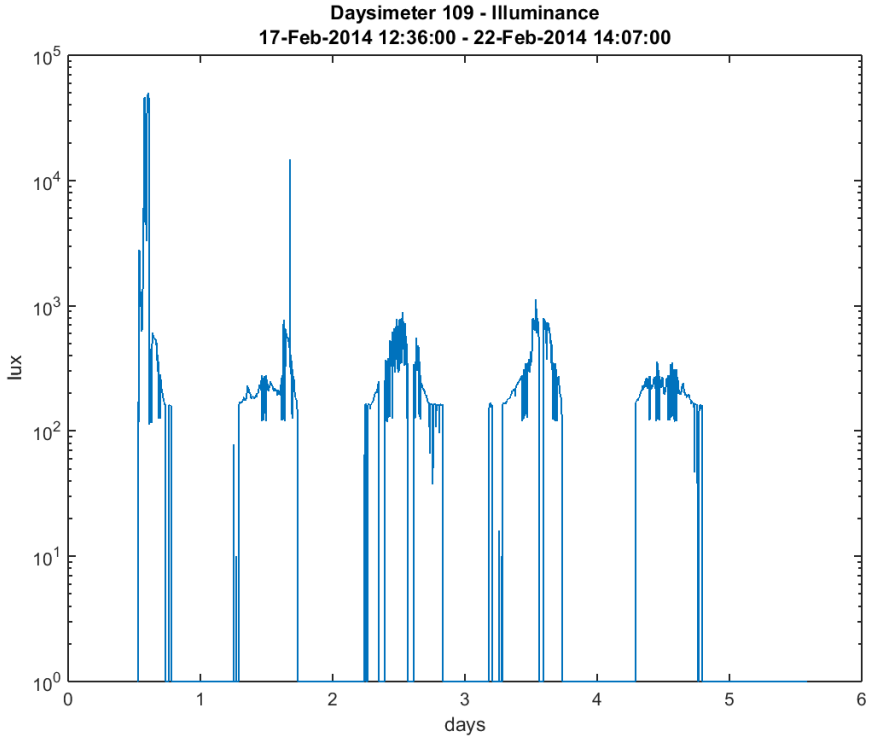


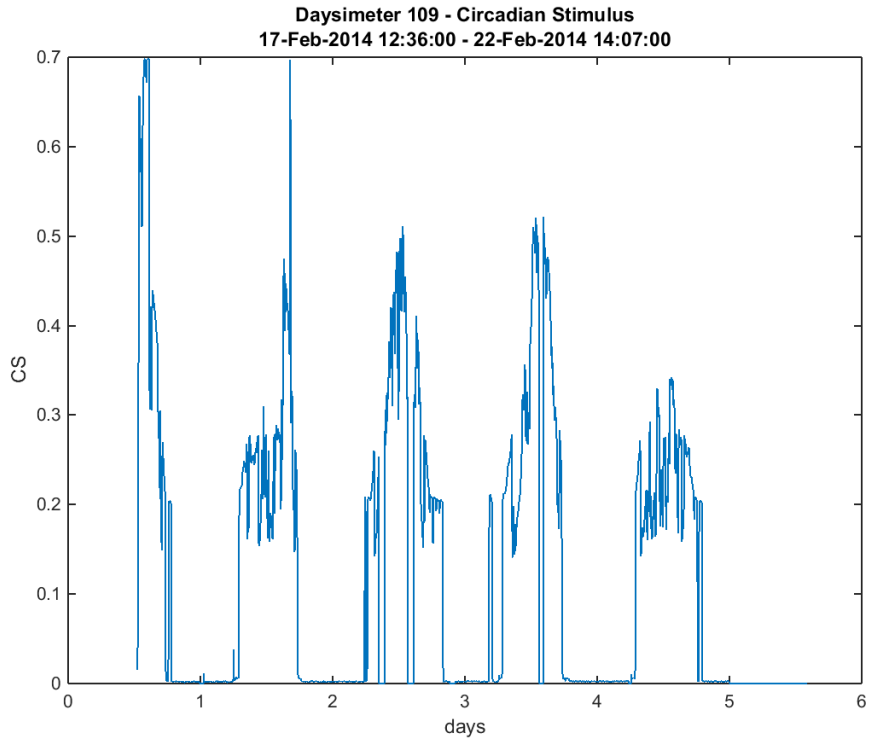
Deskspace 538 (Daysimeter 108). This Daysimeter was placed on a desk situated on the north side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 231 ± 142 lux on cloudy days. The mean CS value on was 0.22 ± 0.05 on cloudy days. There are no sunny days data available. The CS values are slightly below the desired range.

DESK 543



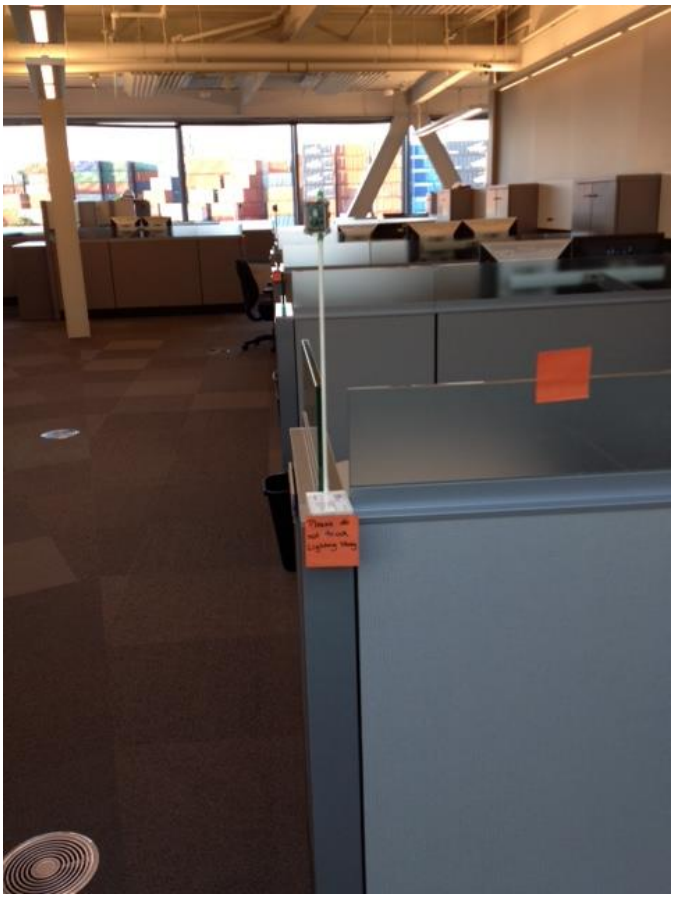
16:35, Desk 543



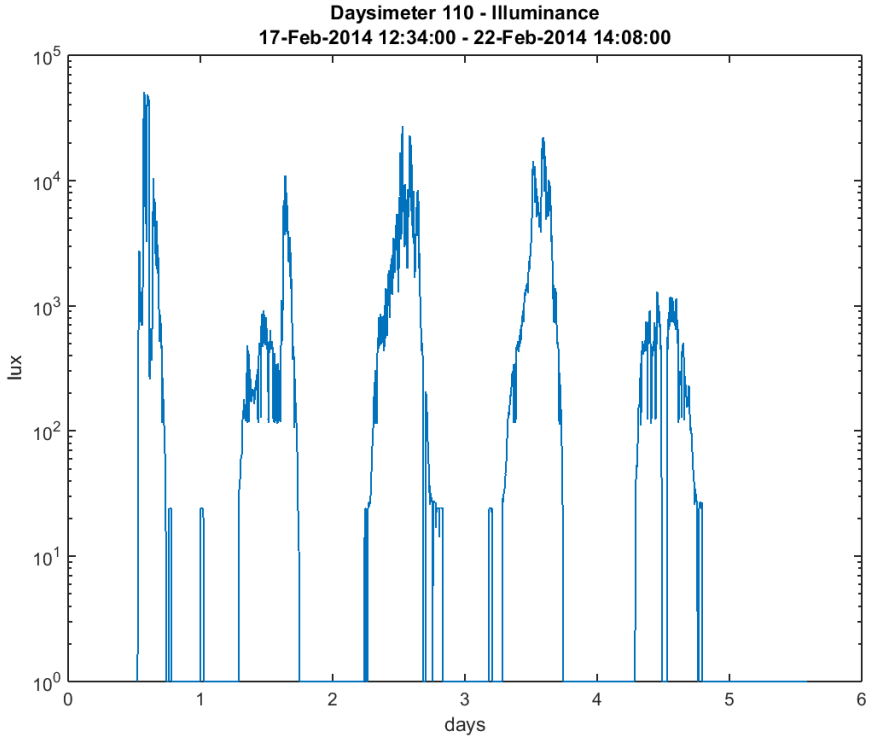


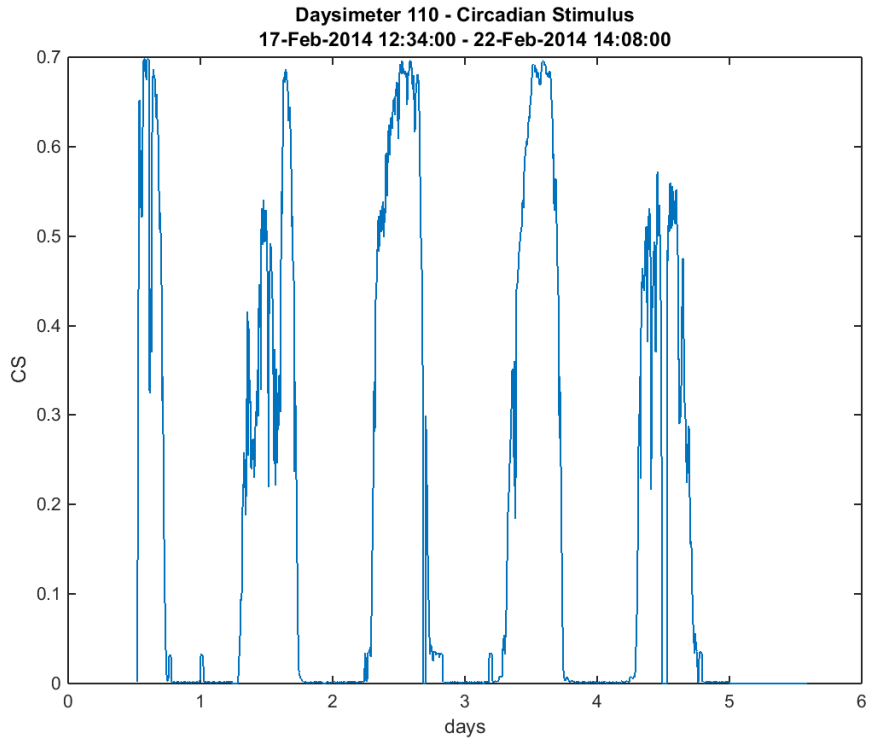
Deskspace 543 (Daysimeter 109). This Daysimeter was placed on a desk situated on the north side of the building, in between the atrium and the perimeter, and was facing the atrium (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 407 ± 209 lux on cloudy days. The mean CS value on was 0.3 ± 0.07 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 545



16:36, Desk 545

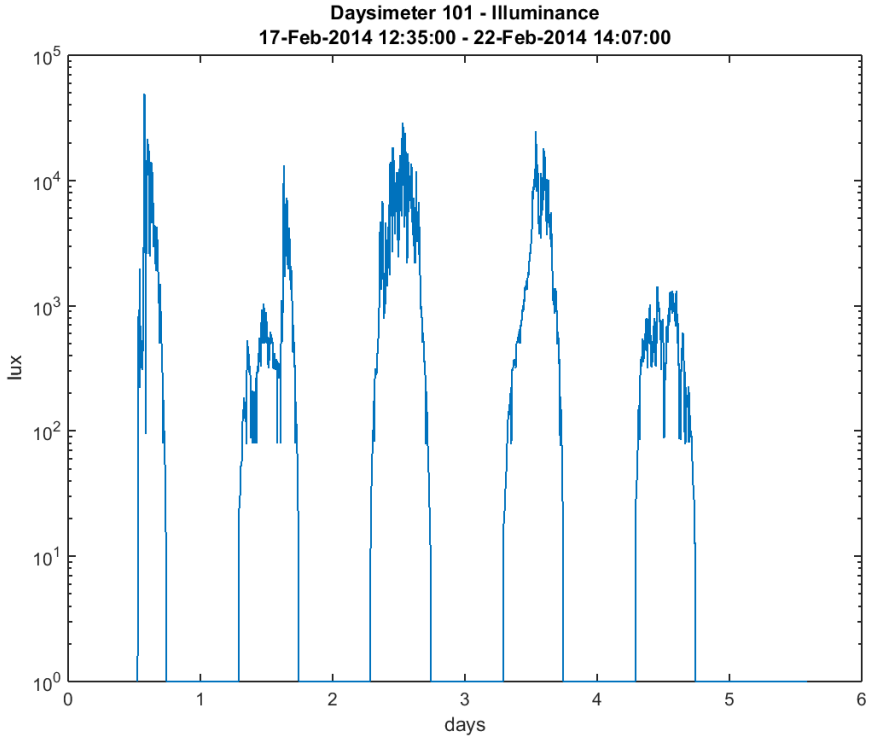


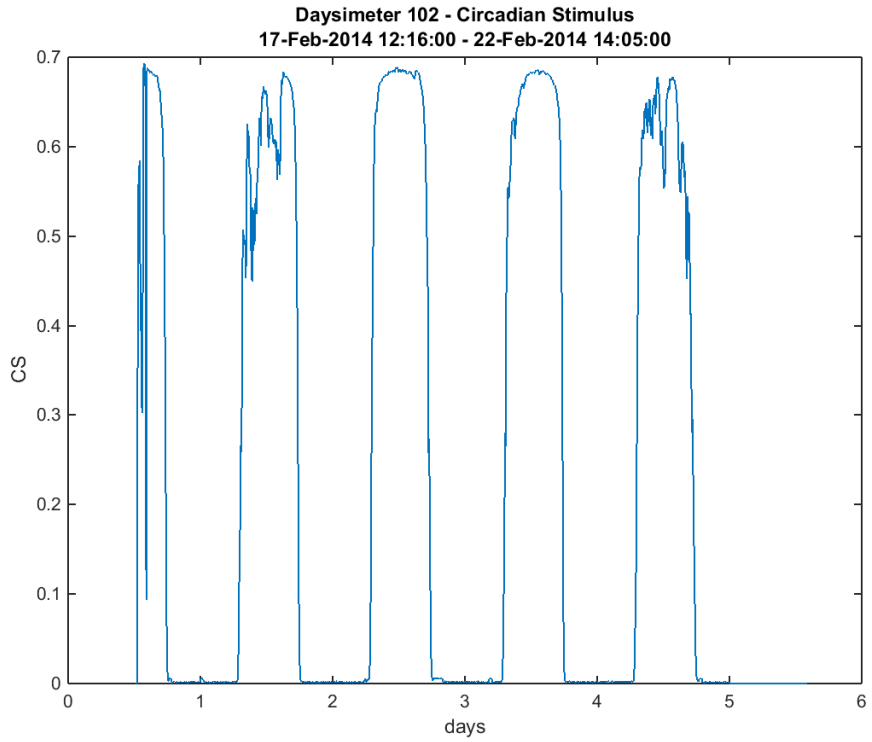


Deskspace 545 (Daysimeter 110). This Daysimeter was placed on a desk situated on the north side of the building but the deskspace was facing the atrium. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1348 ± 861 lux on cloudy days. The mean CS value on was 0.5 ± 0.07 on cloudy days. There are no sunny days data available. The CS values are at the desired range, but the light levels are above the threshold for discomfort glare.

WINDOW UNIT 101

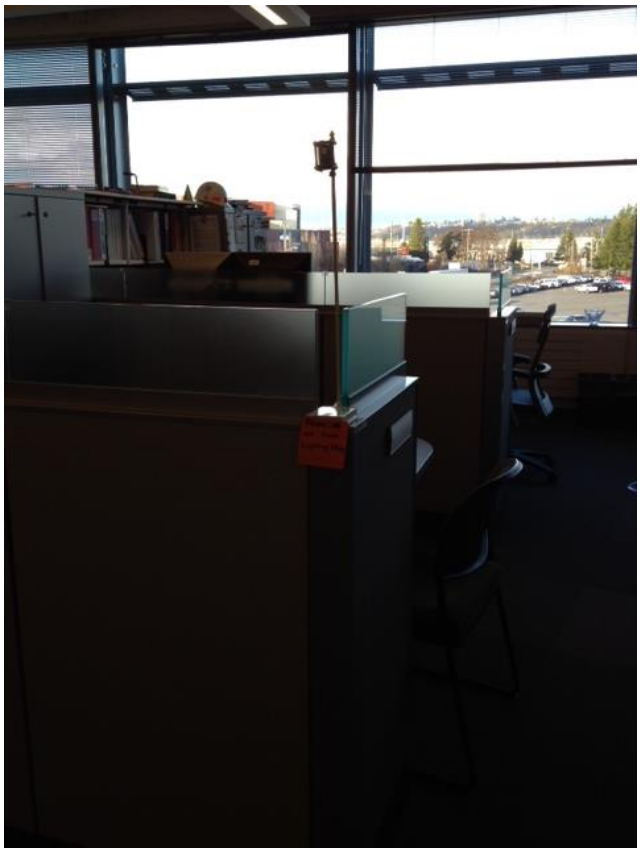
14:30, Window 101, attached by suction cup, facing into atrium



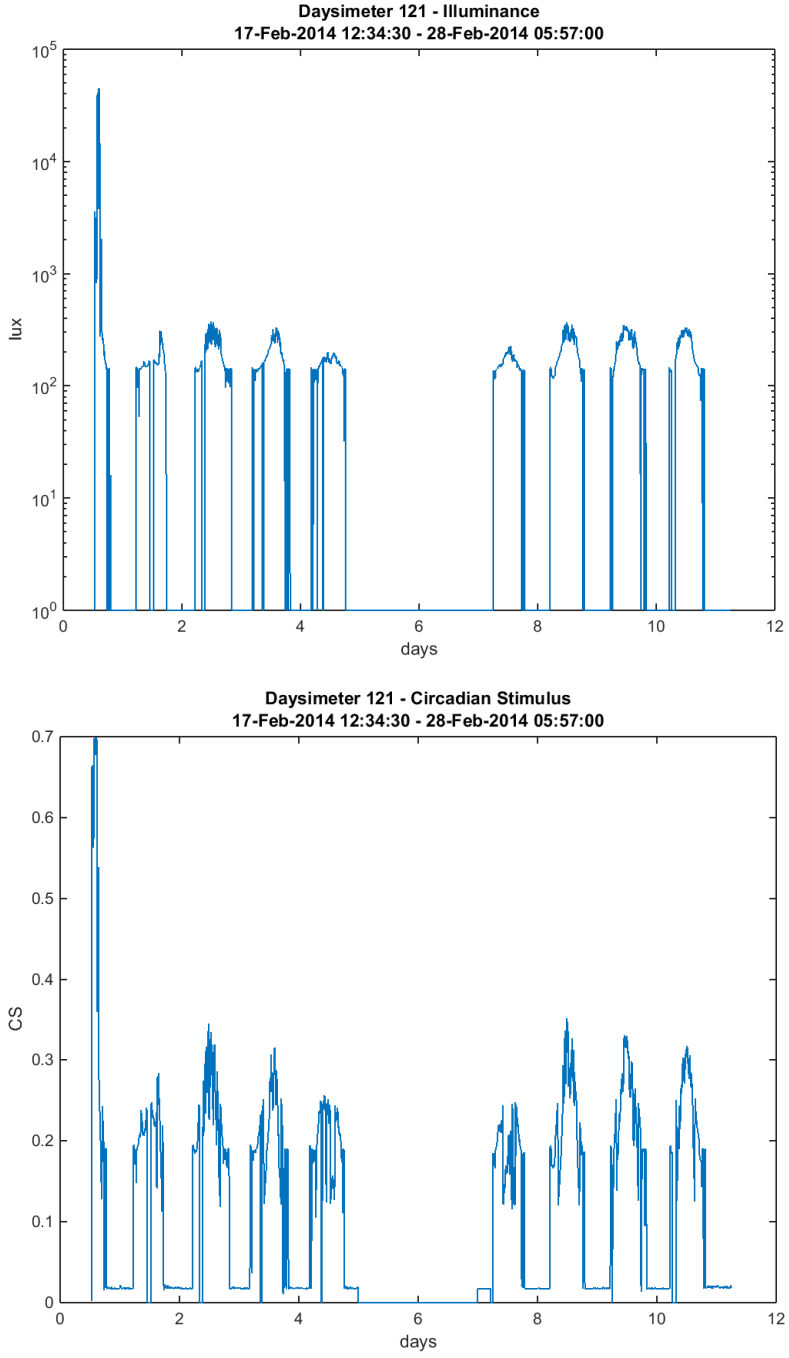


Daysimeter 101 – Atrium (facing west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 2637 ± 2084 lux on cloudy days. The mean CS value on was 0.51 ± 0.14 on cloudy days. There are no sunny days data available.

SPACE 1 (UNKNOWN DESK NUMBER)

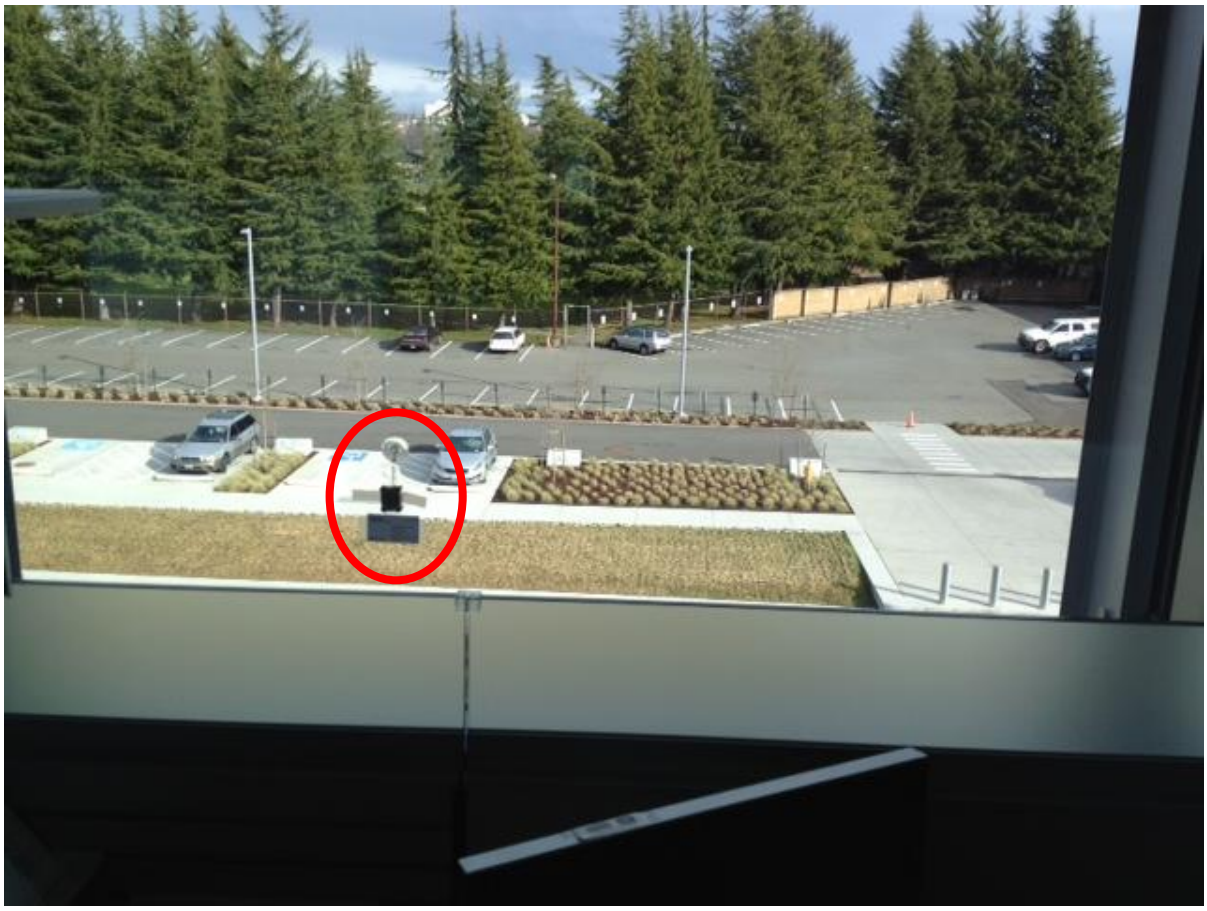


16:38, Space 1

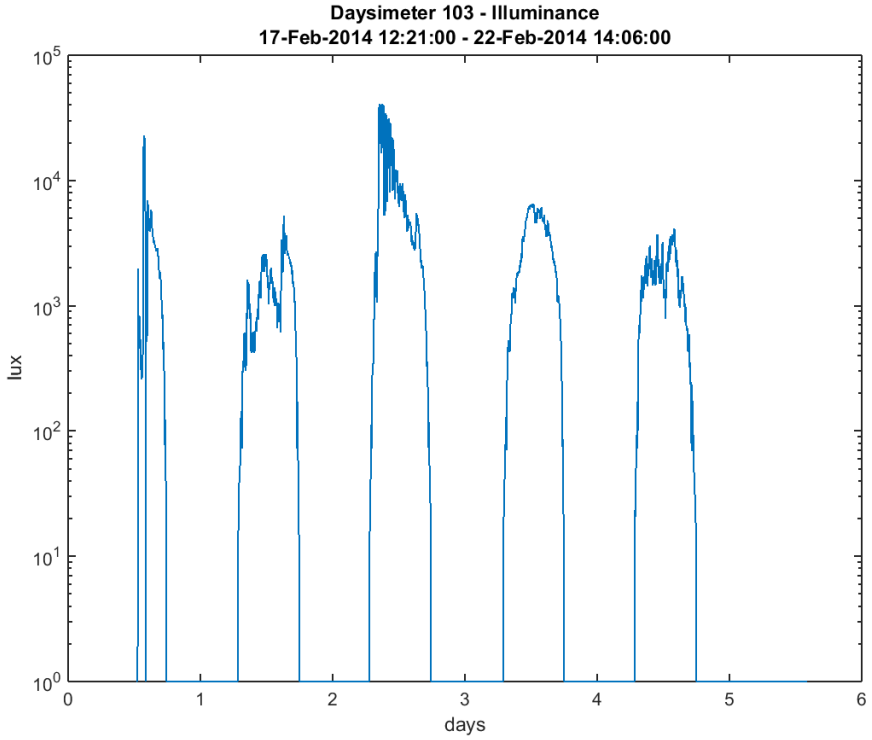


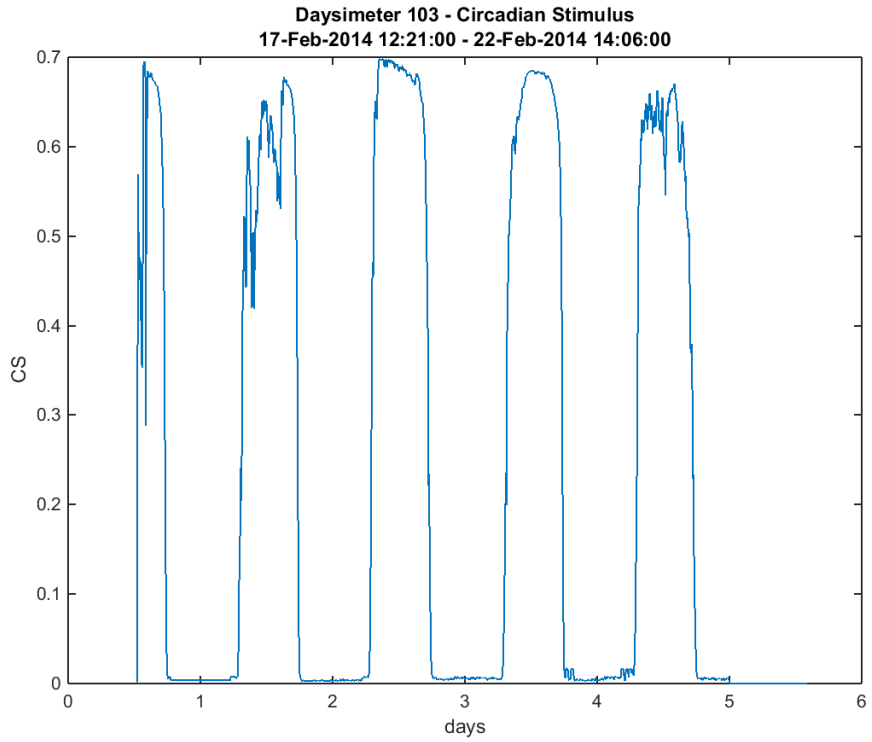
Deskspace sp 1 (Daysimeter 121). This Daysimeter was on a desk situated on the northeast side of the building and the deskspace close to the perimeter. The Daysimeter was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 454 ± 577 lux on cloudy days. The mean CS value on was 0.21 ± 0.04 on cloudy days. There are no sunny days data available.

WINDOW UNIT 103



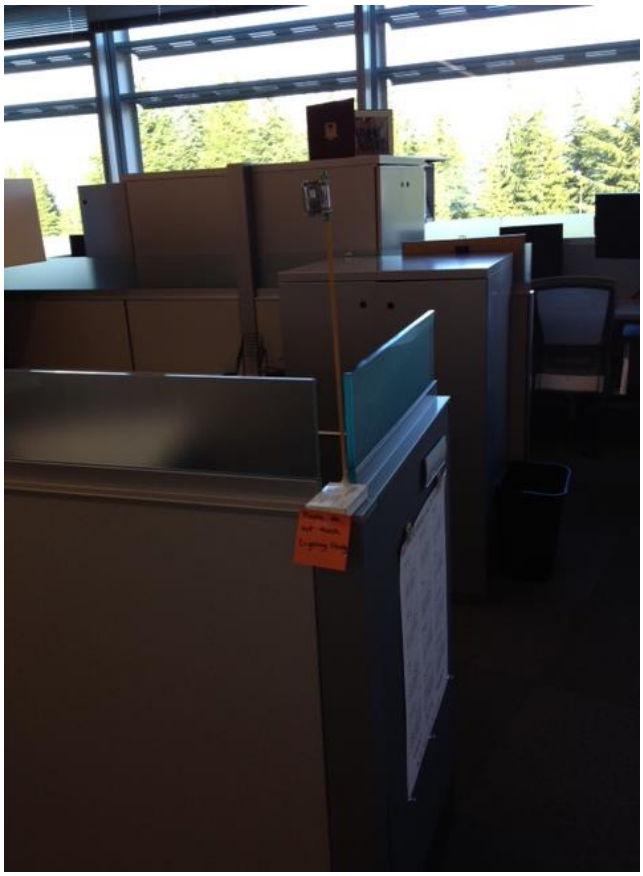
14:30, Window unit 103, attached by suction cup, facing outward



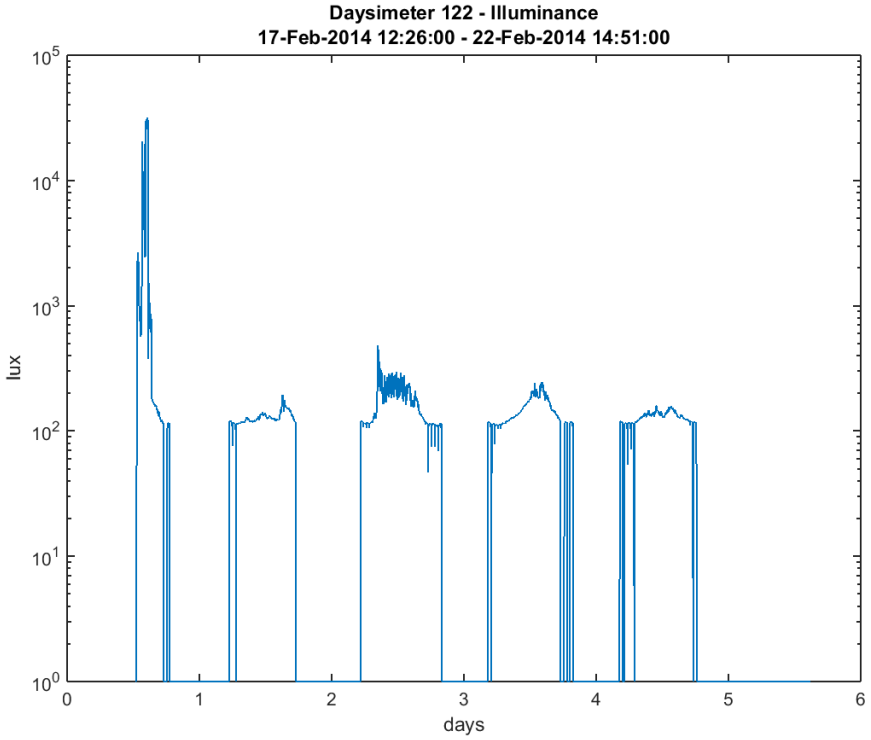


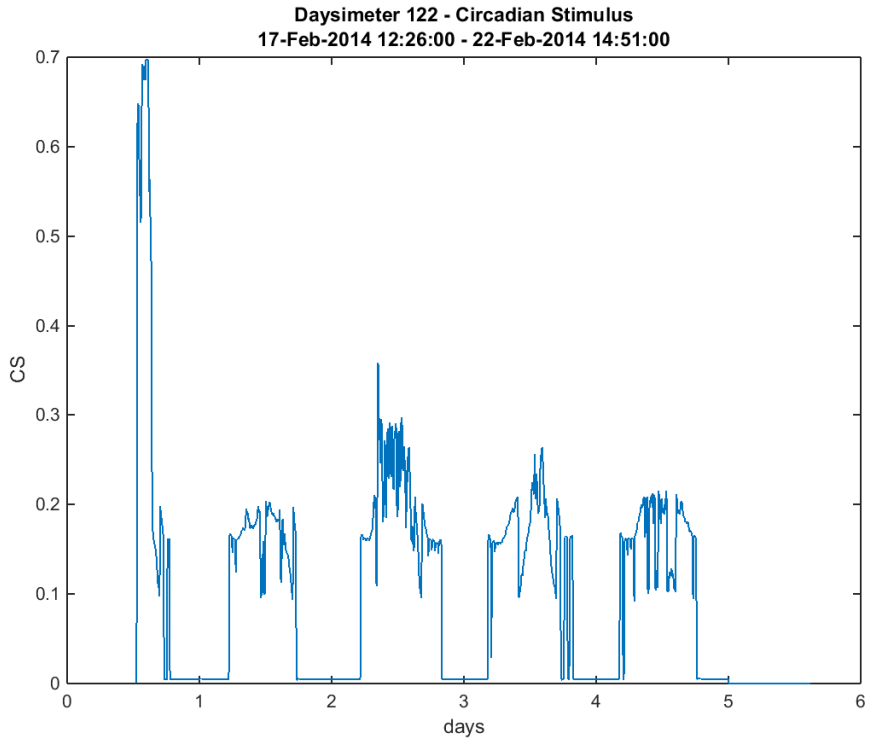
Daysimeter 103 – East Façade. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 2586 ± 768 lux on cloudy days. The mean CS value on was 0.63 ± 0.02 on cloudy days. There are no sunny days data available.

SPACE 2 (UNKNOWN DESK NUMBER)



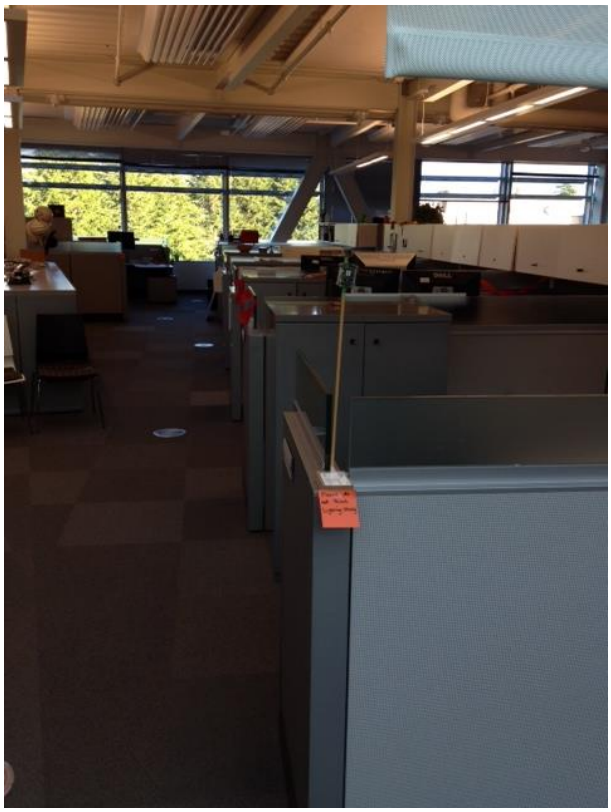
16:39, Space 2



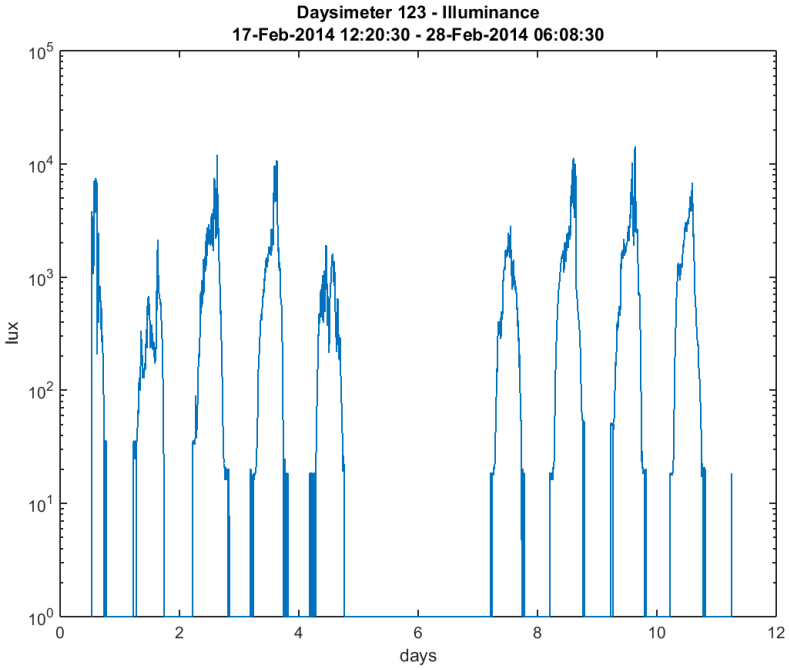


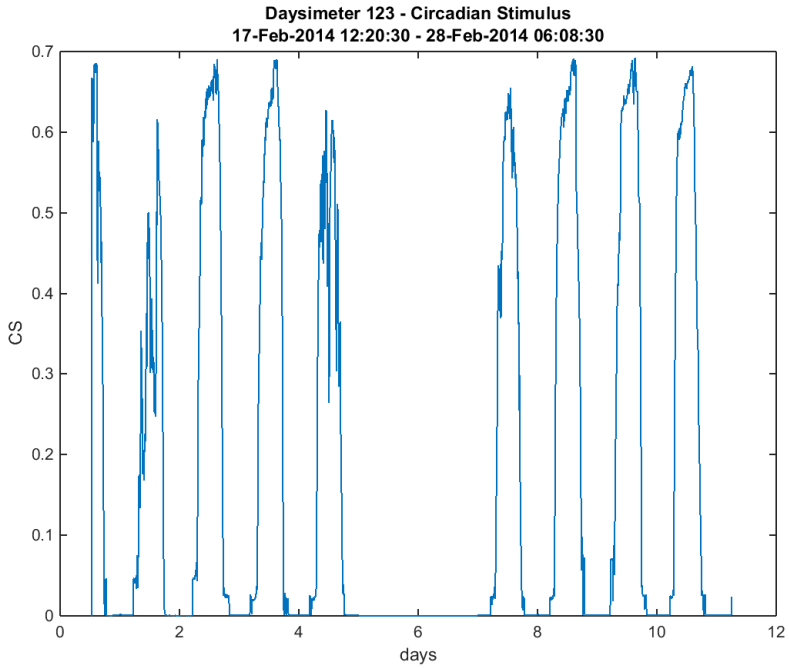
Deskspace sp 2 (Daysimeter 122). This Daysimeter was placed on a desk situated on the east side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 449 ± 783 lux on cloudy days. The mean CS value on was 0.18 ± 0.04 on cloudy days. There are no sunny days data available. The CS values are slightly below the desired range.

SPACE 3 (UNKNOWN DESK NUMBER)



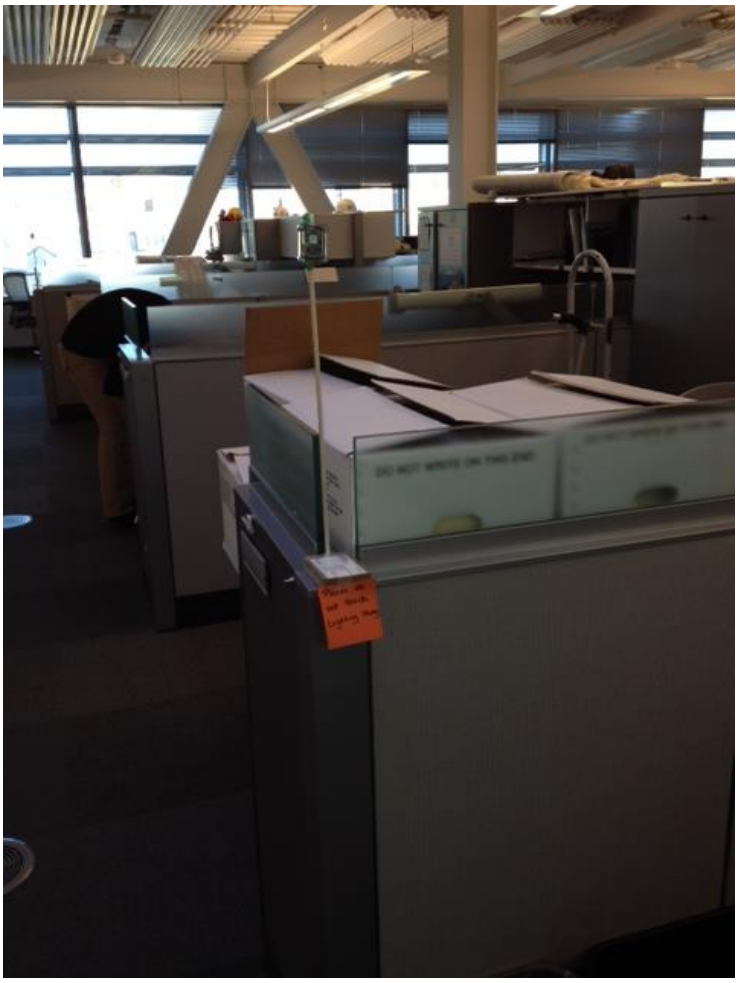
16:39, Space 3



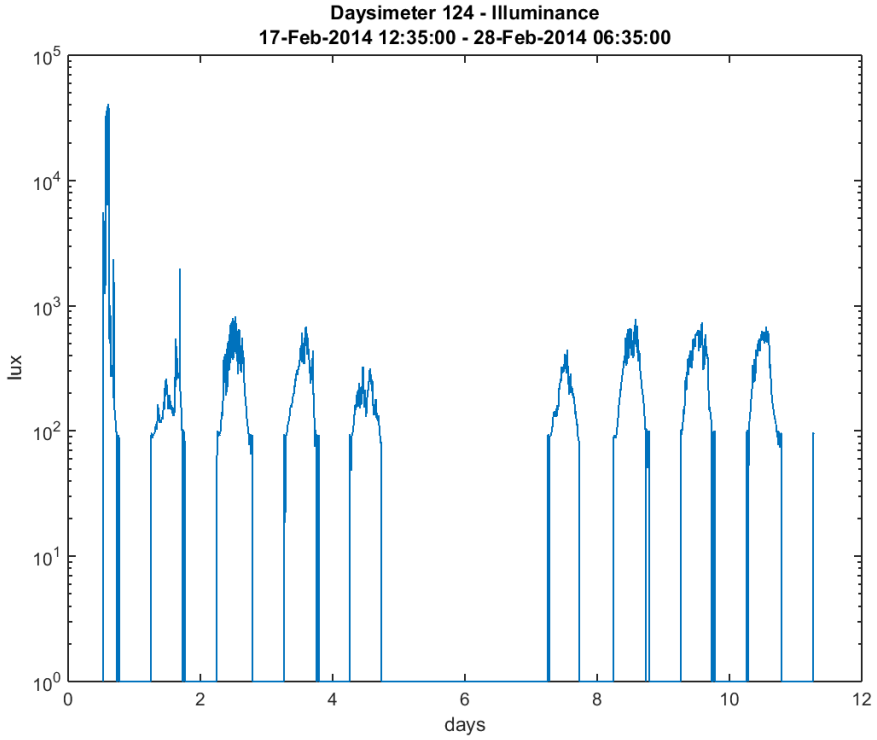


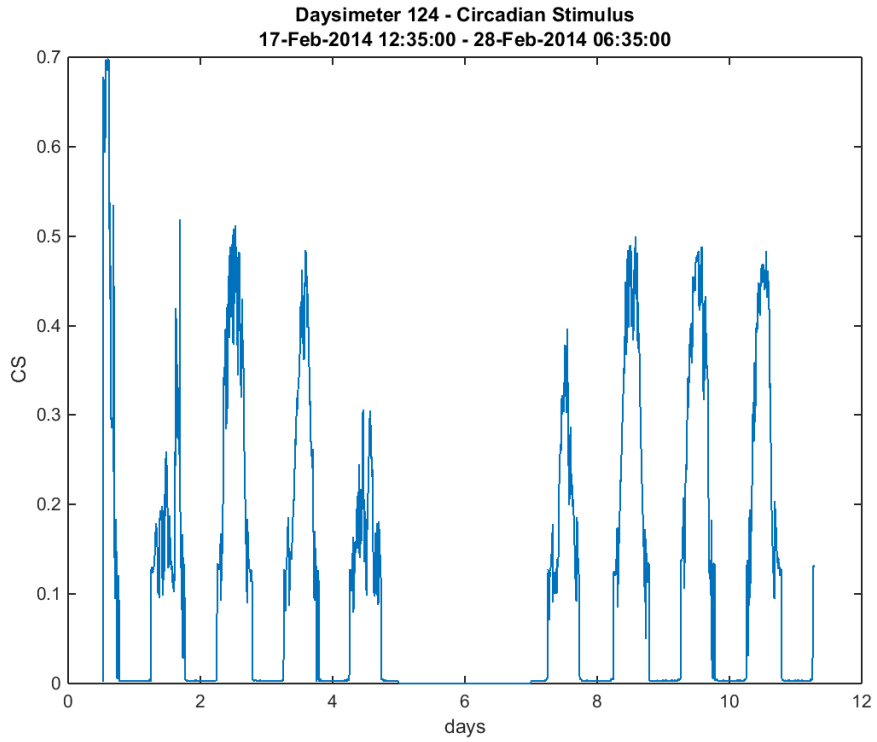
Deskspace sp 3 (Daysimeter 123). This Daysimeter was on a desk situated on the east side of the building, but the deskspace was facing the atrium (west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1410 ± 997 lux on cloudy days. The mean CS value on was 0.50 ± 0.14 on cloudy days. There are no sunny days data available.

DESK 625 (SPACE 4)



16:44, Desk 625

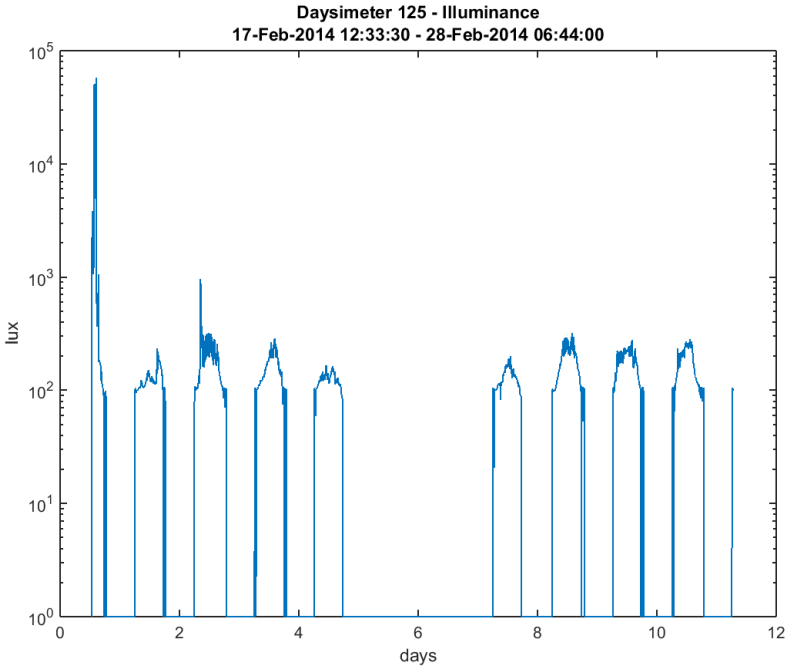


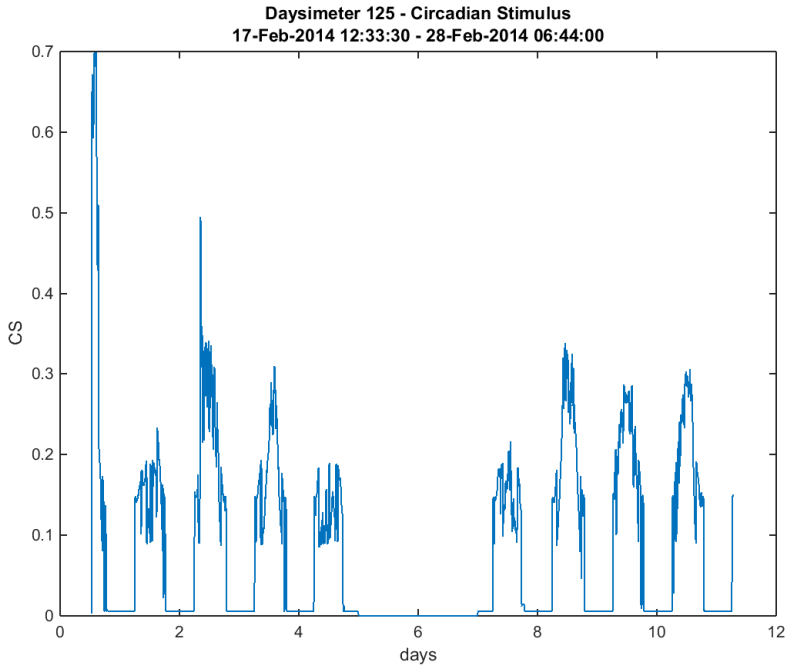


Deskspace sp 4 (Daysimeter 124). This Daysimeter was on a desk situated on the east side of the building, on a deskspace located between the perimeter and the atrium. The deskspace was facing the atrium (west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1410 ± 997 lux on cloudy days. The mean CS value on was 0.50 ± 0.14 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 623 (SPACE 5)

16:45, Desk 623

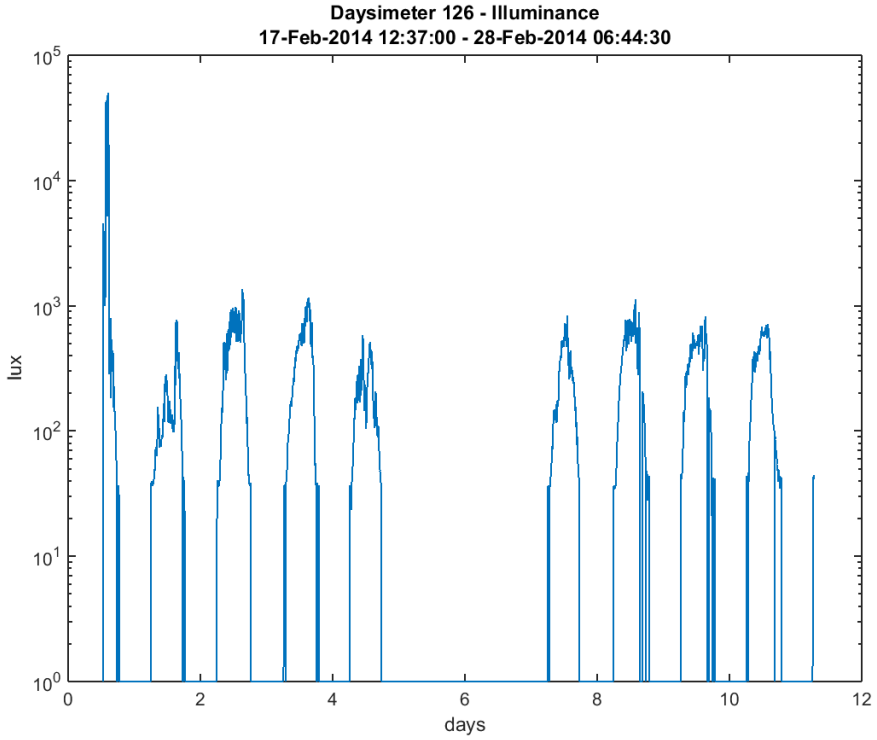


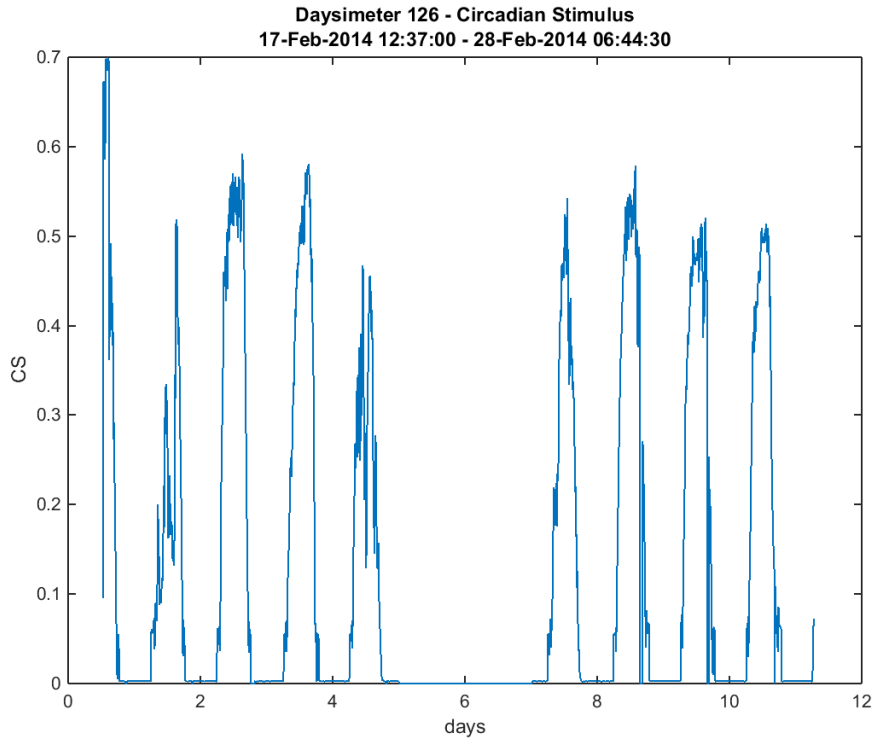


Deskspace 623 (sp 5, Daysimeter 125). This Daysimeter was placed on a desk situated on the east side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 424 ± 593 lux on cloudy days. The mean CS value on was 0.18 ± 0.05 on cloudy days. There are no sunny days data available. The light levels in this area were surprisingly low, perhaps because the shades are pulled most of the time. This deskspace is slightly oriented towards the south and receives a considerable amount of sun, so it is not surprising that the blinds would be pulled down.

SPACE 6

16:41, Space 6

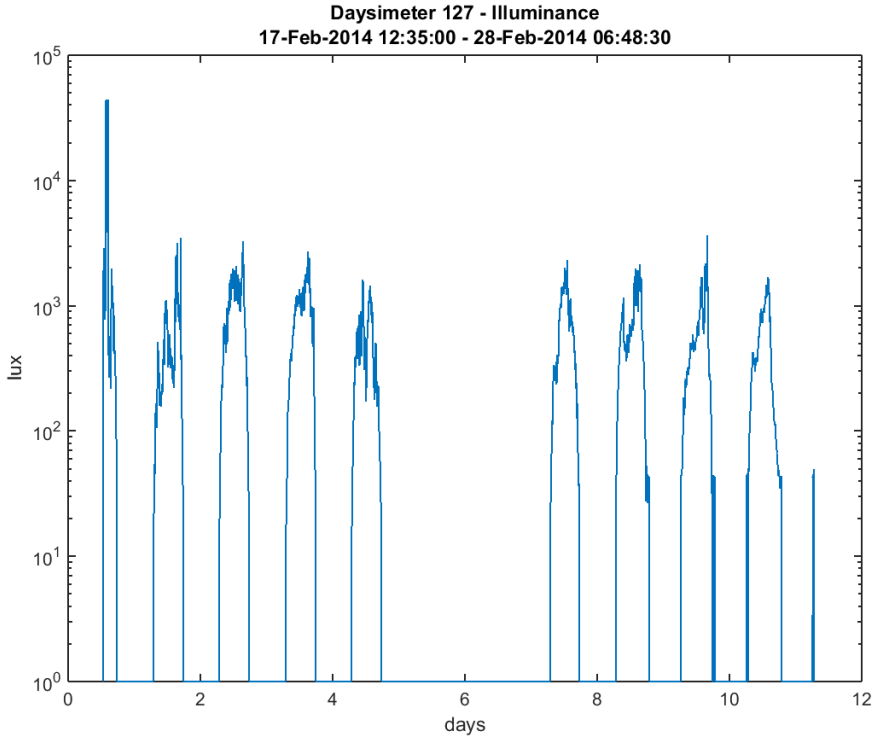


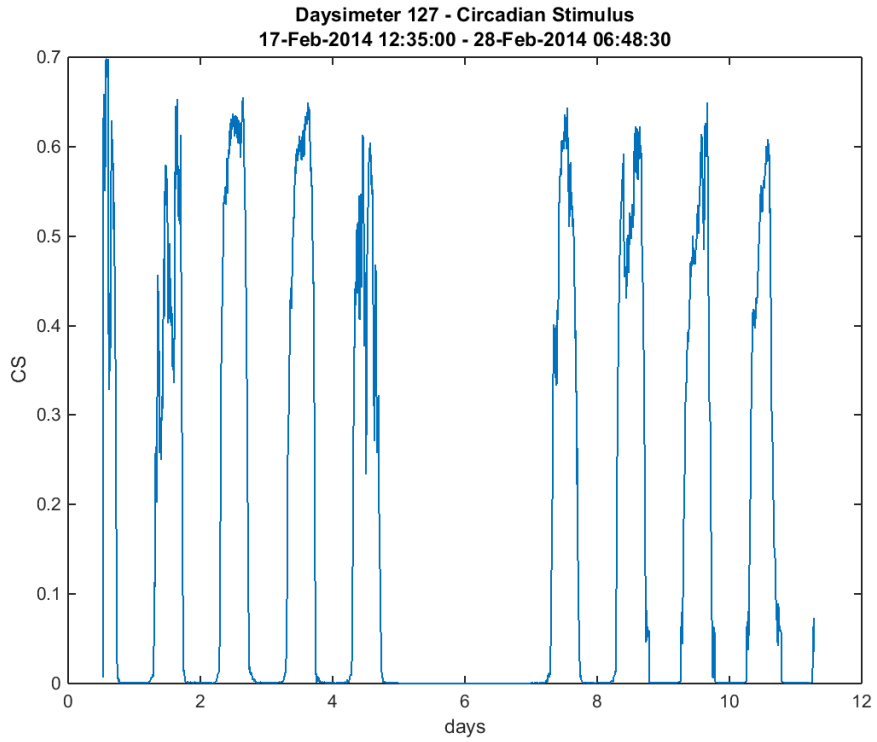


Deskspace sp 6 (Daysimeter 126). This Daysimeter was on a desk situated on the east side of the building, on a deskspace located between the perimeter and the atrium. The deskspace was facing the atrium (west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 624 ± 698 lux on cloudy days. The mean CS value on was 0.34 ± 0.12 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 616

16:42, Desk 616

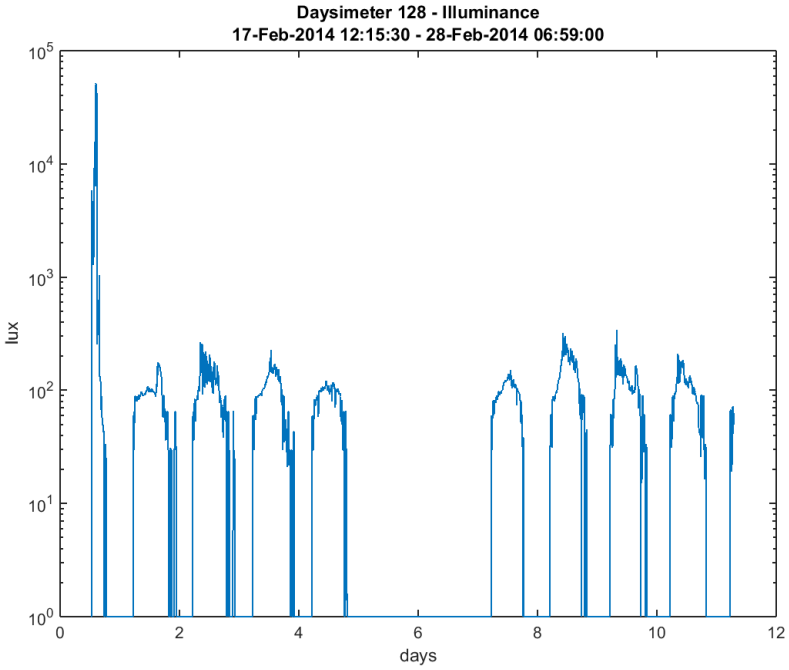


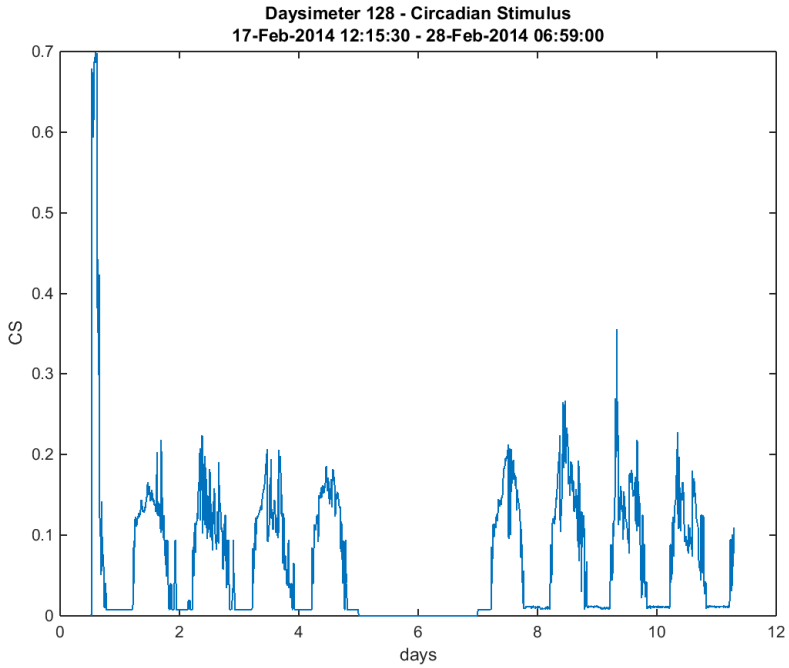


Deskspace 616 (Daysimeter 127). This Daysimeter was on a desk situated on the east side of the building, but the deskspace was facing the atrium (west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 895 ± 628 lux on cloudy days. The mean CS value on was 0.46 ± 0.13 on cloudy days. There are no sunny days data available. The CS values are within the desired range.

DESK 644

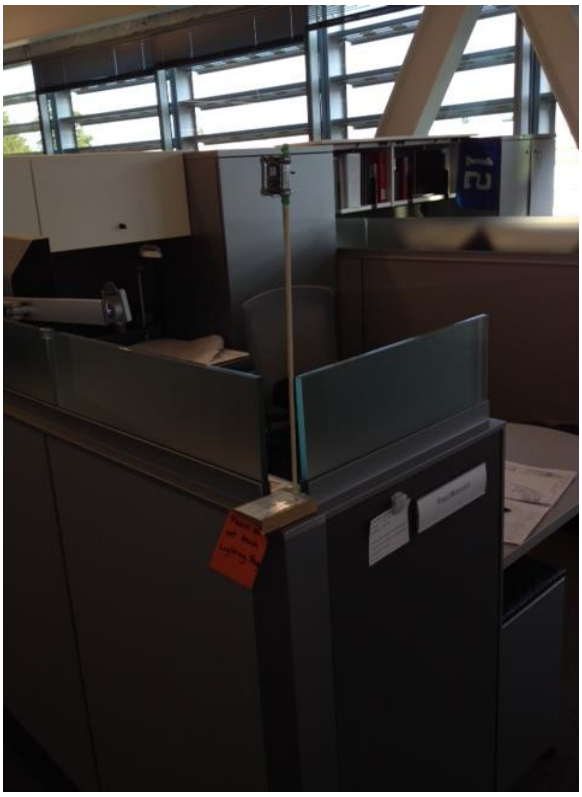
16:46, Desk 644



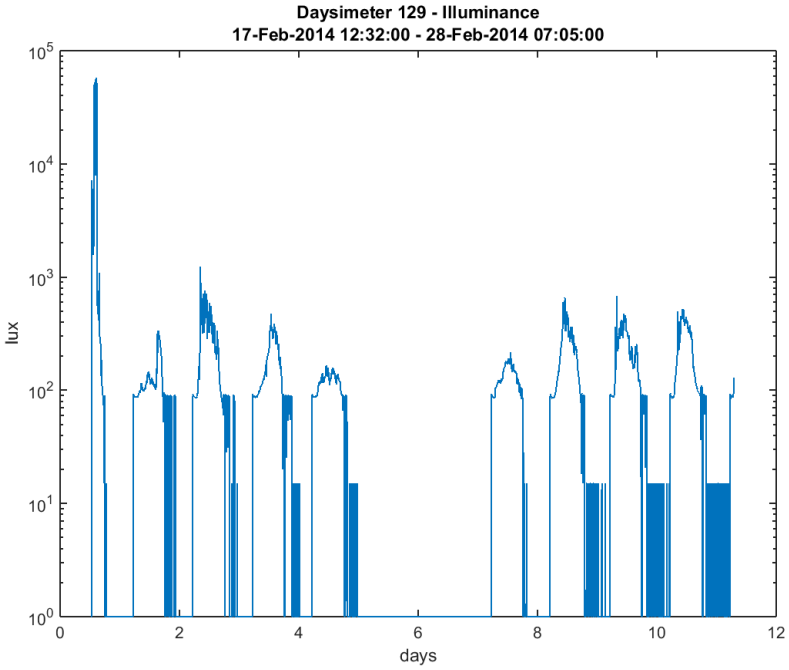


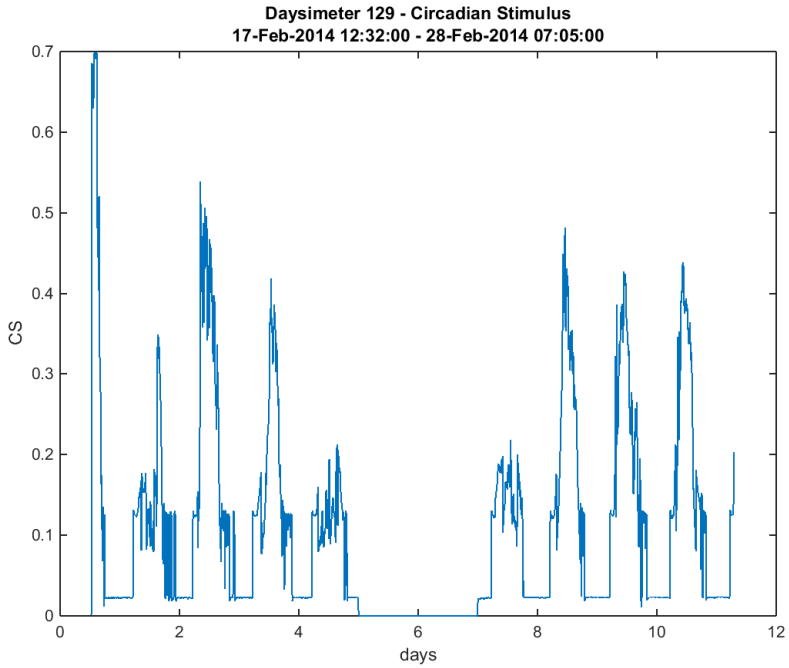
Deskspace 644 (Daysimeter 128). This Daysimeter was placed on a desk situated on the east/southeast side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 383 ± 698 lux on cloudy days. The mean CS value on was 0.14 ± 0.03 on cloudy days. There are no sunny days data available. The CS values are below the desired range, most likely due to shades being down as a result of sunlight penetrating the space.

DESK 658



16:47, Desk 658

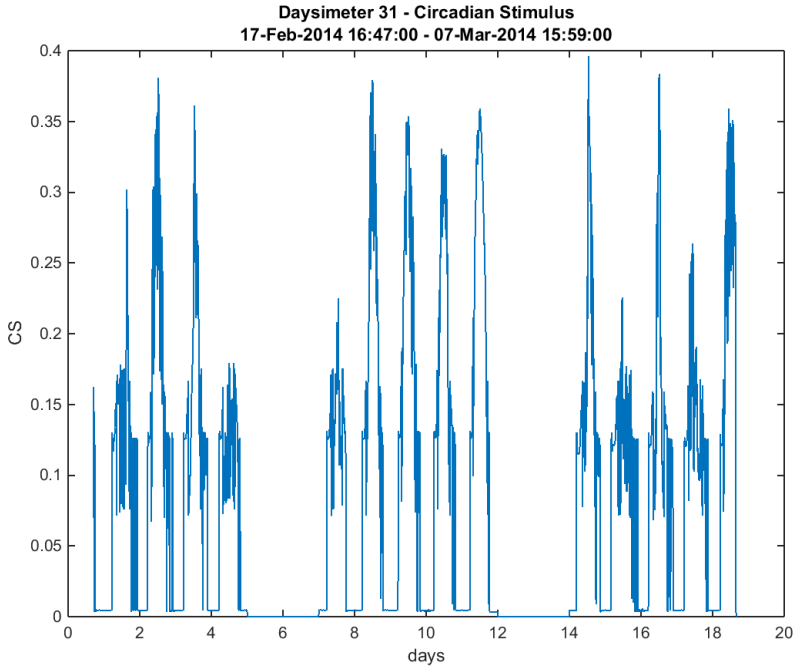


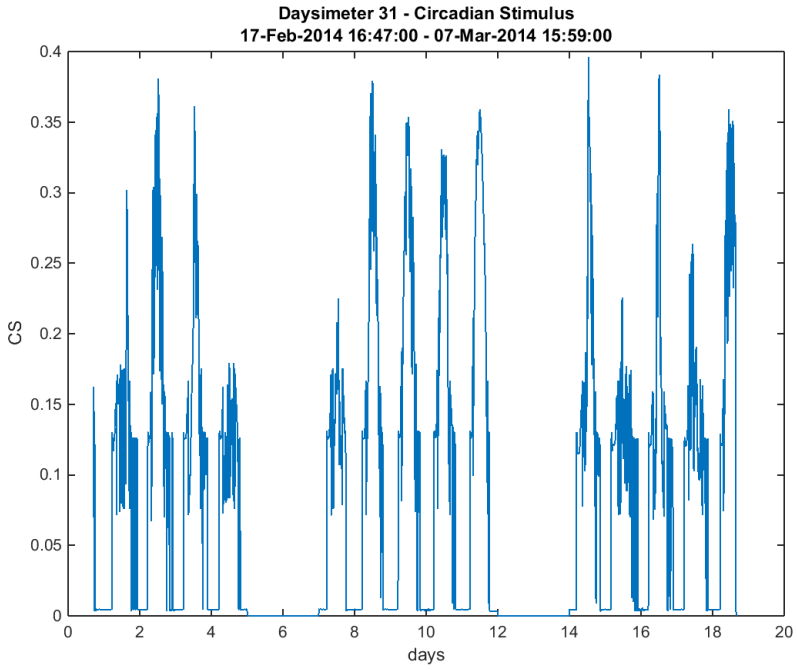


Deskspace 658 (Daysimeter 129). This Daysimeter was placed on a desk situated on the east/southeast side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 601 ± 868 lux on cloudy days. The mean CS value on was 0.21 ± 0.05 on cloudy days. There are no sunny days data available. The CS values are below the desired range, most likely due to shades being down as a result of sunlight penetrating the space. In addition, this area did not seem to be completely occupied, so the electric lighting may have been turned off.

DESK 678

16:48, Desk 678

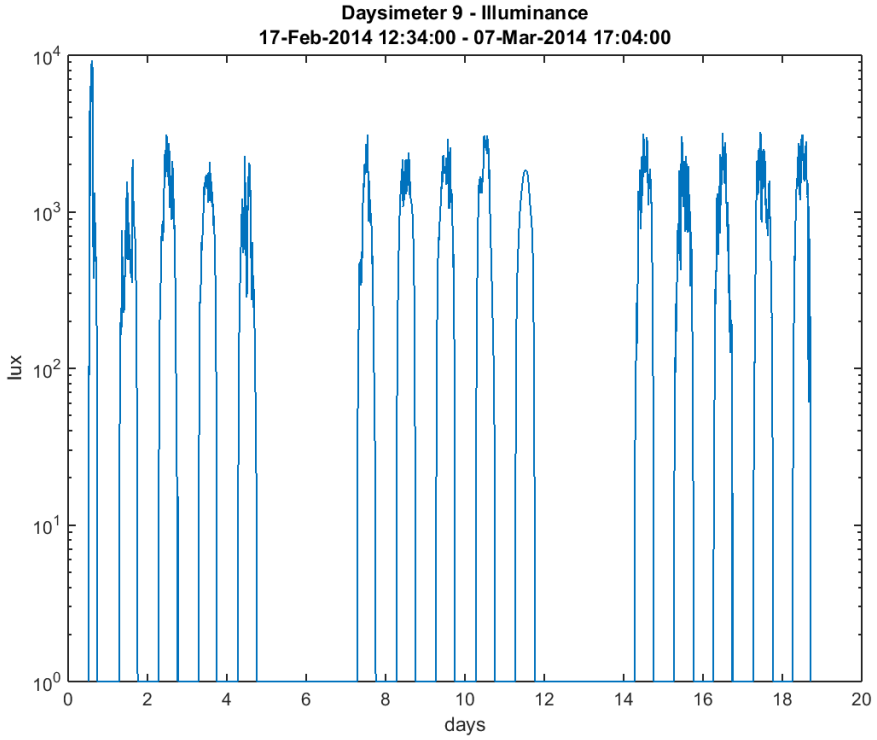


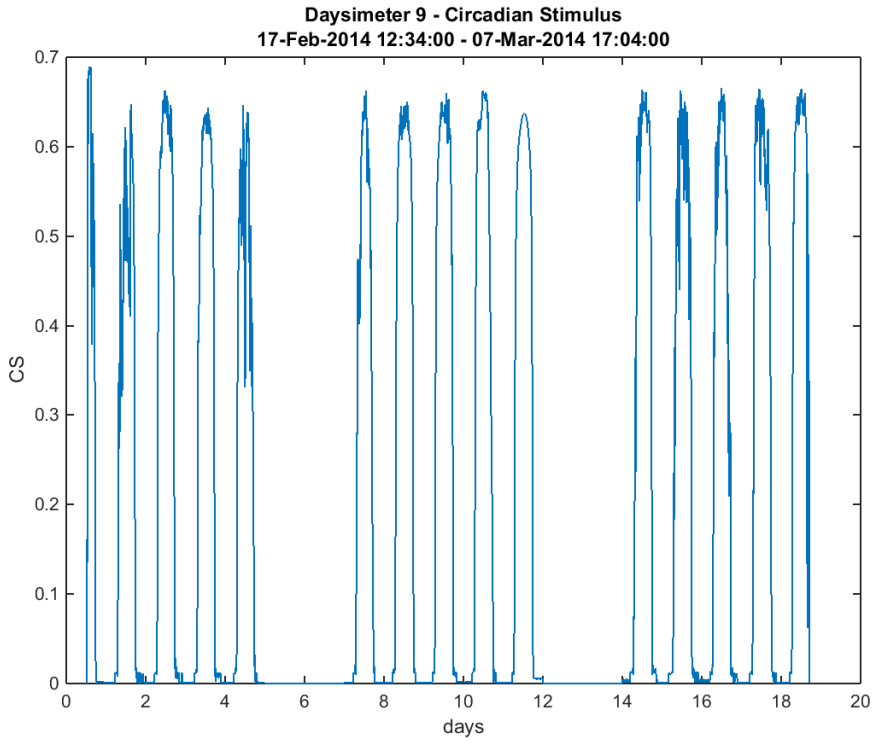


Deskspace 678 (Daysimeter 31). This Daysimeter was placed on a desk situated on the south side of the building, close to the perimeter and was facing against the window (mimicking the sitting position of a user). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 138 ± 37 lux on cloudy days. The mean CS value on was 0.17 ± 0.04 on cloudy days. There are no sunny days data available. The CS values are slightly below the desired range, most likely due to shades being down as a result of sunlight penetrating the space.

DESK 682

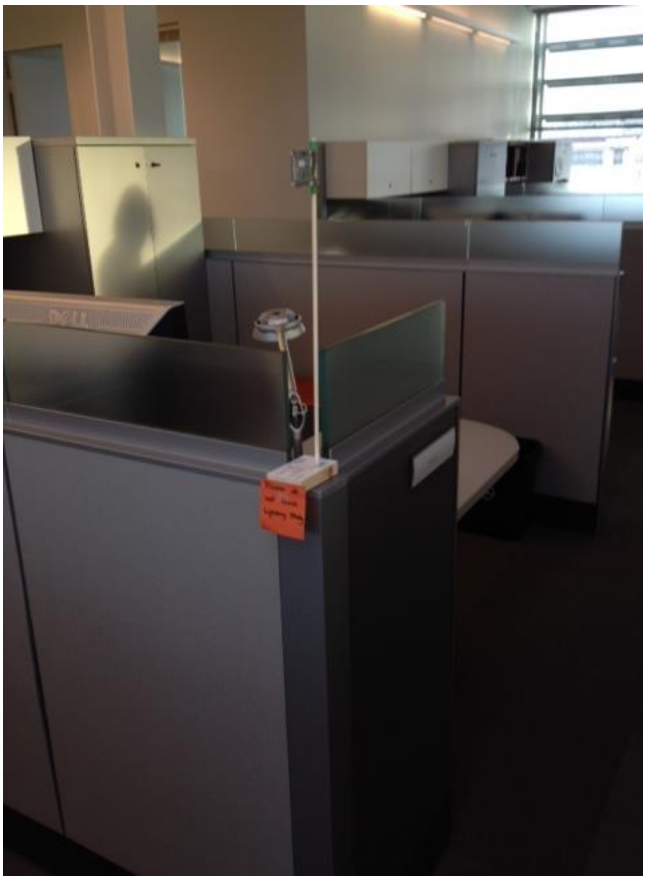
16:49, Desk 682



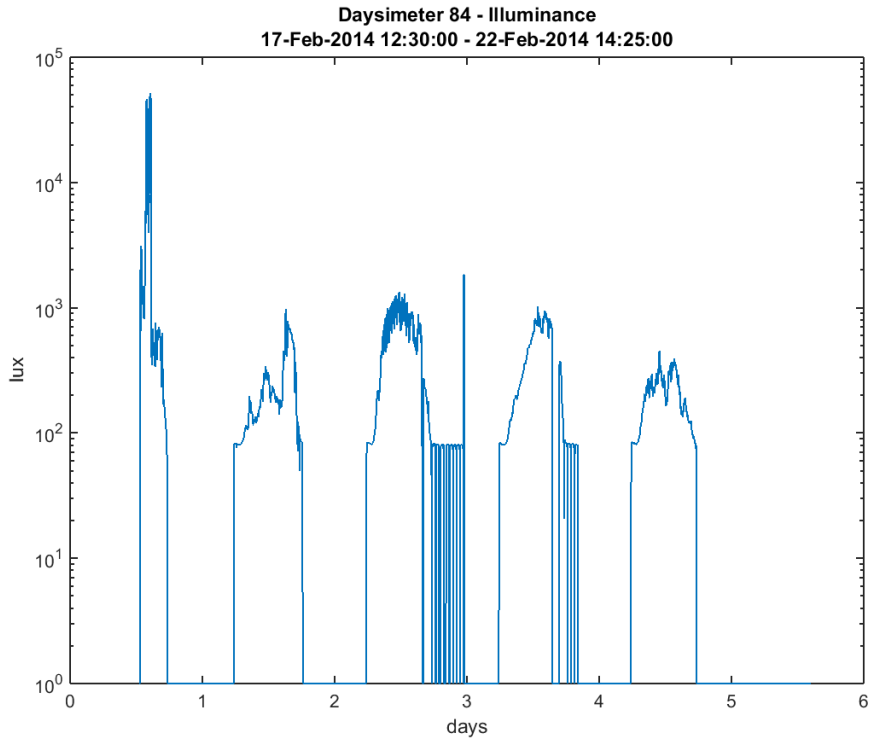


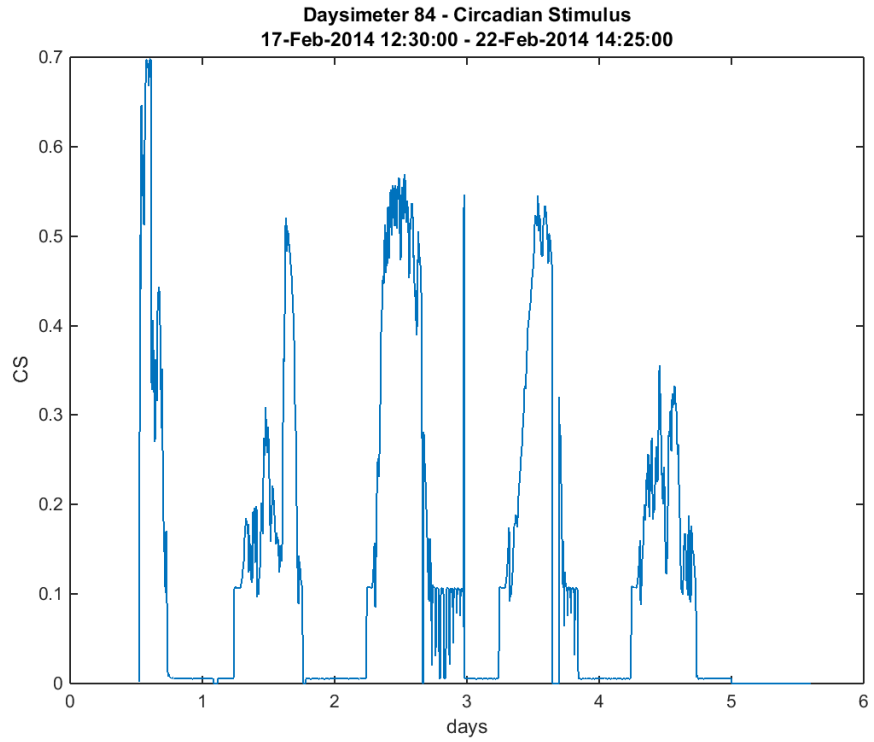
Deskspace 682 (Daysimeter 9). This Daysimeter was on a desk situated on the south side of the building, but the deskspace was facing the atrium (north). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1156 ± 577 lux on cloudy days. The mean CS value on was 0.53 ± 0.13 on cloudy days. There are no sunny days data available. The CS values were within the desired range.

DESK 708



16:52, Desk 708

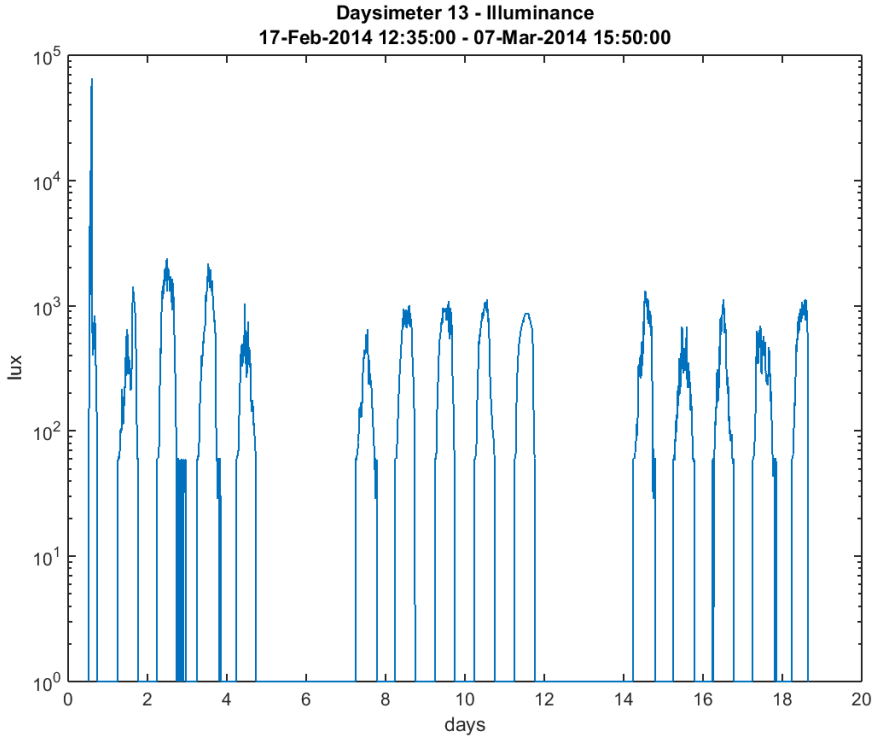


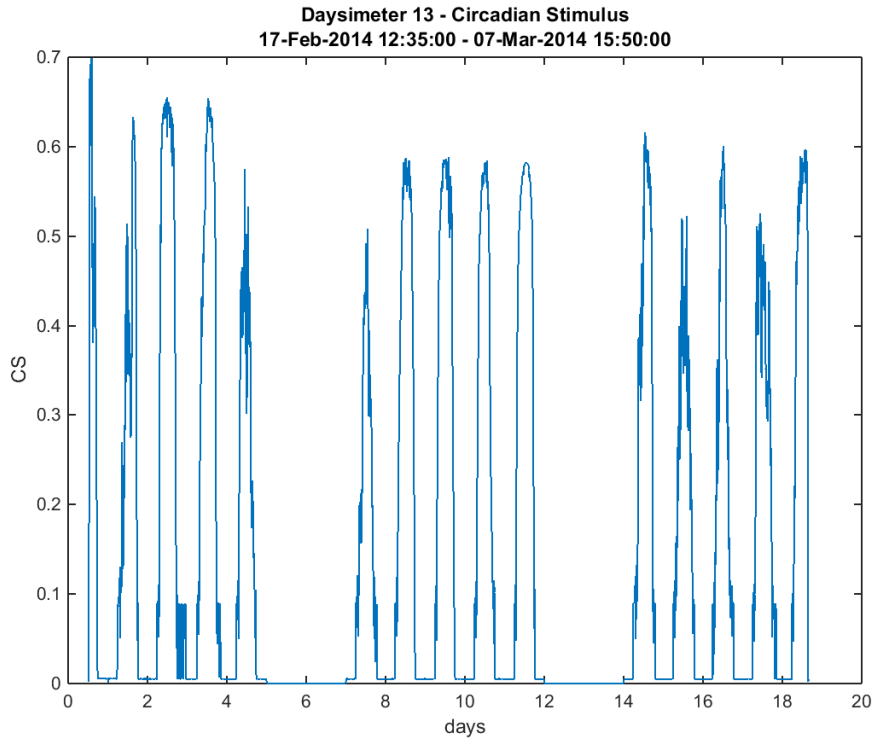


Deskspace 708 (Daysimeter 84). We may have had a malfunction in the device. We are checking the data.

DESK 710

16:51, Desk 710



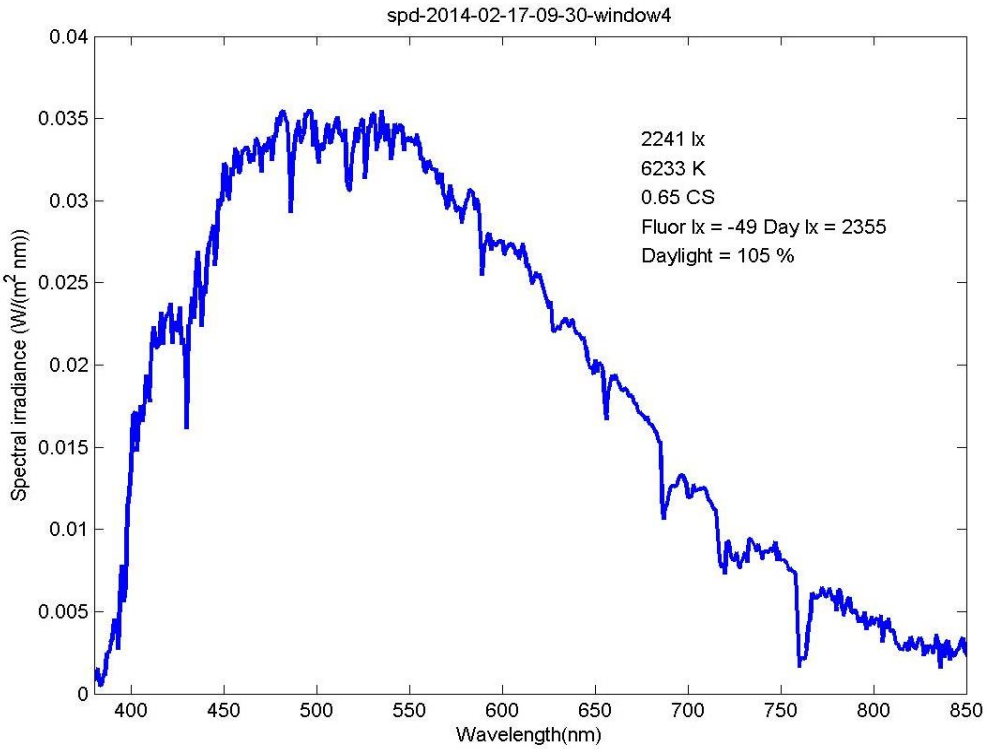


Deskspace 710 (Daysimeter 13). This Daysimeter was on a desk situated on the south side of the building, but the deskspace was facing the atrium (north). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 687 ± 531 lux on cloudy days. The mean CS value on was 0.39 ± 0.12 on cloudy days. There are no sunny days data available.

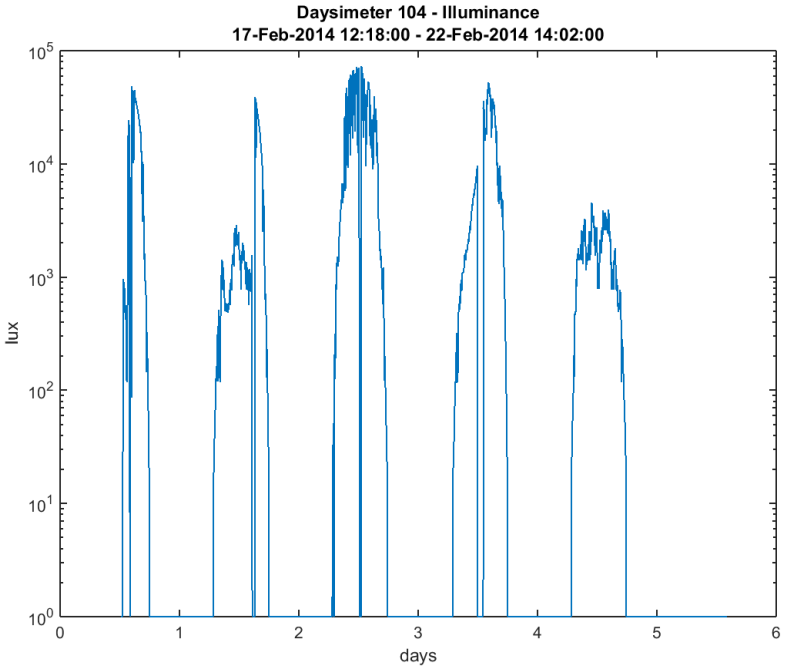
WINDOW UNIT 104

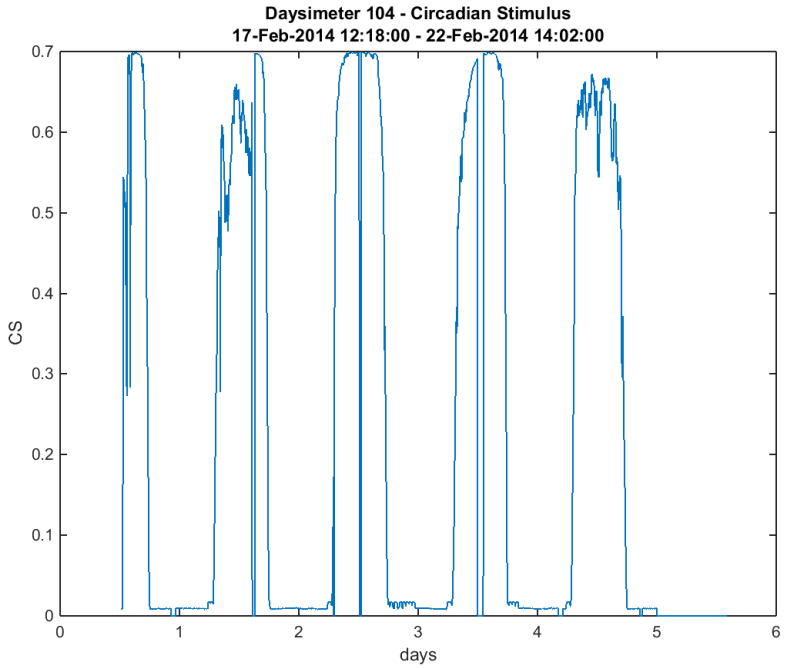
09:31 (left) and 14:27 (right), Window 104

SPD



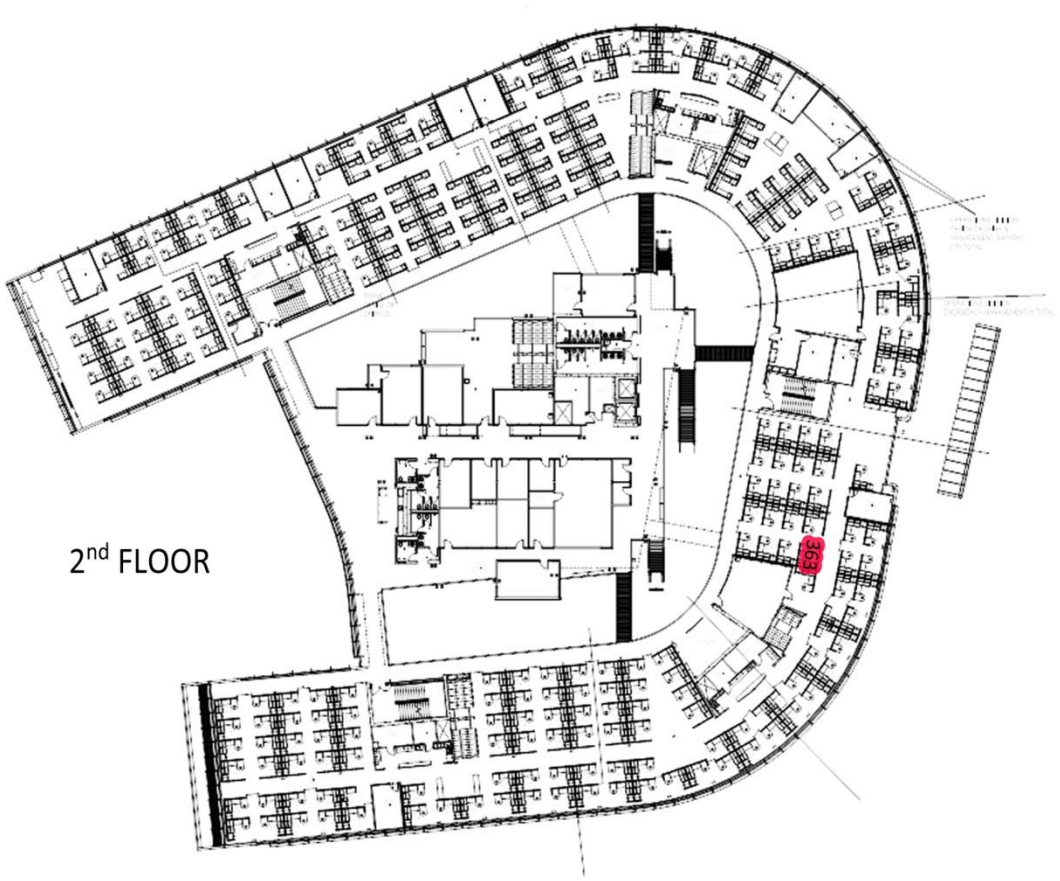
collected at this window, at 9:30AM

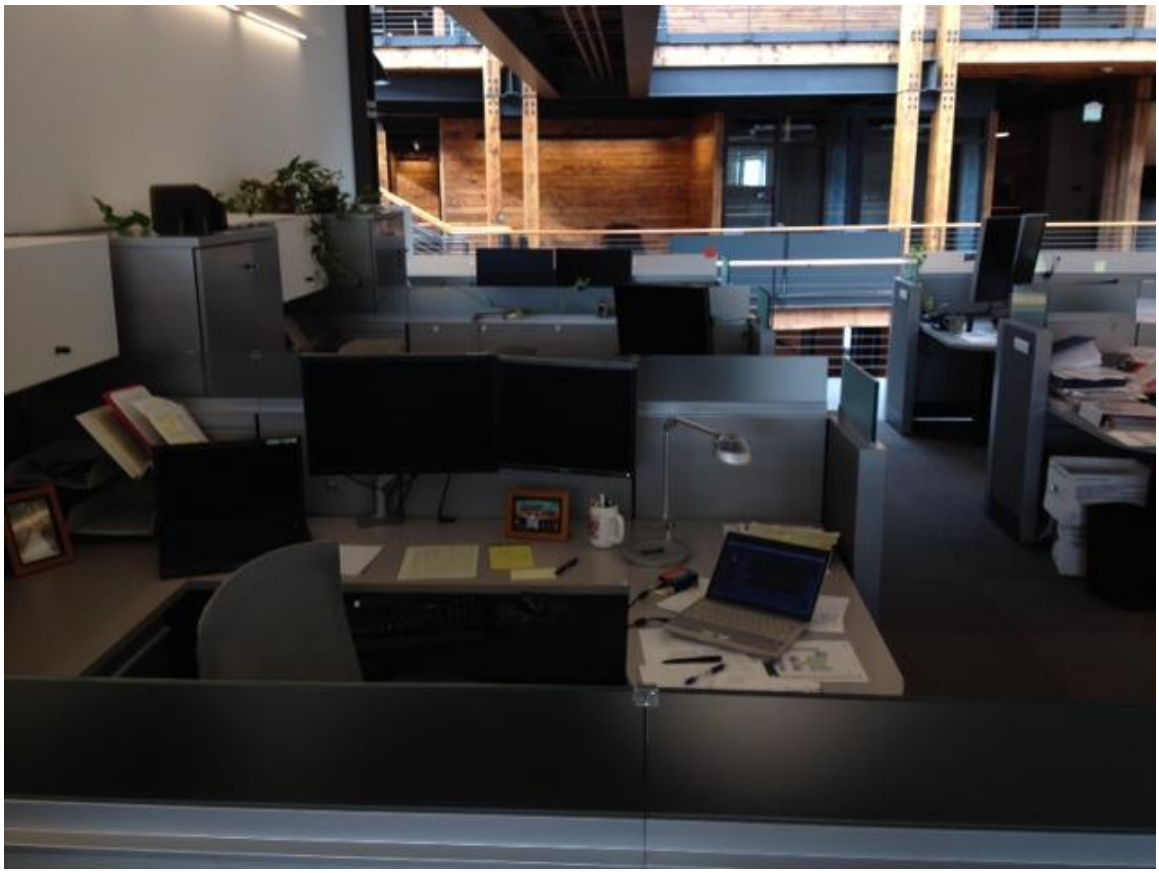




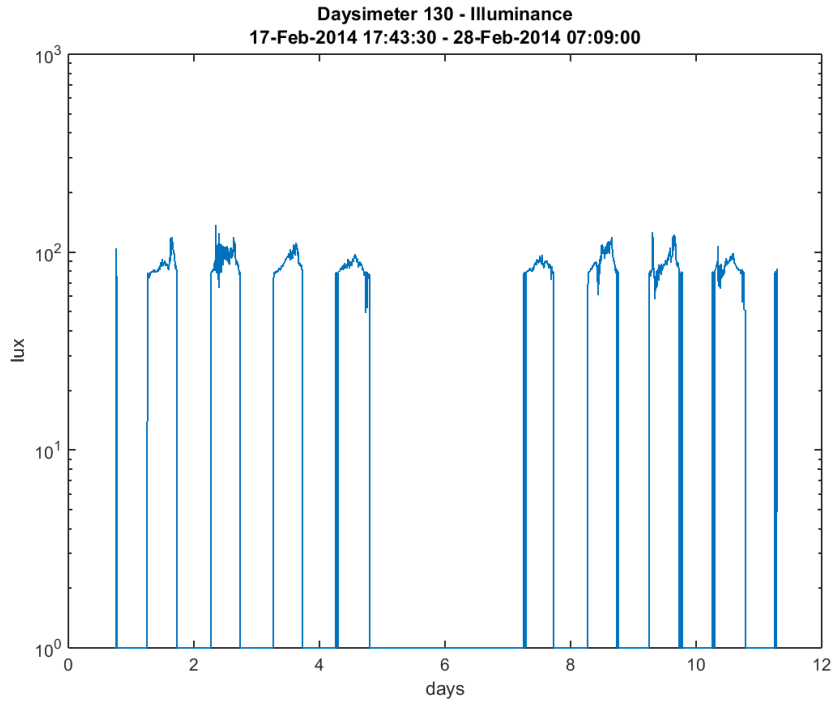
Daysimeter 104 – South Façade. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 9706 ± 6779 lux on cloudy days. The mean CS value on was 0.60 ± 0.11 on cloudy days. There are no sunny days data available.

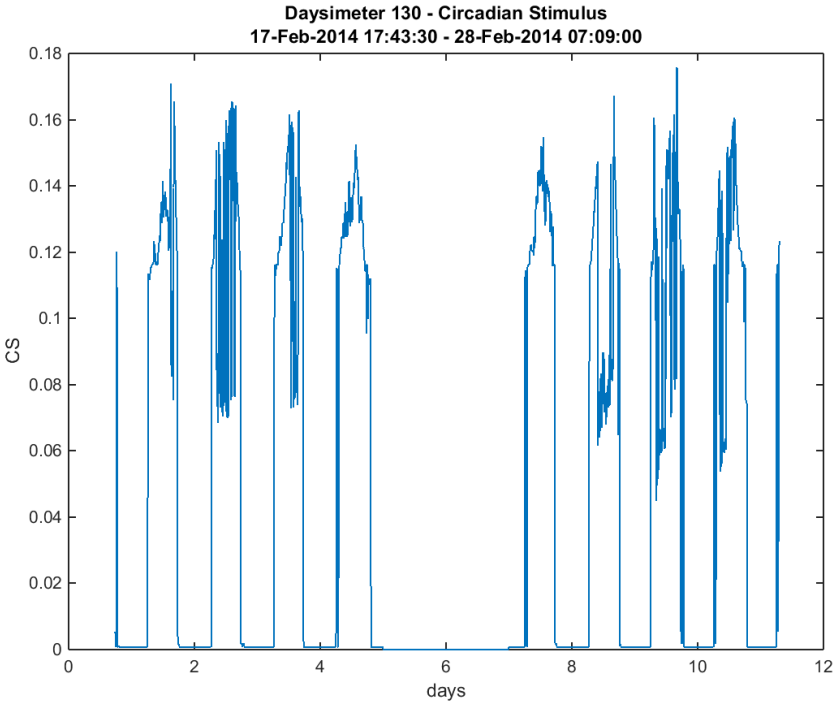
DESK 363 (SECOND FLOOR)





11:21, looking west from Desk 363, towards Desk 364





Deskspace 363 (level 2) (Daysimeter 130). This Daysimeter was on a desk situated on the east side of the building, on a deskspace located between the perimeter and the atrium. The deskspace was facing the atrium (west). Mean photopic light level during working hours (08:00 am to 05:00 pm) was 72 ± 10 lux on cloudy days. The mean CS value on was 0.10 ± 0.01 on cloudy days. There are no sunny days data available. The CS values were below the desired range.

APPENDIX L: SPECTRORADIOMETRY RESULTS TABLE

			Illuminance	Approximate Contribution (+/- 10%)		Color Coordinates		Color Temp	Circadian Light	Circadian Stimulus (up to 0.7)	
Row	Desk	Time	Lux	Fluor	Daylight	CIEx	CIEy	CCT(K)	CL_A	CS	Bright-ness
A	desk253	11:33:00	290.1	43%	57%	0.365	0.3771	4452	238.7	0.27	207.9
D	desk256	11:31:00	319.1	41%	59%	0.366	0.3788	4431	258.4	0.29	226.7
A	desk361	11:23:00	244.3	39%	61%	0.361	0.3767	4555	207.3	0.25	176.5
A	desk415	11:09:00	117.4	59%	41%	0.38	0.3842	4069	76.8	0.11	79.2
D	desk364	18:36:00	53.9	1%	99%	0.423	0.3958	3186	57.9	0.08	31.8
D	desk364	11:21:00	104.5	68%	32%	0.398	0.3958	3704	50.7	0.07	64.9
D	desk412/398	11:13:00	175.5	68%	32%	0.404	0.3958	3560	80.8	0.11	107.7
F	desk410	11:11:00	332.2	7%	93%	0.338	0.3636	5313	375.2	0.36	264.6
F	desk258	11:27:00	1011.8	9%	91%	0.341	0.3702	5195	1126.0	0.55	779.8
F	desk366	11:17:00	187.4	6%	94%	0.328	0.3574	5701	230.2	0.27	155.7
A	desk515	08:30:00	95.4	100%	0%	0.41	0.4017	3478	105.7	0.15	56.5
B	desk538	08:37:00	170.8	93%	7%	0.406	0.3975	3537	194.8	0.24	103.7
B	desk538	18:17:00	126.5	100%	0%	0.429	0.4121	3205	117.5	0.16	69.4
B	desk639	09:09:00	138.7	98%	2%	0.412	0.3995	3430	152.1	0.20	82.4
B	desk644	09:13:00	118.8	97%	3%	0.412	0.3987	3429	128.9	0.17	71.0
B	desk658	09:16:00	222.2	100%	0%	0.419	0.4027	3316	230.8	0.27	128.4
B	desk658	10:12:00	600.6	7%	93%	0.345	0.375	5079	613.0	0.45	450.9
B	desk678	10:18:00	403.9	9%	91%	0.343	0.3706	5117	421.4	0.38	308.8
B	desk678	18:01:00	127.8	100%	0%	0.426	0.403	3181	128.6	0.17	72.8
B	desk678	09:19:00	135.0	98%	2%	0.415	0.4026	3401	143.6	0.19	78.9
B	desk678	17:59:00	98.5	100%	0%	0.444	0.4204	3014	82.9	0.12	50.5
B	desksp1	08:41:00	197.1	89%	11%	0.404	0.3885	3521	95.8	0.13	124.4
B	desksp1	18:13:00	249.4	100%	0%	0.424	0.4031	3227	243.4	0.28	142.3
B	desksp2	08:45:00	235.9	100%	0%	0.415	0.4016	3377	246.5	0.28	138.2
B	deskSp5	09:00:00	107.4	88%	12%	0.402	0.3953	3614	48.4	0.07	66.3
B	deskSp5	18:07:00	108.1	100%	0%	0.406	0.3893	3470	47.6	0.07	67.2
C	desk708	09:27:00	200.6	48%	52%	0.352	0.3627	4802	201.0	0.24	155.6
C	desk708	10:25:00	608.4	0%	100%	0.318	0.341	6183	914.1	0.52	545.6
D	desksp4	08:57:00	215.7	78%	22%	0.389	0.3826	3829	134.3	0.18	143.8
D	desksp4	18:09:00	139.7	100%	0%	0.419	0.3947	3242	142.6	0.19	82.9
E	desk498	10:38:00	437.1	36%	64%	0.352	0.3674	4826	434.2	0.39	333.0
E	desk498	18:34:00	61.8	100%	0%	0.424	0.3751	2978	24.1	0.03	39.4
E	desk501	10:42:00	779.3	9%	91%	0.339	0.3732	5275	845.8	0.51	596.8
E	desk501	18:32:00	78.0	100%	0%	0.418	0.3918	3251	78.8	0.11	46.1
E	desk511/500	10:44:00	925.9	7%	93%	0.335	0.3714	5403	1051.8	0.54	718.8
E	desk511/500	18:30:00	87.5	100%	0%	0.408	0.3838	3381	42.9	0.06	55.5
E	desk710	09:25:00	191.3	17%	83%	0.319	0.3485	6084	258.7	0.29	166.9
E	desk710	10:24:00	756.0	0%	100%	0.308	0.3395	6673	1205.2	0.56	696.3
E	desksp6	09:06:00	182.1	68%	32%	0.378	0.3797	4101	129.0	0.17	125.9
F	desk521	09:50:00	976.5	3%	97%	0.321	0.3548	6000	1349.7	0.57	830.2
F	desk521	09:57:00	1719.0	1%	99%	0.325	0.3607	5782	2354.7	0.62	1416.3
F	desk521	09:58:00	1942.8	1%	99%	0.328	0.3637	5697	2620.0	0.63	1576.6
F	desk521	09:59:00	2034.7	2%	98%	0.325	0.3624	5801	2818.1	0.64	1667.2
F	desk521	10:33:00	14217.8	0%	100%	0.333	0.374	5478	24970.8	0.69	10981.1
F	desk521	11:03:00	2003.5	0%	100%	0.327	0.364	5703	2710.8	0.63	1624.1
F	desk521	11:04:00	1740.7	0%	100%	0.326	0.3638	5757	2333.8	0.62	1415.8
F	desk521	08:21:00	178.0	17%	83%	0.33	0.3589	5612	212.5	0.25	146.3
F	desk521	13:52:00	16169.3	0%	100%	0.339	0.3772	5285	27685.9	0.69	12209.2
F	desk545	08:34:00	333.2	13%	87%	0.329	0.3589	5634	404.1	0.37	274.1
F	desk545	18:18:00	41.2	89%	11%	0.432	0.3896	2958	14.6	0.02	24.7
F	desk616	08:54:00	299.2	13%	87%	0.33	0.3587	5596	361.2	0.35	246.2
F	desk616	13:55:00	1647.5	0%	100%	0.318	0.3565	6107	2397.2	0.62	1397.8
F	desk616	18:10:00	29.9	84%	16%	0.44	0.4245	3110	19.0	0.03	15.8
F	desk682	09:22:00	234.4	9%	91%	0.322	0.3521	5958	307.7	0.32	201.0
F	desk682	10:20:00	1014.0	0%	100%	0.29	0.3291	7827	1885.9	0.60	1005.7
F	desk682	18:03:00	28.3	72%	28%	0.415	0.349	2902	21.0	0.03	21.1
F	desksp3	08:49:00	217.6	49%	51%	0.364	0.3777	4486	178.4	0.22	156.0
A	window4	09:30:00	2240.6	0%	100%	0.315	0.3522	6233	3514.3	0.65	1941.9

AVERAGE SPECTRORADIOMETRY RESULTS

Deskspace Locations	Lux	CCT(K)	CLA	CS	Bright-ness
A	598	4558	829	0.29	492
B	203	3594	193	0.21	130
C	404	5492	558	0.38	351
D	168	3659	121	0.15	110
E	389	4663	452	0.30	309
F	2208	5329	3542	0.43	1734

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 λ<450 nm, 450< λ <730 nm, and λ >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 M: DAYLIGHT GLARE VALIDATION STUDY

DAYLIGHT GLARE VALIDATION STUDY

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MARCH 4, 2014

INTRODUCTION

The present document summarizes a short observation study to validate the use of vertical illuminance in a daylighted office space as a preliminary metric for discomfort glare within the office space.

BACKGROUND

A number of metrics to predict the degree of discomfort glare associated with the presence of windows have been developed, including daylight glare index (DGI: Hopkinson 1972) and daylight glare probability (DGP: Wienold and Christoffersen 2006). A recent study of occupant comfort in a daylighted office building by Van Den Wymelenberg and Inanici (2014) suggests that the vertical illuminance at observers' eyes serves as a better predictor of visual comfort/discomfort than DGI and DGP. They estimated that the border between comfort and discomfort in their study occurred when the vertical illuminance at the eye was between 875 and 1250 lx. To confirm and validate the findings of Van Den Wymelenberg and Inanici (2014), evaluation data were collected for a daylighted space in a conference room at the Lighting Research Center.

METHOD

Observations of discomfort glare were collected by eight observers, all employees of the Lighting Research Center, in a conference room with east-facing windows and indirect overhead lighting. Between the windows a large flat-screen computer monitor was mounted. This screen displayed a subjective rating scale used in many studies for assessing discomfort glare, the De Boer (1967) scale (1=unbearable, 3=disturbing, 5=just permissible, 7=satisfactory, 9=just noticeable glare). All of the observations were conducted between 8:30 and 9:30 am on a partly cloudy day, to maximize daylight entering through the windows.

Each observer made five observations. For each observation, the window blinds were either entirely opened or set to produce a vertical illuminance from daylight of approximately half the level when they were fully opened, and the electric lighting was adjusted to produce its full output or a value of approximately half this value. To account for natural fluctuations in daylight, vertical illuminances at observers' eye locations were made during each trial. There were four (2 blinds positions × 2 electric lighting levels) conditions viewed by each observer. In addition, observers wore orange wraparound goggles (transmission 45%) and viewed the blinds-open, half-electric-lighting condition while wearing the goggles. Each of the five conditions were viewed by each observer in a different, randomized order.

RESULTS

Figure 1 shows the relationship between the total vertical illuminances (including contributions from both daylight and electric light) and the daylight-only vertical illuminances for each trial. There is a very strong correlation ($r > 0.99$, $p < 0.05$) between the two sets of values; primarily this is because the vertical illuminance from the electric lighting was usually relatively small (100-200 lx) compared to the illuminance from the windows (up to nearly 4500 lx).

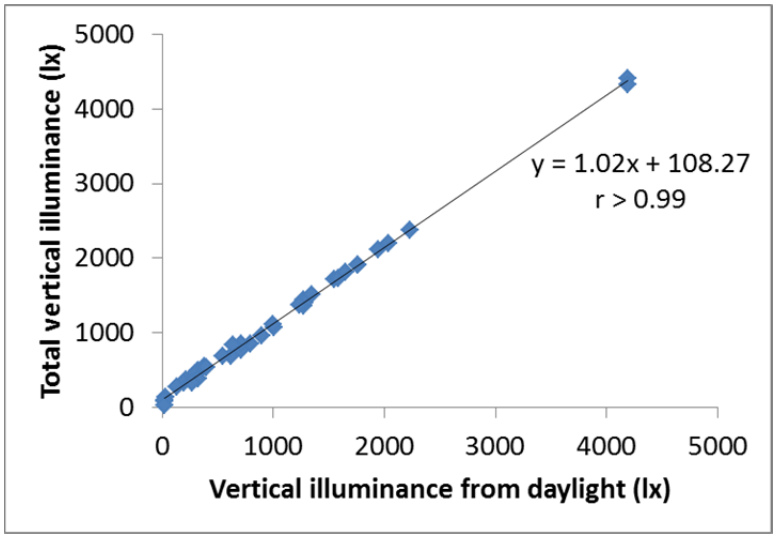

Figure 1. Relationship between total vertical illuminance and daylight-only vertical illuminance at the observers' eye position.

Figure 2 shows the discomfort glare ratings plotted as a function of the vertical illuminance from daylight for each of the individual observations. There is a moderate and statistically significant ($r = 0.58$, $p < 0.05$) but negative correlation between the sets of values, but as seen in Figure 2 there can be substantial variation among ratings for conditions with similar vertical illuminances from daylight.

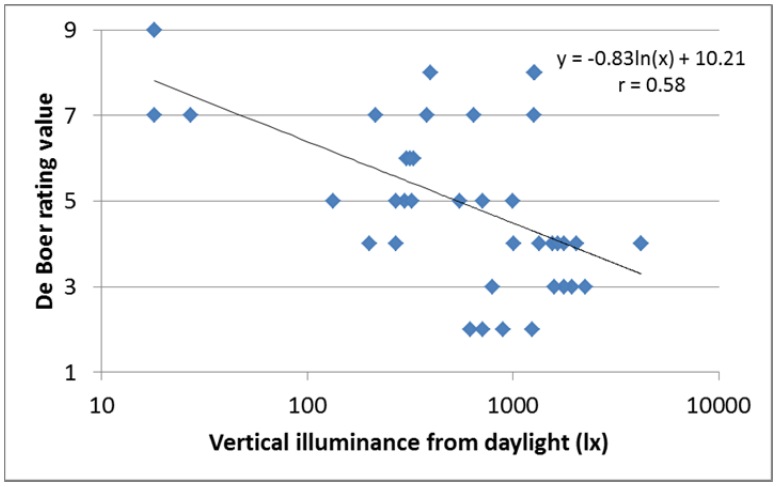

Figure 2. Individual discomfort ratings, plotted as a function of the vertical illuminance from daylight at each observation.

A within-subjects analysis of variance (ANOVA) was conducted on the ratings using the blinds position (open or partially closed) and the electric light level setting (full or half) as independent variables. There were statistically reliable ($p < 0.05$) main effects for both variables, with ratings being numerically higher (less glare) for the partially closed blinds setting and for the higher electric lighting level. The interaction between blinds position and electric lighting level on the glare ratings was not statistically reliable ($p > 0.05$).

Figure 3 shows the mean ratings for each combination of blinds position and electric lighting level, plotted as a function of the mean illuminance from daylight for each condition. The data closely follow a logarithmic function of vertical illuminance with a strong, statistically significant correlation ($r = 0.97$, $p < 0.05$) between

the mean illuminance values and the mean ratings. Also shown in Figure 3 is the mean vertical illuminance and glare rating value for the blinds-open, half-electric-lighting condition, when viewed through the orange goggles.

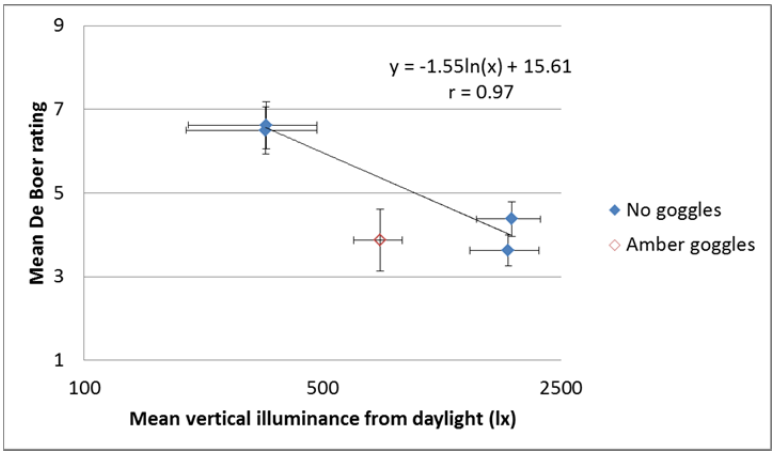

Figure 3. Mean discomfort ratings for each blinds and electric lighting condition, plotted as a function of the mean vertical daylight illuminance from each condition. Also shown is the mean rating to the blinds-open, half-electric-lighting level when wearing orange goggles.

DISCUSSION

The results from this preliminary validation study suggest that there is a relationship between the vertical illuminance at the eye from daylight and the level of discomfort experienced by occupants. Because of the very strong correlation between total and daylight-only illuminances at the eye (Figure 1), the present study do not differentiate between these quantities as predictors of discomfort glare, although it was found that the correlation coefficients were slightly lower when using total illuminance than when using the daylight-only illuminance as a predictor. Van Den Wymelenberg and Inanici (2014) used total illuminance as a predictor in their study, but since the majority of vertical illuminances they measured exceeded 1000 lx, it is very likely that the illuminances in their study were also dominated by daylight contributions as they were in the present evaluations.

De Boer rating values of 4 and 5 have been suggested (Bullough et al. 2003; Bhise et al. 1977; Rumar 2001) as an approximation of the border between comfort and discomfort. Using the logarithmic function in Figure 3, De Boer ratings of 4 and 5 occur when the vertical daylight illuminance is 940 lx and 1790 lx, respectively. This overlaps well with the range of 875 to 1250 lx identified by Van Den Wymelenberg and Inanici (2014) as the border between comfort and discomfort.

Of interest, it can be seen that when observers wore the orange goggles, the mean discomfort glare rating value decreased (indicating increased discomfort) relative to the predicted value estimated based on illuminance without the goggles. Perceptions of discomfort glare and brightness are influenced by the spectral content of illumination (Bullough 2009; Rea et al. 2011; Bullough et al. 2014). Kelly (1990) and Perez et al. (2003) found amber lenses to increase brightness perception of a scene; and although Bullough et al. (2009) would have predicted lower discomfort glare with the orange goggles, observers may have been judging their sensations of glare in part by the perceived brightness of the overall scene. Daylight is variable in both intensity and spectral content, so understanding the role of spectral content in discomfort glare could be helpful in planning daylighted environments in the future.

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