Results Report:

Facility Lighting — Summer

General Services Administration

Central Office Building

1800 F Street NW

Washington, D.C.

Submitted to:

U.S. General Services Administration
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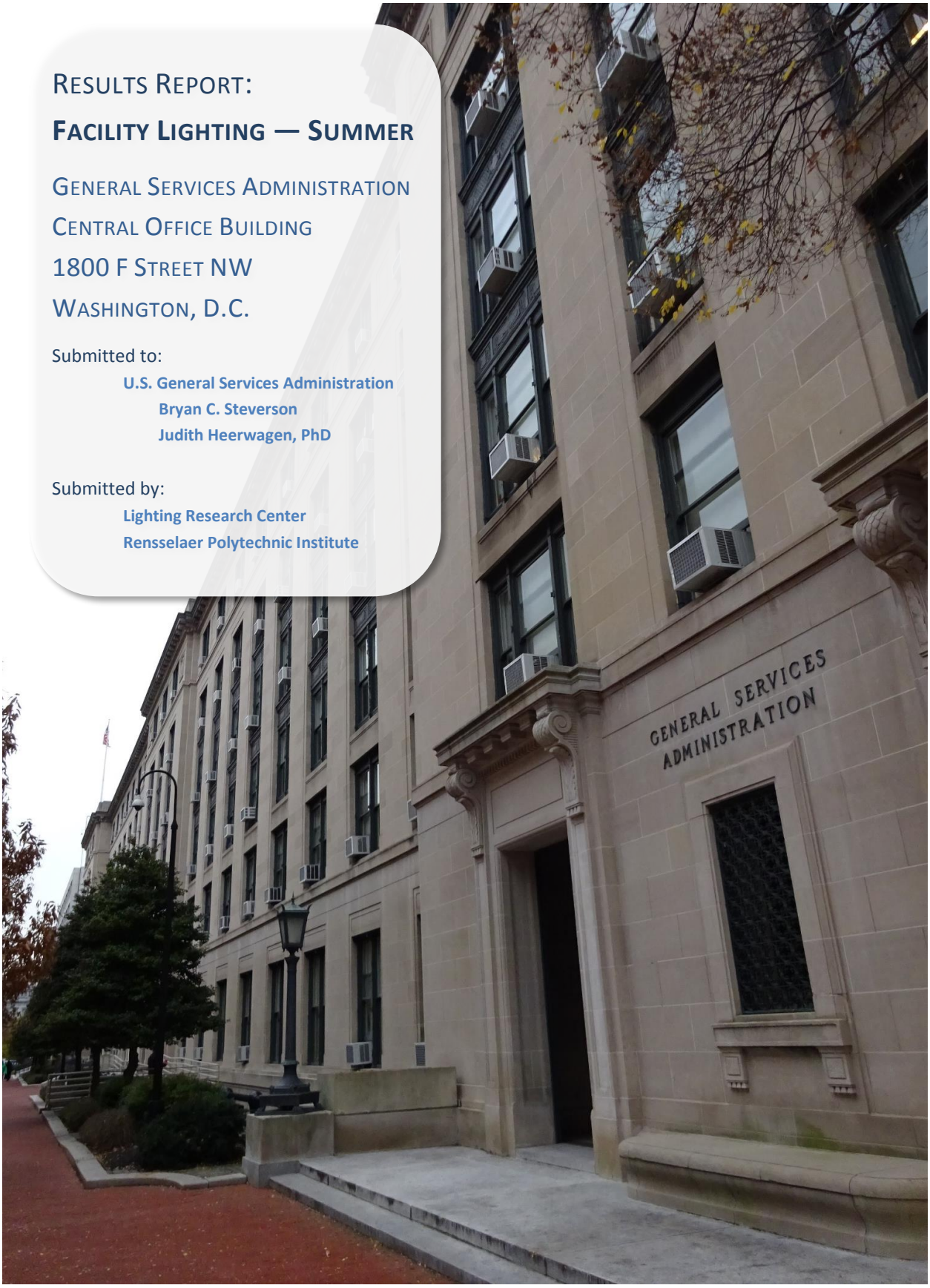

RESULTS REPORT:
FACILITY LIGHTING — SUMMER

GENERAL SERVICES ADMINISTRATION CENTRAL OFFICE BUILDING
1800 F STREET, WASHINGTON, D.C.

SUBMITTED DATE JULY 31, 2015

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EXECUTIVE SUMMARY

The U.S. General Services Administration (GSA) Central Office Building is a 9-story building located at 1800 F Street NW in Washington, D.C. The building was originally constructed in 1917; Phase I modernization[1] of about half the building was completed in 2013. Since the renovation, most staff do not permanently use one desk, but rather, they use a "hoteling" strategy, in which different desk locations are temporarily assigned to workers.[2]

In June 2015, researchers from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, together with GSA staff, returned to the site to repeat the seasonal data collection originally performed in December 2014. LRC researchers made photometric measurements at the same or adjacent open-plan deskspaces located on the ground floor (G), as well as floors 2 and 7. In addition to the field measurements, the LRC placed Daysimeter devices on the same deskspaces as the winter visit to continously measure photopic lux and circadian light over the course of several days. Daysimeters measure continuous light exposures, allowing researchers to perform calculations of how much light that is effective for the circadian system may be reaching deskspaces (i.e., circadian stimulus, or CS).

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

Based on the LRC's previous work, it is hypothesized that CS values above or close to 0.3 should provide enough circadian stimulation to maintain entrainment of circadian rhythms to the local time on Earth. Due to availability of daylight and ease of access, research has continued[3] to focus on open-plan offices. While Daysimeters placed at deskspaces in the building may not be representative of workers' overall personal light exposures, they give an indication of how much circadian light is available in that part of the building. Another component of this research project, not discussed in this report, is the data collection of personal light exposures by building occupants.

In addition to measuring CS at various deskspaces, this report also documents the measured photometric conditions as they relate to occupant visibility, comfort, as well as occupants' behavior and acceptance of the lighting in their deskspaces. However, it is important to keep in mind that measurements on this visit were only made on one June day with variable weather. Photometric values will vary substantially in many spaces due

[1] http://www.thorntontomasetti.com/projects/gsa_headquarters_renovation/

[2] Successful Hoteling: GSA's 10 Tips (http://www.gsa.gov/graphics/admin/Successful-Hoteling-Tips_Final.pdf)

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

to daily and seasonal changes in daylight. Some of this variability is shown in the Daysimeter measurements.

Below are some of the main findings from the June site evaluation at the GSA Central Office Building:

- The data from the LRC's visit to the GSA Central Office Building in June showed moderate overall levels of circadian stimulus in many spaces, though higher than the December measurements.
- As expected, based on measurements from the Daysimeter sticks, the average CS values for most deskspaces on the G floor was below the desired amount of 0.3, with only one deskspace in the west façade reaching CS values above 0.3 in the afternoon. Deskspaces with western exposures in Wing 1, however, reached CS values close to and above the desired value of 0.3 during the midday and afternoon on sunny days. At the end of the workday, CS values dropped to 0.1 for deskspaces that are furthest from windows. Some deskspaces away from windows had CS values at 0.14, which is possibly close to the threshold for the circadian system. These values were higher than during winter months.
- With the exception of two deskspaces, the 2nd floor CS values were at or above 0.3 for most of the workday. Deskspaces in Wing 4 were slightly higher than those in Wing 2. Desk spaces in the southern and western parts of the building had higher CS values than those in the north and the east. Proximity to windows does not appear to have made a significant difference in CS values. Overall, the CS values in summer were higher than those in winter, with Wing 4 having the highest CS during winter.
- With the exception of one deskspace, the 4th floor CS values were above 0.3 for most of the workday. Deskspaces in Wing 1 and with eastern exposure had slightly higher mean CS. Deskspaces that are close to windows had CS values above 0.3. The CS values were lower in the winter months, with deskspaces in Wing 1 being the only ones to reach a CS value of 0.3.
- With the exception of one location, most deskspaces on the 7th floor had CS values above 0.3 for most of the workday. The highest CS values were reached at deskspaces in Wing 4 that had southern window exposure. The 7th floor CS levels are significantly higher in summer than in the winter months, with deskspaces in the eastern part of the building having CS levels at or above 0.3.
- On the June visit, as in the December visit, most of the deskspaces had a horizontal illuminance of greater than 30 footcandles (approximately 300 lux). Half (50%) of the summer occupants surveyed reported that they use their task light. Controls for the task lights seem to be confusing to occupants. Overall, the amount of light on their desks was neither too much nor too little in summer.

INTRODUCTION

The U.S. General Services Administration (GSA) Central Office Building is a 9-story building located at 1800 F Street NW in Washington, D.C. The Lighting Research Center (LRC) collected photometric measurement data at a site visit June 16, 2015. This report is a summer-season repeat of the data reported from December 2014.[4]

The GSA Central Office Building fills a city block. Like many other buildings constructed in the early 1900s, it has light-well courtyards. As shown in Figure 1, each wing bears a number and an assigned color code. Each desk has an alphanumeric address, which is necessary for workers to locate their assigned space from week to week. Over half of the available desks have an east or west window orientation, while the rest have a north or south orientation.

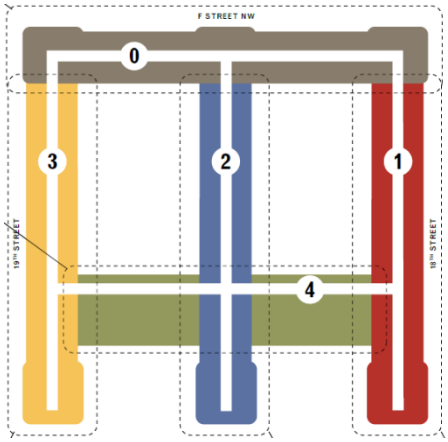

Figure 1. Generic floor plan at the GSA Central Office Building. Each wing bears a number and assigned color code.

[4] LRC. (2015). Results Report: Facility Lighting – Winter, GSA Central Office Building, Washington, D.C.

RESEARCH OBJECTIVES

LRC repeated photometric measurements at the GSA Central Office Building in June 2015, at the same or similar locations as in December 2014. The goal of the research was to compare seasonal photometric conditions as they relate to occupant comfort, productivity, and circadian health.

The follow-up evaluation took place on June 15-16, 2015. Daylighting conditions were representative of summer, as the visit was during daylight savings, and summer solstice occurred the week after the visit. LRC researchers included Dr. Mariana Figueiro (LRC Light and Health Program Director), Jennifer Brons (LRC DELTA Program Director[5]), and research assistant Kassandra Gonzales. The LRC team was escorted and assisted by Bryan Steverson of GSA.

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

METHODS

On Day 1 (June 15, 2015), measurement locations were set up on four floors with open-plan offices (ground floor [G], and floors 2, 4, and 7), in both the Phase I-renovated area, as well as spaces with only new furniture. Also on Day 1, battery-powered measurement equipment was installed and documented. Data collection started on the morning of Day 2, and continued until evening (June 16, 2015). Each member of the research team was responsible for one aspect of data collection (detailed below). Two researchers collected illuminance and luminance measurements while one researcher performed spectral power distribution measurements. Questionnaires were administered on Day 2.

Five types of measurements were completed at the GSA Central Office Building:

Illuminance: Illuminance is a measure of the amount of light falling on a surface, in units of lux (lx [SI]) or footcandles (fc [in the U.S.]). Illuminance measurements are important because they are used conventionally as design criteria. LRC measured illuminance multiple times over the measurement day, on horizontal and vertical surfaces, at desks on three floors, and at all window orientations. Two researchers collected these illuminance data using Gigahertz-Optik (model: X91) lux meters. Illuminance data were collected on floors G, 2, and 7, in wings 0, 1, 2, and 3.

Luminance: Luminance is a measure of the amount of light emitted or reflected by a surface. Luminance relates to perceptions of brightness and glare. Luminance is measured in units of candela per square meter (cd/m^2), using a meter device that resembles the viewfinder of a camera aimed at luminous surfaces. Because viewing position impacts luminance, measurements were collected at the desk chair location when facing key surfaces, such as a computer monitor, and the nearest window. Two researchers collected luminance data using Minolta (models: LS-110 and LS-100) luminance meters. Luminance data were collected on floors G, 2, and 7, in wings 0, 1, 2, and 3.

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 the GSA Central Office Building to allow researchers to calculate, using different response functions, measures such as brightness, glare, and circadian stimulus. SPD data were collected on floors G, 2, and 7, in wings 0, 1, 2, and 3. Researchers collected these data 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 R2014a to generate curve functions.

Daysimeter photopic and circadian light exposure devices: Daysimeter devices collected continuous light exposures that allowed researchers to perform calculations of how much light that is effective for the circadian system was reaching deskspaces. Briefly, light sensing by the Daysimeter is performed with an integrated circuit (IC) sensor array (Hamamatsu model S11059-78HT) that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR). The R, G, B, and IR photo-elements have peak spectral responses at 615 nm, 530 nm, 460 nm, and 855 nm, respectively. The Daysimeter is calibrated in terms of orthodox photopic illuminance (lux) and of circadian illuminance (CL_A). CL_A calibration is based upon the spectral sensitivity of the human circadian system. From the recorded CL_A values it is then possible to determine the 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 31 desks and 13 windows. These collected data for one month after LRC visited the site. The devices were removed by Mr. Steverson, and were returned by mail to LRC for read-out.

Questionnaires: LRC administered questionnaires to 18 employees at the GSA Central Office Building. The questions were the same as LRC used at other GSA evaluation sites, and on the previous evaluation of this site.

RESULTS

ILLUMINANCE RESULTS

LRC measured photometric conditions (illuminance and luminance) at the GSA Central Office Building. Photometric data were collected for 19 desks, and were organized by perimeter proximity, by perimeter window orientation, and by collection time. Desks located on the outer perimeter are referred to as 'A desks,' while desks not directly next to a window are 'B desks.' The skies were primarily sunny on the measurement day, though there were intermittent clouds.

Figure 2 shows an example of typical horizontal illuminance measurement locations at the 19 desks. Because partitions at the GSA Central Office Building are below eye height, LRC did not measure vertical illuminance on partitions. However, LRC did measure vertical illuminance at the eye. Figure 3 is a key plan showing the 19 measurement locations on floors G, 2, and 7. Measurement locations were in both Phase I-renovated spaces as well as non-renovated spaces with new furniture and task lighting.

Measurements occurred in the morning, midday, afternoon, and after dark. Measurements included additional daylight contribution. Some spaces in the Phase I-renovated areas may have seen reduction of electric lighting in response to increased daylighting. The resulting measurements are shown in detail in Appendix A.

Figure 2. Typical horizontal measurement points at a row A desk.

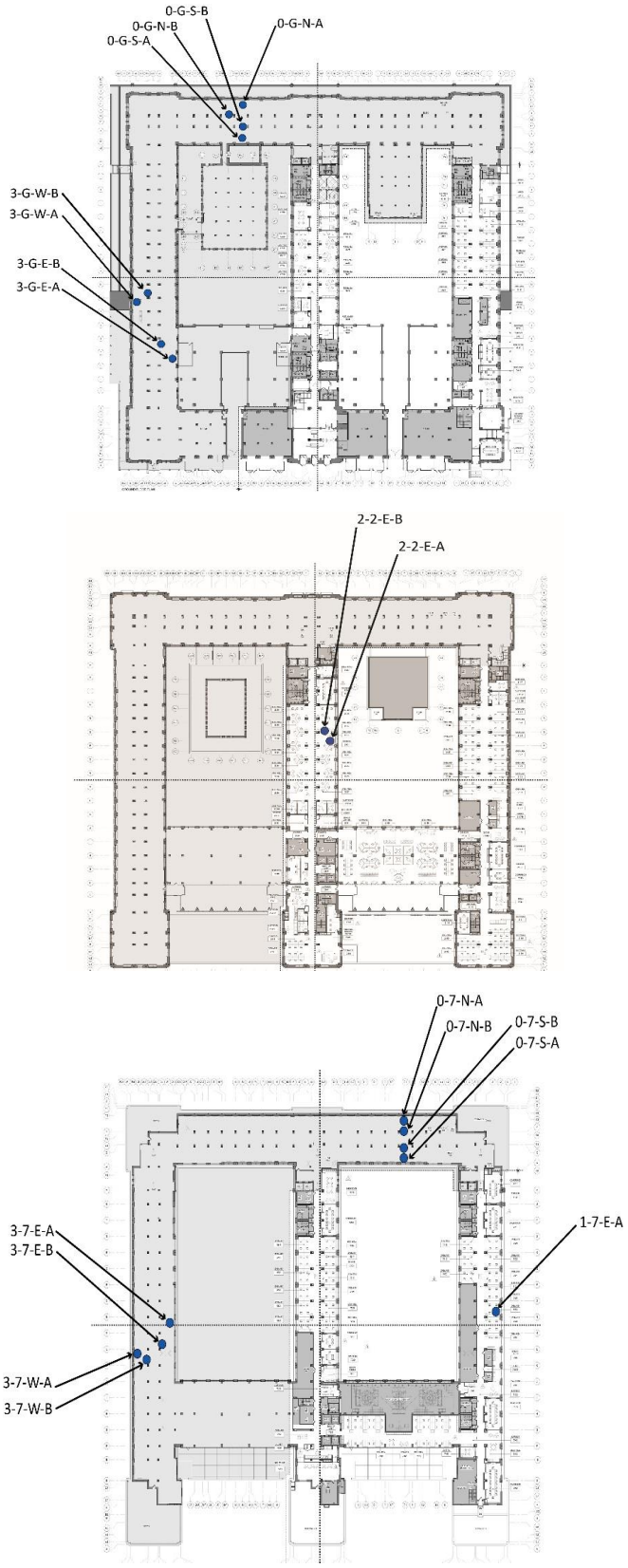

Figure 3. Photometric measurement locations on floors G, 2, and 7. Numbering convention: (Wing#)-(Floor)-(Window Orientation)-(Window proximity). Grey color indicates new furniture/task lights, not full Phase I remodel.

As shown in Appendix A, horizontal illuminances were high (400-900 lx) at A desks. Illuminances were higher compared to the winter measurements. At B desks, illuminances were often lower than A desks. However two B desks had higher light levels than A desks (Figure 4). The continuous, high measurements indicate that electric light was the cause, not daylight.

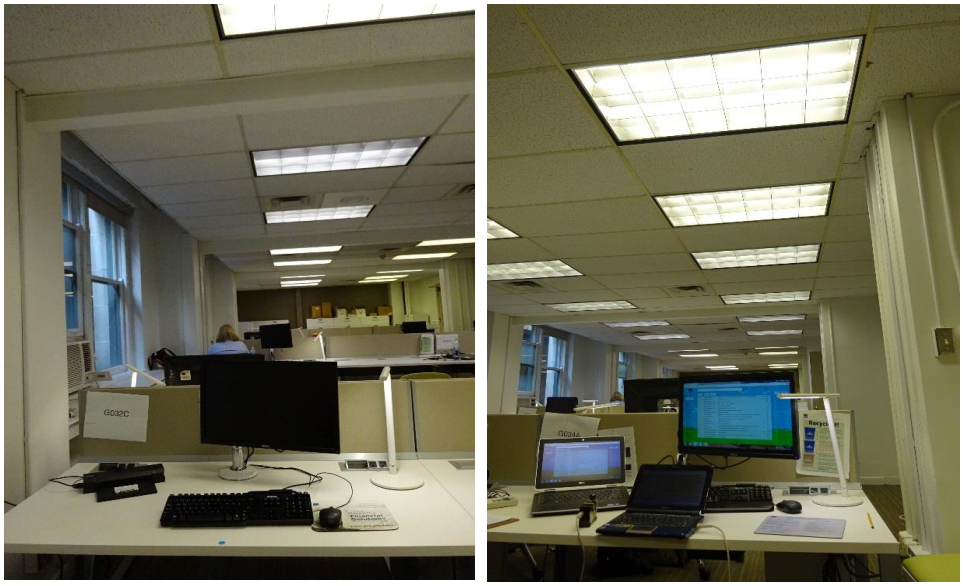

Figure 4. The measurement point on the desk closer to the window (0-G-N-A, left) had lower horizontal illuminances than the desk closer to the door (0-G-N-B, right)

Wing 2 and Wing 1 are in the Phase I renovation area, thus have new overhead lighting that may be controlled by photosensors; even so, desk illuminances in these areas were high (600-900 lx, during the day). There were some desks with low illuminances (<100 lx); this was primarily in spaces not exposed to daylight (ground floor south, as well as 7th floor north).

Vertical illuminances at the eye were mixed as well. A and B desks had similar vertical illuminances at the eye in many cases, and in a few cases, B desks had higher vertical illuminances than A desks. It should be noted that most of the measurement desks had to be changed to nearby vacant desks on this June visit, so these desk locations and seating orientations do not exactly match the December visit.

LUMINANCE RESULTS

LRC measured luminance at the same time interval and desk locations used for illuminance measurements. For each of the desks, LRC measured luminance of the nearest window during the daytime measurements, as well as desk surface and computer monitor bezel.

The resulting measurements are shown in detail in Appendix A. On the north facade, there were a few desks with a view of the sun at multiple times of day, and thus potential window glare; questionnaires, however, showed little concern about sun (see Appendix B).

LRC also measured luminance of key surfaces commonly viewed at the desk: on the desk and on the computer monitor bezel. As observed at other GSA evaluation sites (and as shown in Appendix A), the desk typically has higher luminances than the computer bezel, because it is a more reflective (lighter) color and because task lights shine on it. When the eye shifts from these lower luminance surfaces to the window, cubicle occupants may experience glare.

Questionnaire Results

LRC administered a brief questionnaire to 18 people working in the GSA Central Office Building in June 2015. Appendix B shows detailed questionnaire results. Where possible, the questionnaire data for this site were compared to results from other office case studies, to previous GSA site evaluations publications, and the previous December visit at this site (see References).

Most respondents (89%) only work during the day, similar to other sites, and the December visit at this site. Workers answered the questionnaire on the day that LRC evaluated this site. For much of that time, skies were sunny, though there were some clouds periodically. All four window orientations were represented (north: 11%; east: 33%; south: 28%; west: 28%). Most respondents (55.6%) worked on the 7th floor, followed by 5.6% on the 2nd floor, and 38.9% on the ground floor.

Most workers were satisfied by the amount of light provided; 83% reported that the amount of light on their desk was neither too much nor too little, compared to 63% in winter.

Use of task lights was reported by 50% of occupants. On the summer visit, there were several comments about the task lights, primarily the occupancy sensor controls. One person demonstrated that they disliked the occupancy sensor control so much that, instead of turning off the task light, they hid it upside-down, between segments of the desk (Figure 5); they didn't seem to be aware that they could simply turn off the task light.

Figure 5. A sensor-controlled task light annoyed one occupant who turned it upside-down, rather than simply turning it off.

As in winter, mesh window shades are often adjusted by the occupants in summer, partly due to changes in weather, and partly due to time-of-day sun position. As in winter, sun seemed to be a concern at this site in Washington, D.C., more so than at a previous GSA site in the Pacific Northwest.[6] None of the occupants (0%) reported that they keep shades

[6] Edith Green Wendell Wyatt Federal Building, Portland, OR.

up all the time in summer, compared to 19% in winter. As in winter, more people reported adjusting shades downward due to sunny weather (28%) than reported opening them due to cloudy weather (6%). Two of the respondents (11%) reported that they do not have control over the shades, presumably because they were automated/motorized.

More people reported that the windows at this building are comfortable to look at (83% in summer vs. 56% in winter). As in winter, many respondents rated their luminaires as comfortable to look at (76% in summer vs. 63% in winter).

As shown in Figure 6, the overall lighting at this building was rated as "better" or "much better" by fewer (39%) of the respondents in summer compared to winter (50%), possibly due to the fact that different people responded to the questionnaire in the different seasons. As shown in Figure 6, these results are slightly more neutral, less positive, than other office lighting case studies, including the GSA Regional Office Building (ROB).

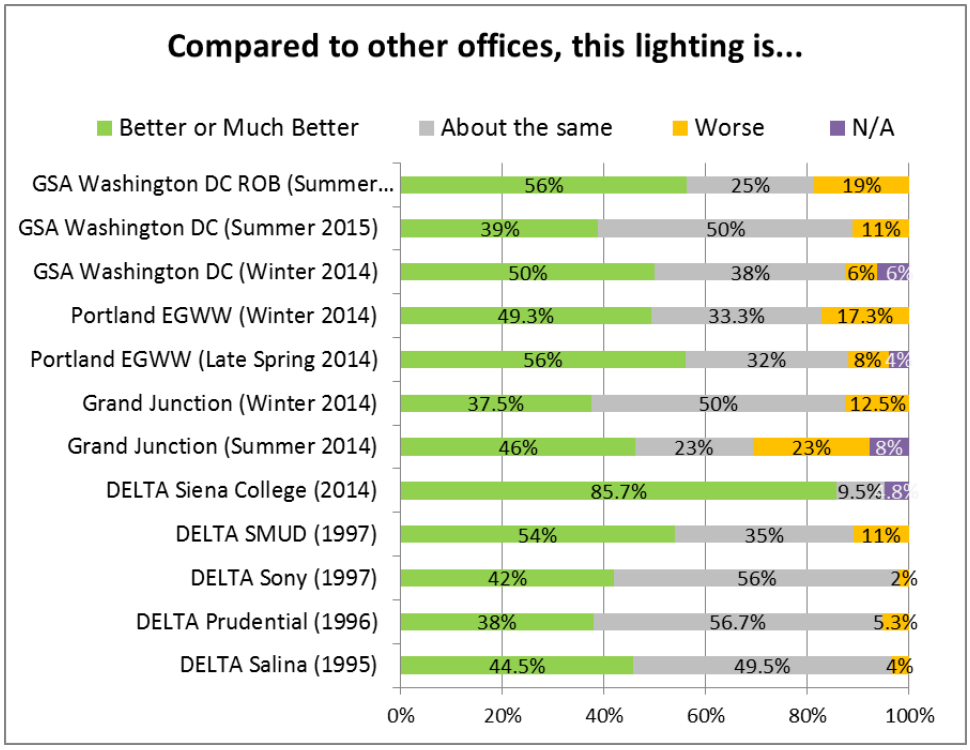

Figure 6. Overall questionnaire results at the GSA Central Office Building, compared to other office lighting evaluations by the LRC.

Spectral Power Distribution (SPD) Results

Shown at below is a photo of the equipment used for measurement of spectral characteristics in summer (Figure 7). The measurement probe was held at the eye and aimed at the computer screen to simulate the eye position of the person working at each desk. As in winter, measurements were collected three times during the day (morning, midday, and afternoon) with both electric light and daylight, as well as after dark (with only electric light, no daylight contribution.)

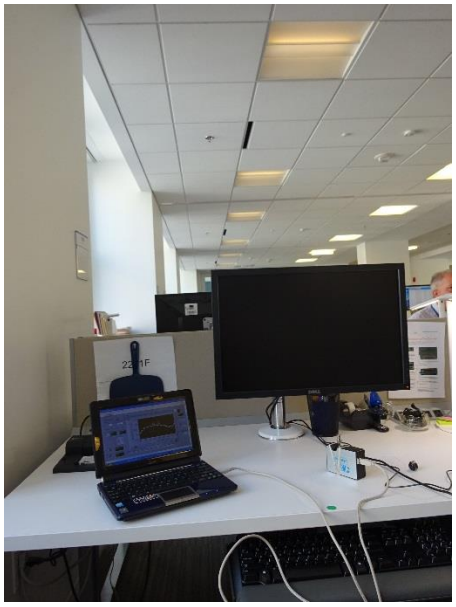

Figure 7. A spectroradiometer taking measurements at desk level.

SPDs were measured at the same desk locations used for hosting other site measurements (see Figure 3). The SPD measurements were later used to estimate the photopic lux and circadian stimulus (see Table 1).

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

Detailed results are shown in Appendices C-E and summarized in Appendix F. Table 1 shows average results of summer daytime measurements (excluding evening measurements, since workers are not present after dark).

Table 1. Summer average daytime measurements using a spectroradiometer

Deskspace Locations	Illuminance	Color Temp.	Circadian Light		Circadian Stimulus (up to 0.7)		
	Lux	CCT (K)	Average CL_A	Median CL_A	Average CS	Median CS	Brightness
A	447	4324	351	224	0.294	0.263	316
B	452	4117	340	275	0.295	0.301	301
Orientation							
E	573	4149	426	331	0.348	0.336	395
N	440	4484	359	234	0.306	0.271	281
S	146	4084	114	77	0.130	0.105	105
W	545	4243	422	405	0.353	0.374	388
Floor							
G	410	3817	275	218	0.245	0.258	260
2	812	4361	656	510	0.425	0.416	568
7	403	4559	340	230	0.309	0.268	293

Table 2. Winter average daytime measurements using a spectroradiometer (with slightly different desk locations), for comparison

Deskspace Locations	Illuminance	Color Temp.	Circadian Light		Circadian Stimulus (up to 0.7)		
	Lux	CCT (K)	Average CL_A	Median CL_A	Average CS	Median CS	Brightness
A	360	4029	258	221	0.261	0.260	244
B	322	3917	215	191	0.233	0.234	211
Orientation							
E	457	3873	319	285	0.310	0.307	306
N	336	3905	197	174	0.227	0.219	213
S	232	4138	198	174	0.216	0.216	160
W	265	4054	181	112	0.193	0.152	182
Floor							
G	279	3776	167	150	0.193	0.194	178
2	378	3984	276	264	0.294	0.293	252
7	391	4151	293	233	0.286	0.270	269

The data from LRC's visit to the GSA Central Office Building in June showed moderate overall levels of circadian stimulus at many locations. Most spaces had higher measured values in summer (Table 1) than winter (Table 2); as a reminder, most of the measurement desks had to be changed to nearby vacant desks for this June visit, thus these desk locations do not exactly match the December visit.

One of the two desks with a southern exposure was on the ground floor, with little exposure to daylight and extremely low light levels; as a result, average values for the south orientation are lower than other building orientations in Table 1.

There are some desks with occasional CS values close to or greater than 0.3, which is considered the lower end of the recommended amount for circadian stimulation. In general, the 2nd and 7th floors have the highest CS values we measured. It was interesting to observe how much higher these CS values were. These data are, however, snapshots of what the exposures are over the course of one working day in summer. Daysimeter measurements, discussed below, may be a better representation of the continuous light availability over the course of the working day.

Daysimeter Stick and Window Results

Appendices G-J show the hourly averages from 8:00 a.m. to 5:00 p.m. of the CS values and the photopic lux values for each Daysimeter. Desk locations are also shown in Figures 8 and 9; these device mounting locations were the same as in the winter evaluation. Below are some of the main findings:

- As expected, based on measurements from the Daysimeter sticks, the average CS values for most deskspaces on the G floor was below the desired amount of 0.3, irrespective of Wing number and proximity to window. Deskspaces with western exposures in Wing 1, however, reached CS values close to and above the desired value of 0.3 during the midday and afternoon of sunny days. At the end of the workday, CS values dropped to 0.1 for deskspaces that are furthest from windows. Deskspaces away from windows had CS values at 0.14, which is possibly close to the threshold for the circadian system. These values were higher than during winter months.
- With the exception of two deskspaces, the 2nd floor CS values were at or above 0.3 for most of the workday. Desk spaces in Wing 4 were slightly higher than those in Wing 2. Desk spaces in the southern and western parts of the building had higher CS values than those in the north and the east. Proximity to windows does not appear to have made a significant difference in CS values. Overall, the CS values in summer were higher than those in winter, with Wing 4 having the highest CS during winter.
- With the exception of one deskspace, the 4th floor CS values were above 0.3 for most of the workday. Deskspaces in Wing 1 and with eastern exposure had slightly higher mean CS. Deskspaces that are close to windows had CS values above 0.3. The CS values were lower in the winter months, with deskspaces in Wing 1 being the only ones to reach a CS value of 0.3.
- With the exception of one location, most deskspaces on the 7th floor had CS values above 0.3 for most of the workday. The highest CS values were reached at deskspaces in Wing 4 that had southern window exposure. The 7th floor CS levels are significantly higher in summer than in the winter months, with deskspaces in the eastern part of the building having CS levels at or above 0.3.

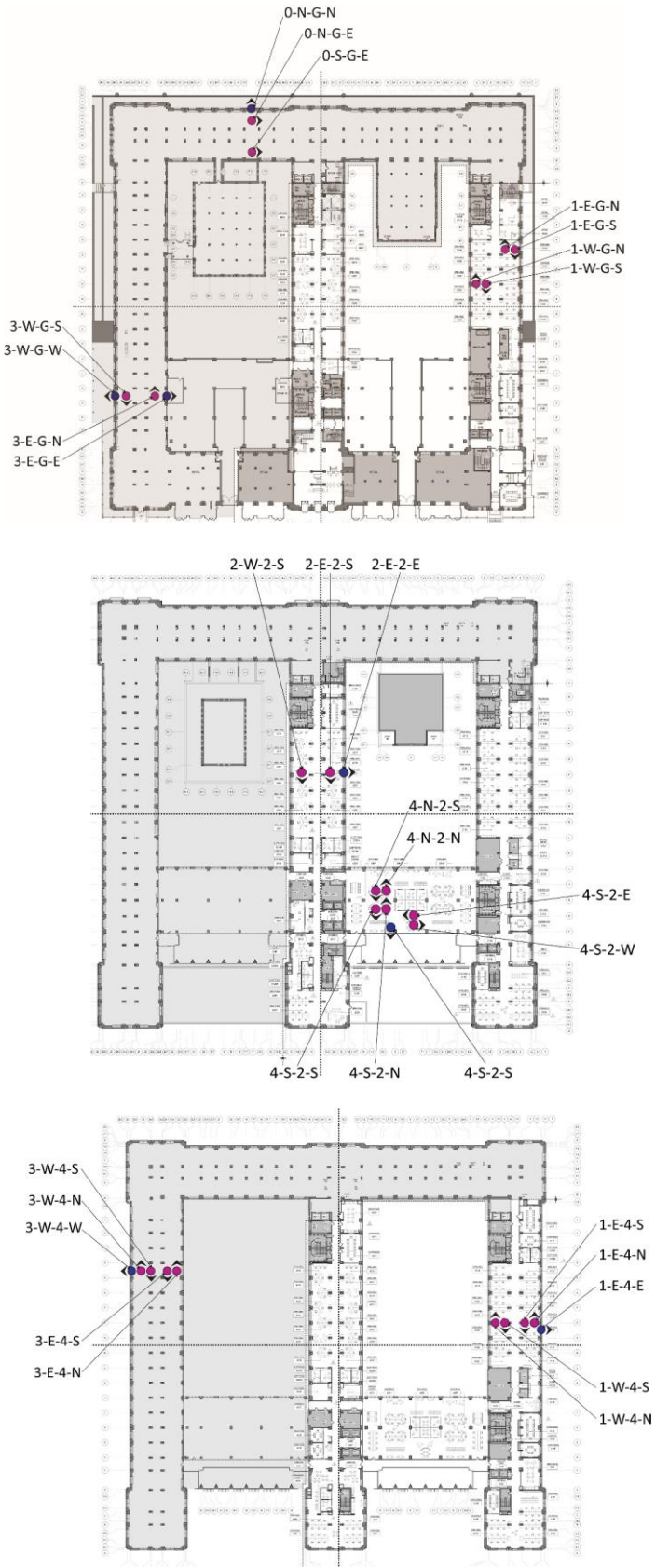

Figure 8. Daysimeters were installed at the same desk locations in the June 2015 visit as in December 2014, on the ground floor (upper), 2nd floor (middle), and 4th floor (lower). Window-mounted devices are shown in blue; stick-mounted devices shown in magenta. Numbering convention: (Wing#)-(Window Orientation)-(Floor#)-(Device Orientation).

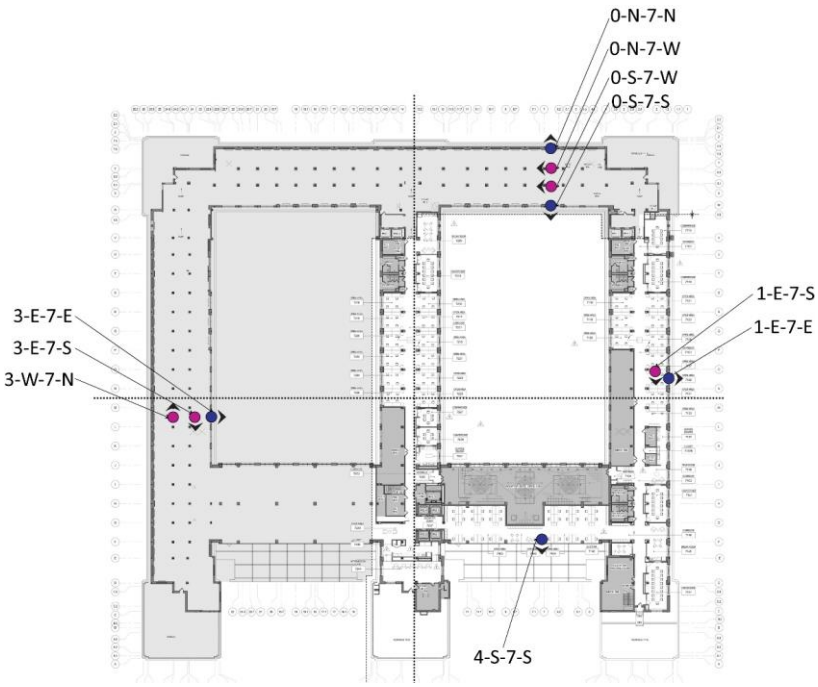

Figure 9. Daysimeters were installed at the same desk locations in the June visit as in December 2014, on the 7th floor (lower). In the June visit, no devices were installed on the 6th floor.

DISCUSSION

A summary of the findings is shown in Appendix K. As shown in Figure 10, pink-shaded portions of the figures in Appendix K reflect areas likely to cause discomfort glare (DG), above 1780 lx, or likely to provide low circadian stimulation (CS), below 175 lx, for a daylight source. The yellow-shaded boundary, between 940 lx and 1780 lx, is considered at or near threshold for evoking a discomfort glare response from occupants. The lower end of the threshold boundary for discomfort glare represents a DG rating of 4.5 whereas the upper boundary represents a DG rating of 4.0. The yellow-shaded boundary, between 175 lx and 300 lx, is considered to be at or near threshold for reliable stimulation of the human circadian system. The lower end of the threshold boundary for circadian stimulation represents a CS value of 0.3, whereas the upper boundary represents a CS value of 0.4. The "ideal" vertical levels of photopic illuminance from daylight, lower than the discomfort glare threshold boundary and above the circadian stimulus threshold boundary, are between 300 lx and 940 lx.

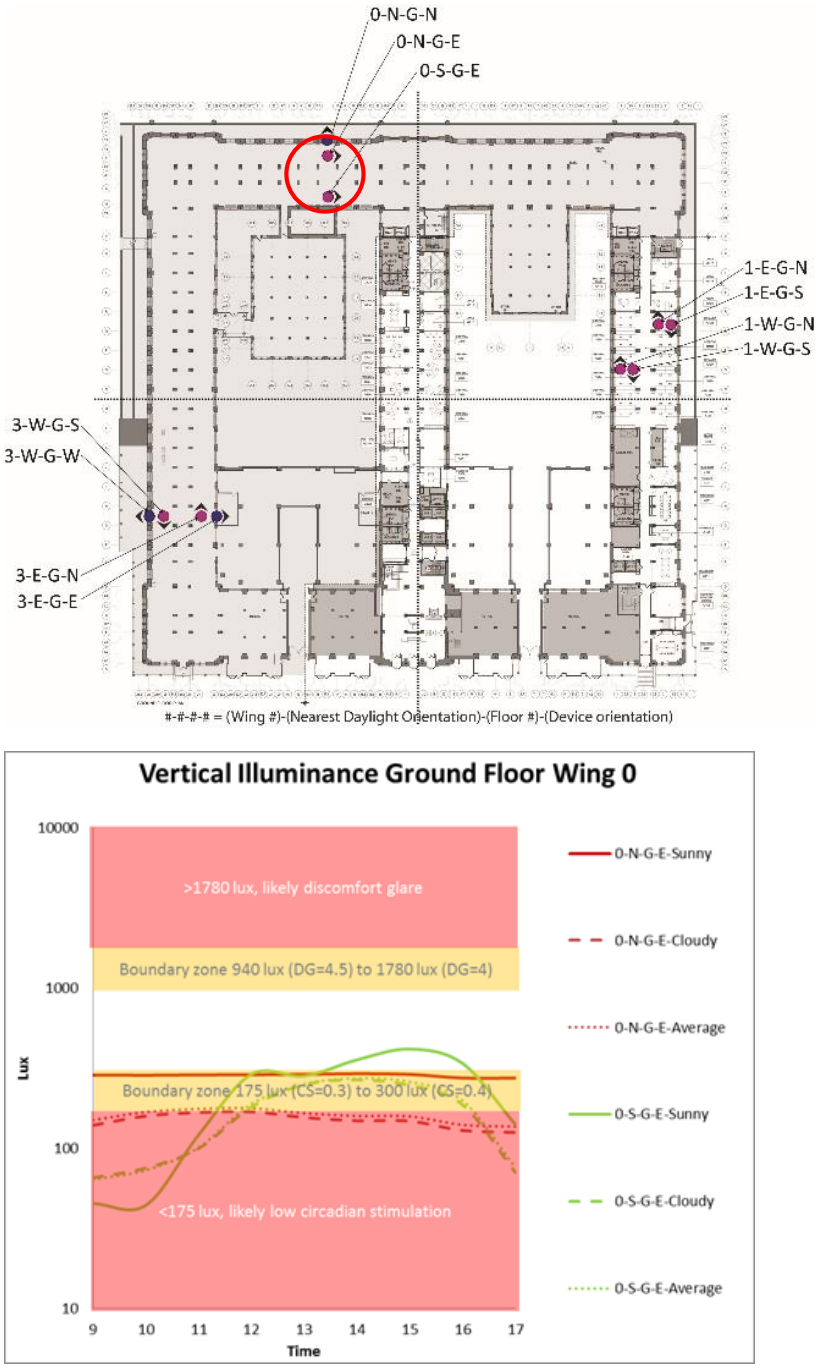

Figure 10. Average vertical illuminance at the eye at two desks at different times of day and sunny vs. cloudy conditions.

In general, with only a few exceptions, CS values are close to or above the desired CS value in Wing 4. Deskspaces located on the G floor receive the least amount of CS and only a few of the deskspaces located in Wing 1 and close to a window received the desired CS value in the afternoon hours.

None of the deskspaces we measured had vertical light levels above 1790 lx, which is the boundary for discomfort glare, as discussed in a previous LRC report. While in winter months some deskspaces in Wing 4 had light levels that were bordering discomfort (between 900 lx and 1780 lx), this was not the case in summer months. This may be due

to a higher sun angle in summer and is consistent with measurements in other GSA buildings.

In summary, while deskspaces located in Wings 2 and 4 received good circadian stimulation, many other spaces had low overall levels of circadian stimulus. Overall, while these measurements cannot be considered representative of the daily light exposure that office occupants are being exposed to, it gives the researchers an idea of the potential for receiving enough circadian stimulation at these deskspaces. It should also be noted that the one-day measurement using the spectroradiometer slightly overestimated the CS values compared to the stick Daysimeter measurements, because the stick Daysimeters are averaging greater number of days.

Several caveats should be stressed, however:

- CS values are based upon melatonin suppression for a standard observer after 1 hour of light exposure. Longer exposures to light are probably sufficient to entrain subjects, but estimates of the trade-off between light level and duration are not available. Functionally, CS levels as low as 0.1 may be sufficient for circadian entrainment for extended (i.e., 5-8 hours) exposures. More research is needed to determine the relationship between light level and exposure duration as it may affect the circadian system.
- Ideal conditions at work where high levels of CS are provided in the morning hours may be compromised by light exposure after work.
- DG ratings are highly variable among people and for different contexts.

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

- In locations where there is little daylight availability (e.g., G floor), fewer deskspaces had circadian stimulation closer to the desired level than did those on higher floors.
- Wings 2 and 4 on the 2nd floor had close to desired CS values throughout the day.
- Wing 1 on the 4th floor had good CS values throughout the day. Some, but not all deskspaces in Wing 3 on the 4th floor were close to desired CS values.
- Wings 1 and 3 on the 7th floor had good morning circadian stimulation. Wing 3 on the 7th floor was within the desired CS value throughout the entire day.
- None of the Daysimeter measurements suggest that workers are experiencing discomfort glare from excessive sunlight penetration in December. The courtyard between the different wings may have played a role in reducing sunlight penetration in the space, while still allowing for daylight penetration.
- Furniture layout in this building is such that most workers sit perpendicular to windows rather than facing windows; this might also explain why building orientation may have not played a key role on circadian stimulus received on the various deskspaces. Moreover, because this is not a deep core building, even deskspaces that are not located immediately adjacent to windows are still close enough to receive daylight.
- Half (50%) of the summer occupants surveyed by LRC reported that they use their task light. Controls for the task lights seem to be confusing to occupants. Overall, the amount of light on their desks was neither too much nor too little in summer.

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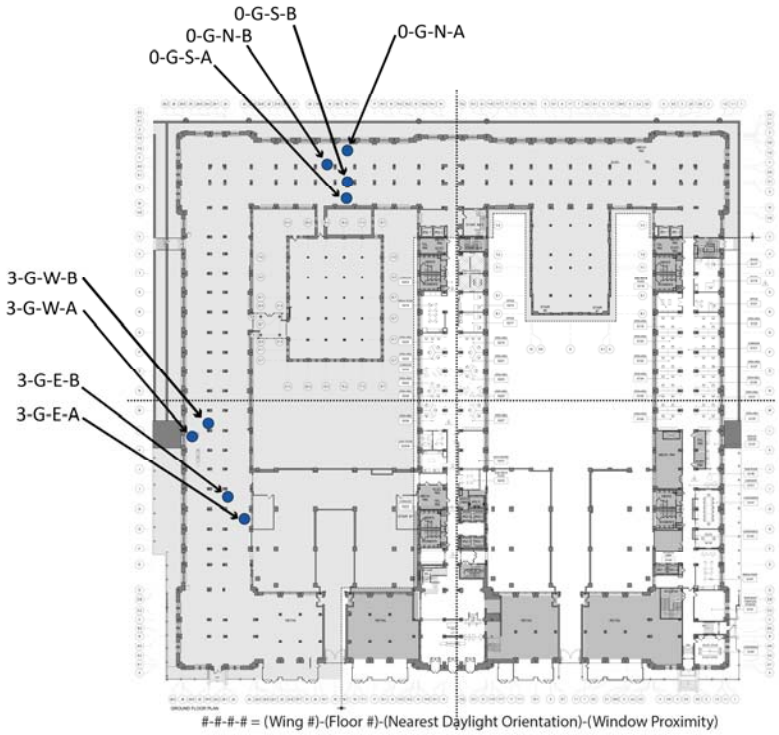
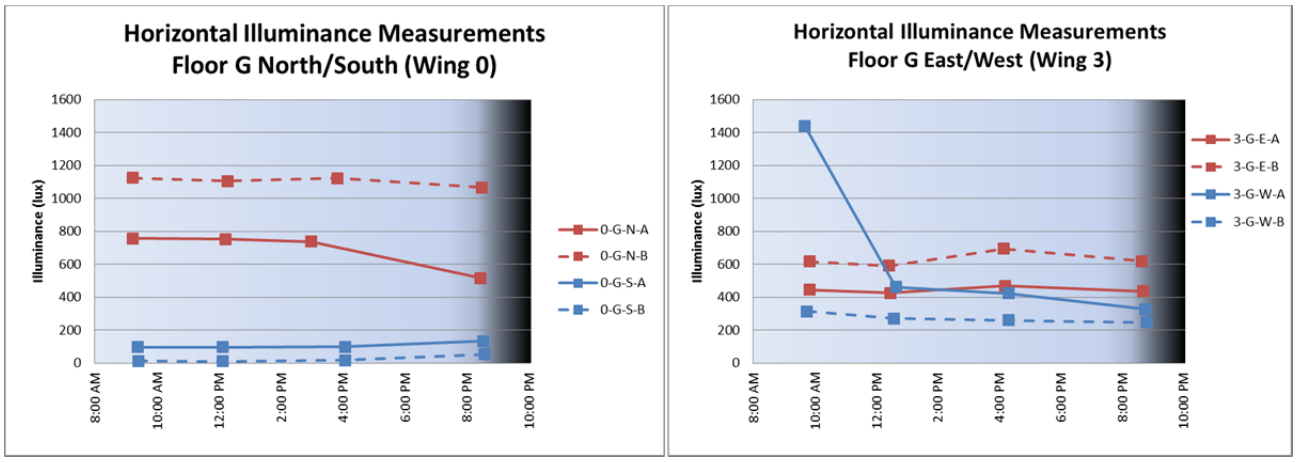
Editor: Rebekah Mullaney

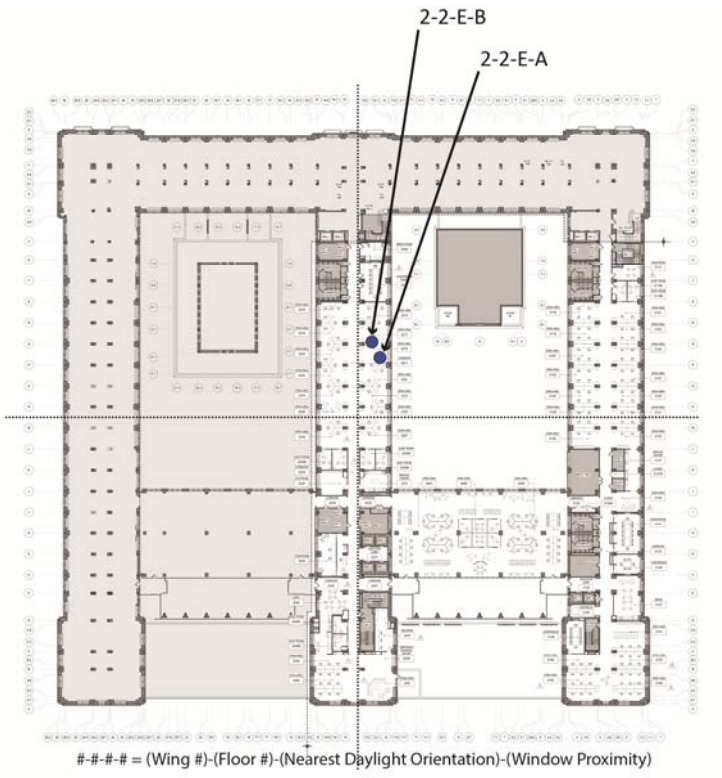
APPENDIX A: PHOTOMETRIC DATA (ILLUMINANCE AND LUMINANCE MEASUREMENTS)



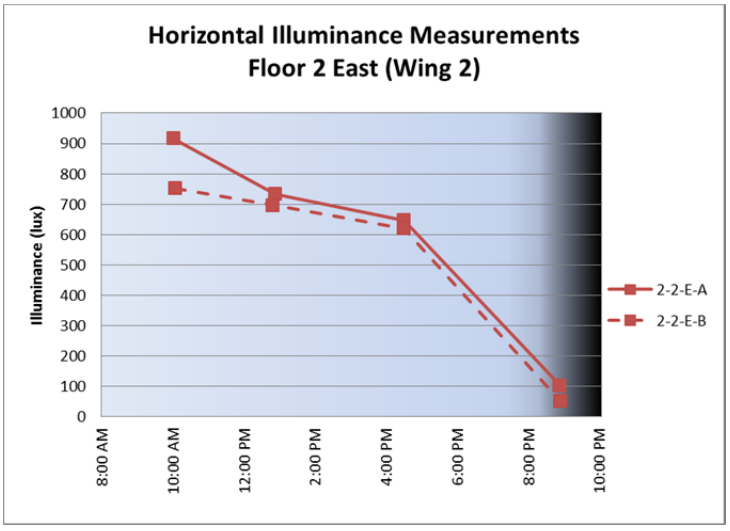
Key plan, showing SUMMER photometric measurement locations on Floor G.
Desks marked "A" are nearest the windows, while desks marked "B" are in the adjacent row.
Grey shading on the plan indicates that the area was not included in Phase I renovation.



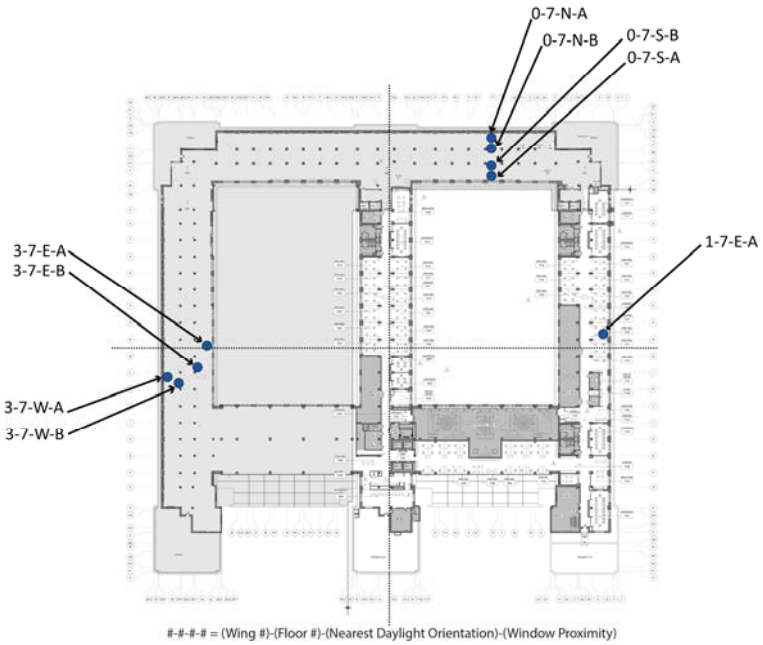
Summer horizontal illuminance measurements at 8 desks on Floor G, during the day and in the evening.



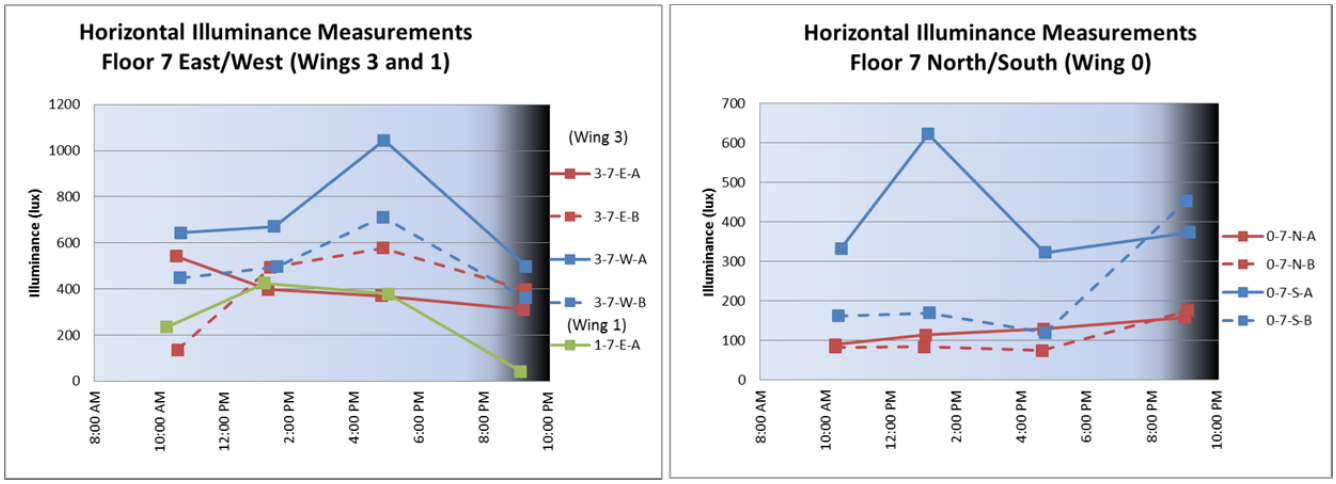
Key plan, showing SUMMER photometric measurement locations on Floor 2
(Grey shading on the plan indicates that the area was not included in Phase I renovation)



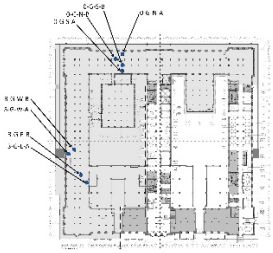
Summer horizontal illuminance measurements at 2 desks on Floor 2, during the day and in the evening.

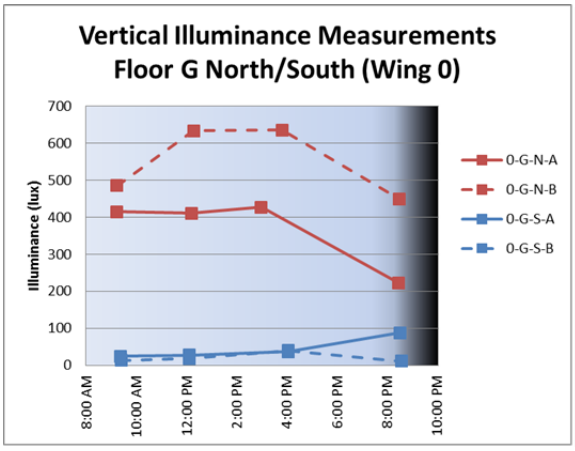


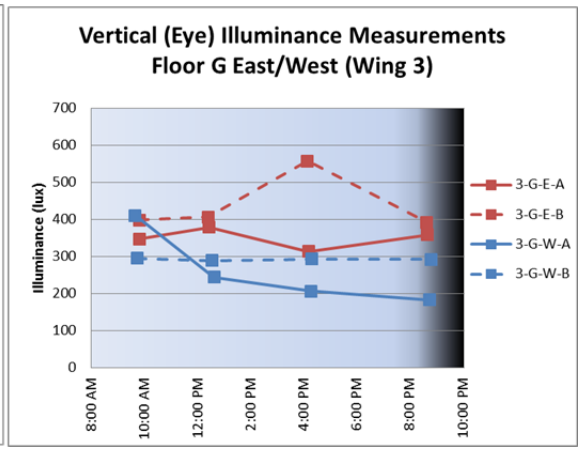
Key plan, showing SUMMER photometric measurement locations on Floor 7

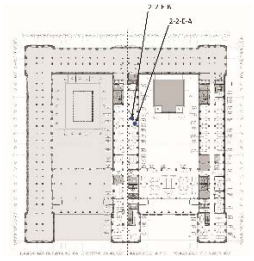


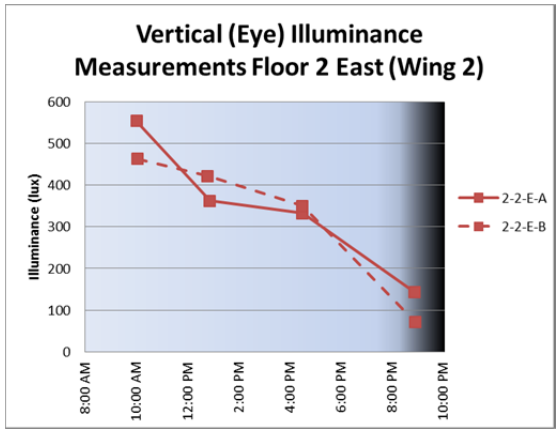
Summer horizontal illuminance measurements at 9 desks on Floor 7, during the day and in the evening.

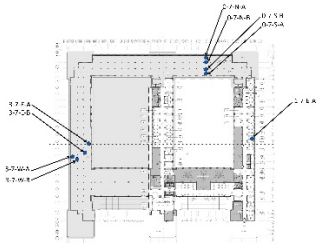


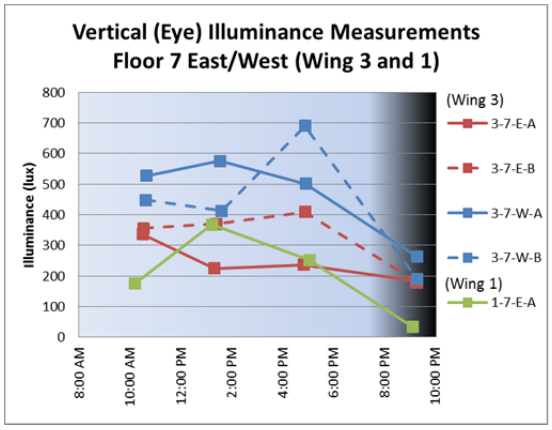


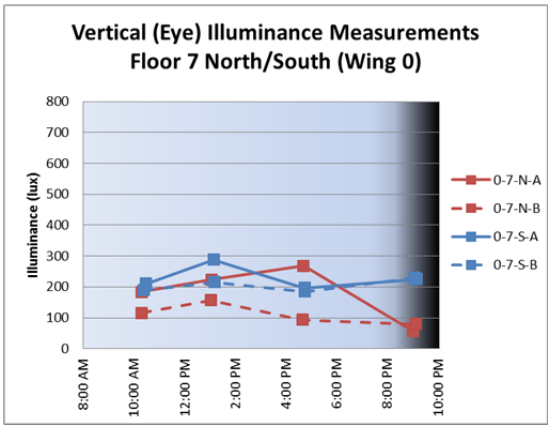




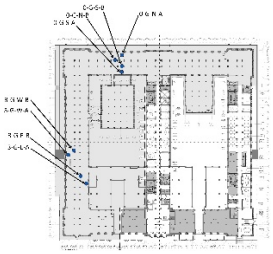


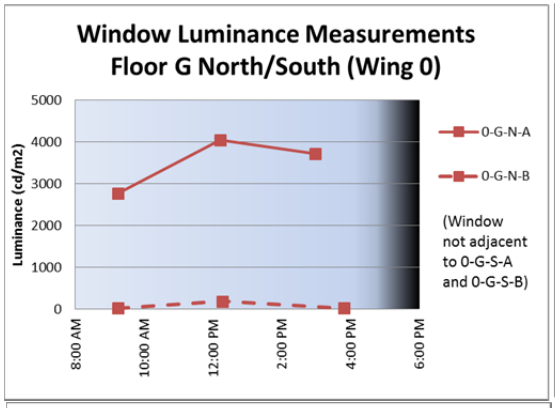


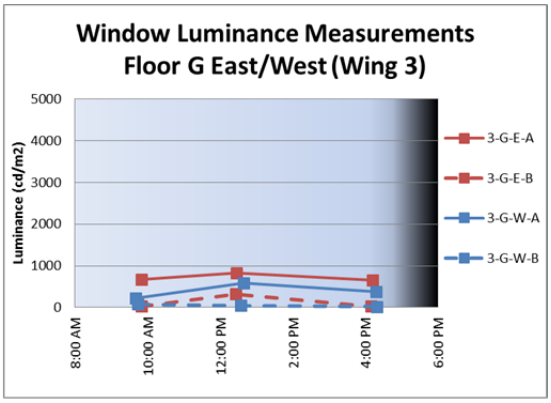


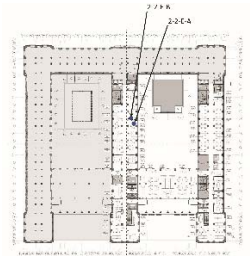


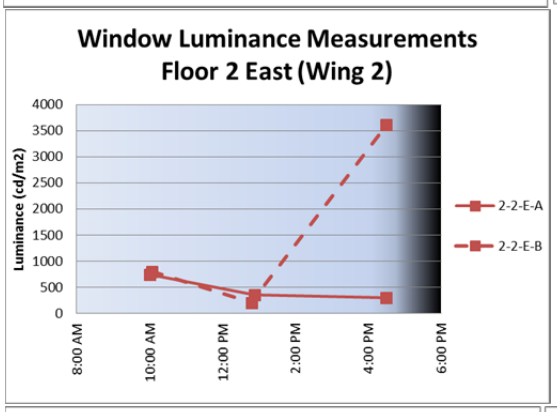
Summer vertical illuminance (at the eye) at 19 desks, during the day and in the evening.

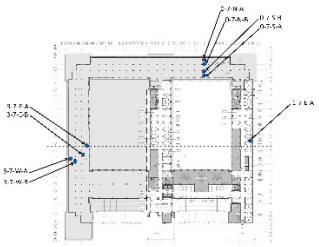


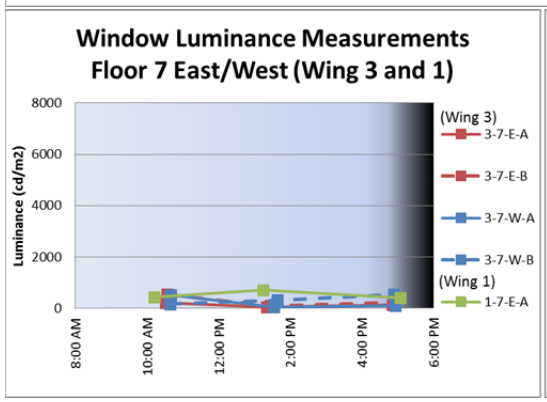


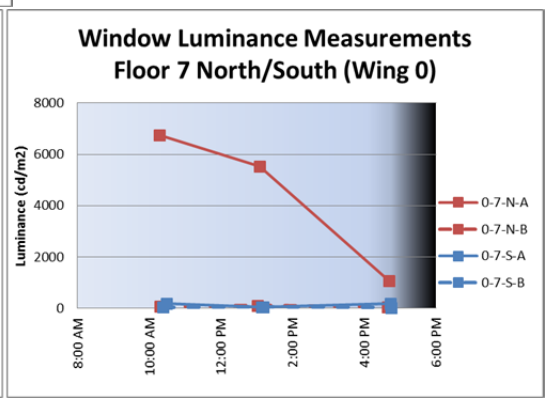




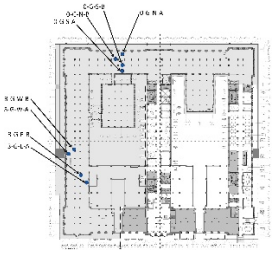


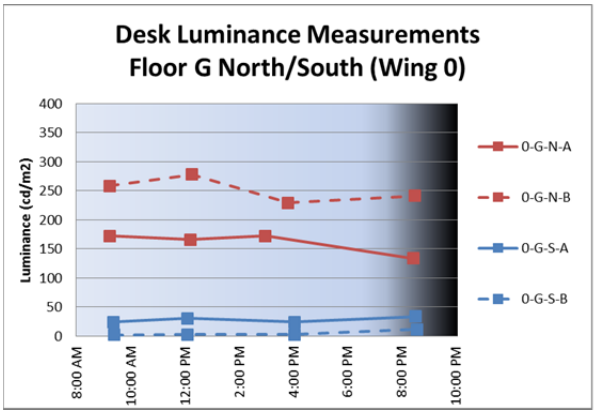


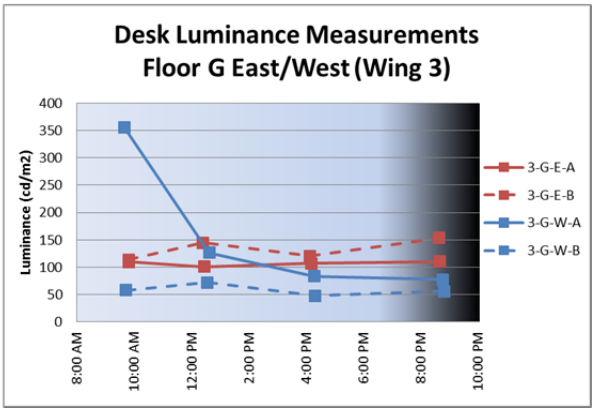


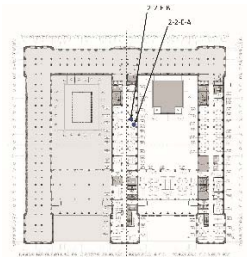


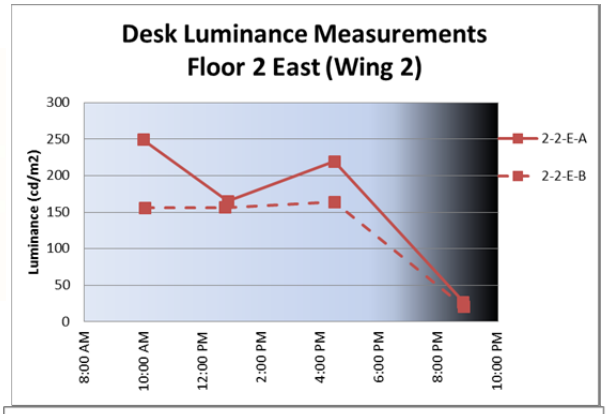
Summer window luminances at 17 desks, during the day only.
(At 2 desks, window was not adjacent)

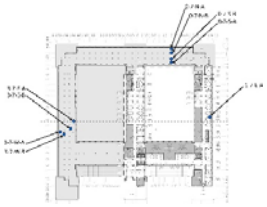


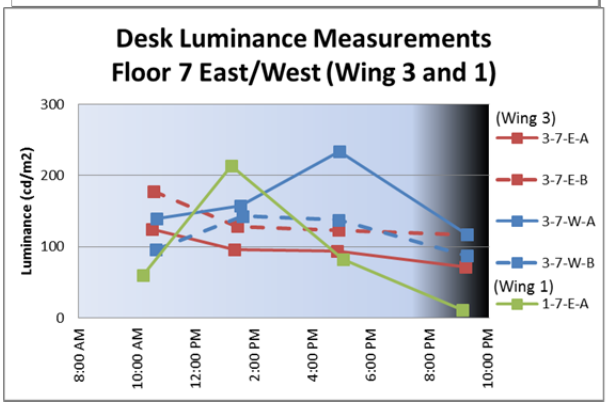


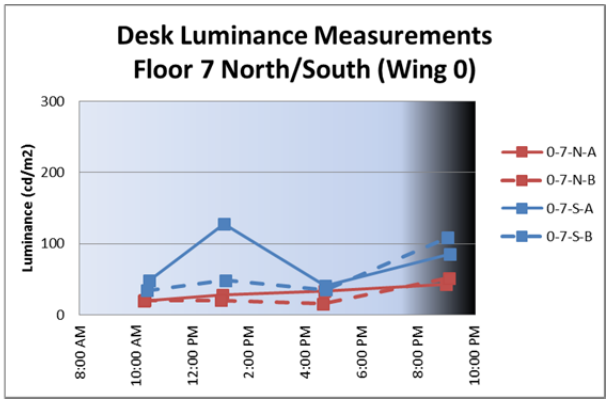




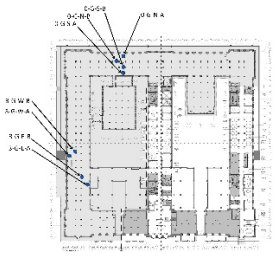


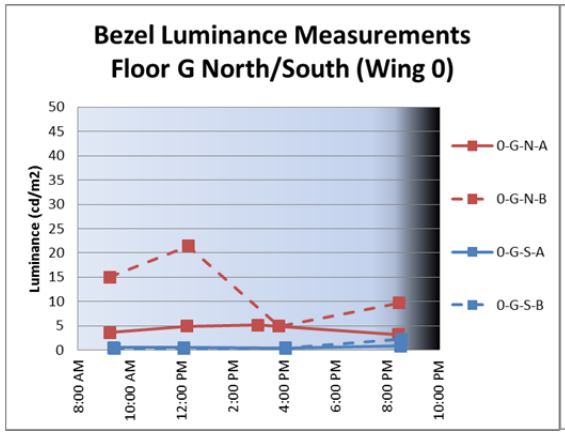


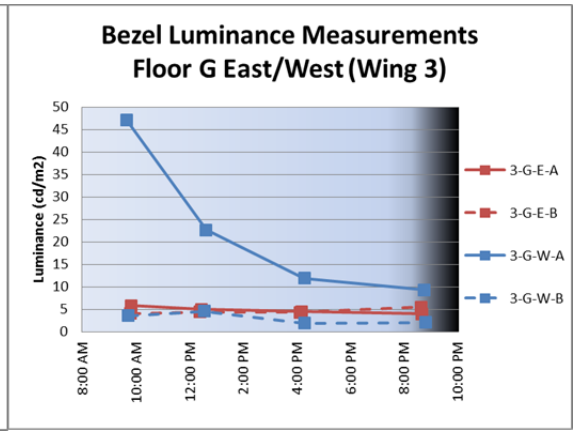


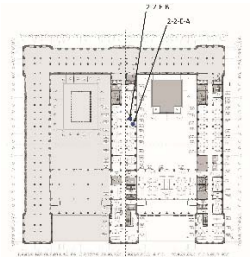


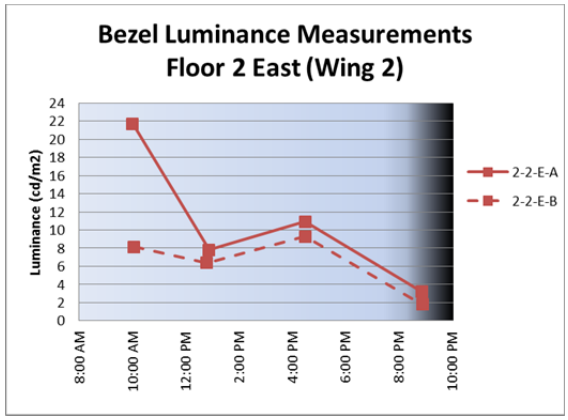
Summer desk luminances at 19 desks, during the day and in the evening.

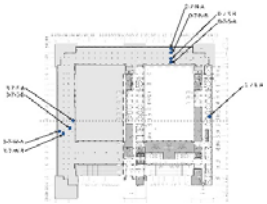


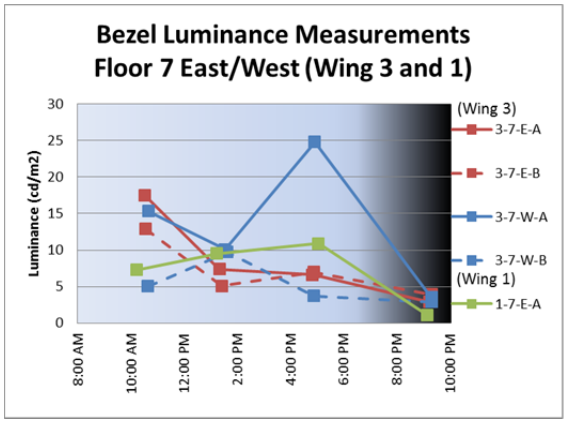


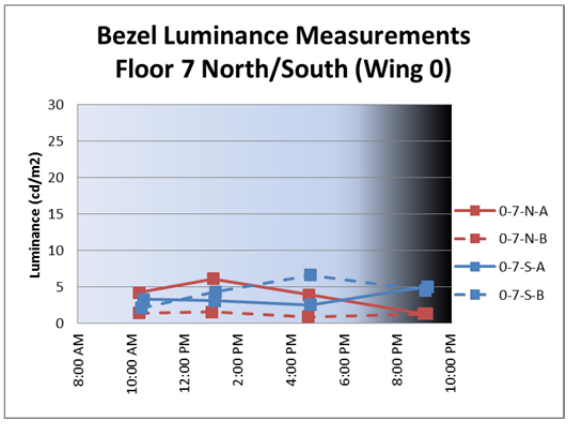






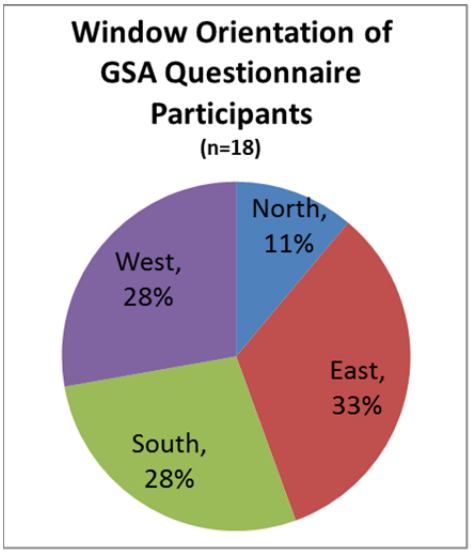


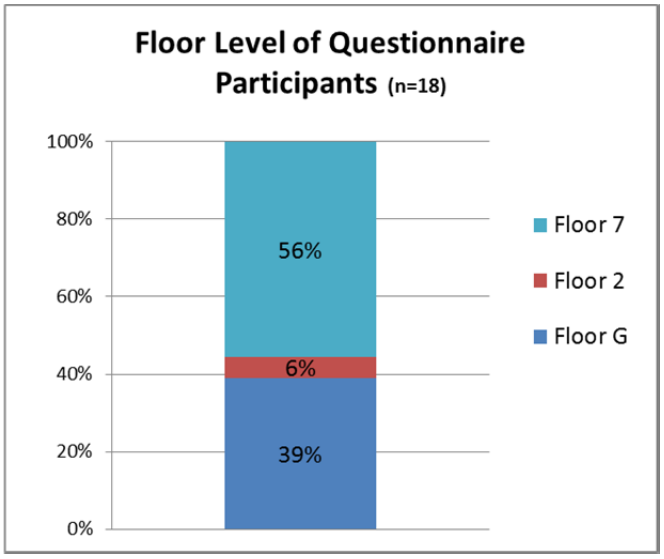


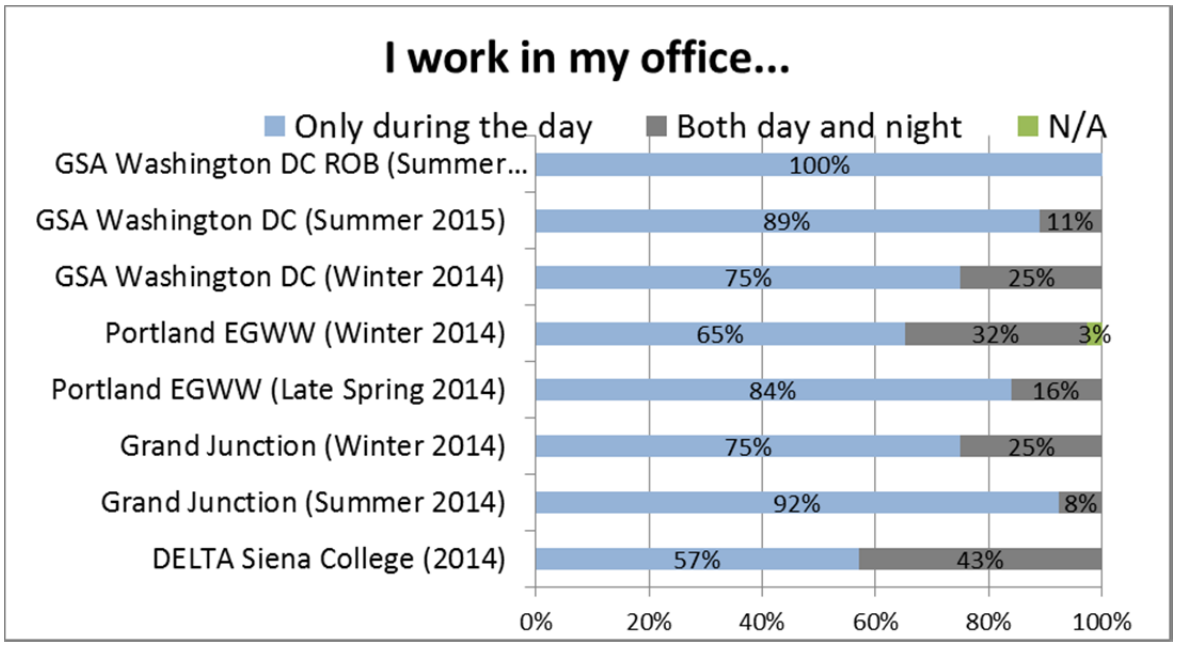


Summer computer monitor bezel luminances at 19 desks, during the day and in the evening.

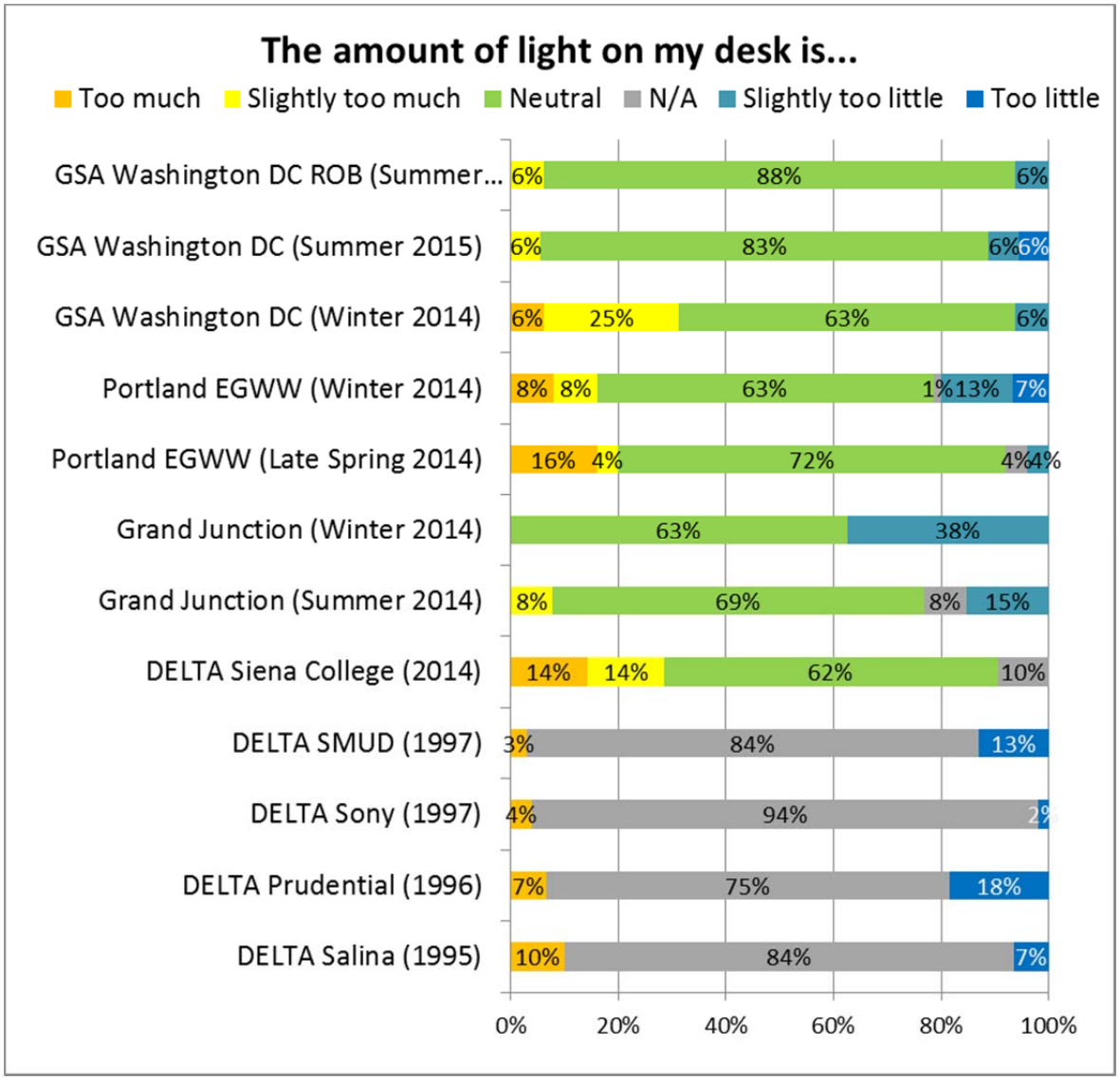
APPENDIX B: QUESTIONNAIRE RESULTS





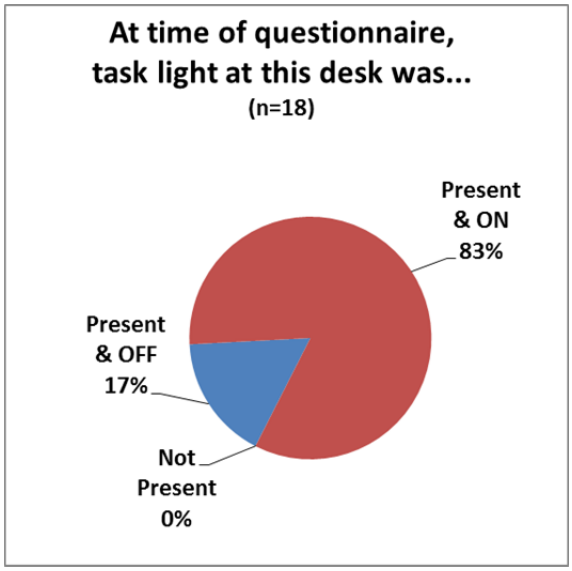


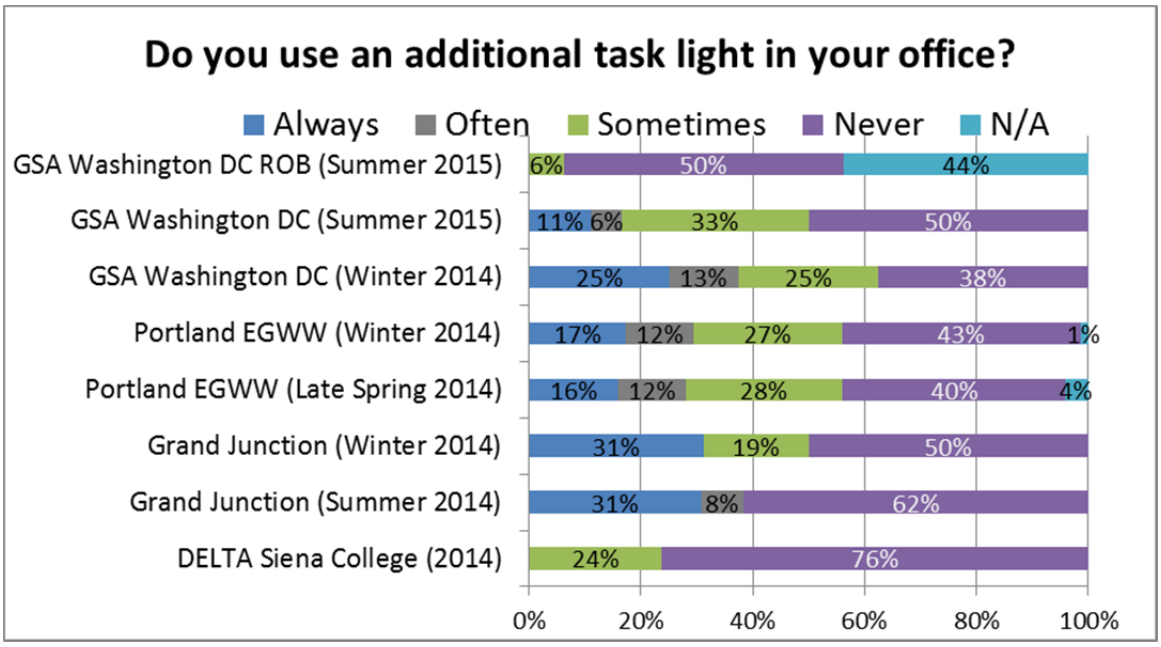
Questionnaire Results (GSA compared to other sites, as available)



Other Comments (about amount of light on the desk)

- "Better desk & ceiling lights would be better"

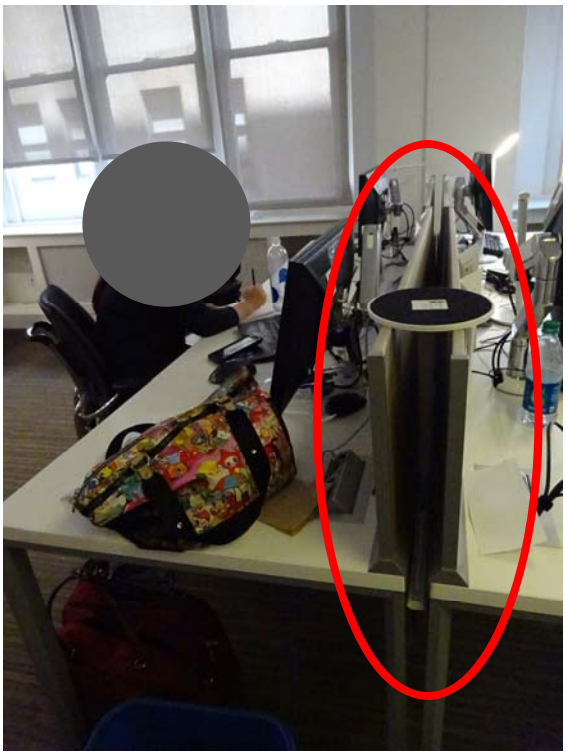

At time of questionnaire, task light at this desk was...
(n=18)
Present & ON 83%
Present & OFF 17%
Not Present 0%

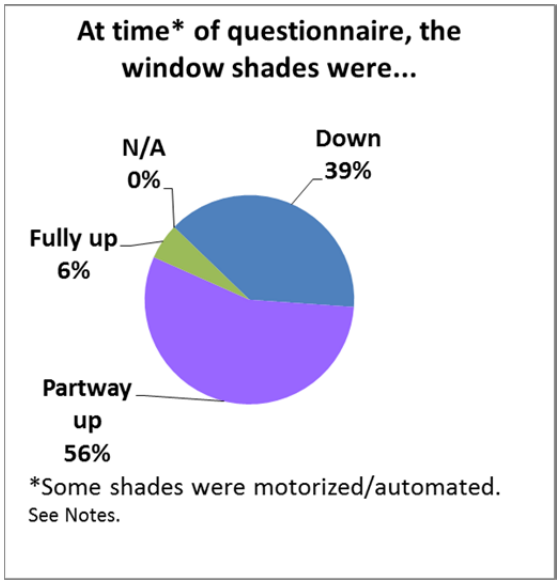

Do you use an additional task light in your office?
Always
Often
Sometimes
Never
N/A
GSA Washington DC ROB (Summer 2015)
GSA Washington DC (Summer 2015)
GSA Washington DC (Winter 2014)
Portland EGWW (Winter 2014)
Portland EGWW (Late Spring 2014)
Grand Junction (Winter 2014)
Grand Junction (Summer 2014)
DELTA Siena College (2014)
6% 50% 44%
11% 6% 33% 50%
25% 13% 25% 38%
17% 12% 27% 43% 1%
16% 12% 28% 40% 4%
31% 19% 50%
31% 8% 62%
24% 76%
0% 20% 40% 60% 80% 100%

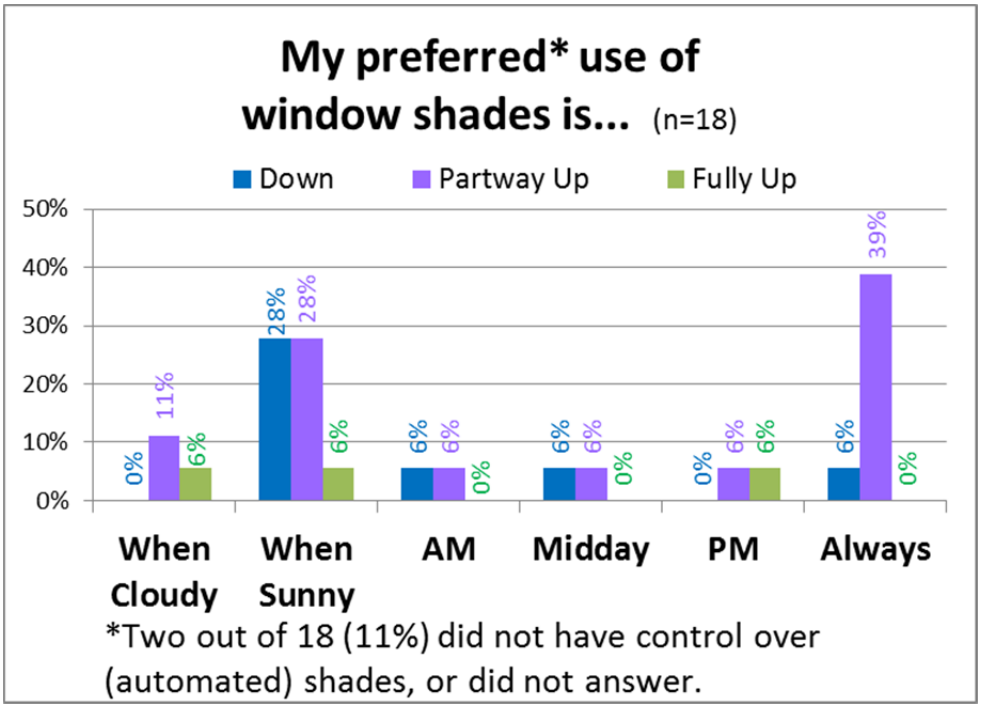
TASK LIGHT COMMENTS

On the Summer visit, there were a lot of comments about the task lights, mostly negative. Many people didn't like how the occupancy sensor turns the light on and off. Some didn't seem to be aware that the user could simply turn off the light:

- I don't turn it on; it just comes on automatically.
- Both are on right now, but not by my choice.
- It's on right now, but I didn't turn it on. Someone else had it on.
- It doesn't always work, but I like it.
- I hate this. It drives me crazy, some days I have eye/visual problems (not occupancy sensor problems).
- Better desk & ceiling lights would be better.
- The sensors turn on the desk lamps even if I turn them off; this repeats all day. (See photos below; subject moves the light out of view, between partitions.)

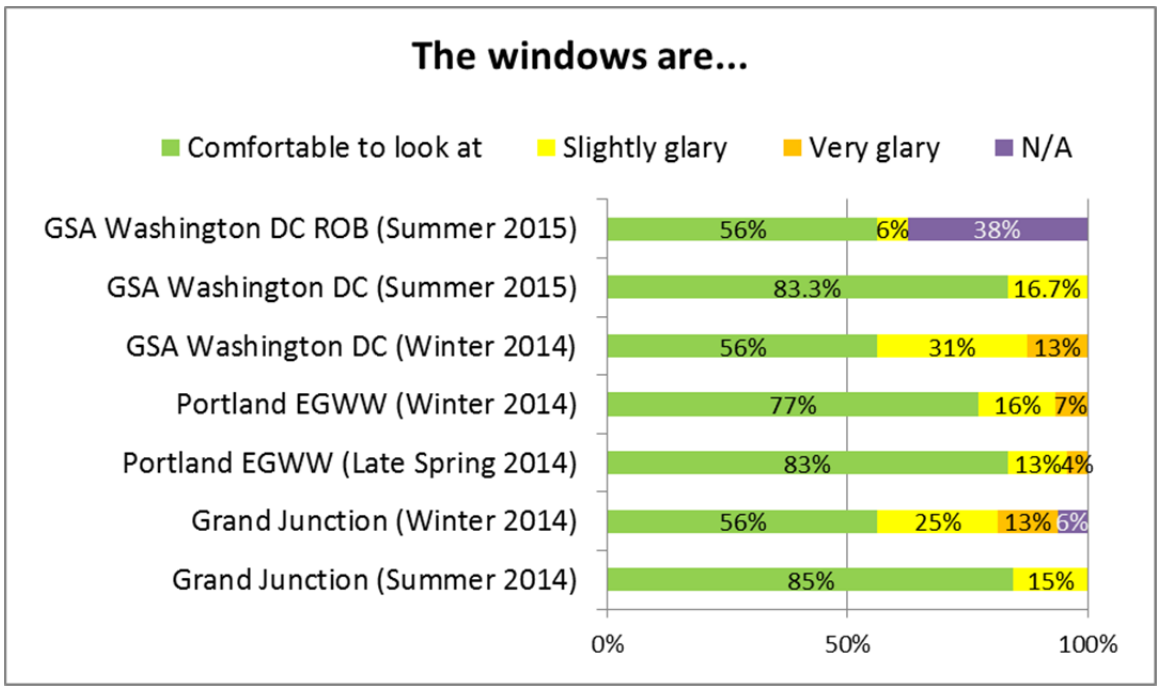






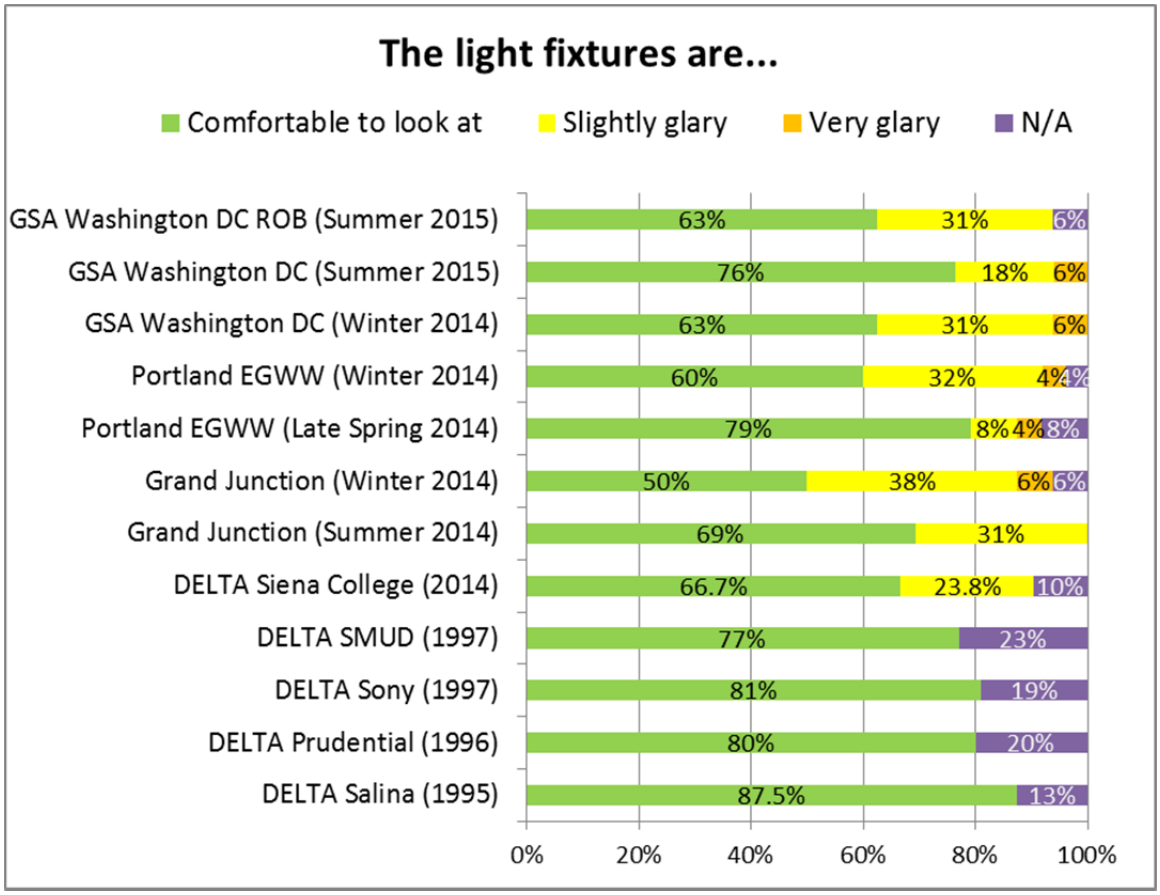
SHADES COMMENTS

- Answered that windows are "slightly glary… depends on time, shades"



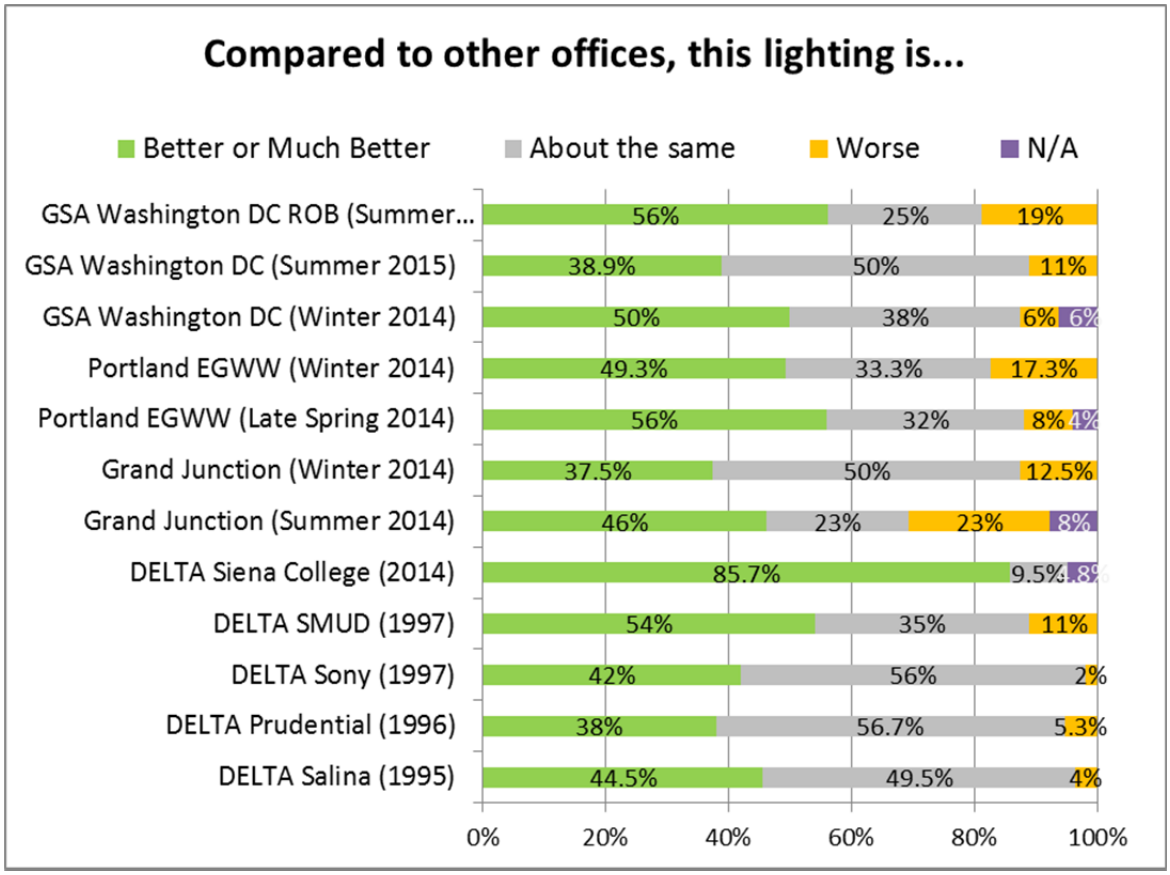
WINDOW GLARE COMMENTS

- Subject answered that windows are "slightly glary… depends on time, shades"



LUMINAIRE GLARE COMMENTS

- Better desk & ceiling lights would be better

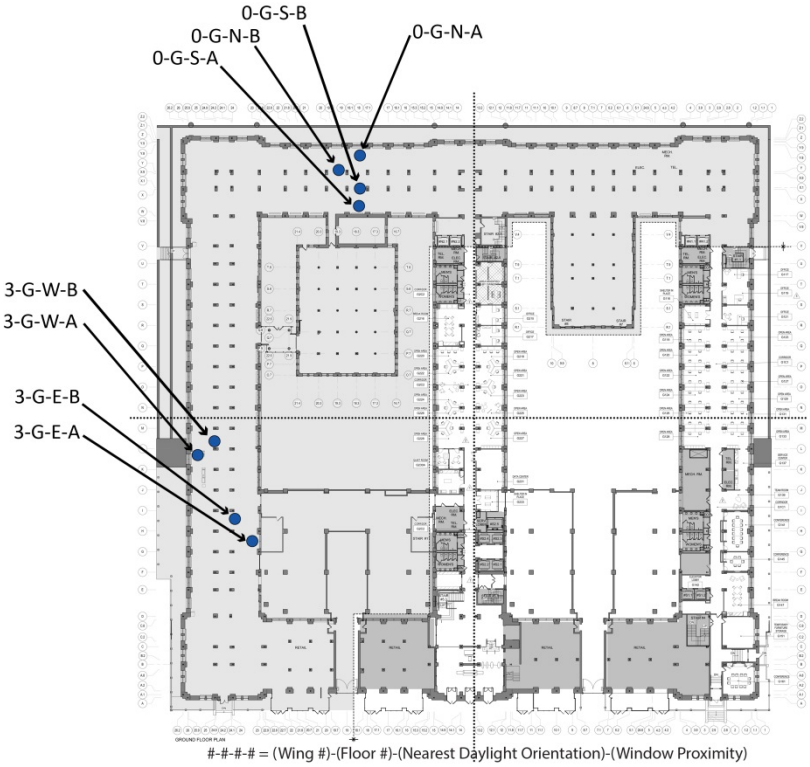


Overall Comments

- Overall "better" due to daylight: "I prefer window light"; if only electric light "about the same overall"
- I like it dark.
- The natural light is good.

APPENDIX C: SPECTRAL PHOTOMETRIC DATA FOR GROUND FLOOR DESKS

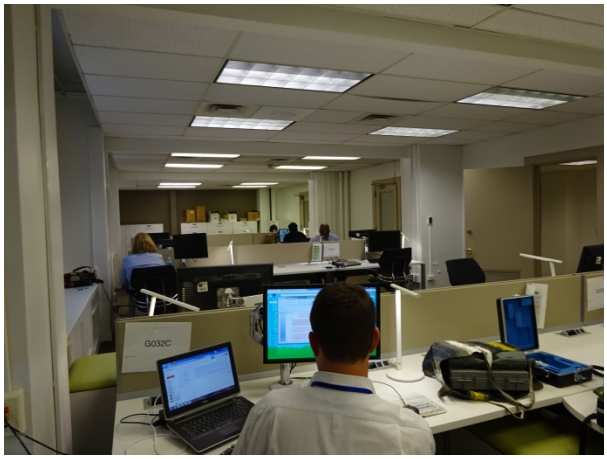
Spectral power distribution (SPD) was measured at 8 desks on the Ground floor at GSA during the winter visit. These were the same desks that hosted other measurements (see Appendix A). SPDs were measured repeatedly over the day and after dark.



Desks on the Ground floor where SPD measurements were collected

As shown below, the resulting SPD curves change as daylight contribution changes. For reference, a photograph is also presented for most of the measurements, as this represents the scene that the occupant experienced at the time of measurement.

WING 0-GROUND FLOOR-NORTH-A



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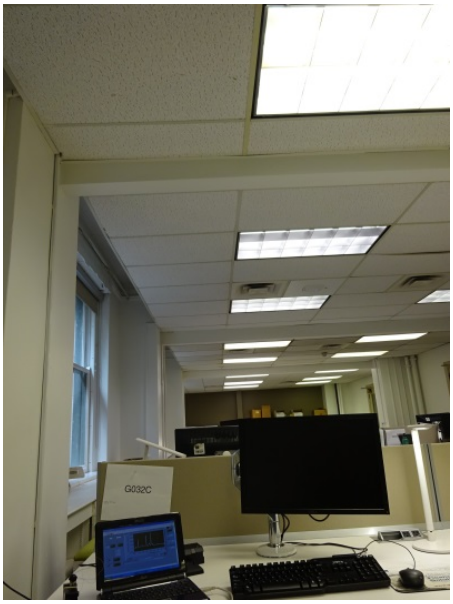

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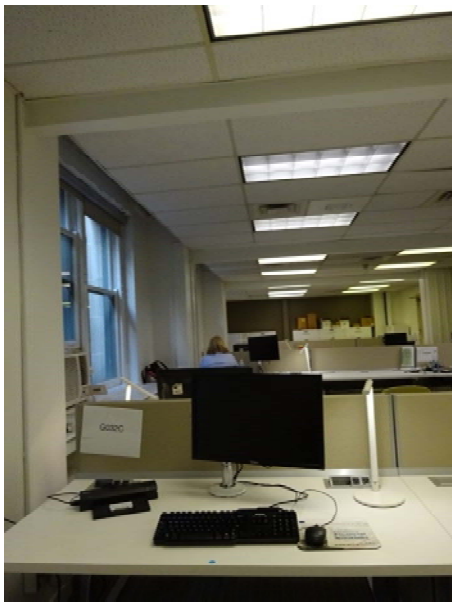
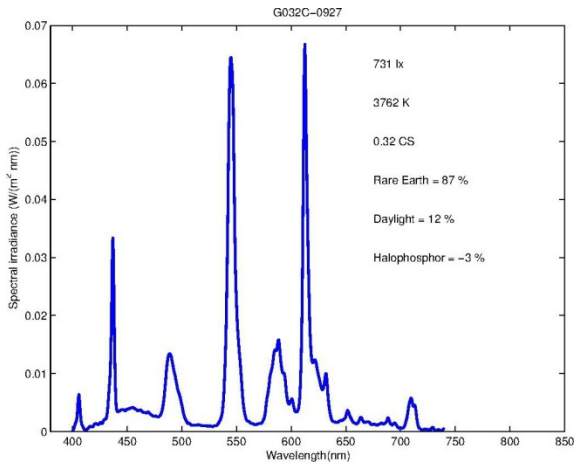


4:05 PM

8:38 PM

WING 0-GROUND FLOOR-NORTH-A

(SPECTRAL POWER DISTRIBUTION)



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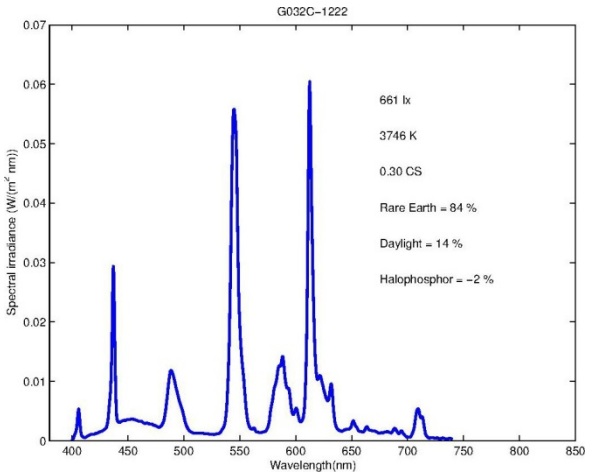

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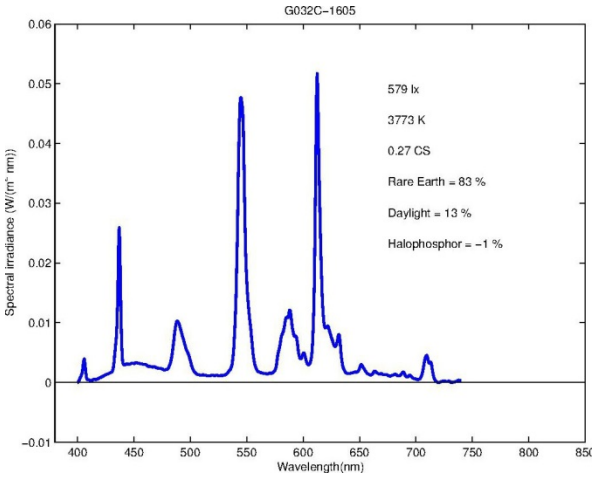

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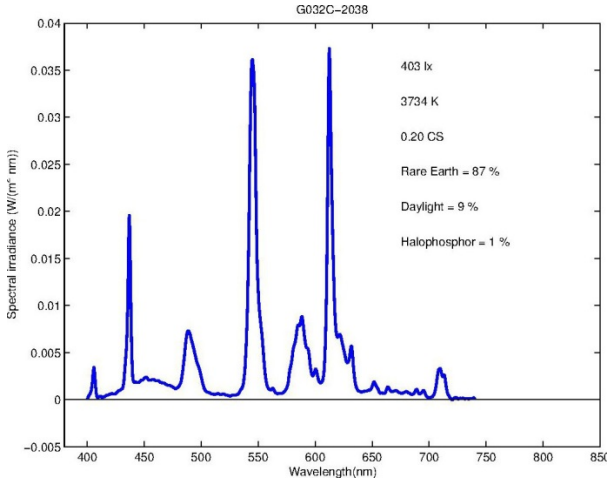

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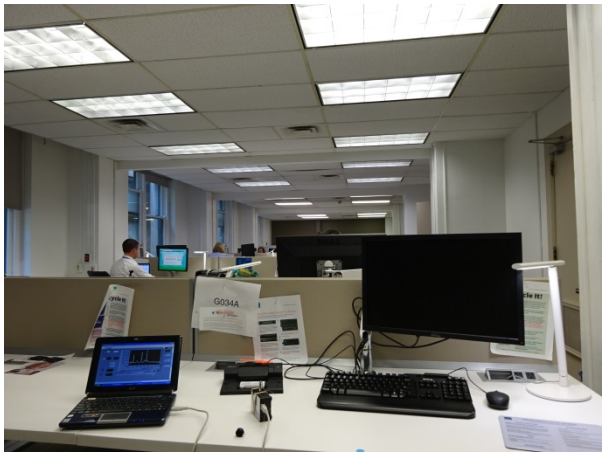
WING 0-GROUND FLOOR-NORTH-B



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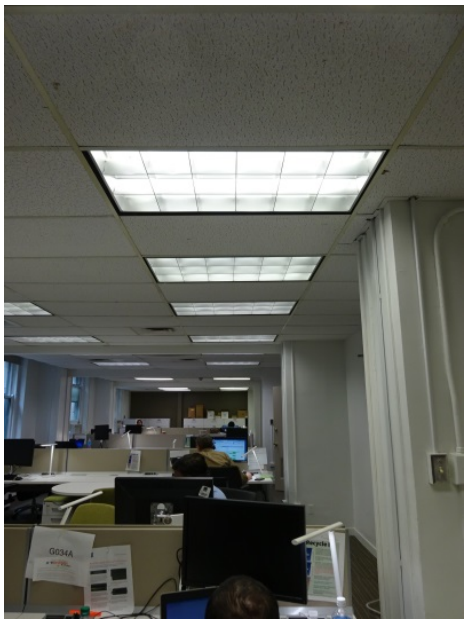

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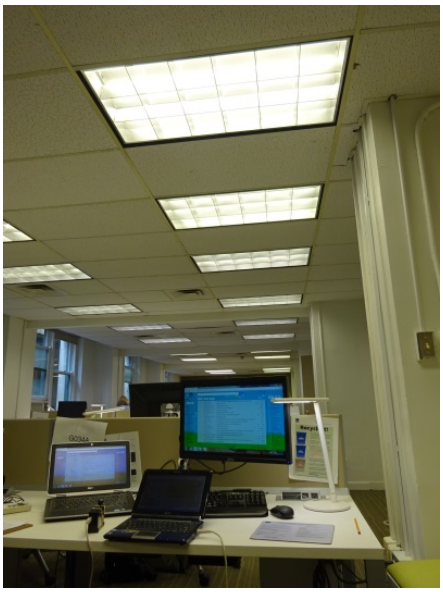

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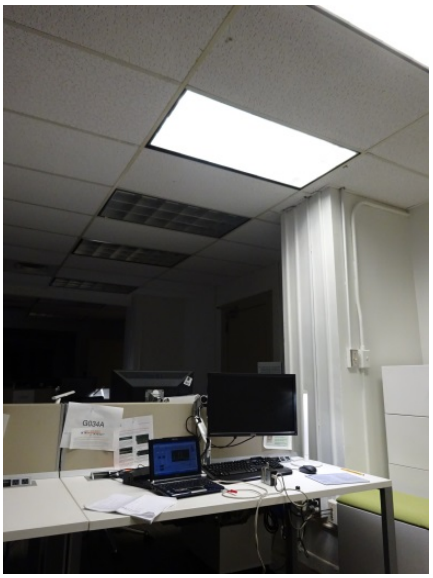

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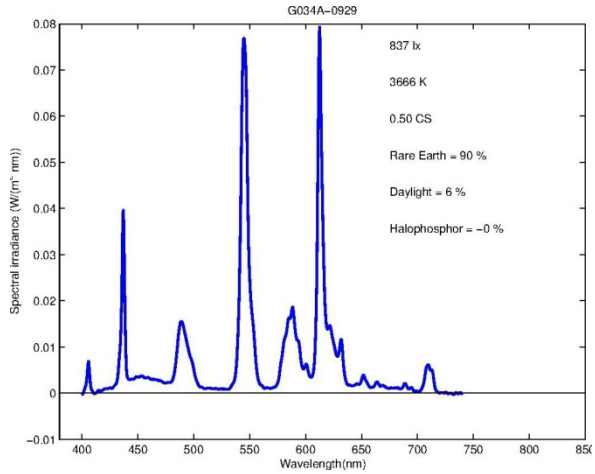
WING 0-GROUND FLOOR-NORTH-B

(SPECTRAL POWER DISTRIBUTION)



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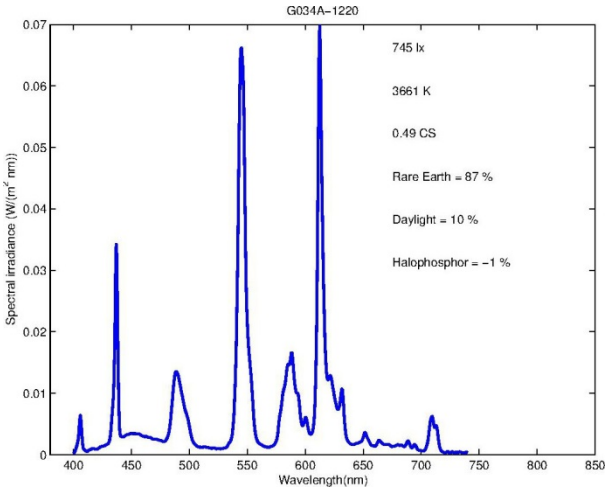

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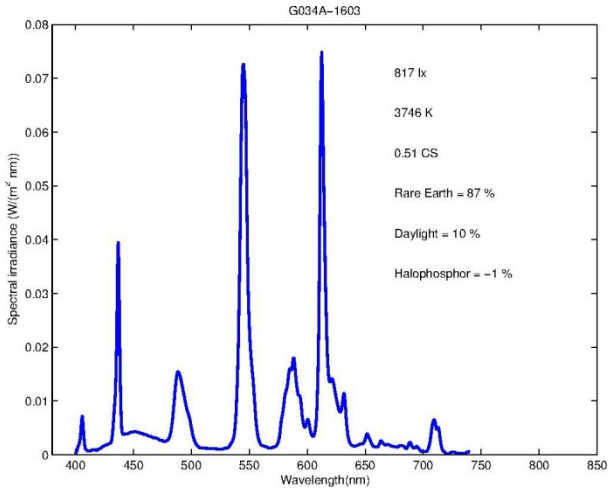

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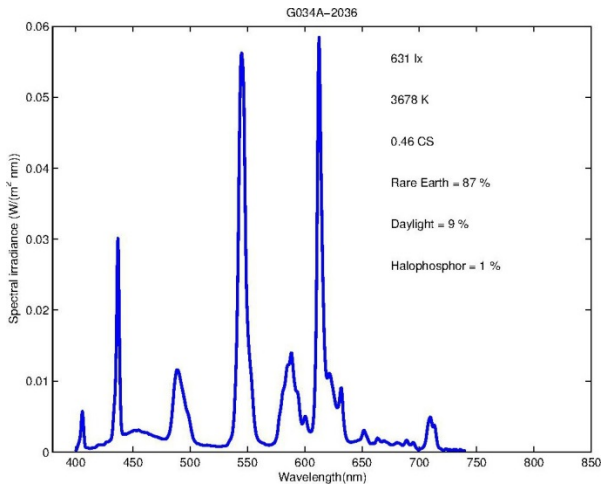

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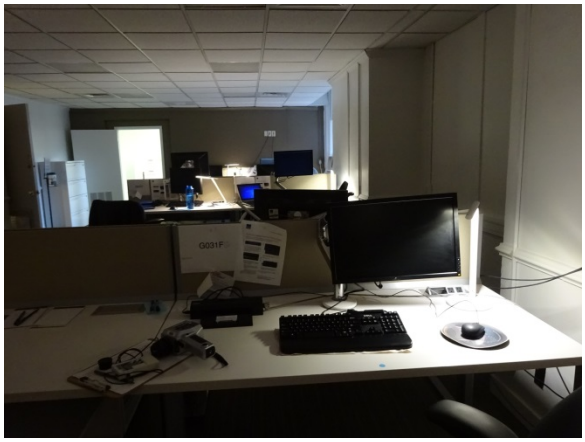
WING 0-GROUND FLOOR-SOUTH-A



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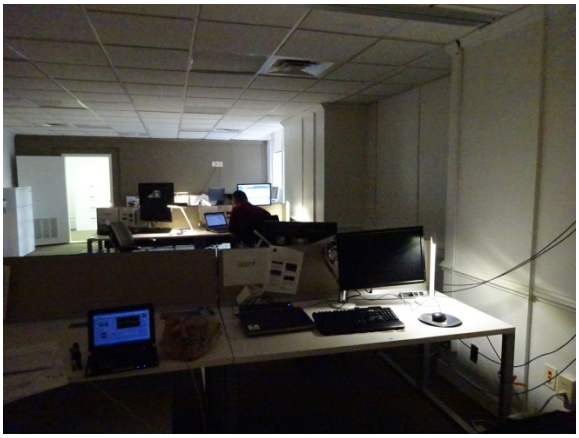

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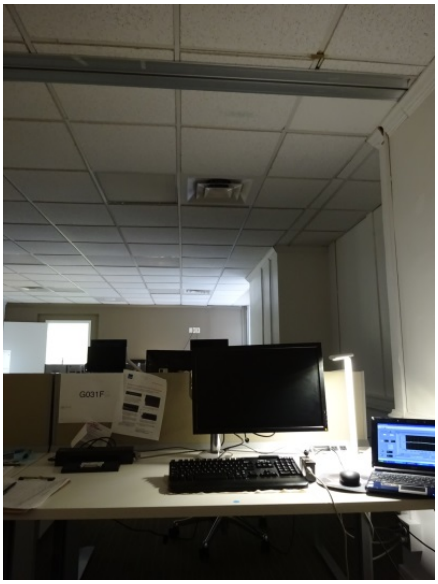

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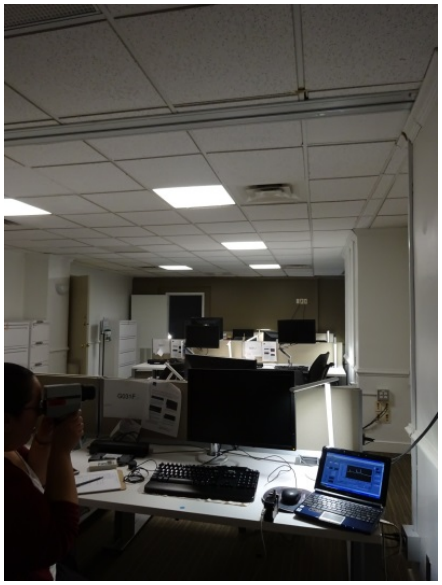

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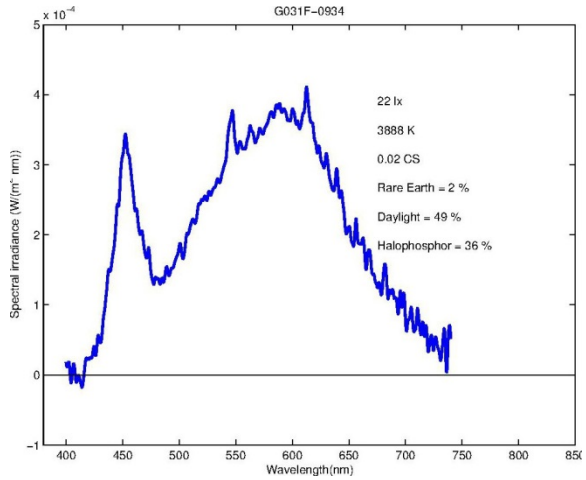
WING 0-GROUND FLOOR-SOUTH-A (SPECTRAL POWER DISTRIBUTION)



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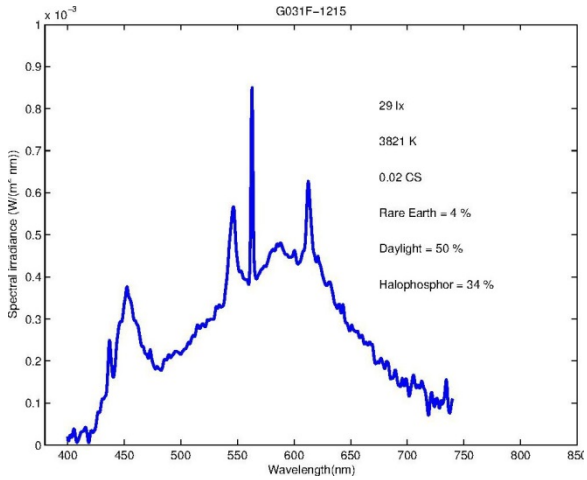

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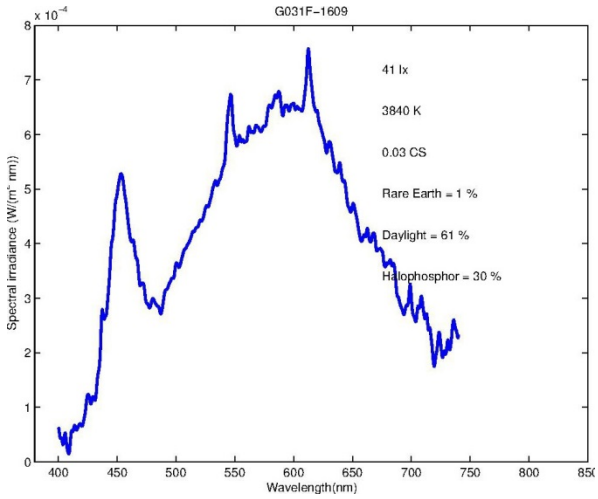

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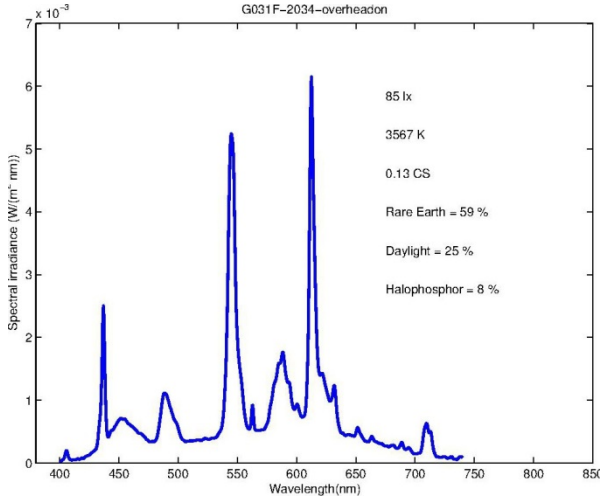

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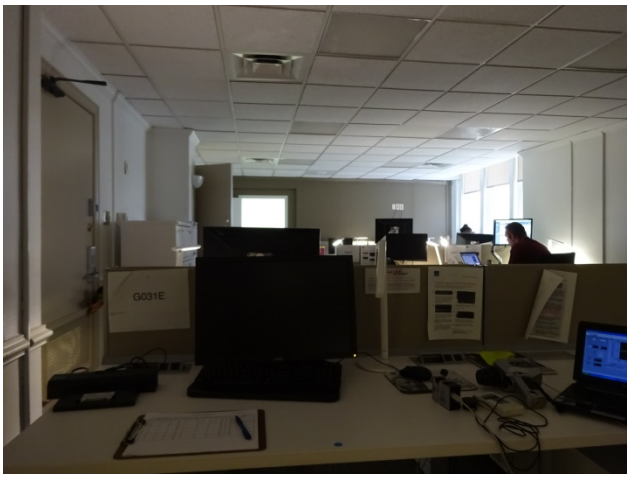
WING 0-GROUND FLOOR-SOUTH-B

9:33 AM



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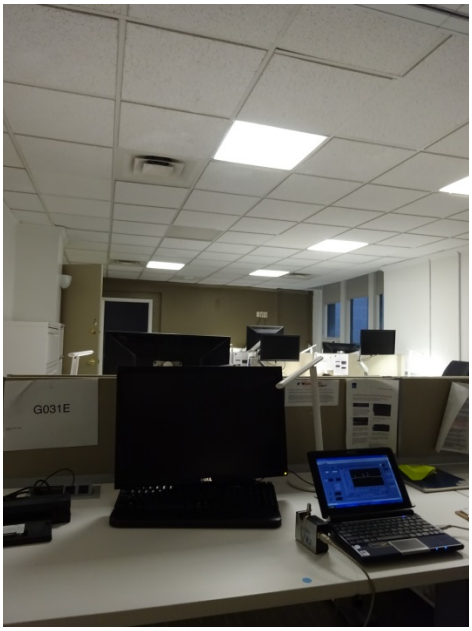

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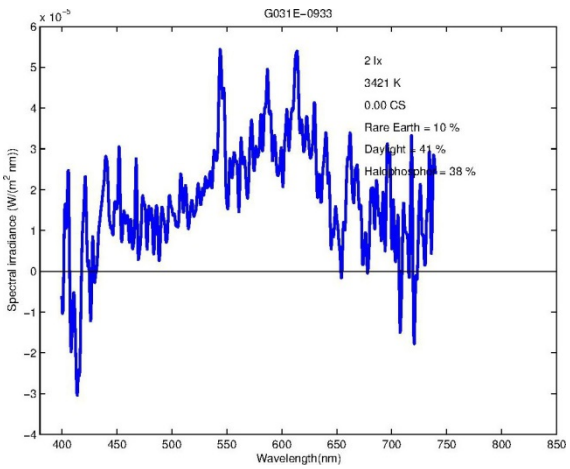
WING 0-GROUND FLOOR-SOUTH-B

(SPECTRAL POWER DISTRIBUTION)



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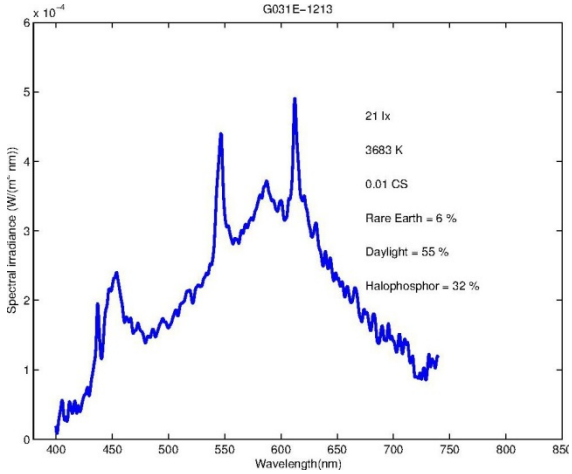

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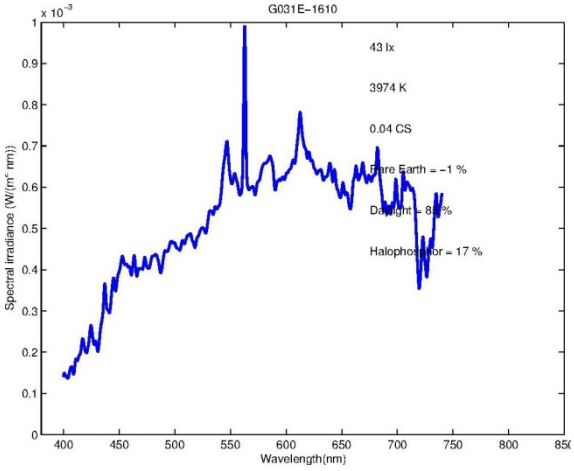

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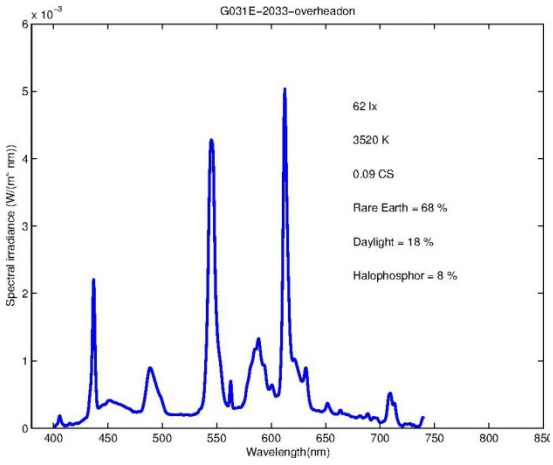

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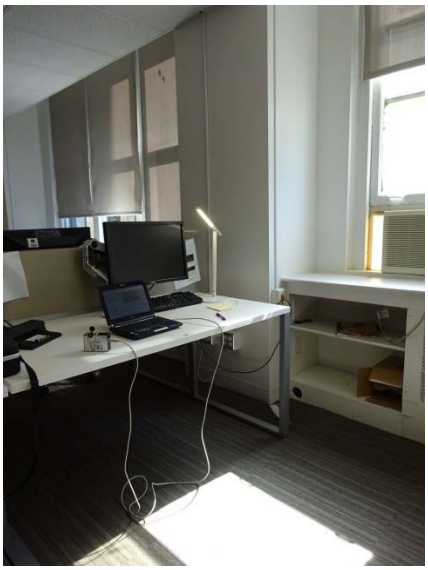
WING 3-GROUND FLOOR-EAST-A



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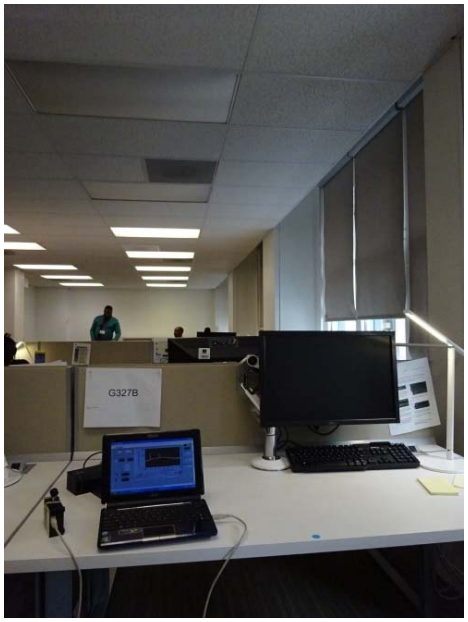

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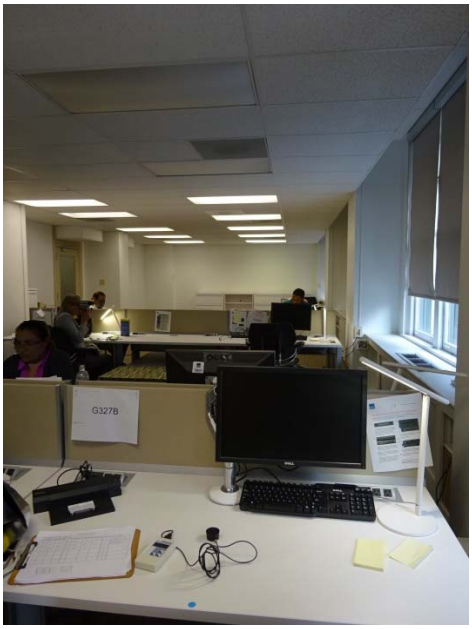

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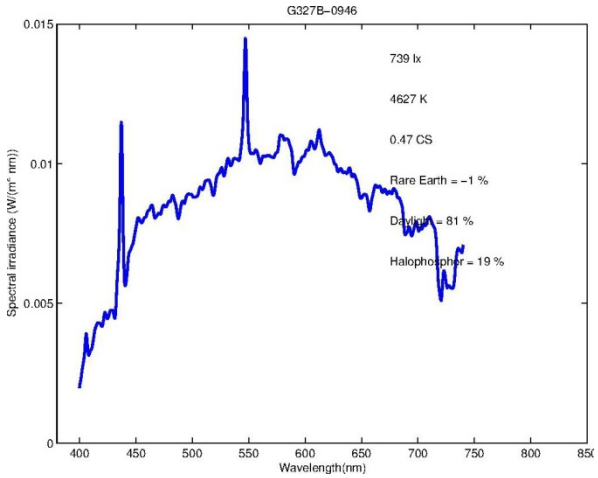
WING 3-GROUND FLOOR-EAST-A

(SPECTRAL POWER DISTRIBUTION)



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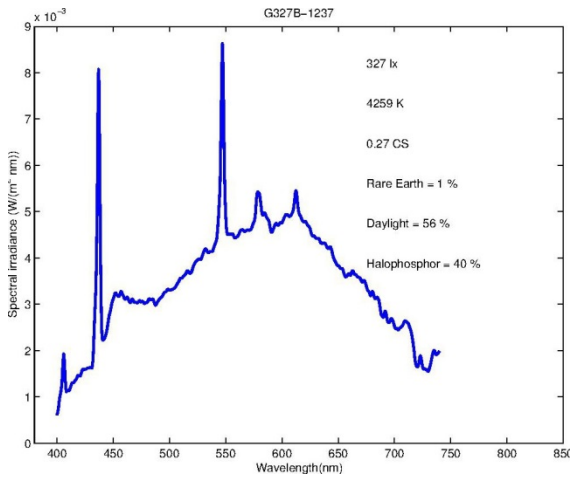

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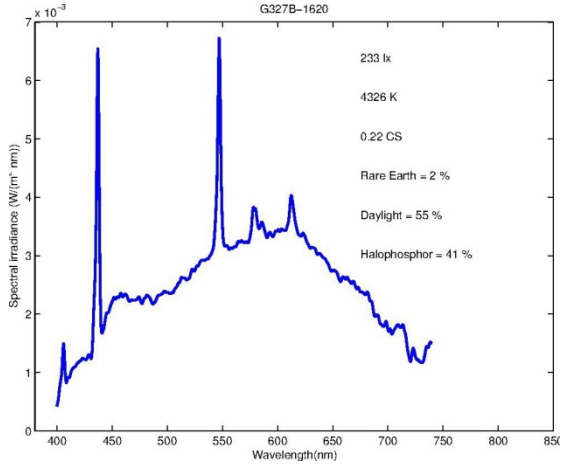

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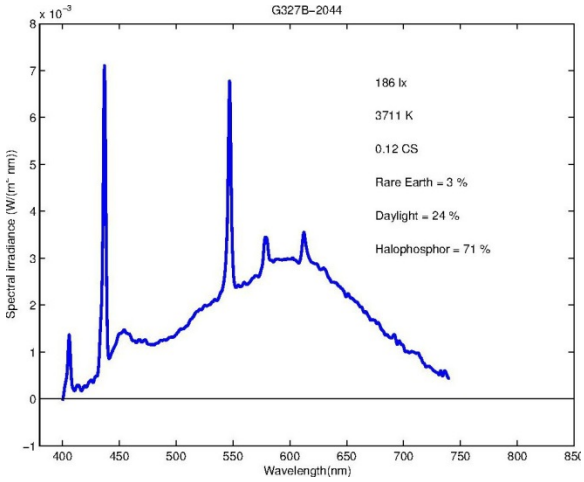

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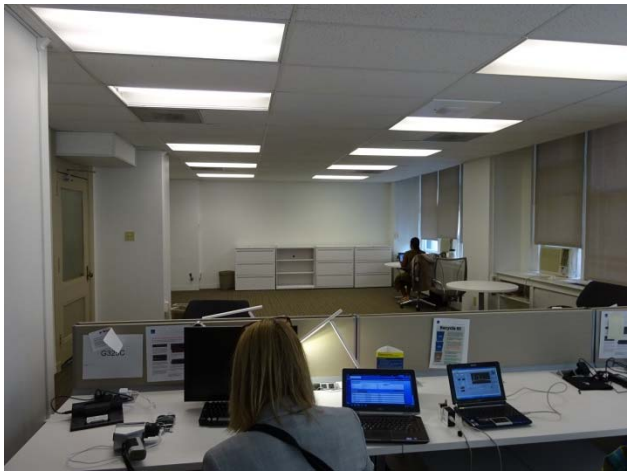
WING 3-GROUND FLOOR-EAST-B



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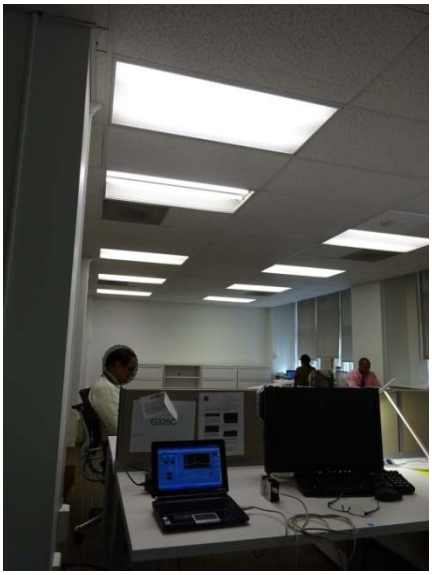

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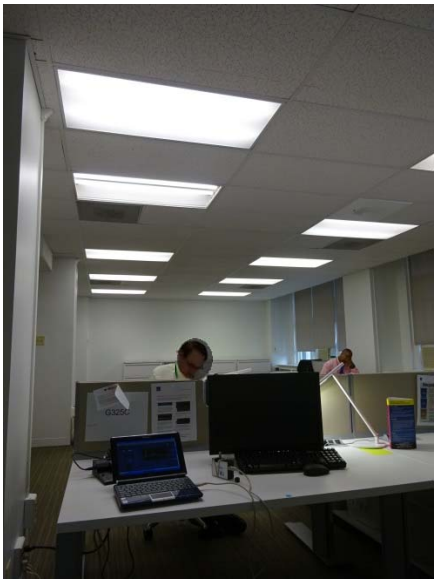

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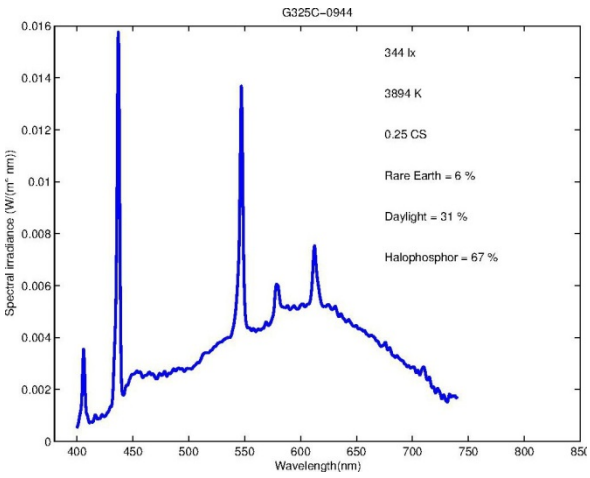
8:42 PM

WING 3-GROUND FLOOR-EAST-B

(SPECTRAL POWER DISTRIBUTION)



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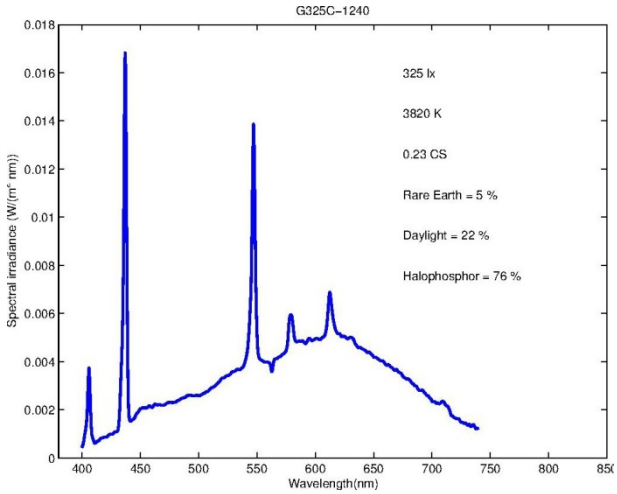

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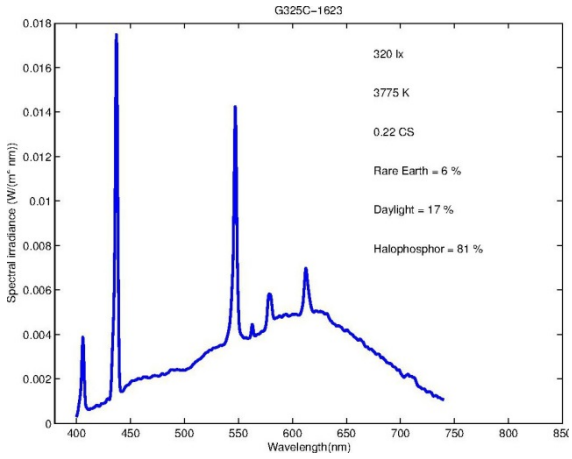

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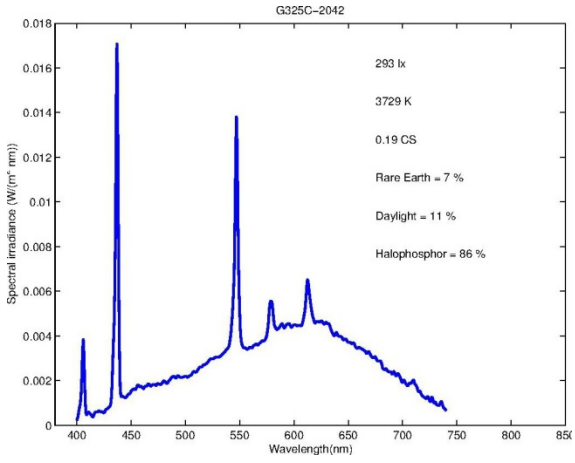

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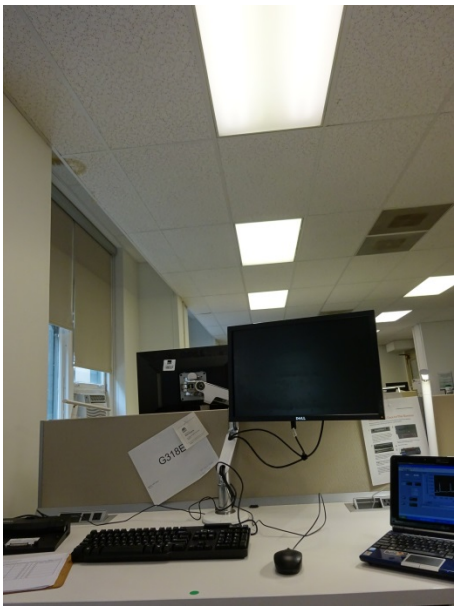
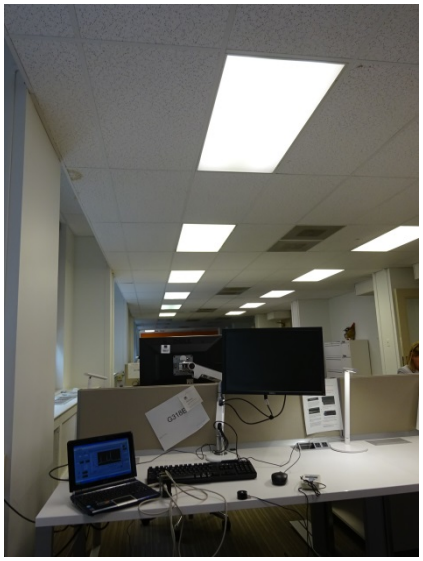
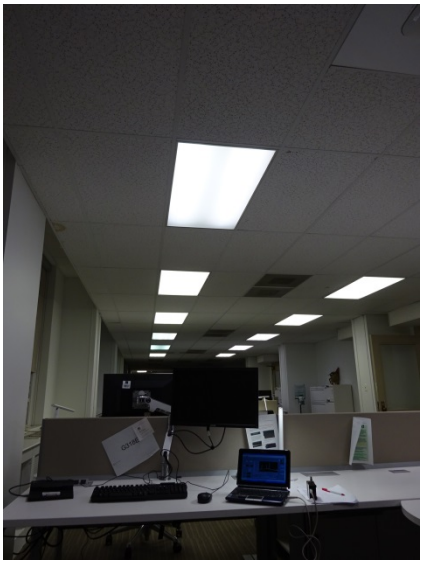
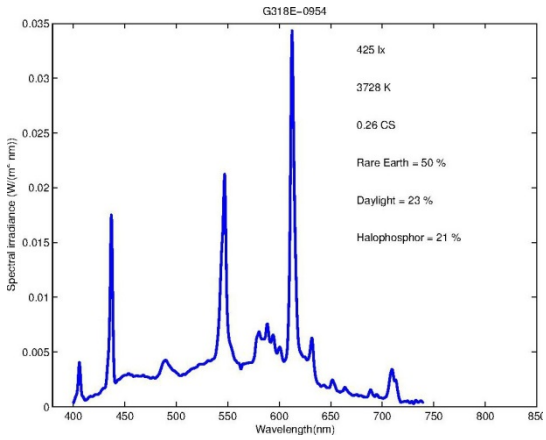
WING 3-GROUND FLOOR-WEST-A

	 ***12:28 PM***
 ***4:16 PM***	 **8:48 PM**

WING 3-GROUND FLOOR-WEST-A

(SPECTRAL POWER DISTRIBUTION)



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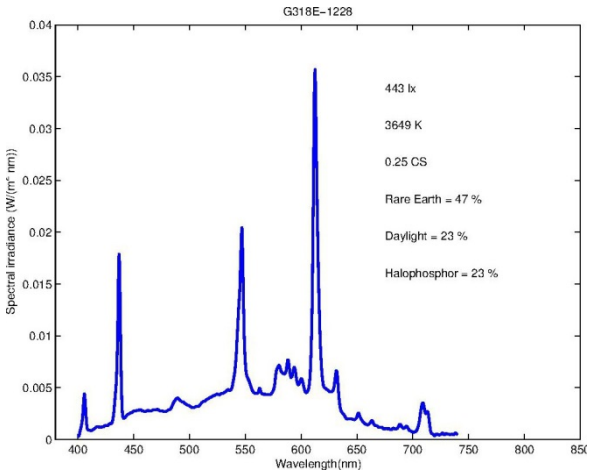

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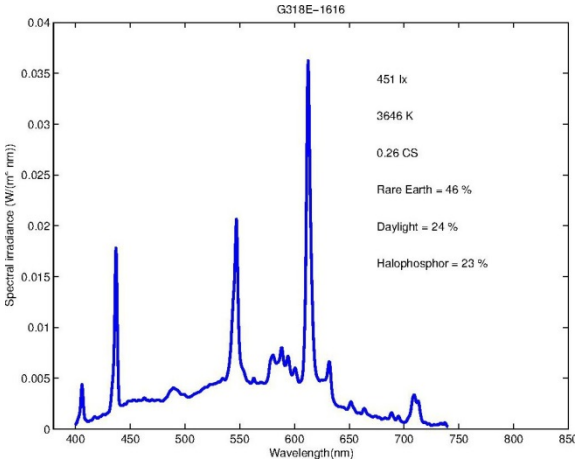

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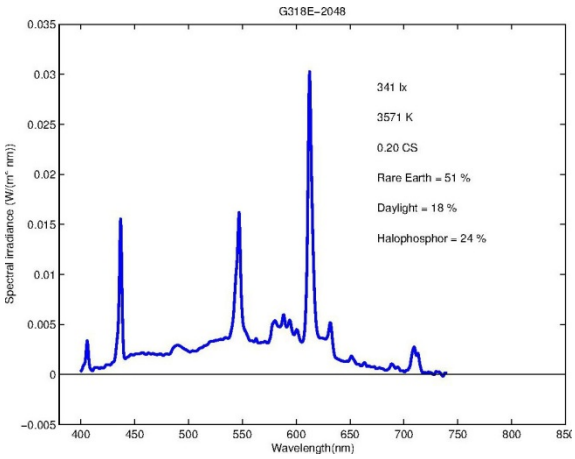
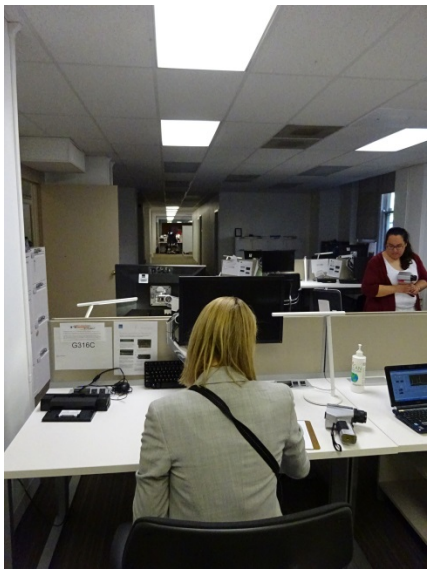


8:48 PM

WING 3-GROUND FLOOR-WEST-B



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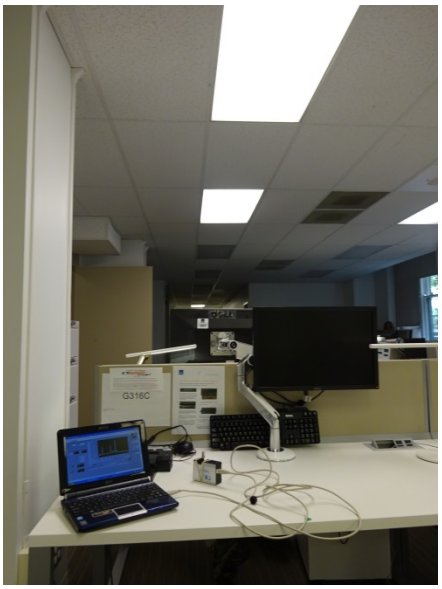

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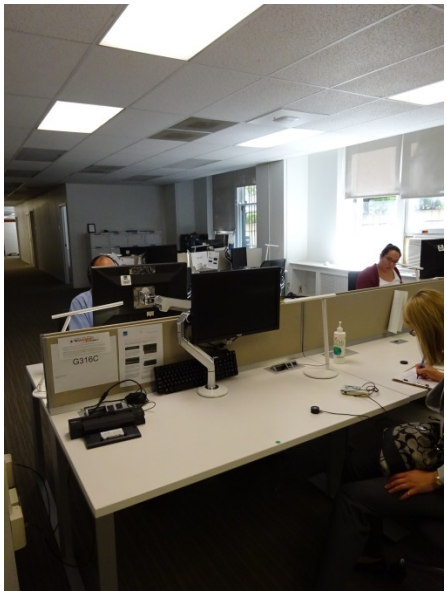
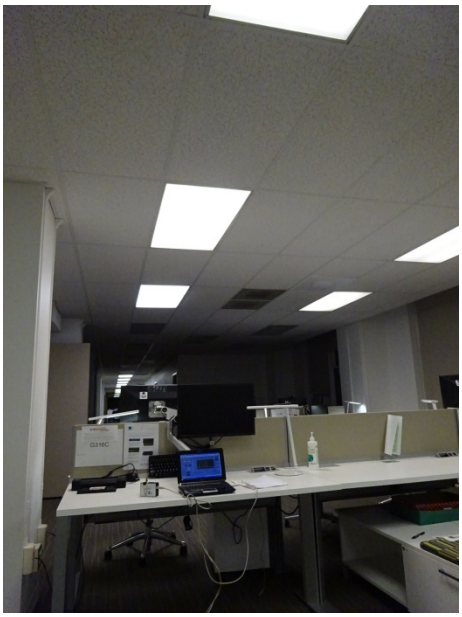


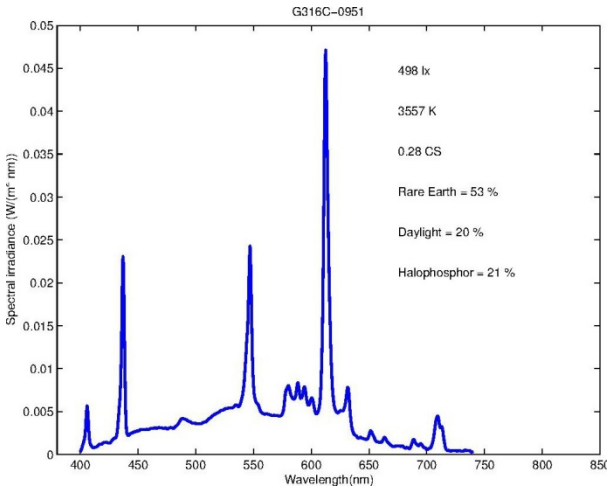
4:14 PM



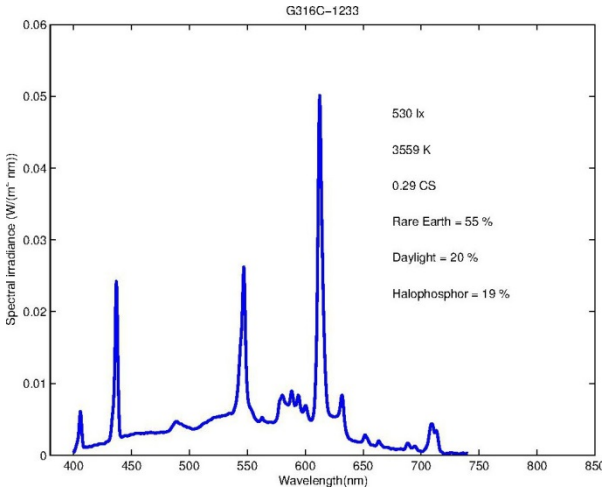
8:46 PM

WING 3-GROUND FLOOR-WEST-B

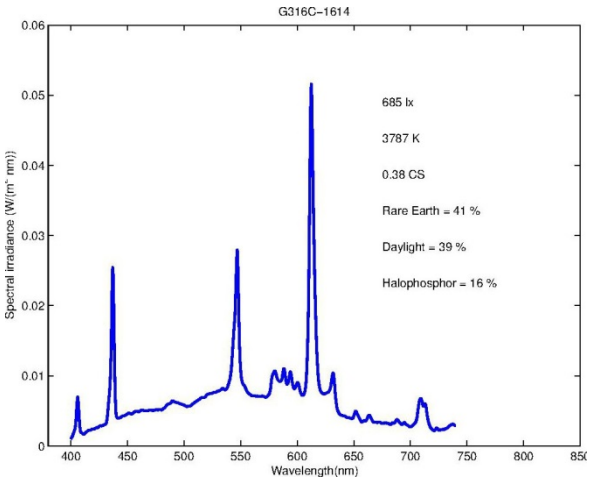
(SPECTRAL POWER DISTRIBUTION)



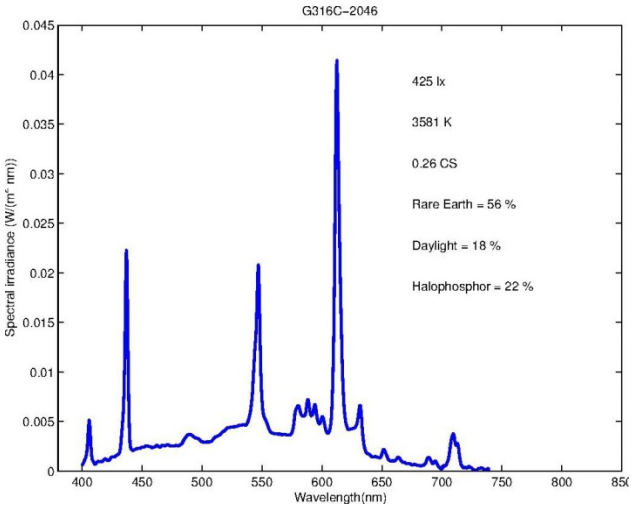
9:51 AM



12:33 PM



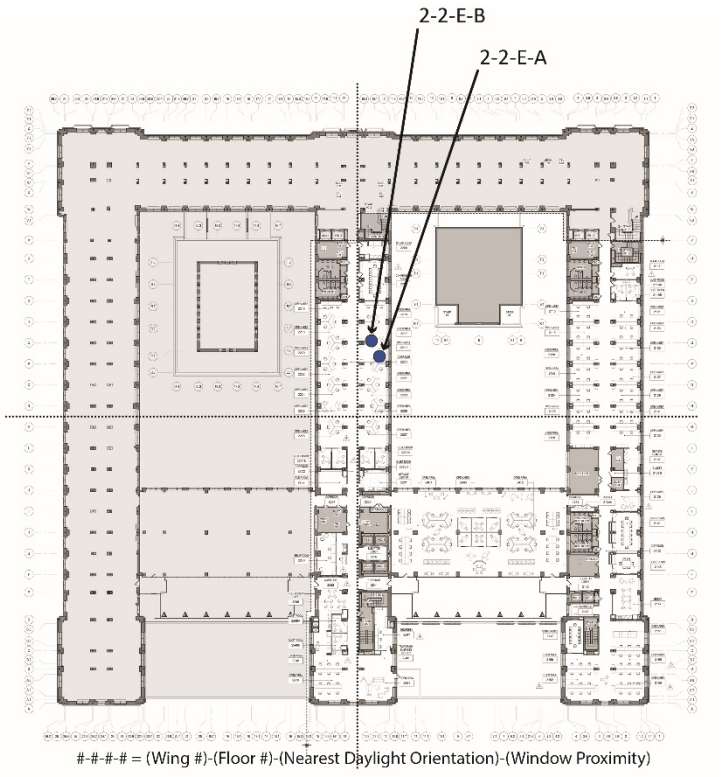
4:14 PM



8:46 PM

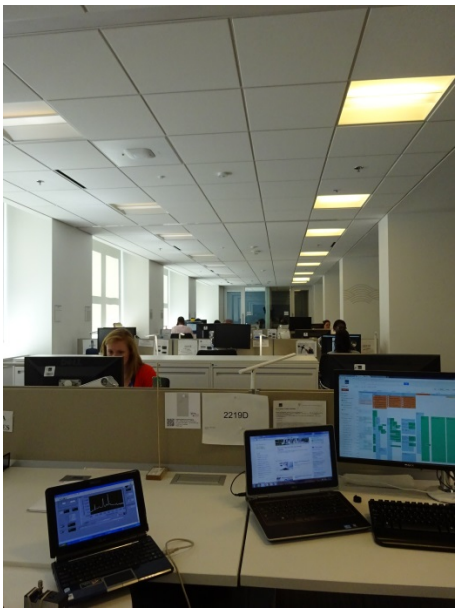
APPENDIX D: SPECTRAL PHOTOMETRIC DATA FOR 2ND FLOOR DESKS

Spectral power distribution (SPD) was measured at 2 desks on the 2nd floor at the GSA headquarters building during the winter visit. These were the same desks that hosted other measurements (see Appendix A). SPDs were measured repeatedly over the day and after dark.

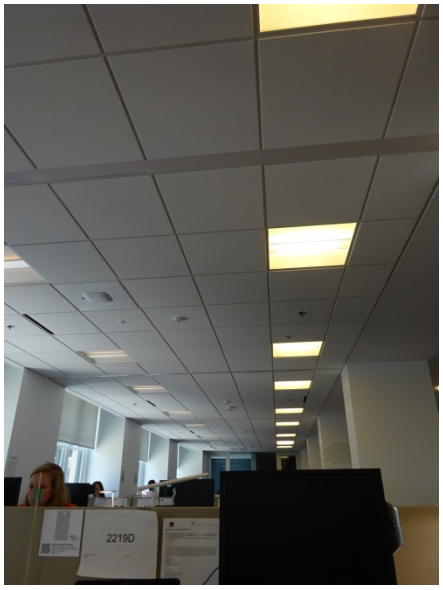


As shown below, the resulting SPD curves change as daylight contribution changes. For reference, a photograph is also presented for most of the measurements, as this represents the scene that the occupant experienced at the time of measurement.

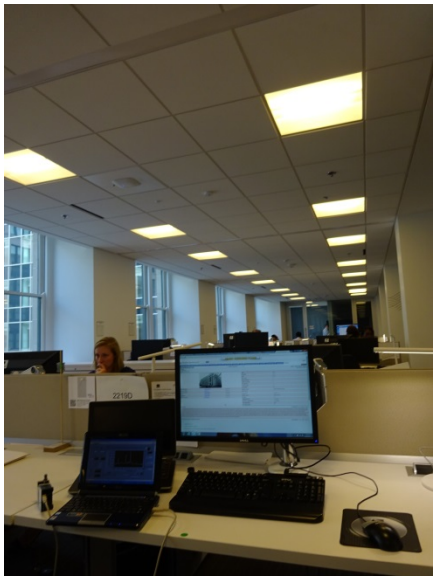
WING 2 - FLOOR 2 - EAST - A



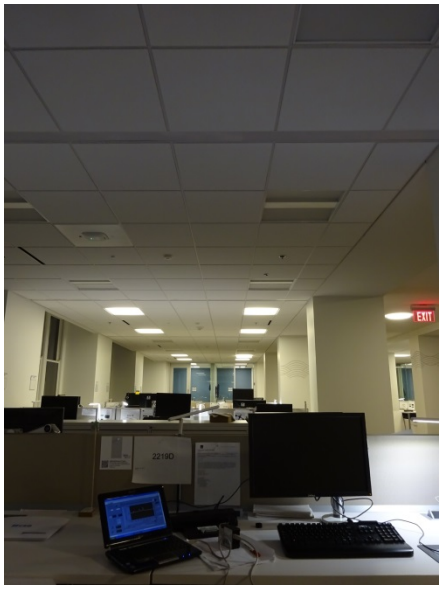
10:06 AM



12:55 PM



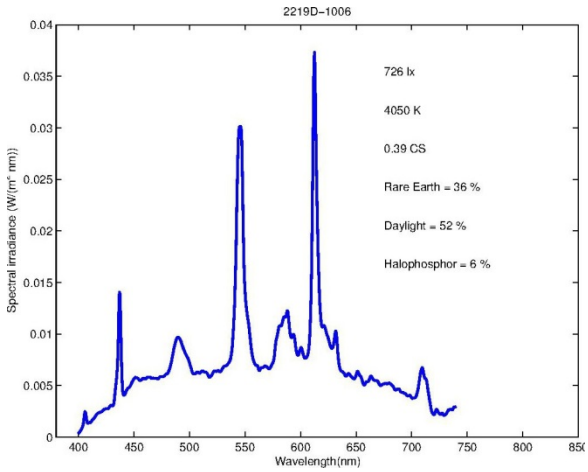
4:38 PM



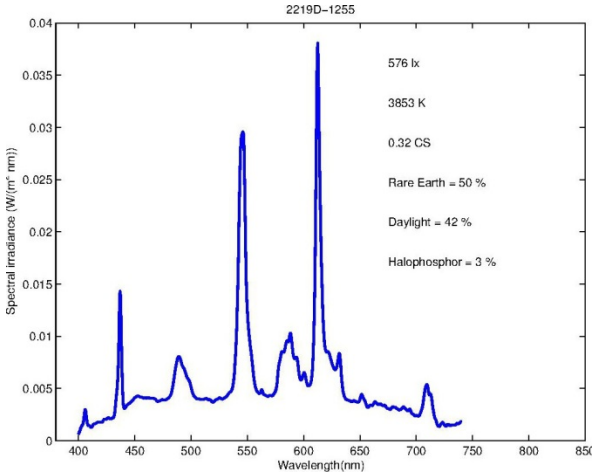
8:58 PM

WING 2 - FLOOR 2 - EAST - A

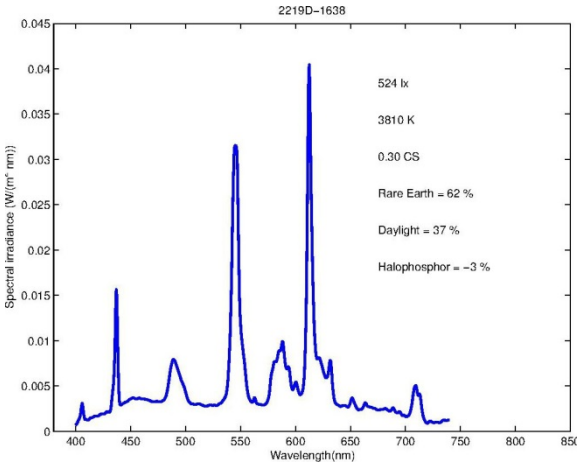
(SPECTRAL POWER DISTRIBUTION)



10:06 AM



12:55 PM



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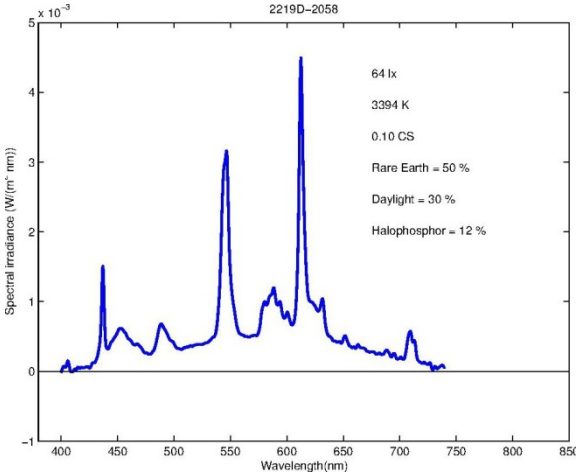
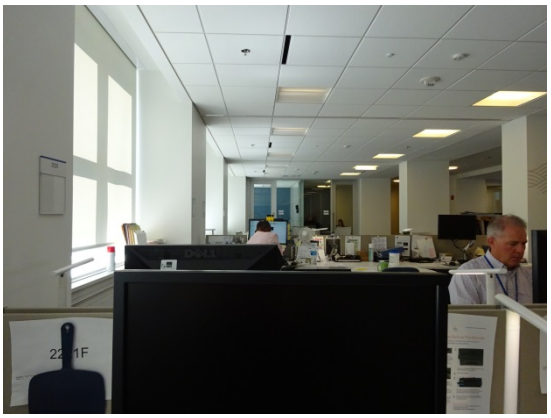
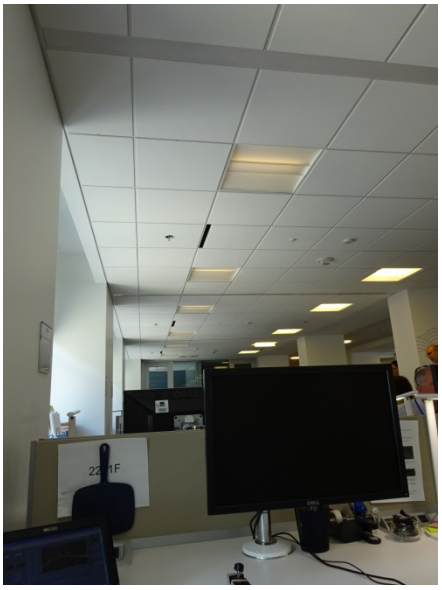


8:58 PM

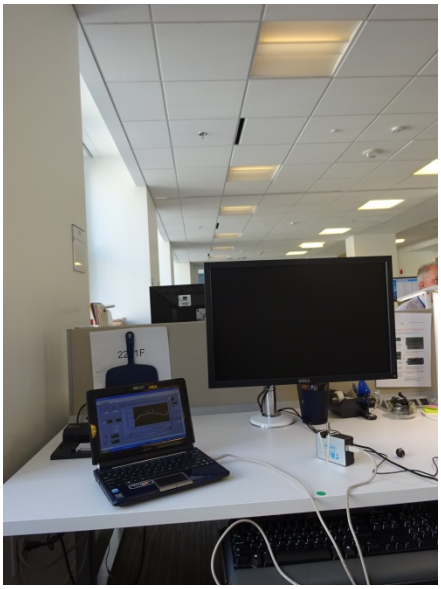
WING 2 - FLOOR 2 - EAST - B



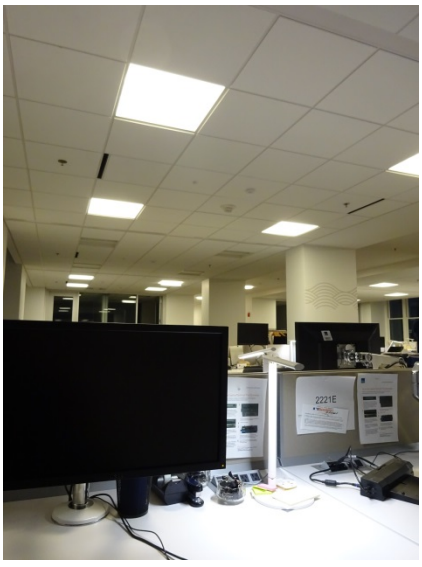
10:05 AM



12:50 PM



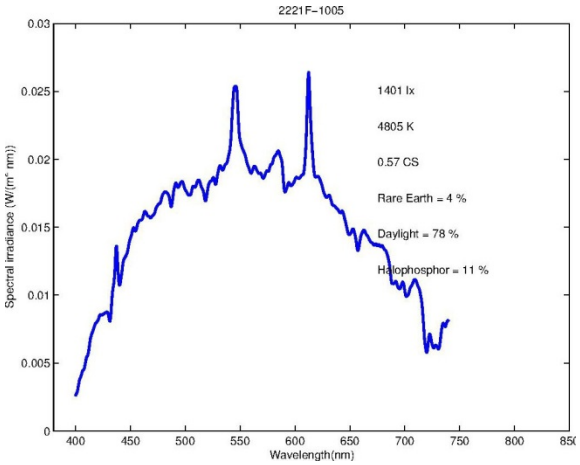
4:35 PM



8:55 PM

WING 2 - FLOOR 2 - EAST - B

(SPECTRAL POWER DISTRIBUTION)



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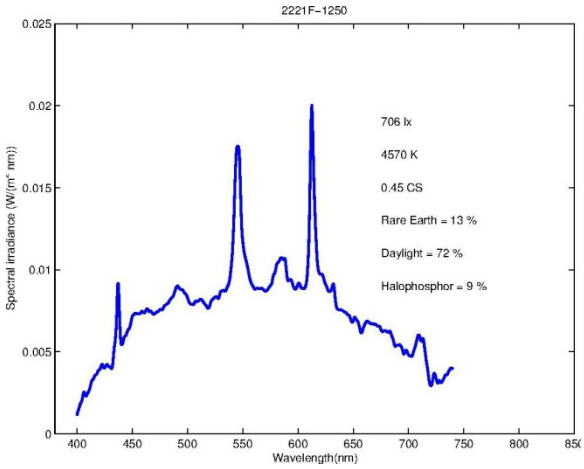
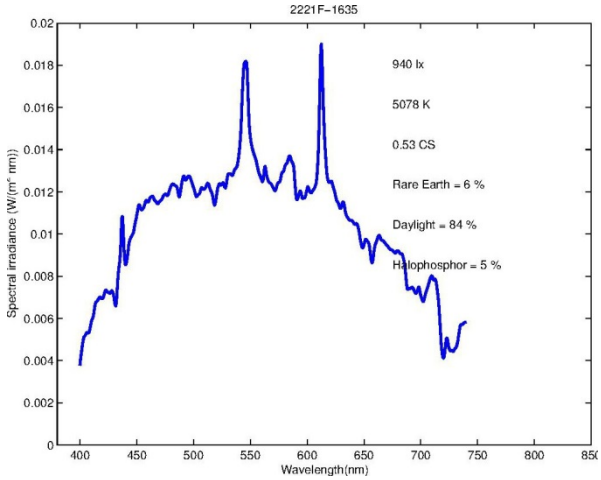
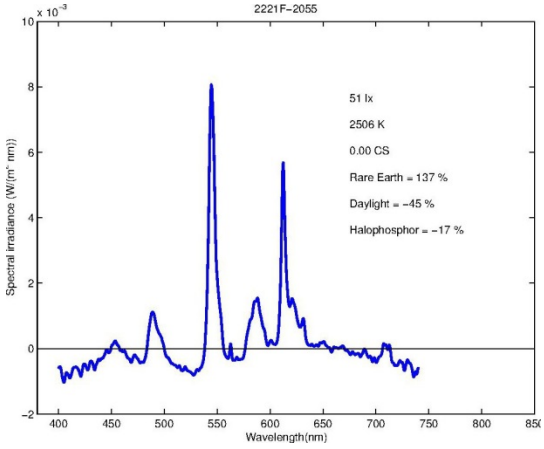


12:50 PM



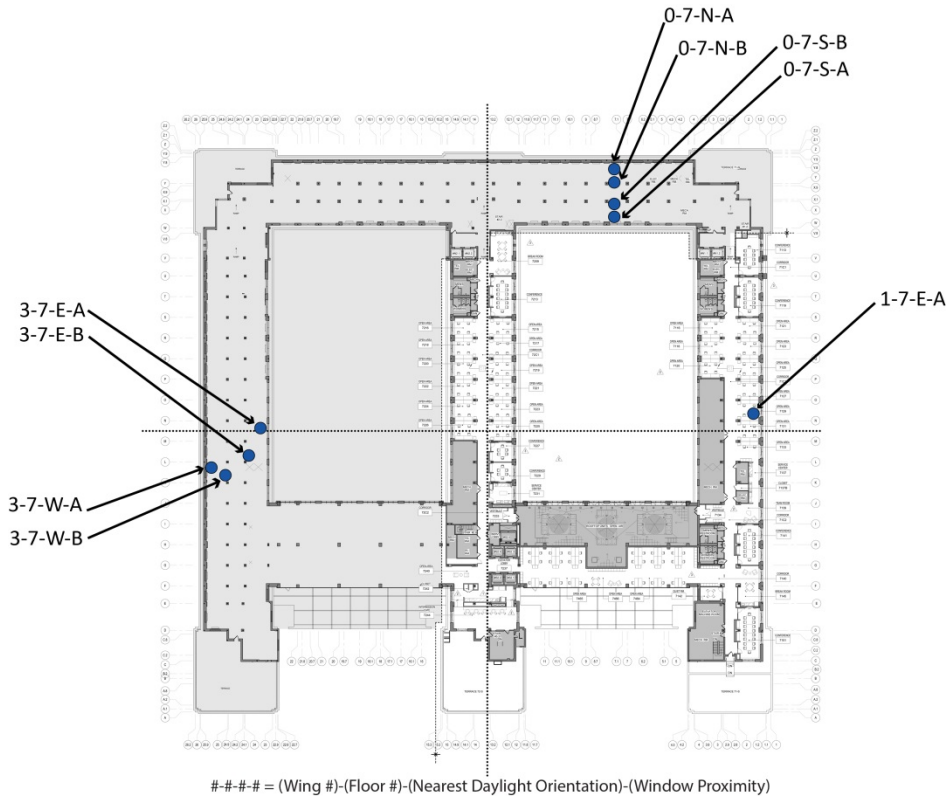
4:35 PM



8:55 PM

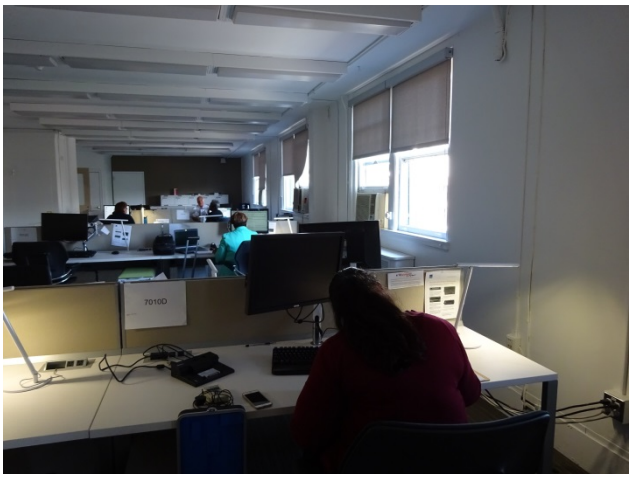
APPENDIX E: SPECTRAL PHOTOMETRIC DATA FOR 7TH FLOOR DESKS

Spectral power distribution (SPD) was measured at 9 desks on the 7th floor at GSA during the winter visit. These were the same desks that hosted other measurements (see Appendix A). SPDs were measured repeatedly over the day and after dark.



As shown below, the resulting SPD curves change as daylight contribution changes. For reference, a photograph is also presented for most of the measurements, as this represents the scene that the occupant experienced at the time of measurement.

WING 0 - FLOOR 7 - NORTH - A



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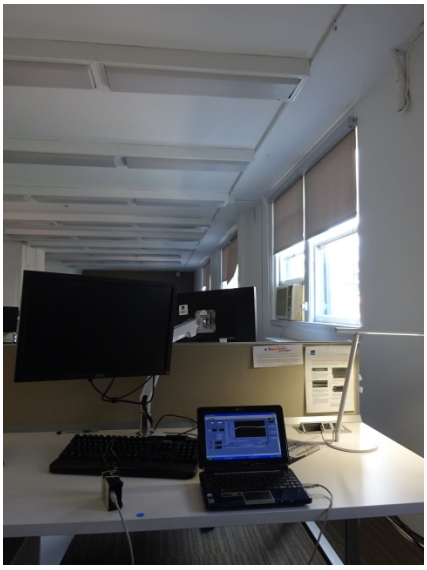
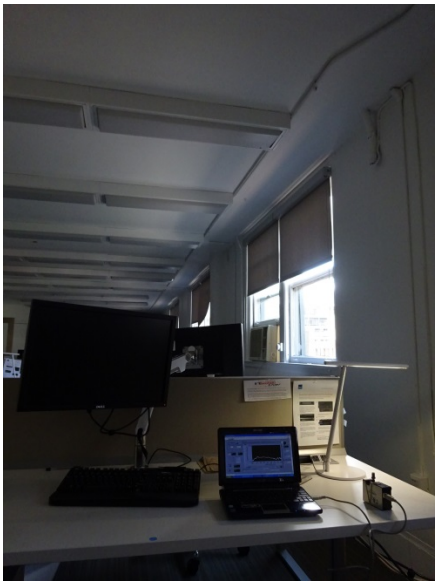


1:04 PM

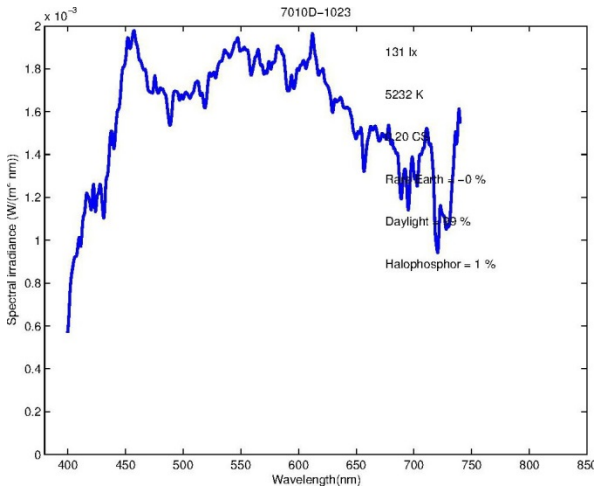


4:48 PM

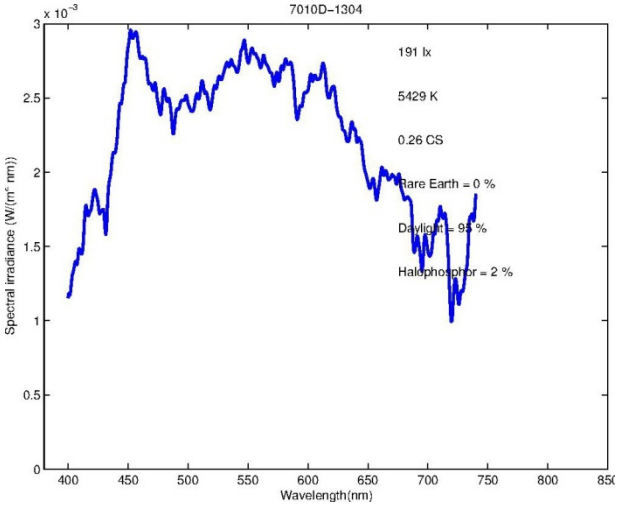
9:05 PM

WING 0 - FLOOR 7 - NORTH - A

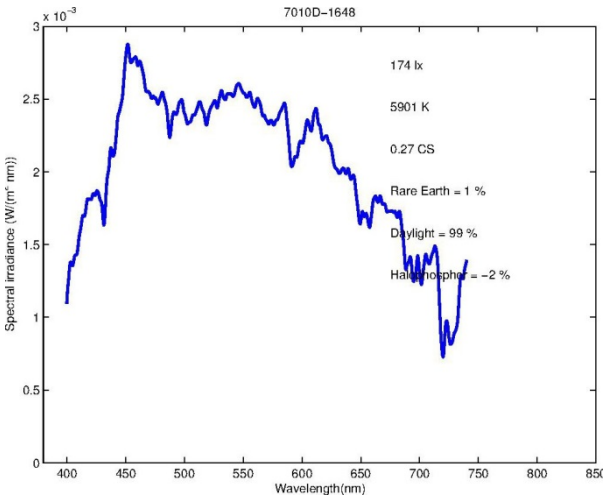
(SPECTRAL POWER DISTRIBUTION)



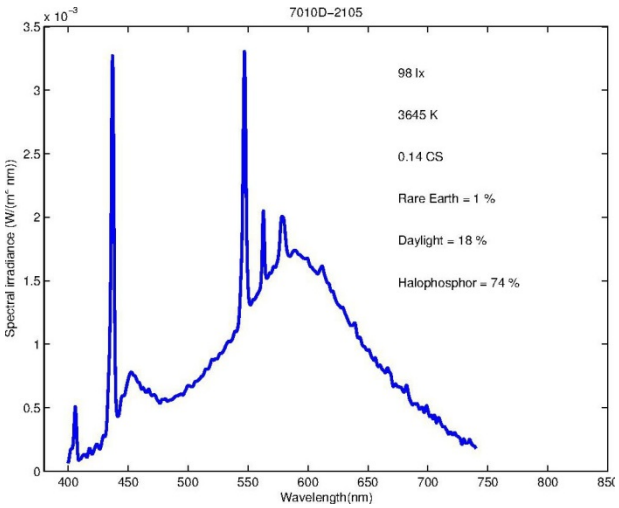
10:23 AM



1:04 PM

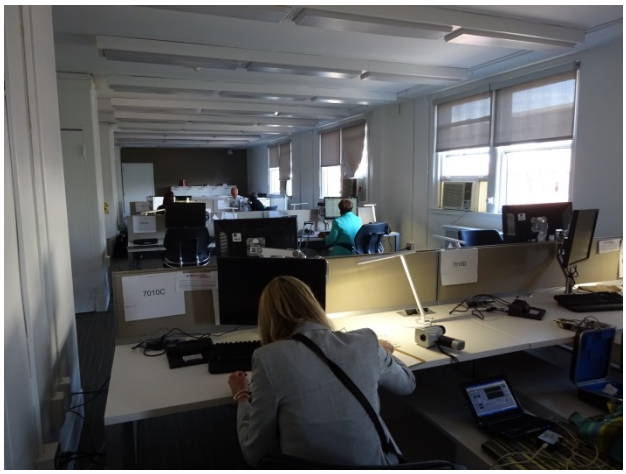


4:48 PM

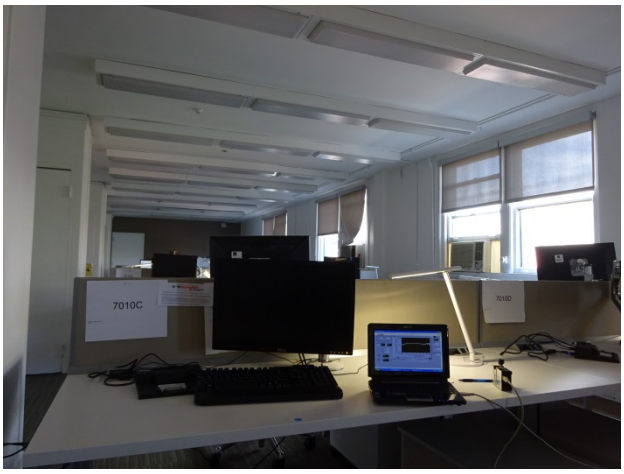


9:05 PM

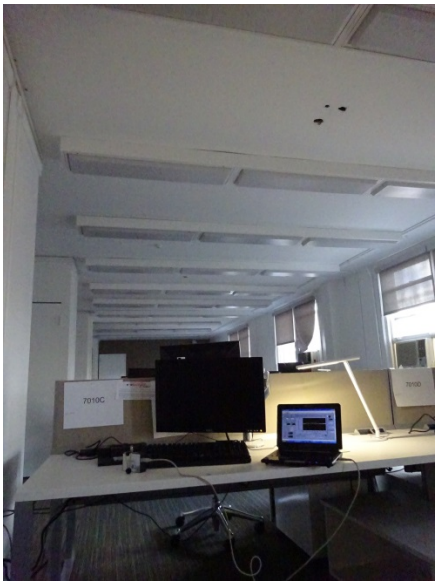
WING 0 - FLOOR 7 - NORTH - B



10:21 AM



1:07 PM

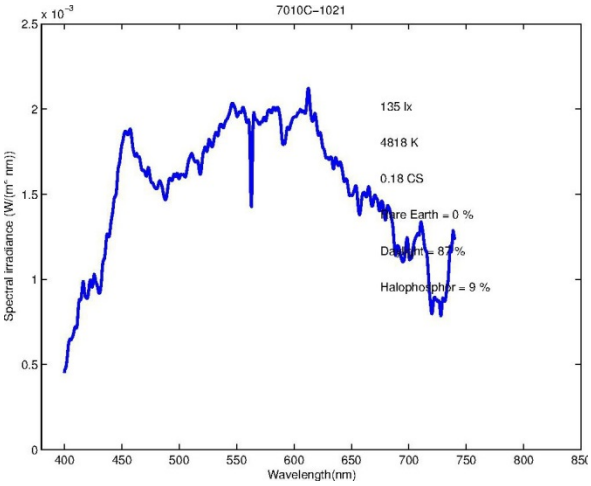


4:47 PM

9:07 PM

WING 0 - FLOOR 7 - NORTH - B

(SPECTRAL POWER DISTRIBUTION)



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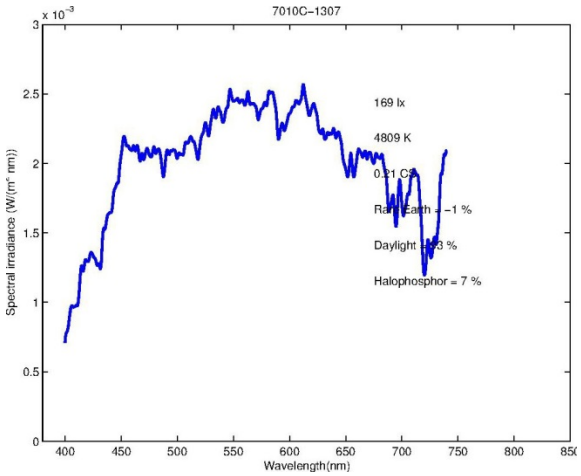
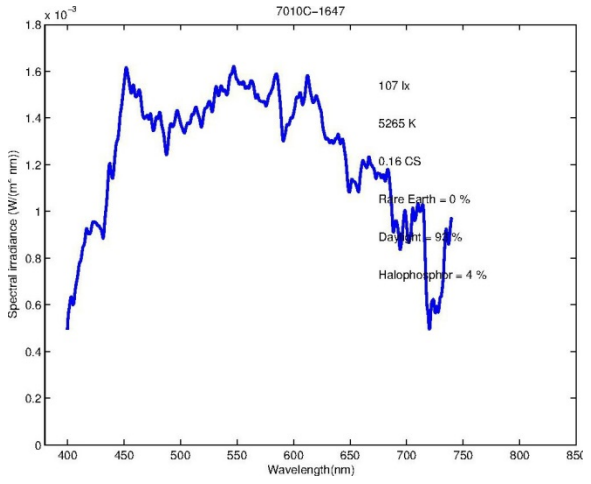
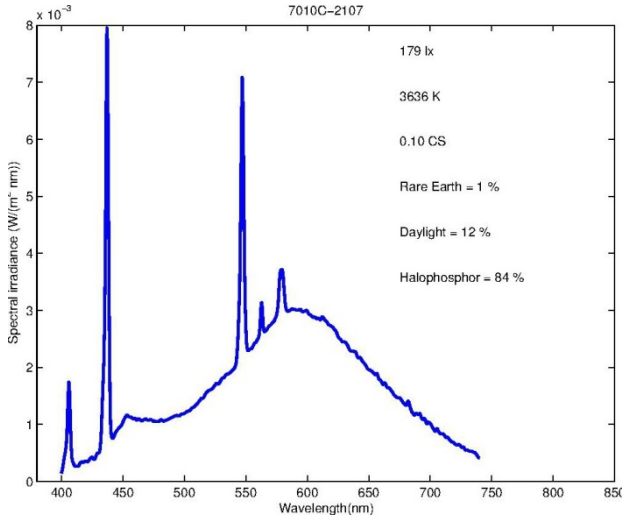


1:07 PM

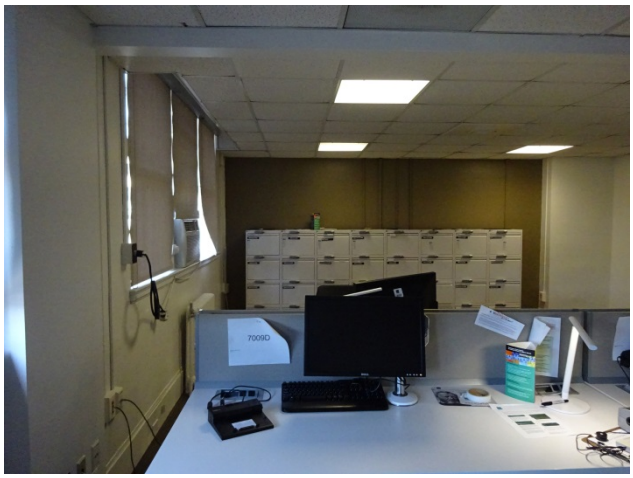


4:47 PM

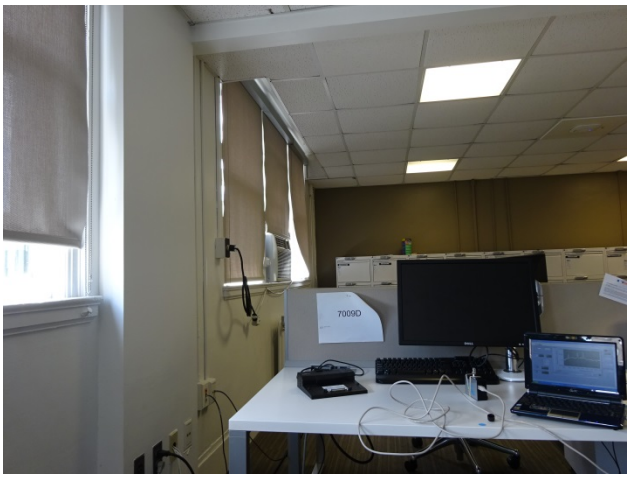


9:07 PM

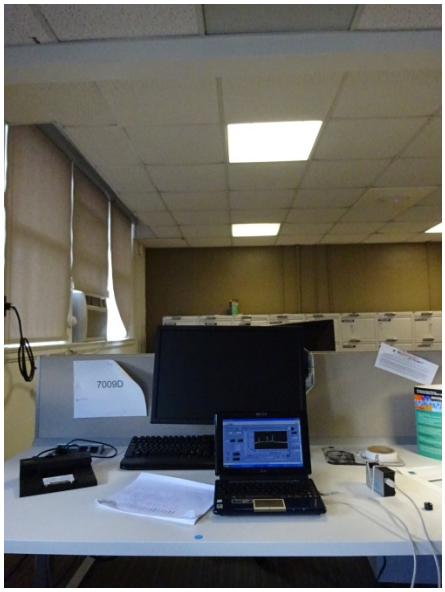
WING 0 - FLOOR 7 - SOUTH - A



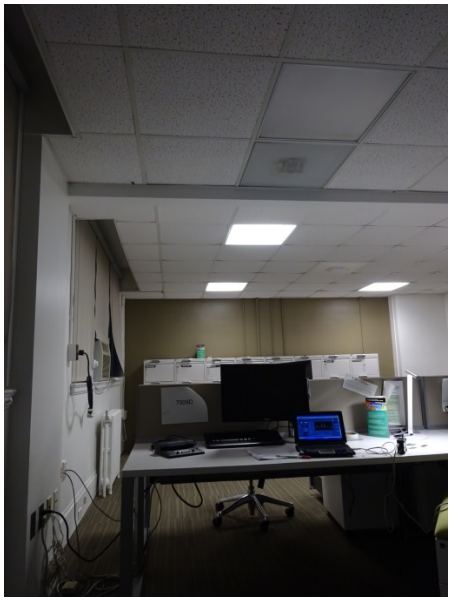
10:25 AM



1:08 PM



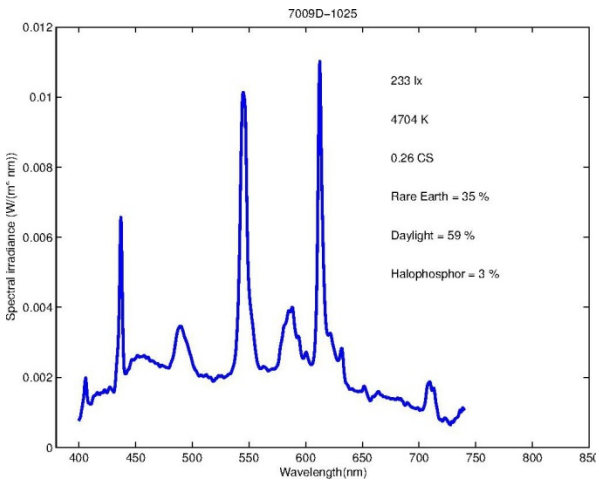
4:43 PM



9:02 PM

WING 0 - FLOOR 7 - SOUTH - A

(SPECTRAL POWER DISTRIBUTION)



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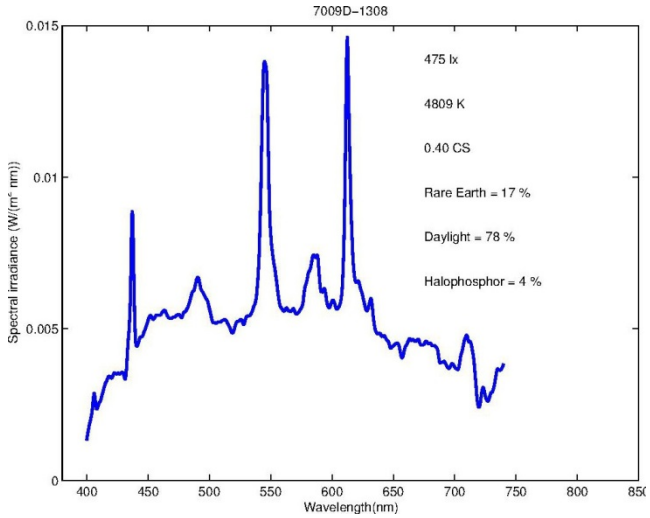
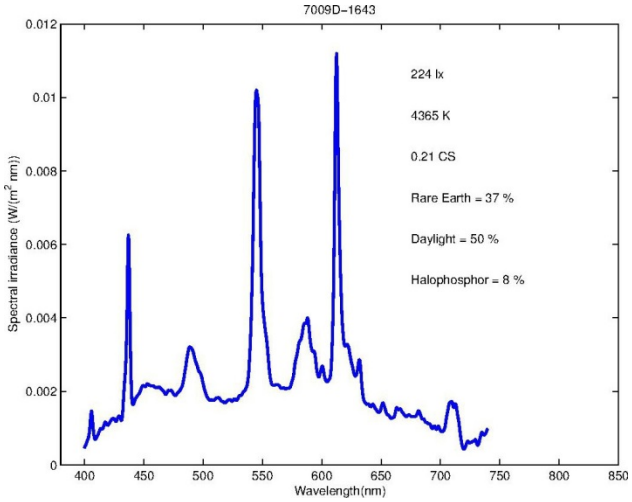
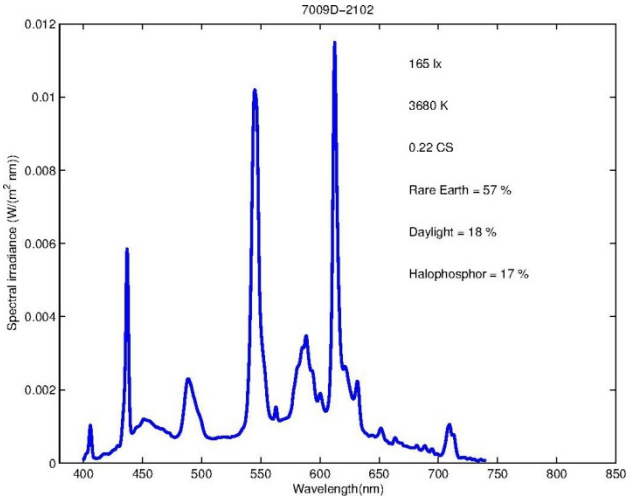


1:08 PM

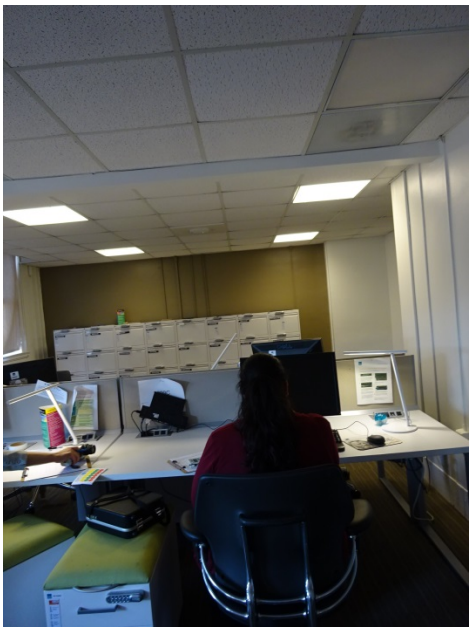


4:43 PM

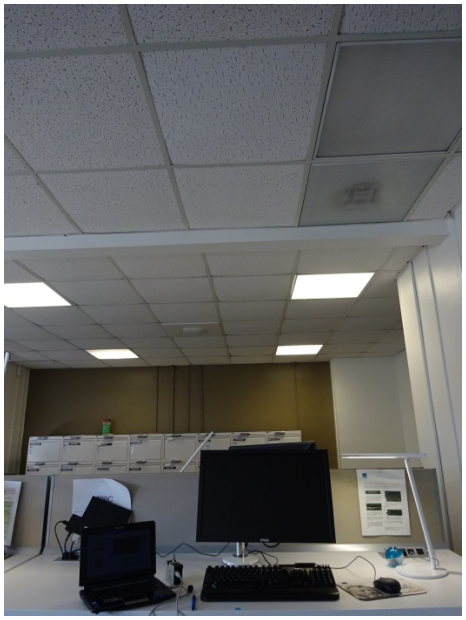


9:02 PM

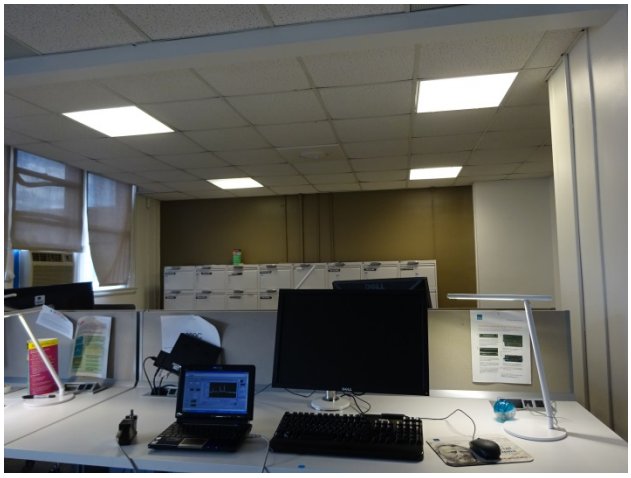
WING 0 - FLOOR 7 - SOUTH - B



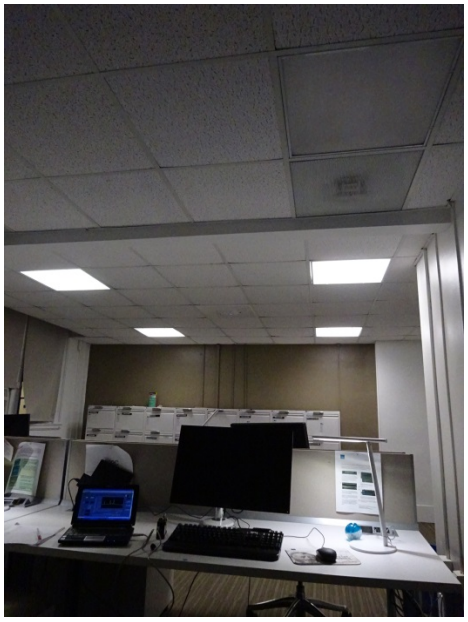
10:27 AM



1:10 PM



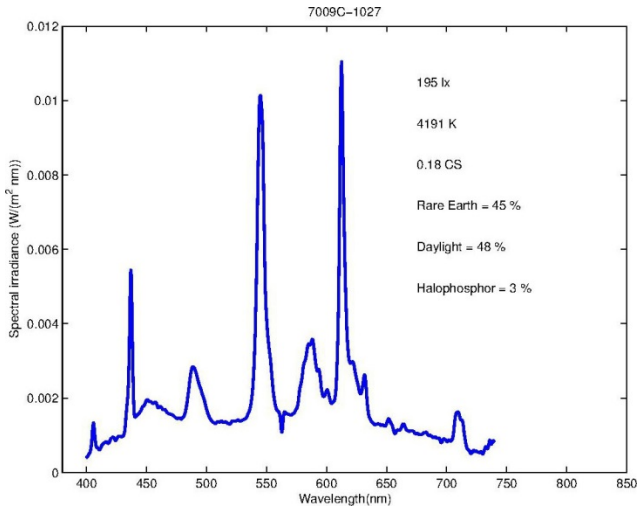
4:44 PM



9:03 PM

WING 0 - FLOOR 7 - SOUTH - B

(SPECTRAL POWER DISTRIBUTION)



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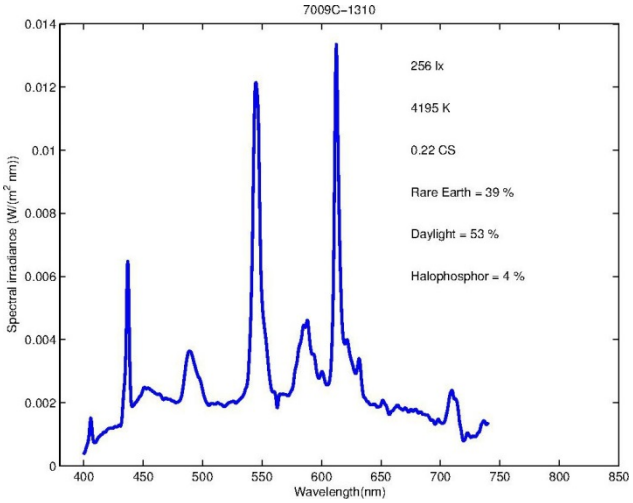
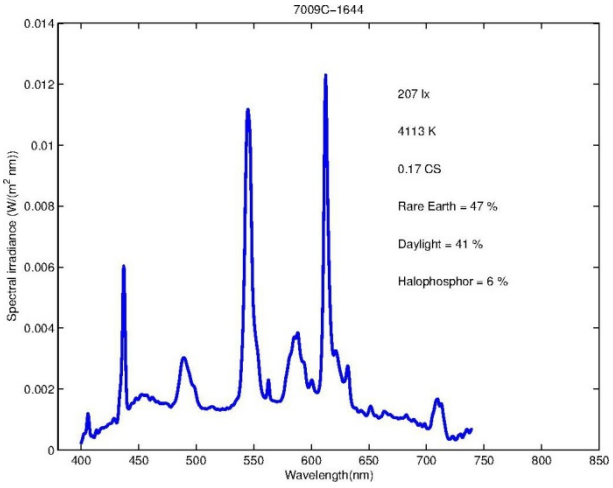
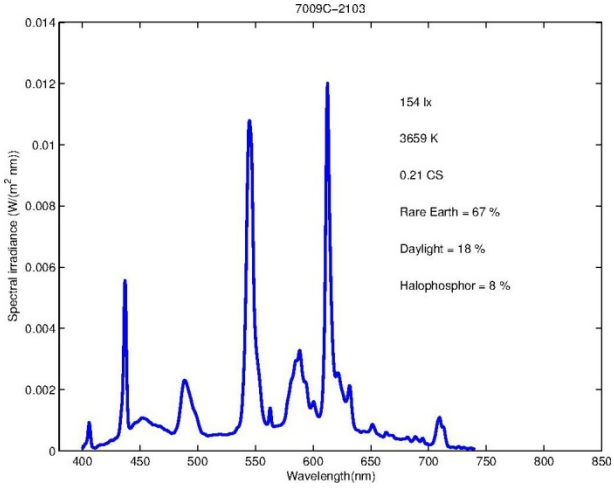


1:10 PM

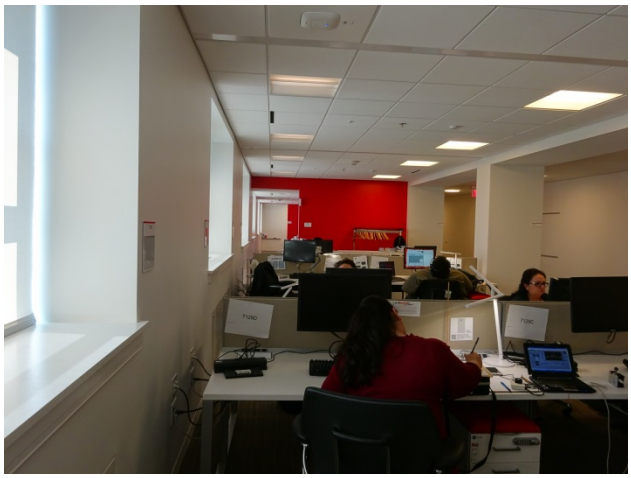


4:44 PM



9:03 PM

WING 1 - FLOOR 7 - EAST - A



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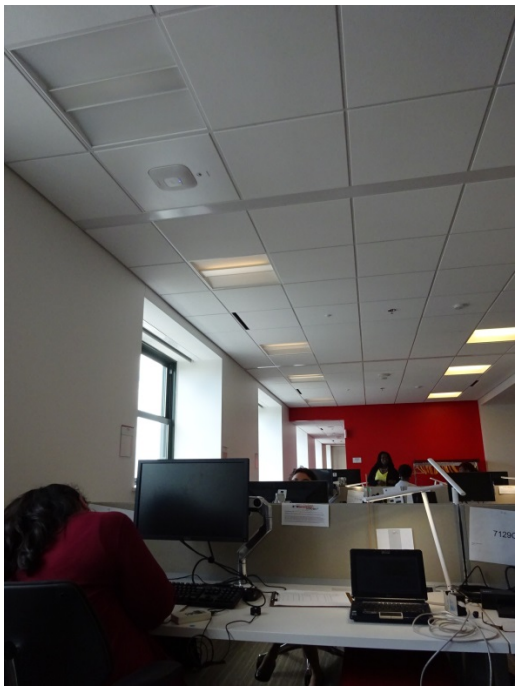
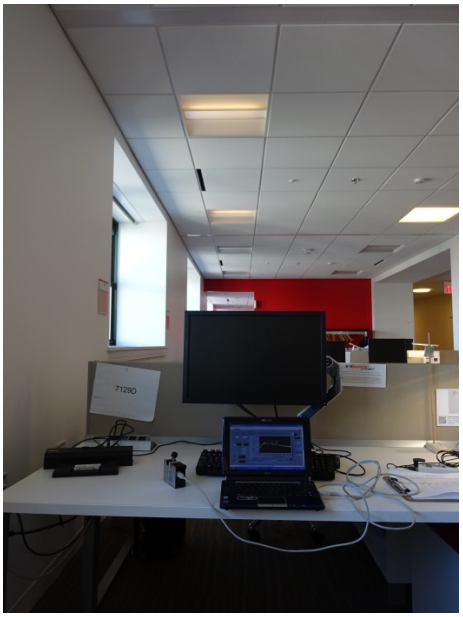


1:17 AM



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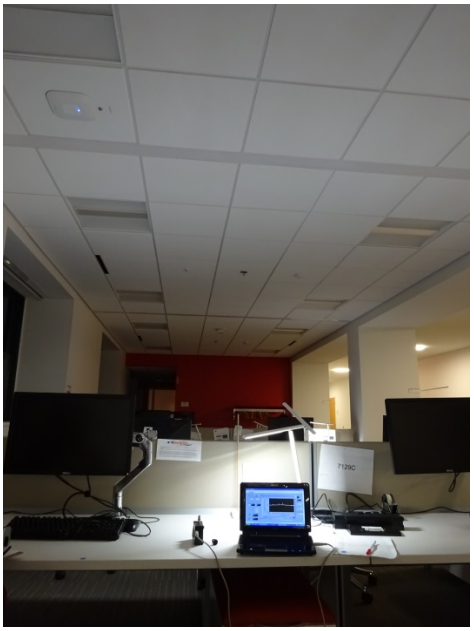
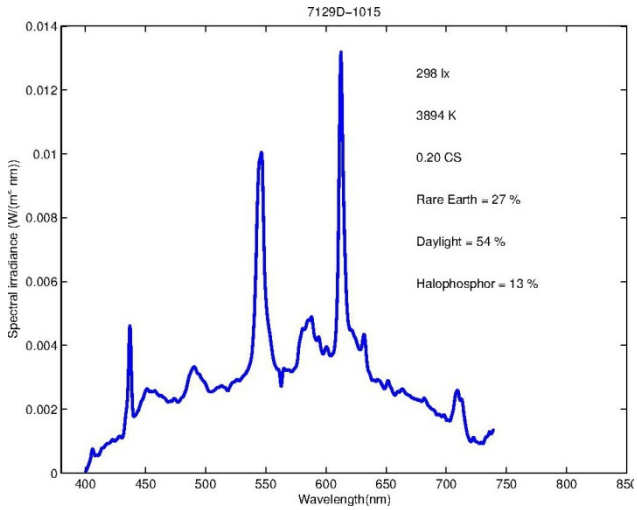


9:13 PM

WING 1 - FLOOR 7 - EAST - A

(SPECTRAL POWER DISTRIBUTION)



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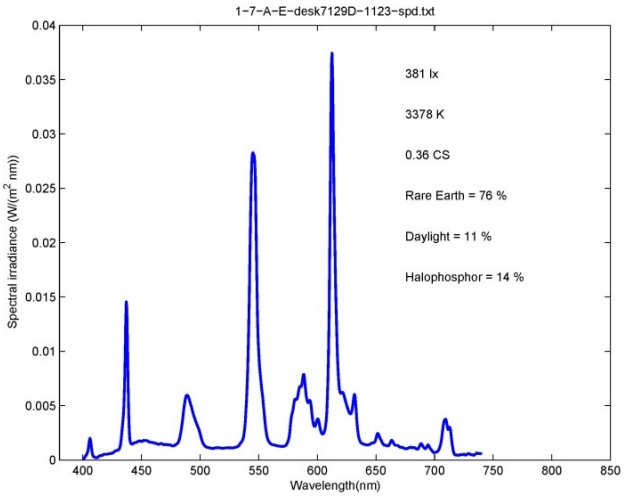

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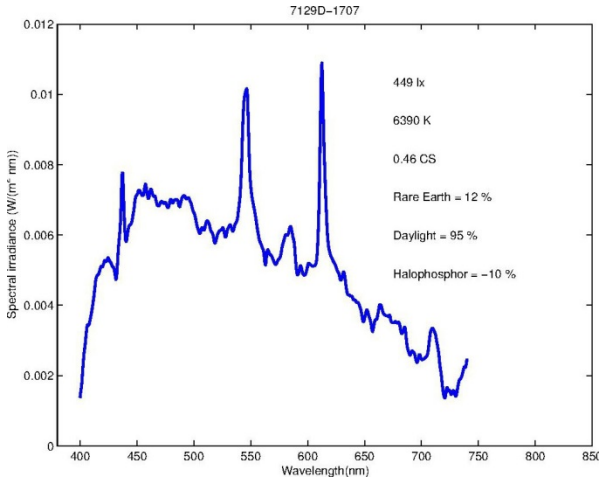

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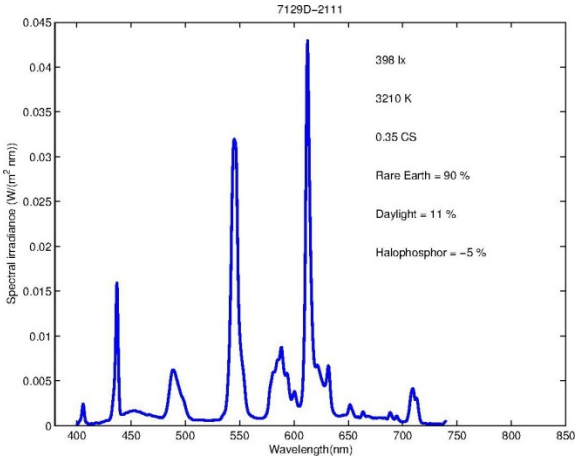
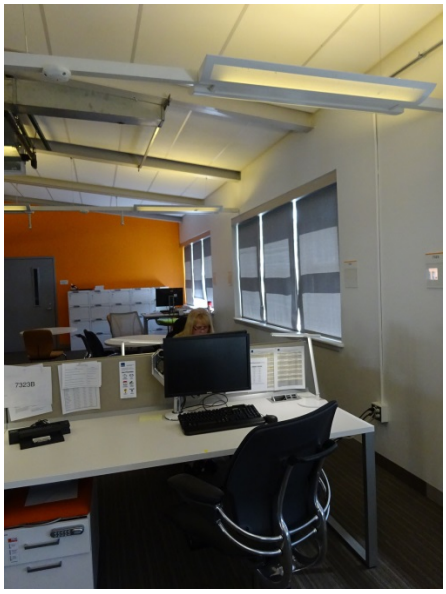


9:11 PM

WING 3 - FLOOR 7 - EAST - A



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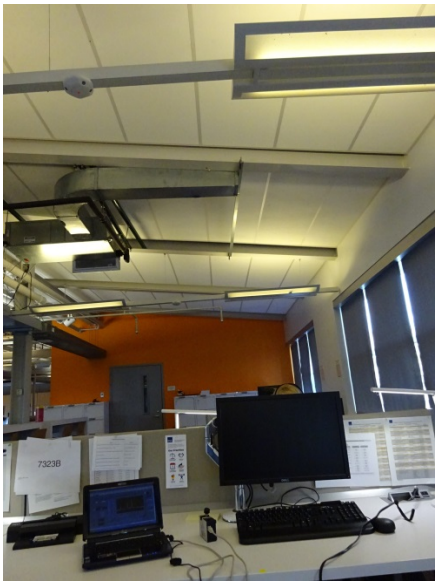

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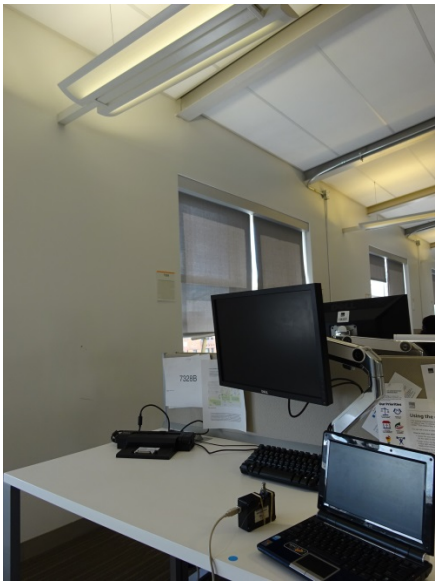
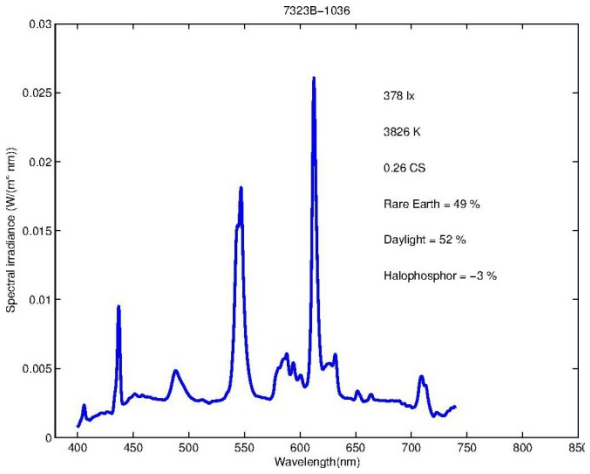


4:57 PM

WING 3 - FLOOR 7 - EAST - A

(SPECTRAL POWER DISTRIBUTION)



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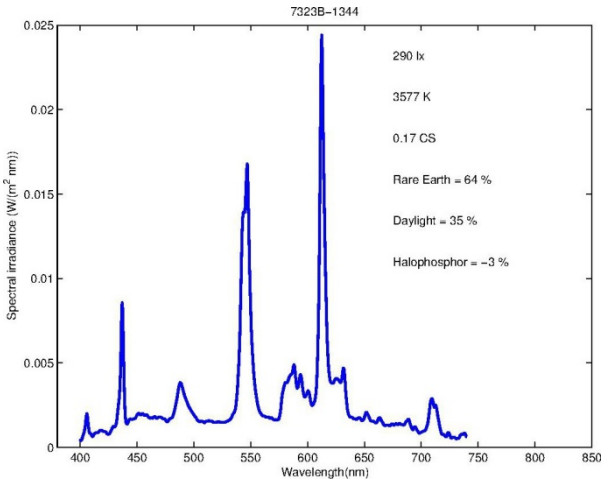

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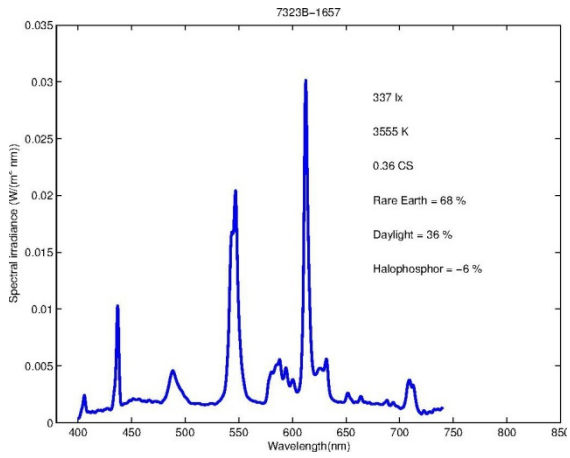

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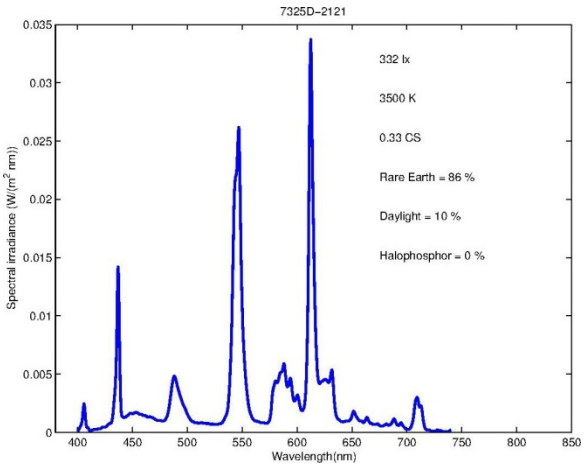
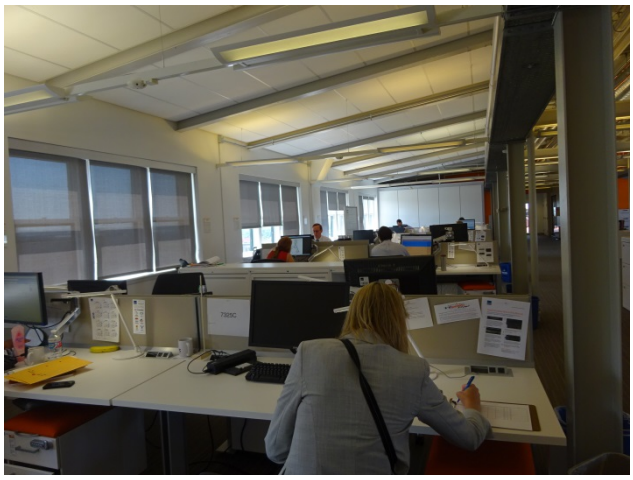


9:21 PM

WING 3 - FLOOR 7 - EAST - B



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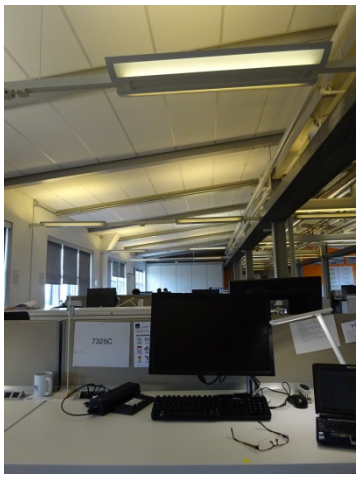

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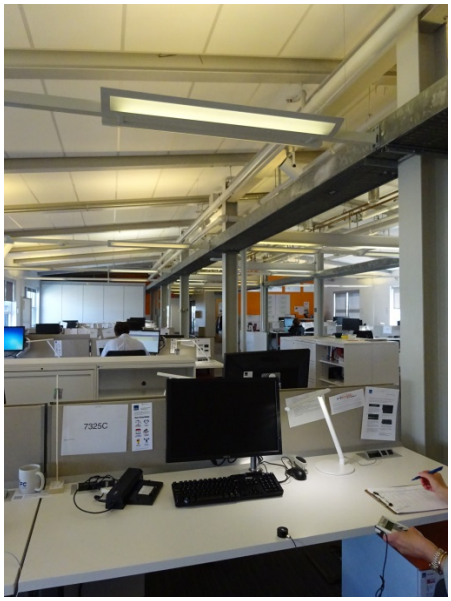

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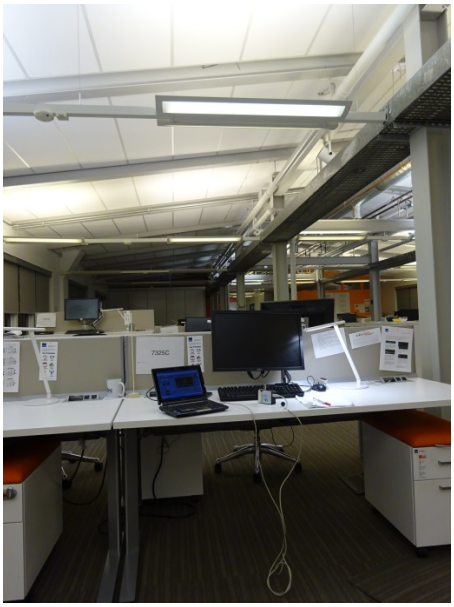

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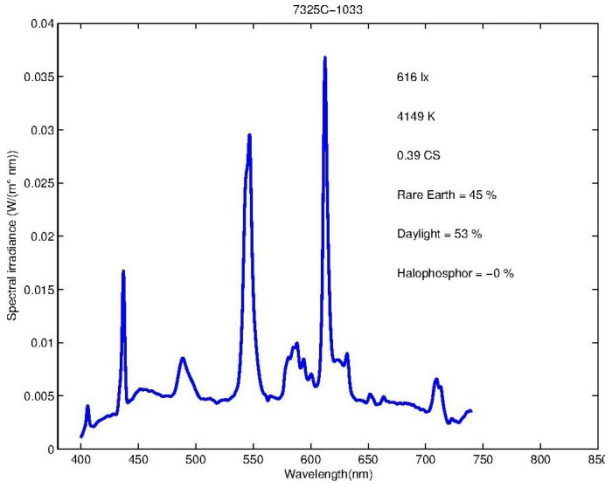
WING 3 - FLOOR 7 - EAST - B

(SPECTRAL POWER DISTRIBUTION)



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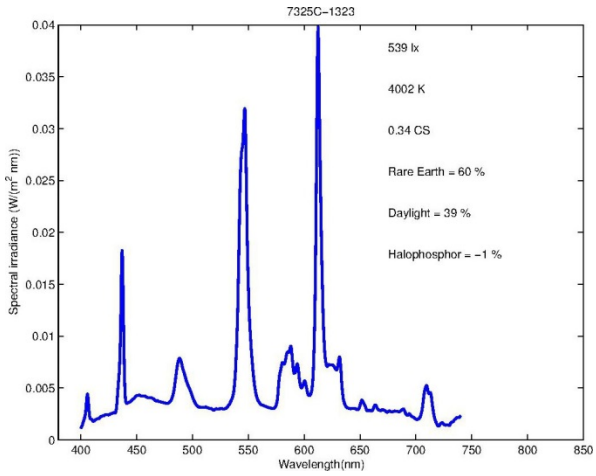

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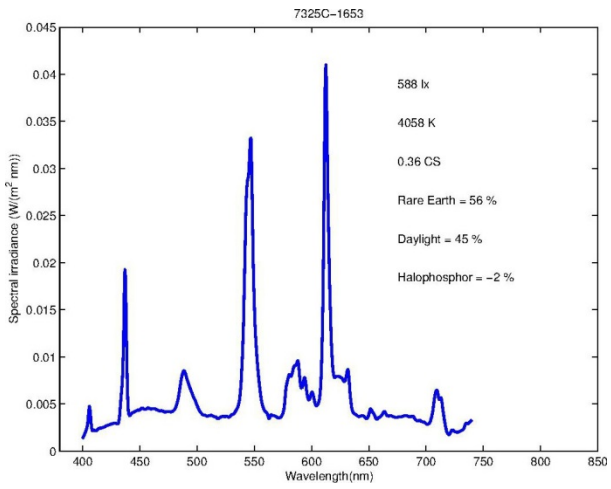

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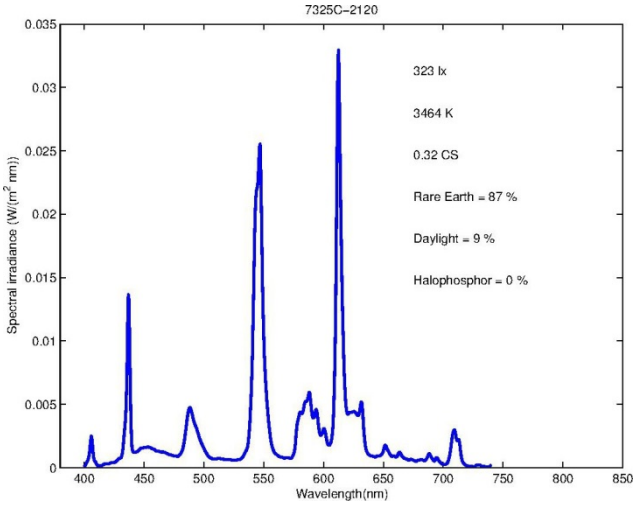
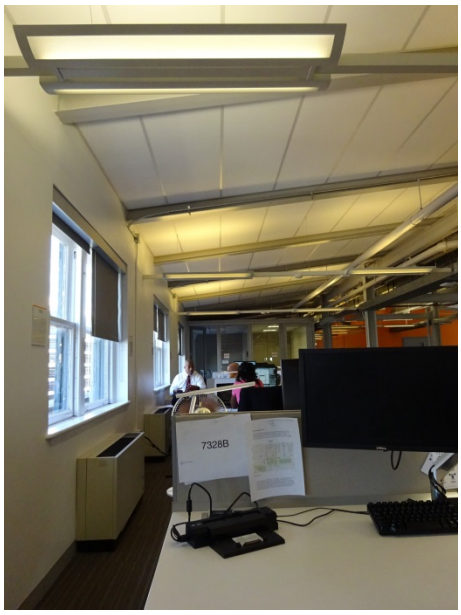


9:20 PM

WING 3 - FLOOR 7 - WEST - A



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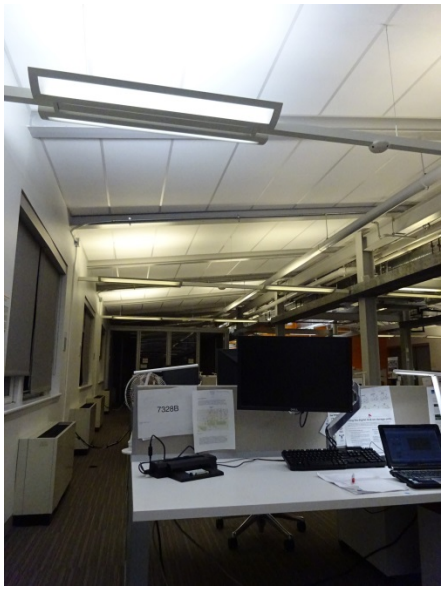
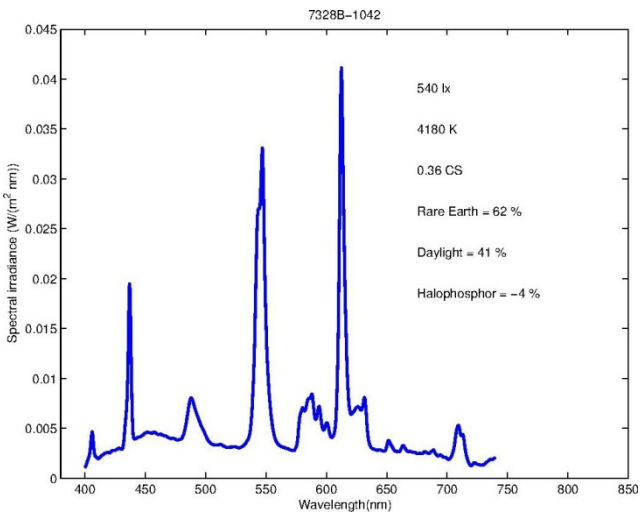


9:19 PM

WING 3 - FLOOR 7 - WEST - A

(SPECTRAL POWER DISTRIBUTION)



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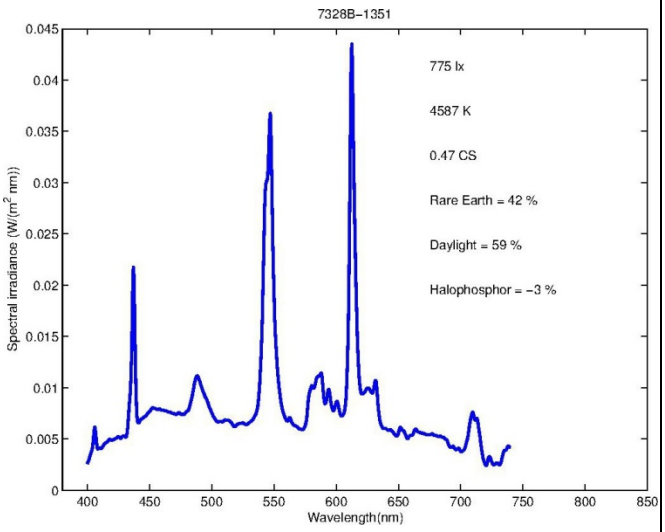

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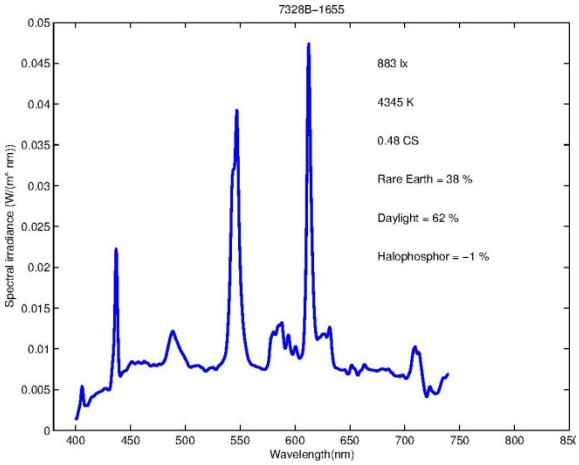

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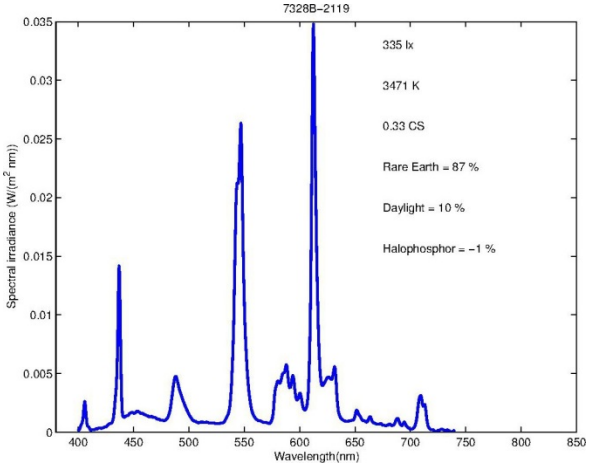
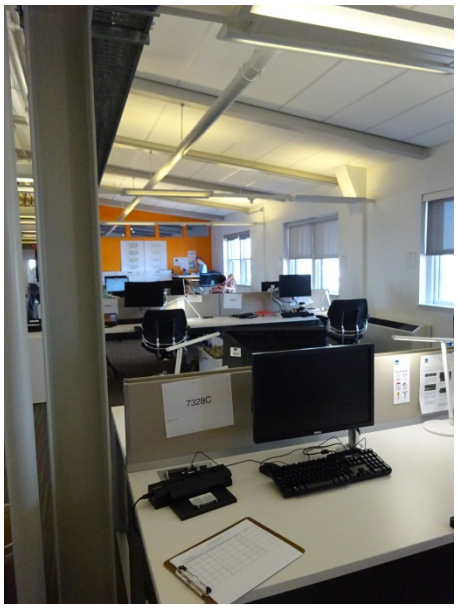


9:19 PM

WING 3 - FLOOR 7 - WEST - B



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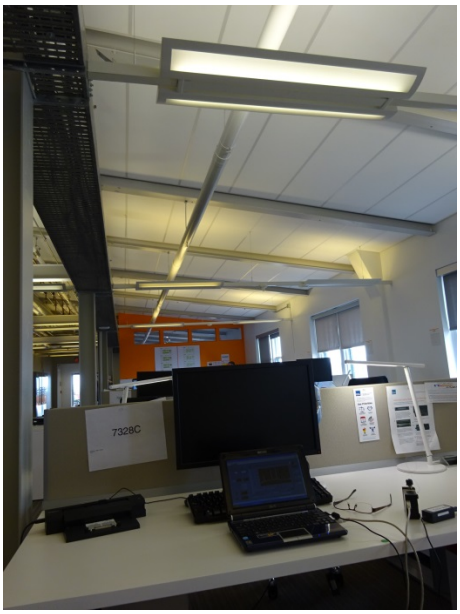

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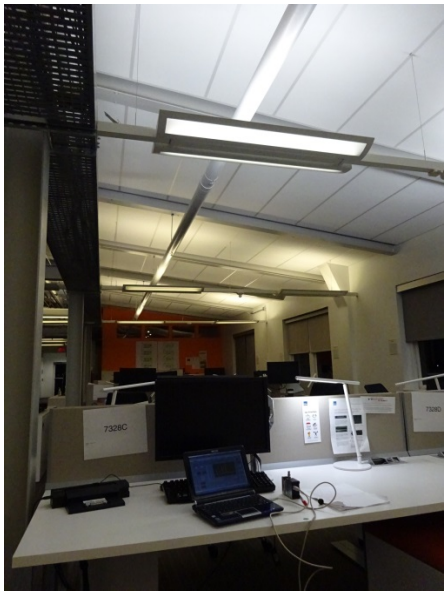
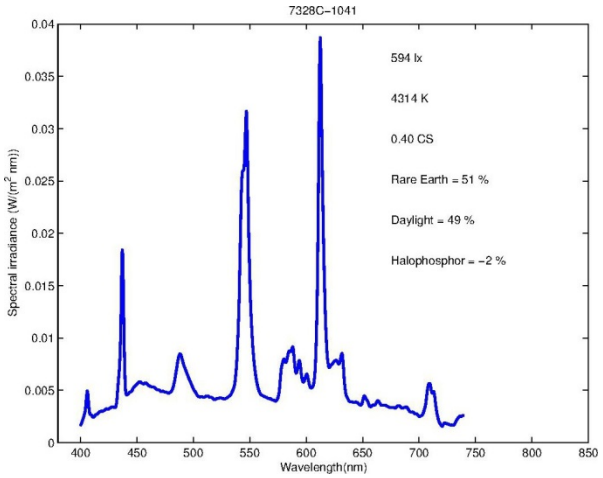
4:54 PM



9:17 PM

WING 3 - FLOOR 7 - WEST - B

(SPECTRAL POWER DISTRIBUTION)



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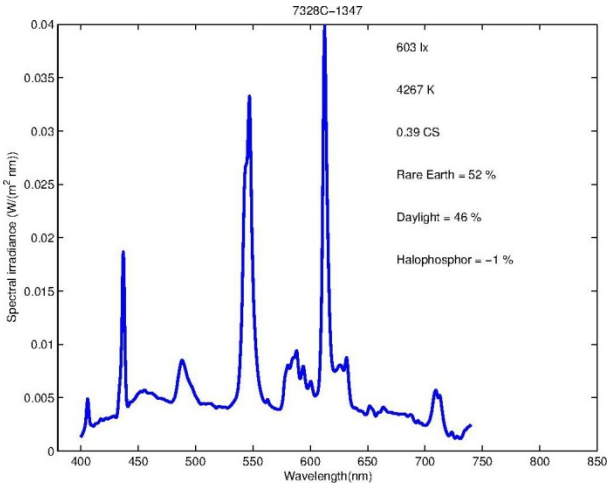

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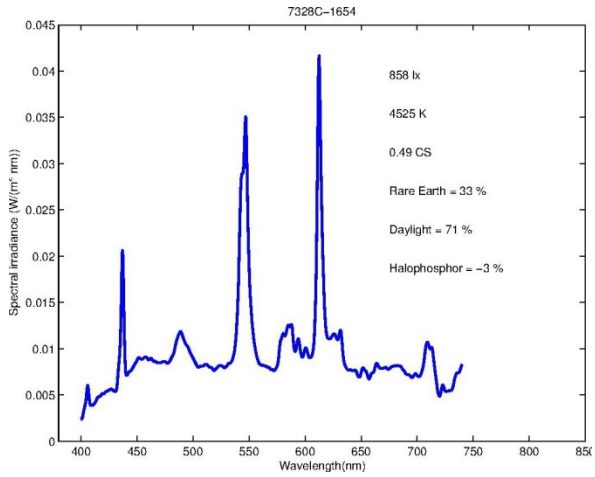

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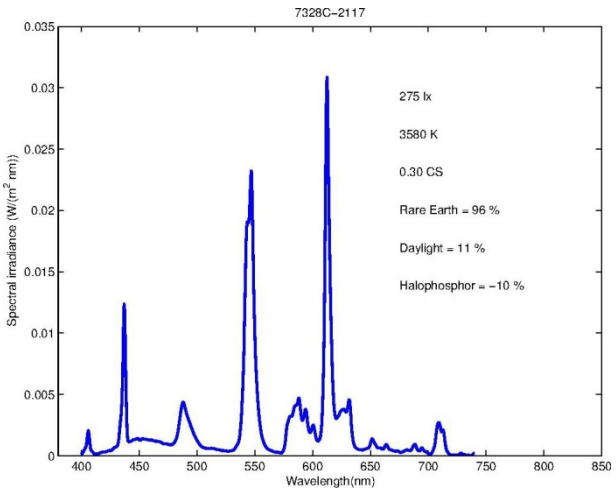


9:17 PM

APPENDIX F: SPECTRORADIOMETRY RESULTS TABLE

						Color Coordinates		Color Temp	Circadian Light	Circadian Stimulus (up to 0.7)	
Wing	**Floor**	**Row**	**Orientation**	**Time**	**Lux**	**CIEx**	**CIEy**	**CCT(K)**	**CLA**	**CS**	**Brightness**
0	G	A	N	9:27	731	0.397	0.401	3762	304	0.32	447
0	G	A	N	12:22	661	0.398	0.401	3746	270	0.30	403
0	G	A	N	16:05	579	0.397	0.401	3773	238	0.27	354
0	G	A	N	20:38	403	0.398	0.400	3734	158	0.20	246
0	G	A	S	9:33	2	0.415	0.406	3421	2	0.00	1
0	G	A	S	12:13	21	0.398	0.392	3683	10	0.01	13
0	G	A	S	16:10	43	0.384	0.385	3974	28	0.04	29
0	G	A	S	20:33	62	0.408	0.401	3520	64	0.09	37
0	G	B	N	9:29	837	0.405	0.411	3666	842	0.50	485
0	G	B	N	12:20	745	0.404	0.408	3661	762	0.49	438
0	G	B	N	16:03	817	0.398	0.402	3746	868	0.51	496
0	G	B	N	20:39	813	0.403	0.405	3660	832	0.50	482
0	G	B	S	9:34	22	0.388	0.389	3888	12	0.02	14
0	G	B	S	12:15	29	0.392	0.394	3821	14	0.02	18
0	G	B	S	16:09	41	0.390	0.389	3840	22	0.03	26
0	G	B	S	20:34	85	0.405	0.398	3567	90	0.13	51
3	G	A	E	9:54	425	0.394	0.388	3728	220	0.26	273
3	G	A	E	12:28	443	0.399	0.391	3649	214	0.25	279
3	G	A	E	16:16	451	0.399	0.391	3646	216	0.26	283
3	G	A	E	20:48	341	0.401	0.389	3571	160	0.20	214
3	G	B	E	9:51	498	0.402	0.387	3557	245	0.28	315
3	G	B	E	12:33	530	0.402	0.388	3559	258	0.29	334
3	G	B	E	16:14	685	0.391	0.384	3787	411	0.38	450
3	G	B	E	20:46	425	0.399	0.383	3581	222	0.26	275
3	G	B	W	9:46	739	0.358	0.373	4627	672	0.47	543
3	G	B	W	12:37	327	0.372	0.380	4259	236	0.27	228
3	G	B	W	16:20	233	0.368	0.374	4326	179	0.22	167
3	G	B	W	20:44	186	0.397	0.393	3711	85	0.12	116
3	G	A	W	9:44	344	0.386	0.381	3894	206	0.25	230
3	G	A	W	12:40	325	0.389	0.383	3820	184	0.23	214
3	G	A	W	16:23	320	0.391	0.383	3775	174	0.22	210
3	G	A	W	20:42	293	0.394	0.386	3729	148	0.19	189
2	2	A	E	10:05	1401	0.354	0.379	4805	1336	0.57	1016
2	2	A	E	12:50	706	0.361	0.380	4570	589	0.45	503
2	2	A	E	16:35	940	0.344	0.366	5078	1005	0.53	731
2	2	B	E	10:06	726	0.384	0.396	4050	431	0.39	465
2	2	B	E	12:55	576	0.392	0.396	3853	302	0.32	362
2	2	B	E	16:38	524	0.393	0.393	3810	275	0.30	333
2	2	B	E	20:58	64	0.413	0.399	3394	66	0.10	38

						Color Coordinates		Color Temp	Circadian Light	Circadian Stimulus (up to 0.7)	
Wing	**Floor**	**Row**	**Orientation**	**Time**	**Lux**	**CIEx**	**CIEy**	**CCT(K)**	**CLA**	**CS**	**Brightness**
0	7	A	N	10:23	131	0.339	0.349	5232	151	0.20	110
0	7	A	N	13:04	191	0.334	0.348	5429	227	0.26	162
0	7	A	N	16:48	174	0.324	0.340	5901	230	0.27	155
0	7	A	N	21:05	98	0.402	0.400	3645	104	0.14	59
0	7	A	S	10:25	233	0.355	0.363	4704	215	0.26	180
0	7	A	S	13:08	475	0.352	0.364	4809	464	0.40	366
0	7	A	S	16:43	224	0.367	0.376	4365	169	0.21	160
0	7	A	S	21:02	165	0.400	0.400	3680	178	0.22	100
0	7	B	N	10:21	135	0.351	0.362	4818	132	0.18	105
0	7	B	N	13:07	169	0.352	0.363	4809	166	0.21	131
0	7	B	N	16:47	107	0.338	0.352	5265	121	0.16	89
0	7	B	N	21:07	179	0.401	0.395	3636	73	0.10	110
0	7	B	S	10:27	195	0.374	0.378	4191	135	0.18	136
0	7	B	S	13:10	256	0.374	0.381	4195	176	0.22	177
0	7	B	S	16:44	207	0.379	0.386	4113	127	0.17	139
0	7	B	S	21:03	154	0.402	0.401	3659	163	0.21	93
1	7	A	E	10:15	298	0.390	0.396	3894	158	0.20	188
1	7	A	E	13:17	628	0.330	0.352	5597	774	0.49	529
1	7	A	E	17:07	449	0.314	0.335	6390	658	0.46	416
1	7	A	E	21:11	398	0.428	0.411	3210	358	0.35	217
3	7	A	E	10:36	378	0.390	0.385	3826	222	0.26	249
3	7	A	E	13:44	290	0.403	0.395	3577	126	0.17	179
3	7	A	E	16:57	337	0.406	0.399	3555	372	0.36	204
3	7	A	E	21:21	332	0.412	0.408	3500	319	0.33	191
3	7	A	W	10:42	540	0.374	0.378	4180	377	0.36	378
3	7	A	W	13:51	775	0.359	0.369	4587	692	0.47	579
3	7	A	W	16:55	883	0.368	0.377	4345	701	0.48	626
3	7	A	W	21:19	335	0.413	0.407	3471	320	0.33	192
3	7	B	E	10:33	616	0.376	0.380	4149	434	0.39	426
3	7	B	E	13:23	539	0.382	0.384	4002	331	0.34	362
3	7	B	E	16:53	588	0.380	0.384	4058	376	0.36	397
3	7	B	E	21:20	323	0.414	0.409	3464	306	0.32	184
3	7	B	W	10:41	594	0.369	0.375	4314	452	0.40	424
3	7	B	W	13:47	603	0.372	0.379	4267	433	0.39	422
3	7	B	W	16:54	858	0.361	0.370	4525	763	0.49	634
3	7	B	W	21:17	275	0.407	0.405	3580	274	0.30	162

AVERAGE SPECTRORADIOMETRY RESULTS

The following table shows average results during the daytime measurements (excluding evening measurements, since workers are not present after dark).

	Illuminance	Color Temp.	Circadian Light		Circadian Stimulus (up to 0.7)		
Deskspace Locations	Lux	CCT (K)	Average CL_A	Median CL_A	Average CS	Median CS	Brightness
A	447	4324	351	224	0.294	0.263	316
B	452	4117	340	275	0.295	0.301	301
Orientation							
E	573	4149	426	331	0.348	0.336	395
N	440	4484	359	234	0.306	0.271	281
S	146	4084	114	77	0.130	0.105	105
W	545	4243	422	405	0.353	0.374	388
Floor							
G	410	3817	275	218	0.245	0.258	260
2	812	4361	656	510	0.425	0.416	568
7	403	4559	340	230	0.309	0.268	293

UNCERTAINTY OF SPECTRORADIOMETRIC MEASUREMENTS

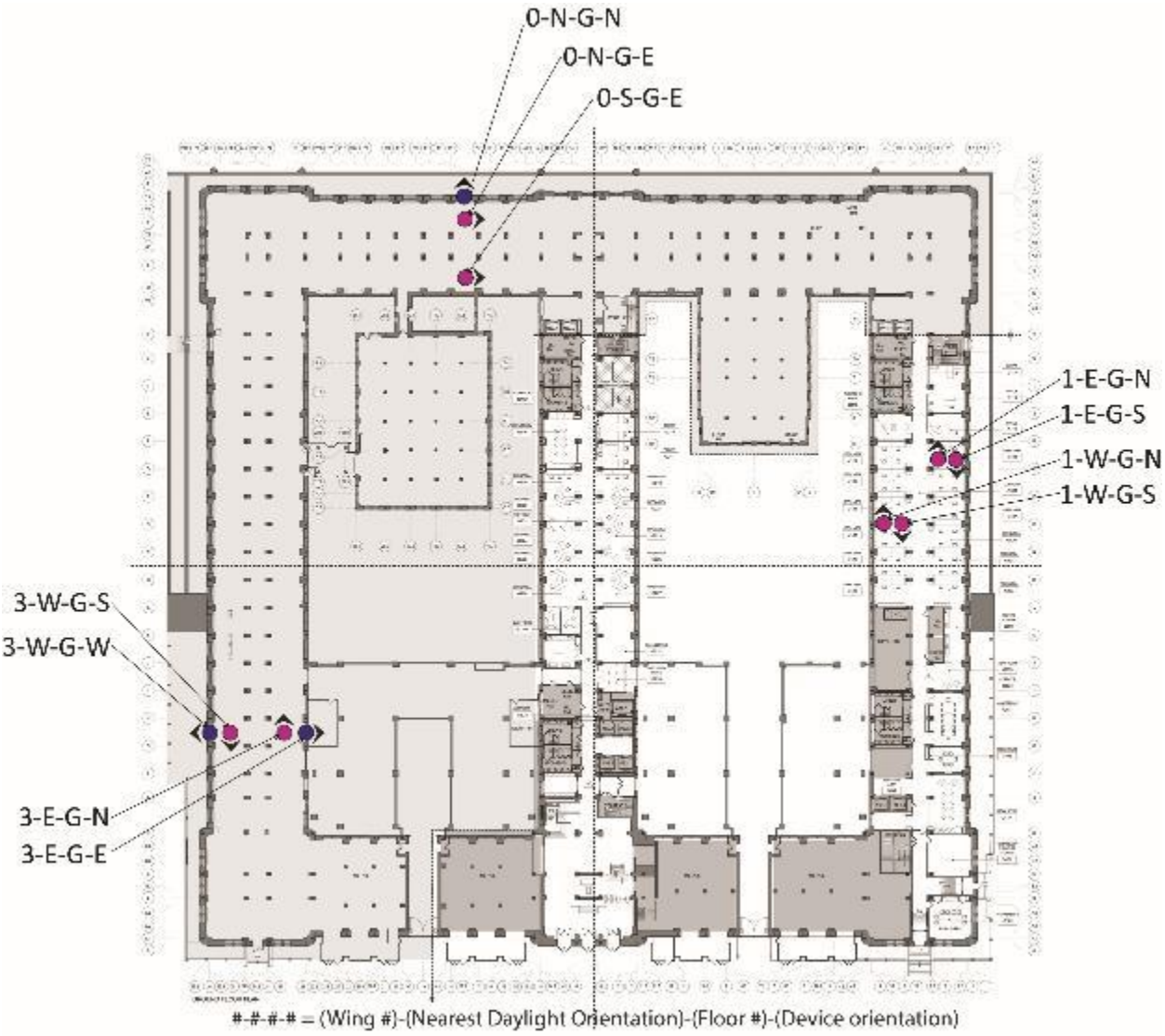
There are three main types of measurement uncertainty associated with the spectrometer used for the spectral measurements: 1) accuracy of the spectral calibration and maintaining it over time, 2) thermal noise due to the nature of the CCD detector employed in the device, and 3) a spatial response that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

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

APPENDIX G: PHOTOMETRIC DATA FOR GROUND FLOOR STATIONARY DEVICES

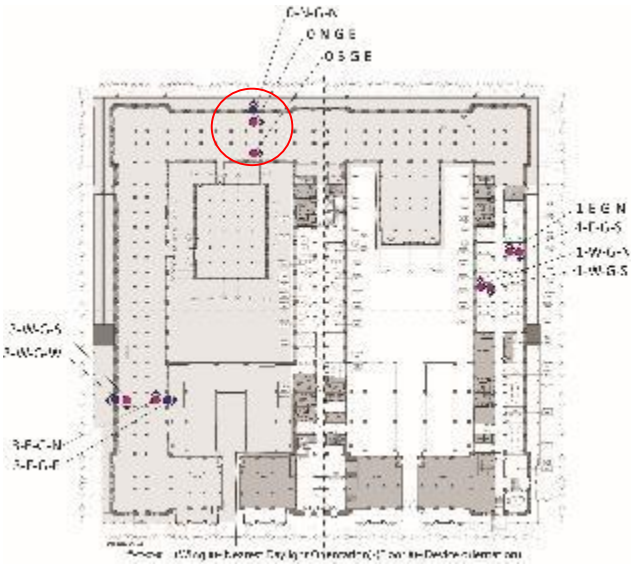
Mounted on sticks and in windows

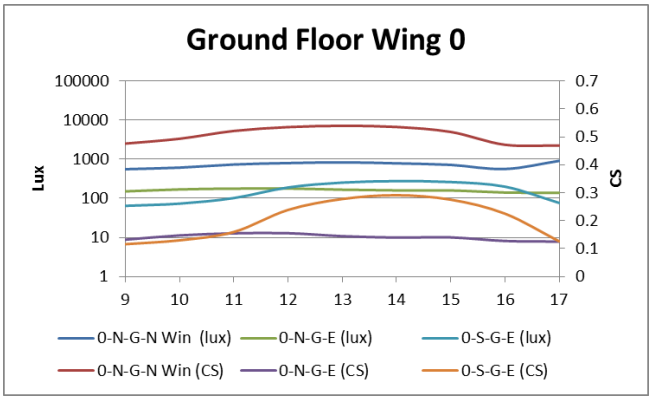
Cropped to June 15th, 2015 – July 12th, 2015 (excluding holiday, July 3, 2015)



Location where measurements were collected.

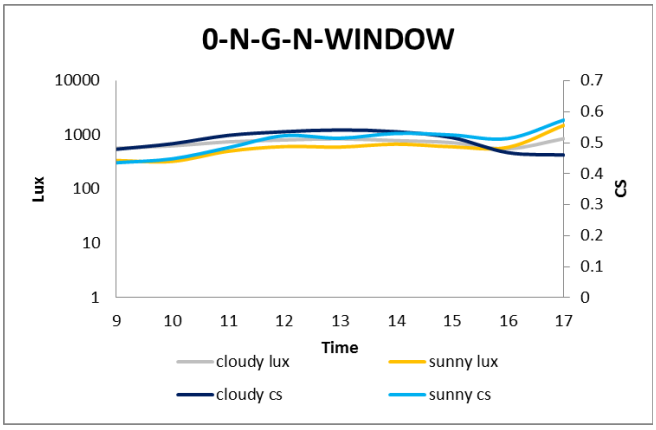
GROUND FLOOR WING 0



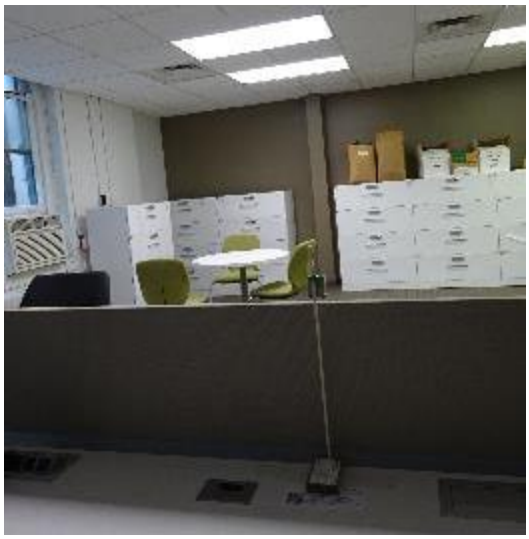


Average Lux and CS

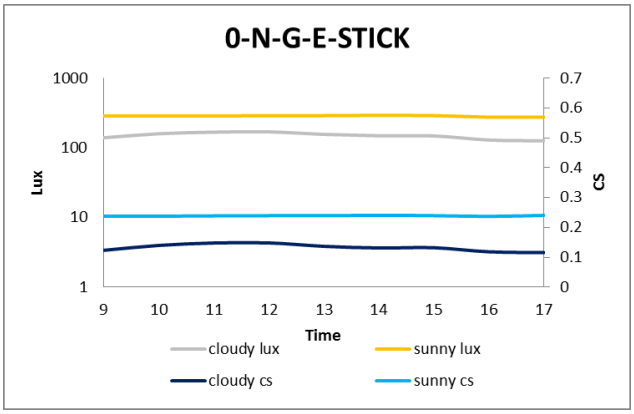
0-N-G-N-Window



Daysimeter 027 – O-N-G-N-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 728 ± 115 lux on cloudy days. The mean CS value on was 0.51 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 642 ± 349 lux. The mean CS value on was 0.51 ± 0.04 on sunny days.

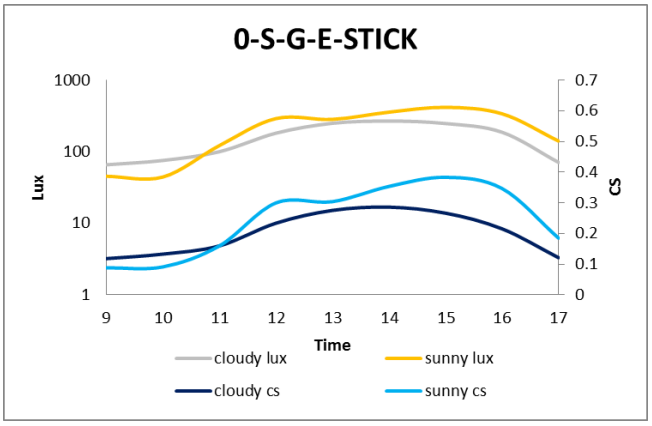


0-N-G-E-Stick



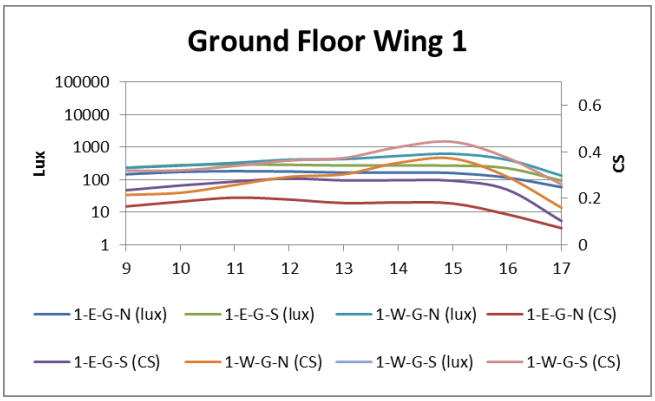
Daysimeter 086 – O-N-G-E-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 150 ± 15 lux on cloudy days. The mean CS value on was 0.13 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 286 ± 6 lux. The mean CS value on was 0.24 ± 0.001 on sunny days.

0-S-G-E-Stick

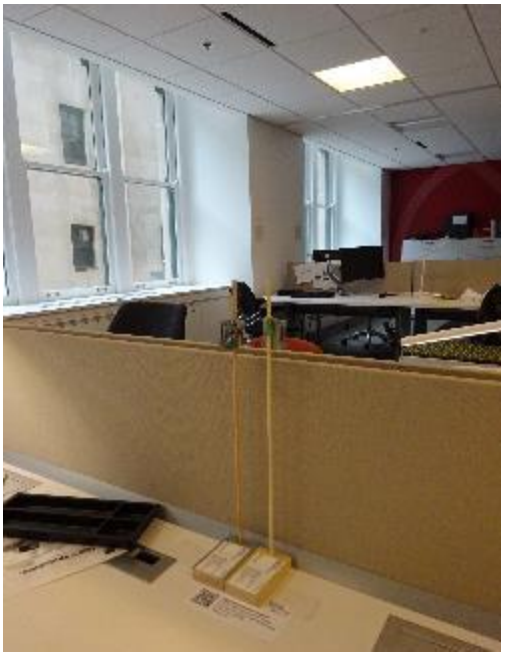


Daysimeter 225 – 0-S-G-E-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 161 ± 84 lux on cloudy days. The mean CS value on was 0.20 ± 0.07 on cloudy days. On sunny days mean photopic light level during working hours was 227 ± 141 lux. The mean CS value on was 0.25 ± 0.12 on sunny days.

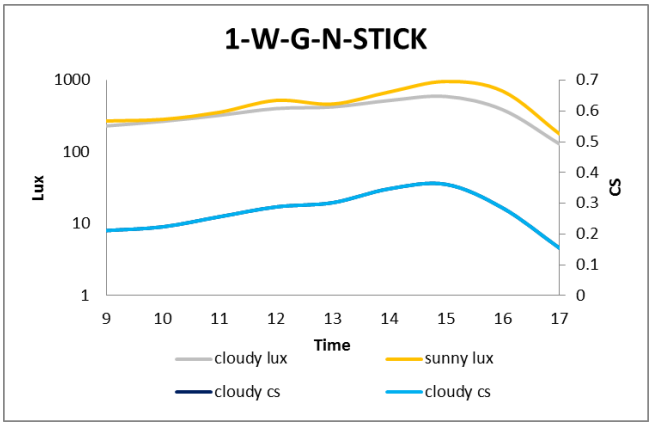
GROUND FLOOR WING 1



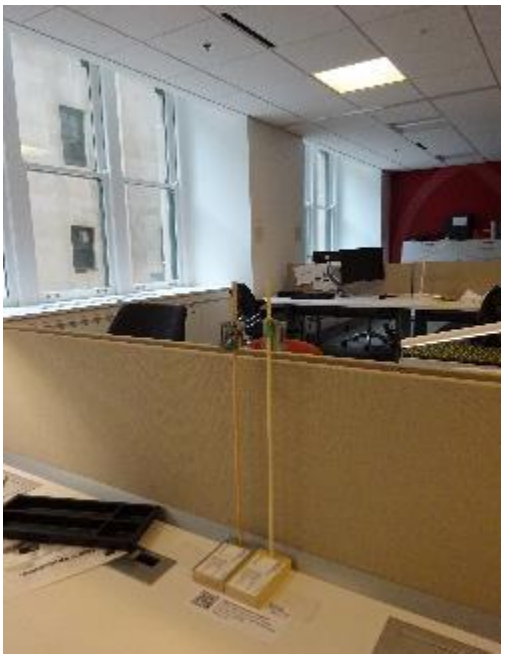
Average Lux and CS



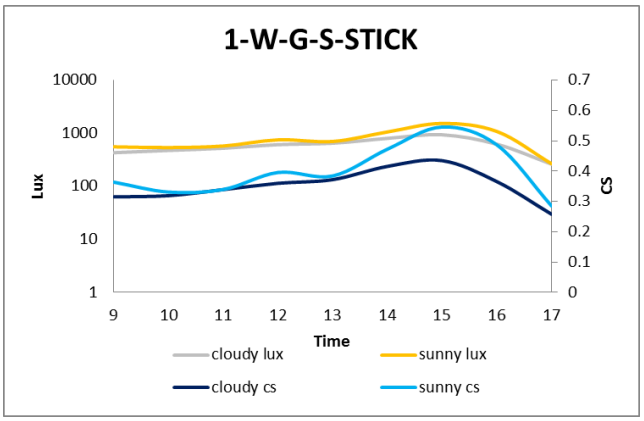
1-W-G-N



Daysimeter 211 – 1-W-G-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 366 ± 145 lux on cloudy days. The mean CS value on was 0.27 ± 0.07 on cloudy days. On sunny days mean photopic light level during working hours was 495 ± 254 lux. The mean CS value on was 0.33 ± 0.09 on sunny days.

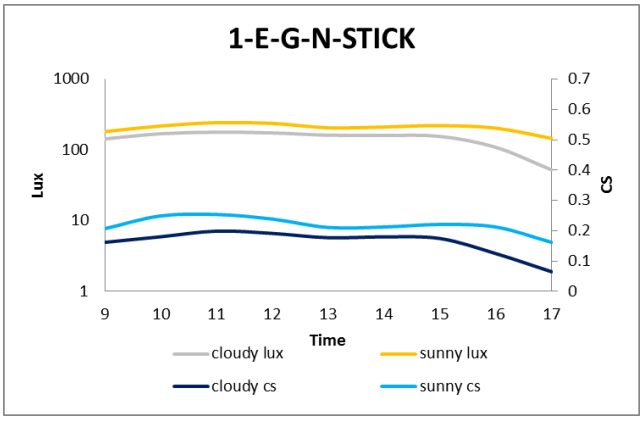


1-W-G-S



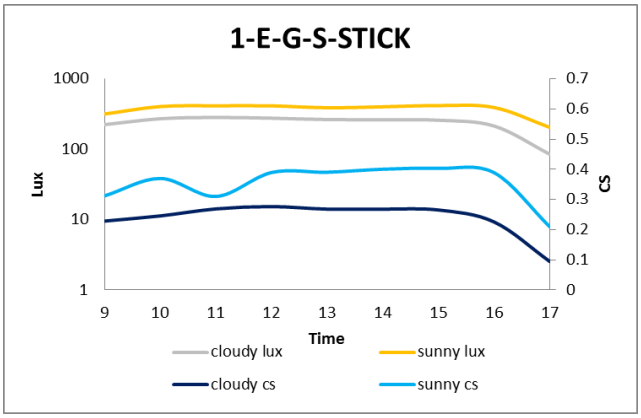
Daysimeter 216 – 1-W-G-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 590 ± 201 lux on cloudy days. The mean CS value on was 0.35 ± 0.05 on cloudy days. On sunny days mean photopic light level during working hours was 786 ± 382 lux. The mean CS value on was 0.40 ± 0.08 on sunny days.

1-E-G-N



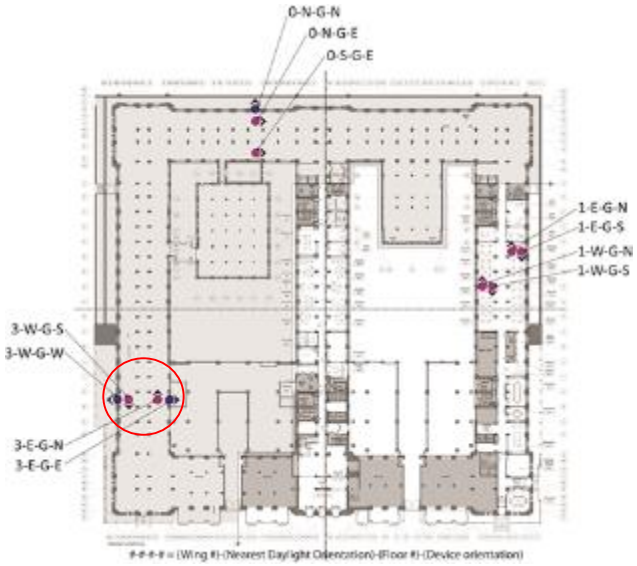
Daysimeter 220 – 1-E-G-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 145 ± 41 lux on cloudy days. The mean CS value on was 0.16 ± 0.04 on cloudy days. On sunny days mean photopic light level during working hours was 208 ± 30 lux. The mean CS value on was 0.22 ± 0.03 on sunny days.

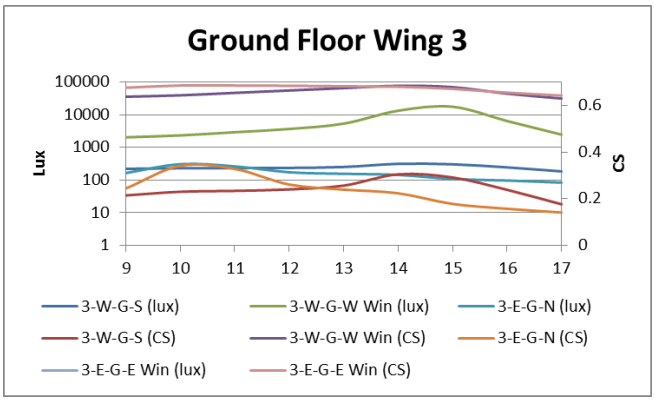
1-E-G-S



Daysimeter 223 – 1-E-G-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 238 ± 62 lux on cloudy days. The mean CS value on was 0.24 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 373 ± 70 lux. The mean CS value on was 0.35 ± 0.06 on sunny days.

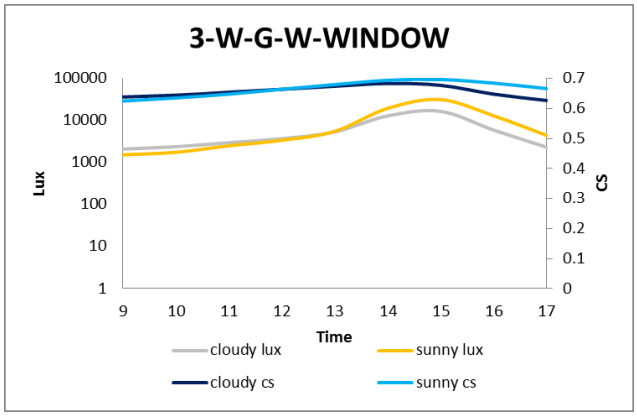
GROUND FLOOR WING 3





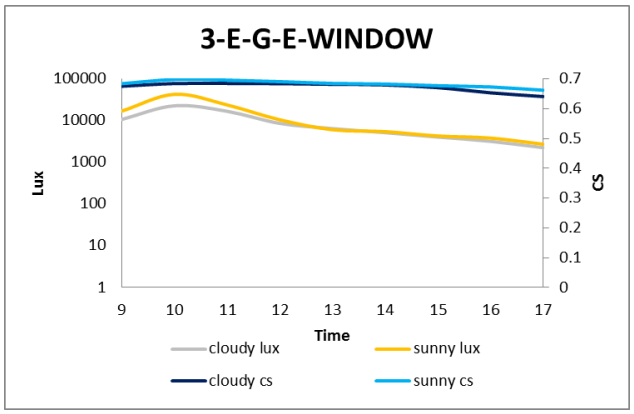
Average Lux and CS

3-W-G-W-Window



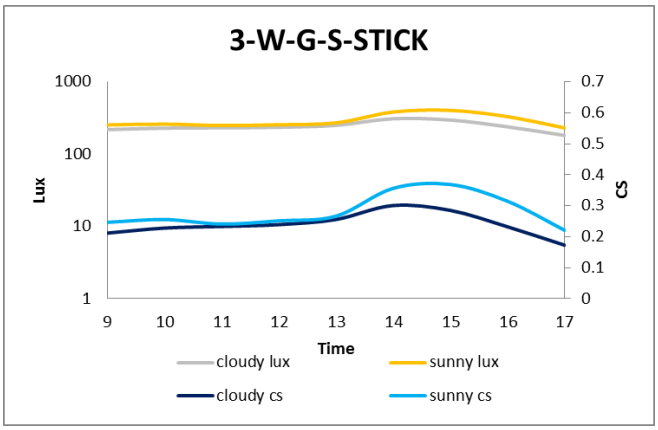
Daysimeter 106 – 3-W-G-W-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 6027 ± 5197 lux on cloudy days. The mean CS value on was 0.66 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 9248 ± 10322 lux. The mean CS value on was 0.67 ± 0.03 on sunny days.

3-E-G-E-Window

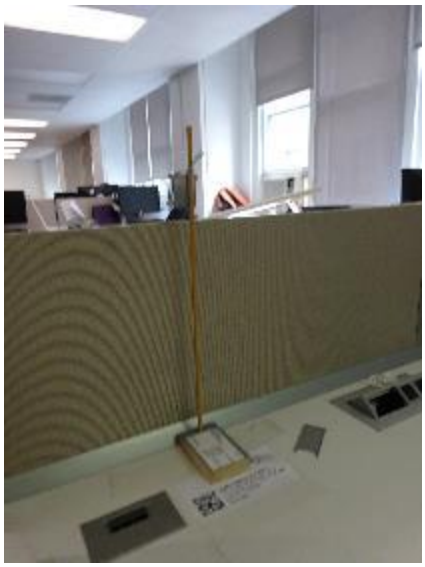


Daysimeter 113 – 3-E-G-E-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 8898 ± 6884 lux on cloudy days. The mean CS value on was 0.67 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 12975 ± 13271 lux. The mean CS value on was 0.68 ± 0.01 on sunny days.

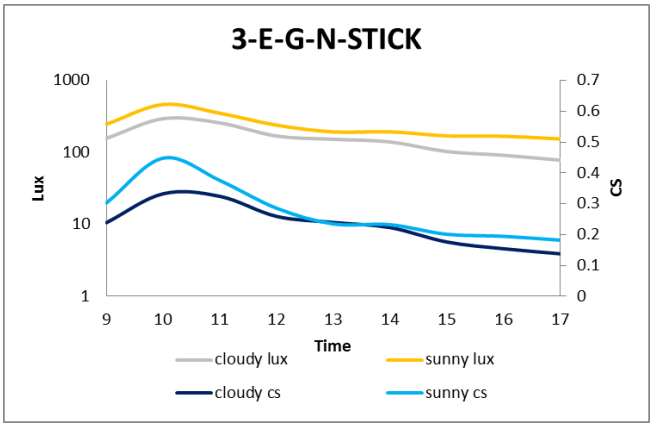
3-W-G-S-Stick



Daysimeter 234 – 3-W-G-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 244 ± 39 lux on cloudy days. The mean CS value on was 0.24 ± 0.04 on cloudy days. On sunny days mean photopic light level during working hours was 293 ± 63 lux. The mean CS value on was 0.28 ± 0.05 on sunny days.



3-E-G-N-Stick

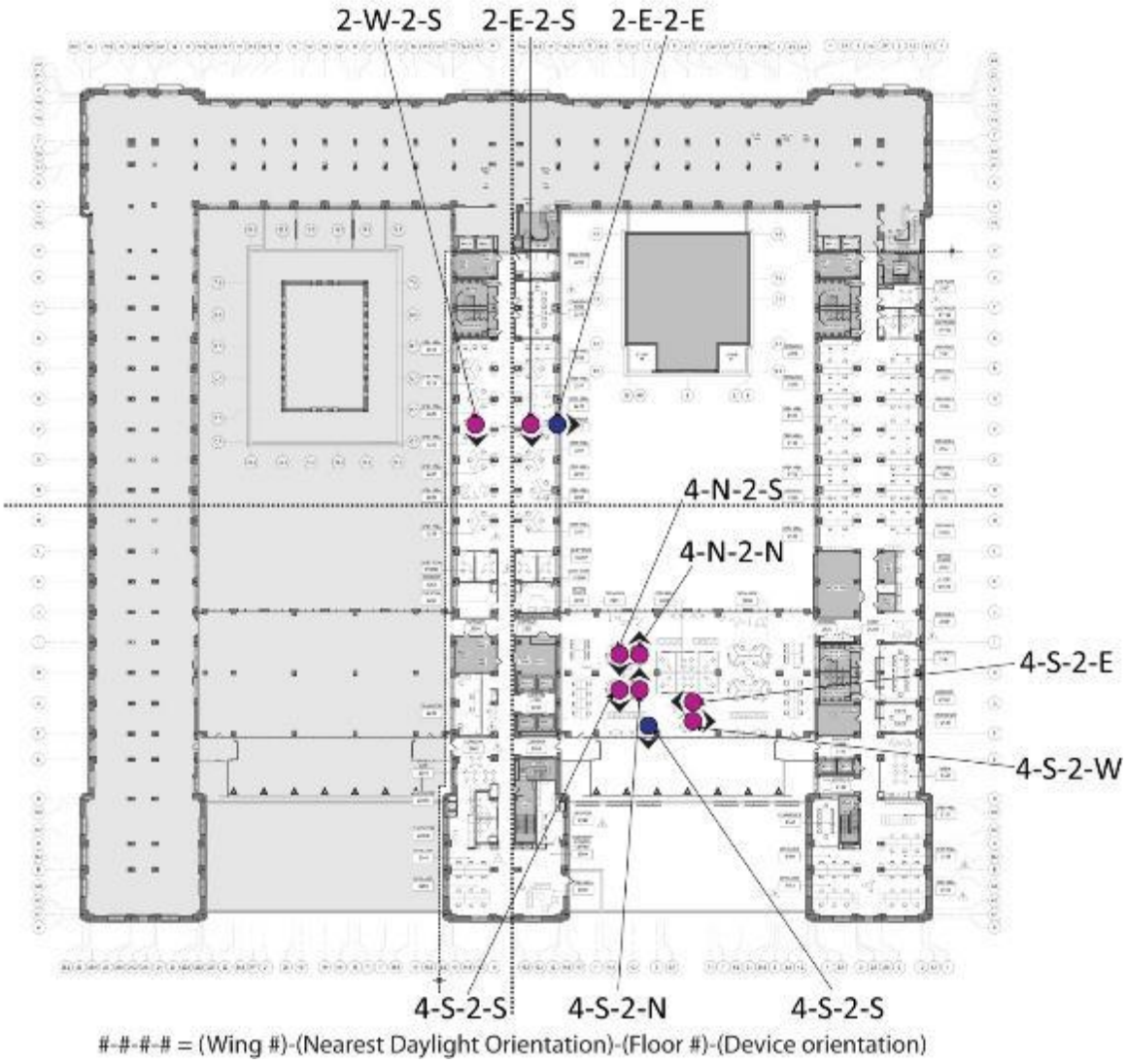


Daysimeter 226 – 3-E-G-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 160 ± 73 lux on cloudy days. The mean CS value on was 0.23 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 242 ± 103 lux. The mean CS value on was 0.27 ± 0.09 on sunny days.

APPENDIX H: PHOTOMETRIC DATA FOR 2ND FLOOR STATIONARY DEVICES

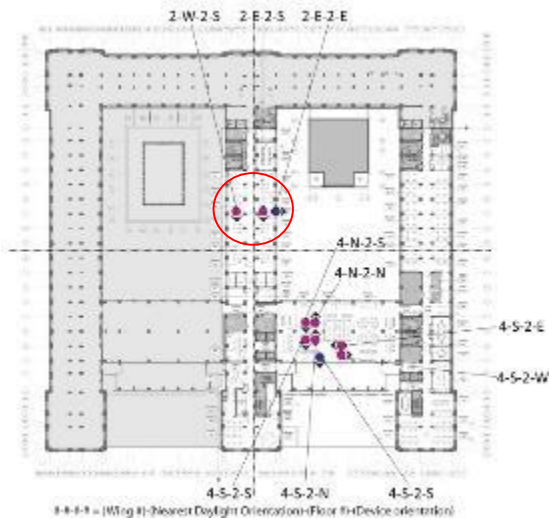
Mounted on sticks and in windows

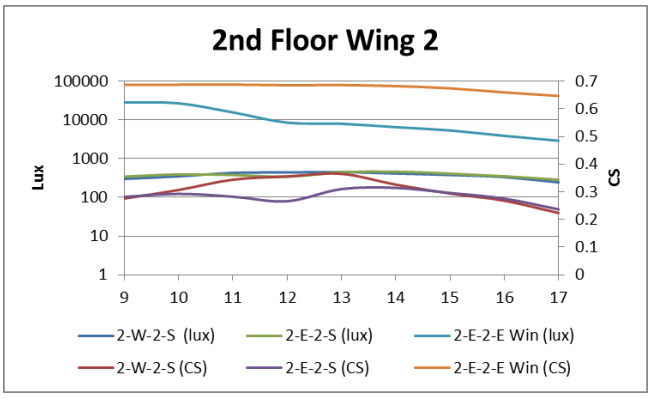
Cropped to June 15th, 2015 – July 12th, 2015 (Excluding holiday, July 3, 2015)



Location where measurements were collected.

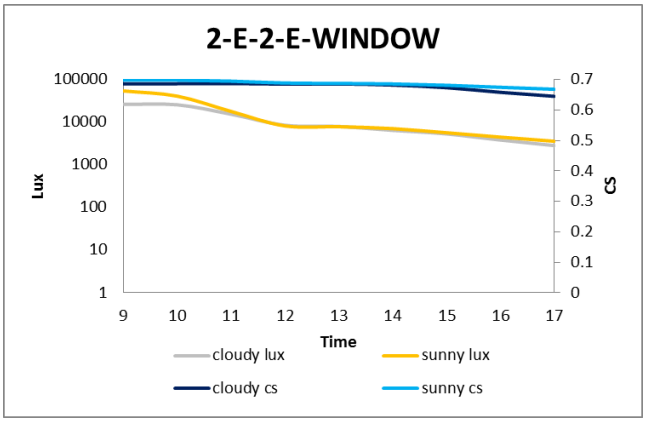
2ND FLOOR WING 2



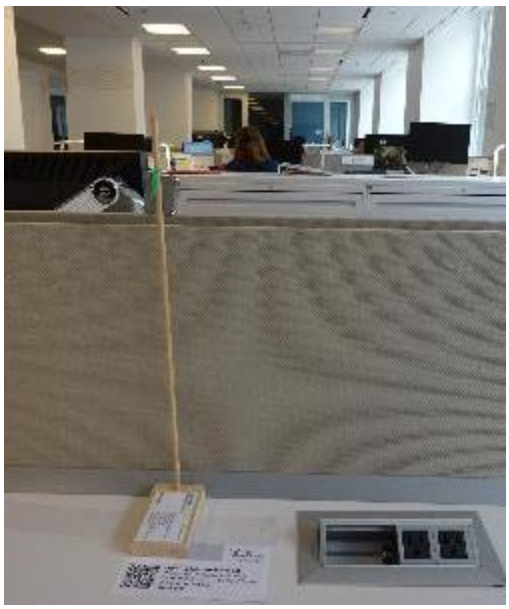


Average Lux and CS

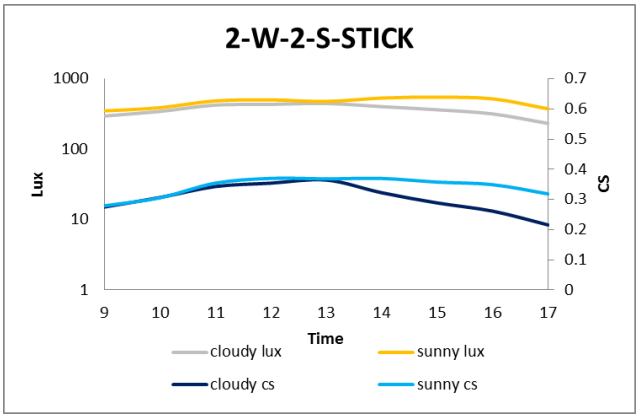
2-E-2-E-Window



Daysimeter 018 – 2-E-2-E-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 11380 ± 9044 lux on cloudy days. The mean CS value on was 0.68 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 16694 ± 18354 lux. The mean CS value on was 0.69 ± 0.01 on sunny days.

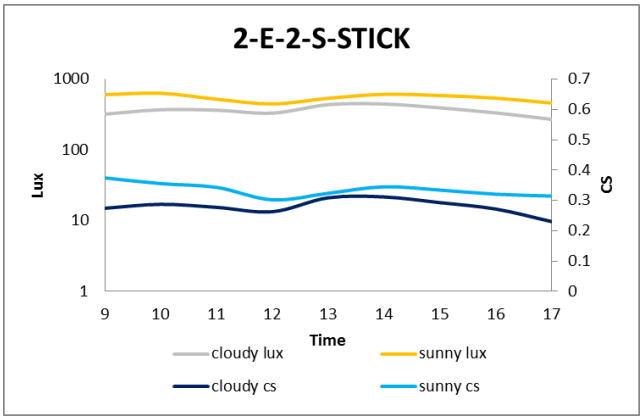


2-W-2-S



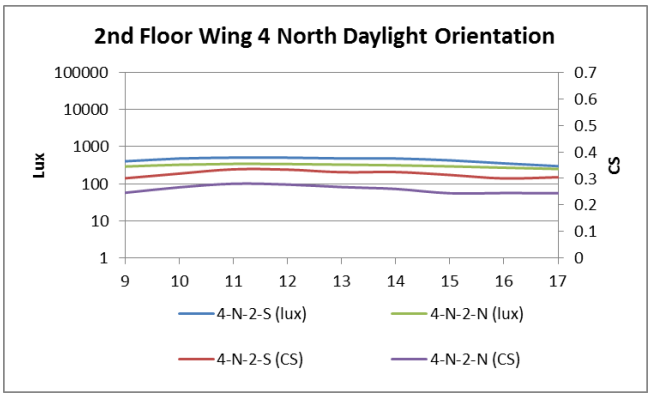
Daysimeter 218 – 2-W-2-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 363 ± 72 lux on cloudy days. The mean CS value on was 0.30 ± 0.05 on cloudy days. On sunny days mean photopic light level during working hours was 465 ± 74 lux. The mean CS value on was 0.34 ± 0.03 on sunny days.

2-E-2-S-Stick



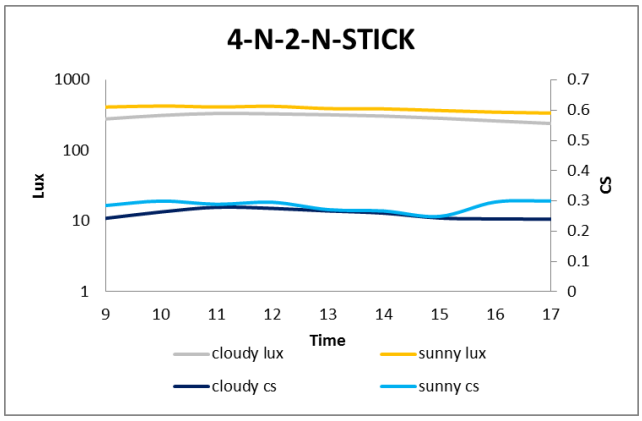
Daysimeter 251 – 2-E-2-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 364 ± 57 lux on cloudy days. The mean CS value on was 0.28 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 550 ± 66 lux. The mean CS value on was 0.33 ± 0.02 on sunny days.

2ND FLOOR WING 4



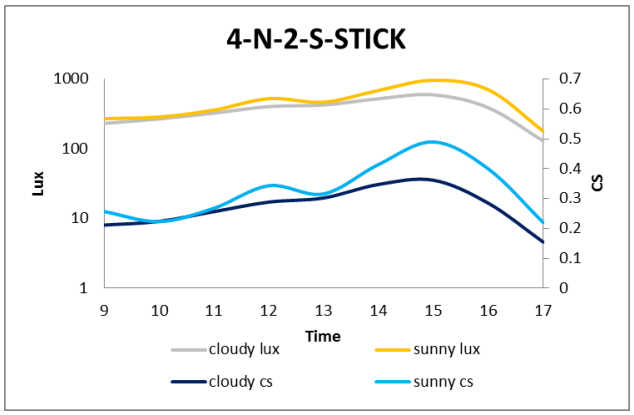
Average Lux and CS

4-N-2-N-Stick

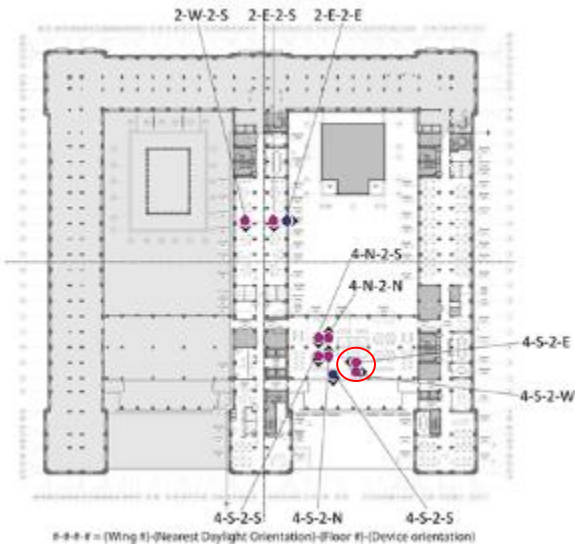


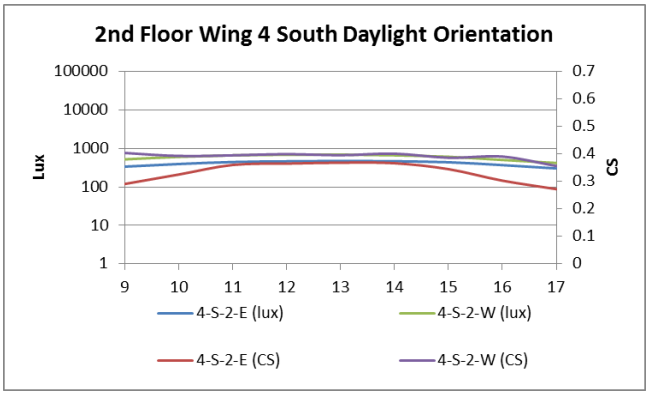
Daysimeter 166 – 4-N-2-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 299 ± 32 lux on cloudy days. The mean CS value on was 0.26 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 392 ± 32 lux. The mean CS value on was 0.28 ± 0.02 on sunny days.

4-N-2-S-Stick



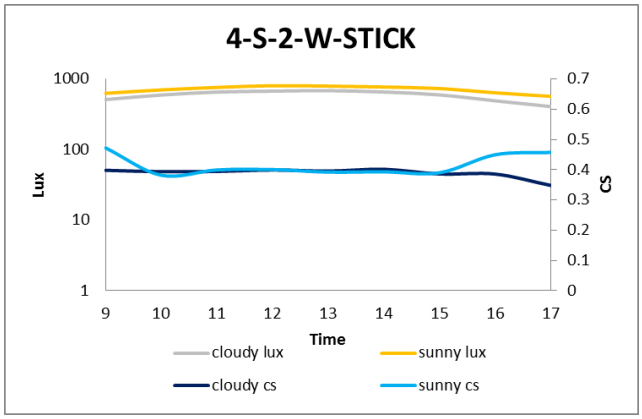
Daysimeter 221 – 4-N-2-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 366 ± 145 lux on cloudy days. The mean CS value on was 0.27 ± 0.07 on cloudy days. On sunny days mean photopic light level during working hours was 495 ± 254 lux. The mean CS value on was 0.33 ± 0.09 on sunny days.





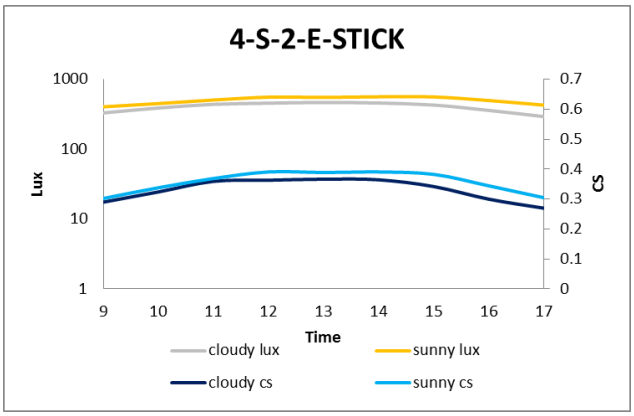
Average Lux and CS

4-S-2-W

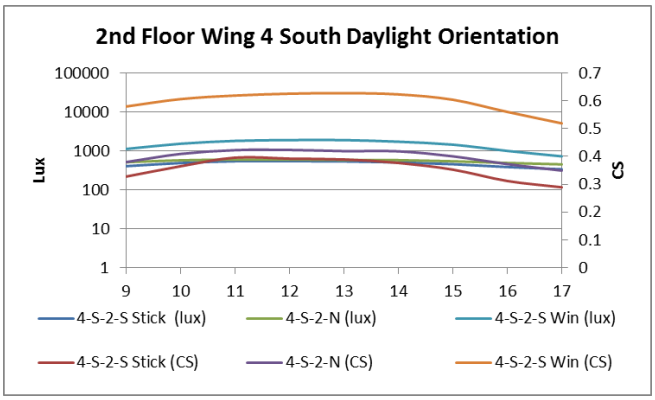


Daysimeter 224 – 4-S-2-W-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 586 ± 96 lux on cloudy days. The mean CS value on was 0.39 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 712 ± 83 lux. The mean CS value on was 0.42 ± 0.03 on sunny days.

4-S-2-E

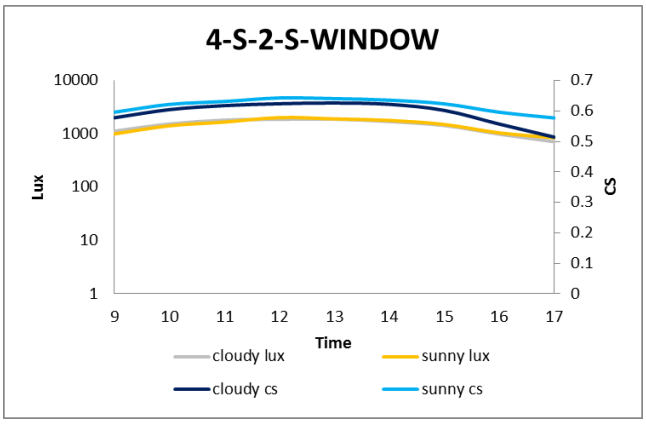


Daysimeter 219 – 4-S-2-E-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 402 ± 62 lux on cloudy days. The mean CS value on was 0.33 ± 0.04 on cloudy days. On sunny days mean photopic light level during working hours was 502 ± 61 lux. The mean CS value on was 0.36 ± 0.04 on sunny days.



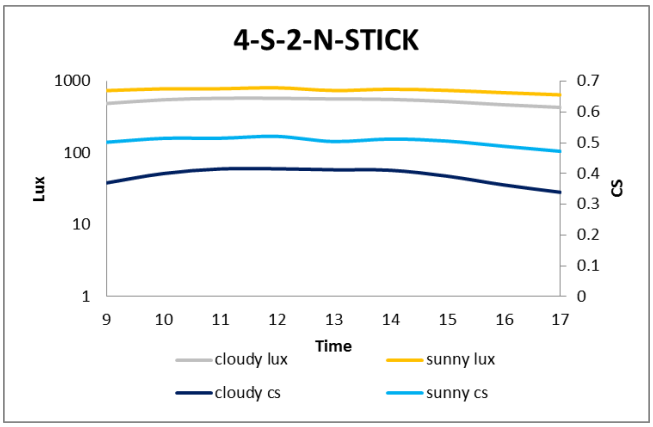
Average Lux and CS

4-S-2-S-Window



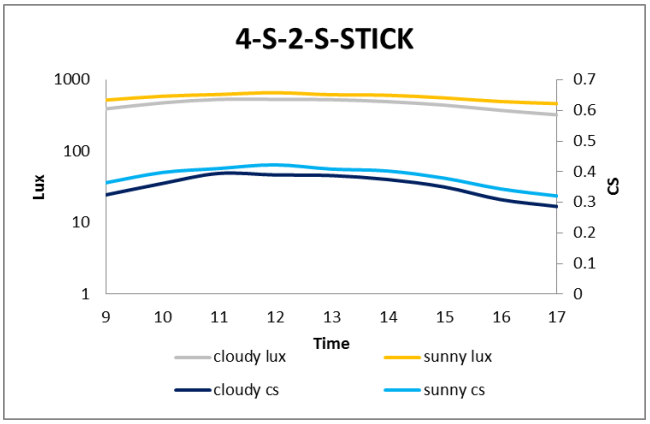
Daysimeter 087 - 4-S-2-S-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 1456 ± 424 lux on cloudy days. The mean CS value on was 0.59 ± 0.04 on cloudy days. On sunny days mean photopic light level during working hours was 1469 ± 424 lux. The mean CS value on was 0.62 ± 0.02 on sunny days.

4-S-2-N-Stick



Daysimeter 214 – 4-S-2-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 530 ± 53 lux on cloudy days. The mean CS value on was 0.39 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 749 ± 51 lux. The mean CS value on was 0.50 ± 0.02 on sunny days.

4-S-2-S-Stick

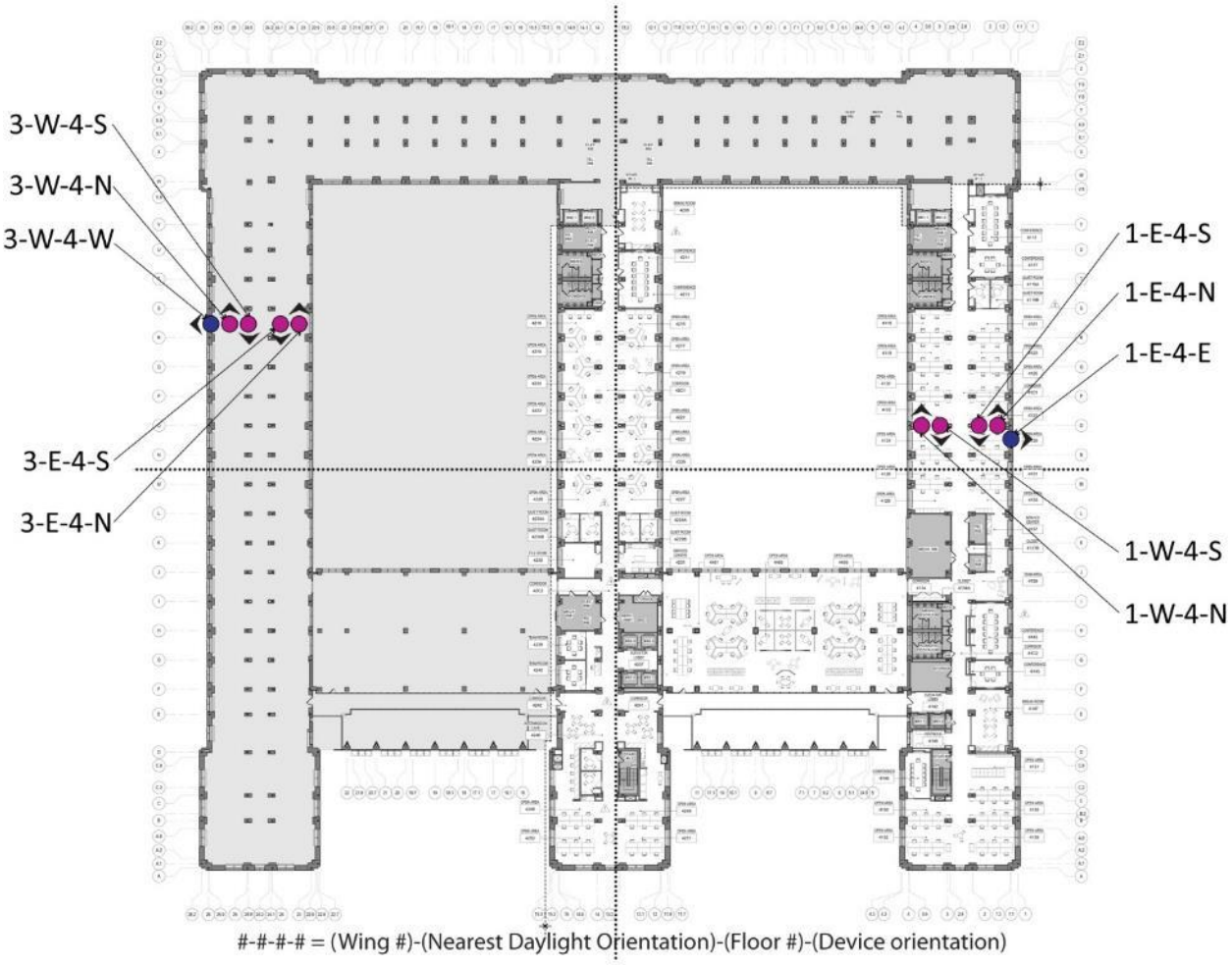


Daysimeter 213 – 4-S-2-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 458 ± 77 lux on cloudy days. The mean CS value on was 0.35 ± 0.04 on cloudy days. On sunny days mean photopic light level during working hours was 574 ± 66 lux. The mean CS value on was 0.38 ± 0.03 on sunny days.

APPENDIX I: PHOTOMETRIC DATA FOR 4TH FLOOR STATIONARY DEVICES

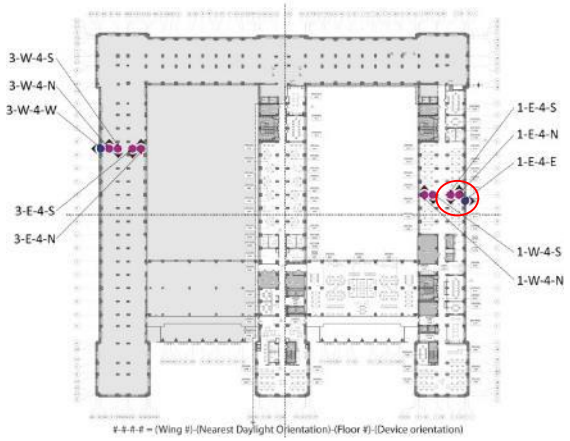
Mounted on sticks and in windows

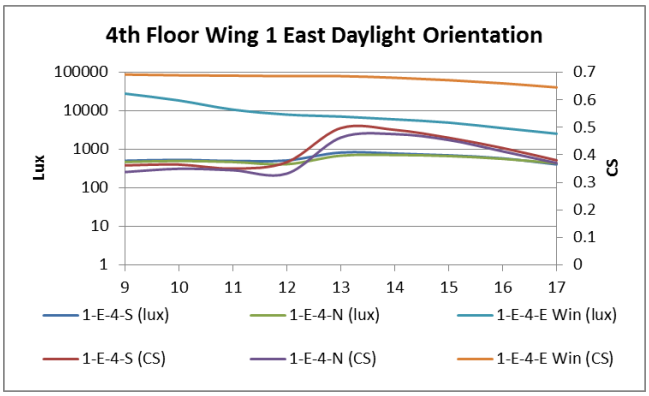
Cropped to June 15th, 2015 – July 12th, 2015 (Excluding holiday, July 3, 2015)



Location where measurements were collected.

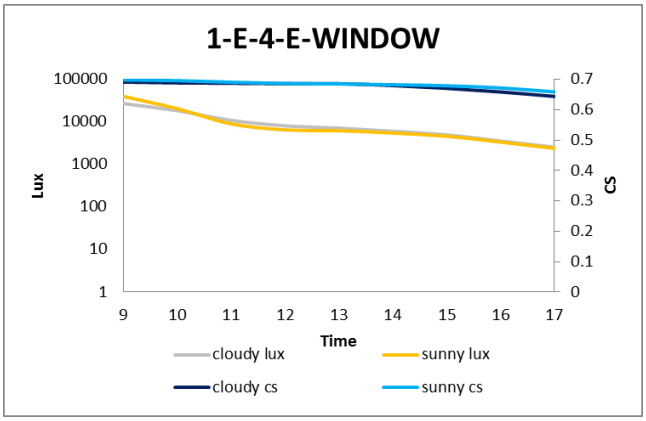
4TH FLOOR WING 1





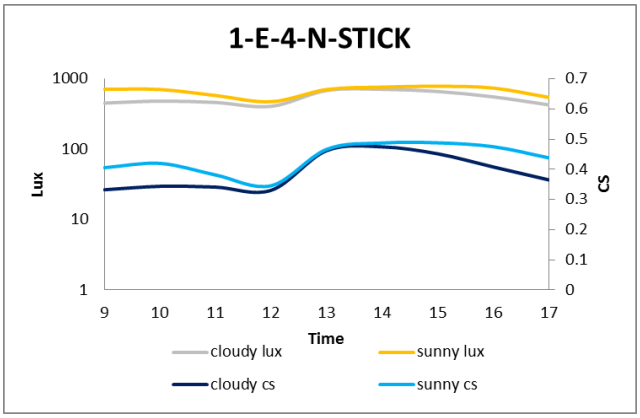
Average Lux and CS

1-E-4-E-Window

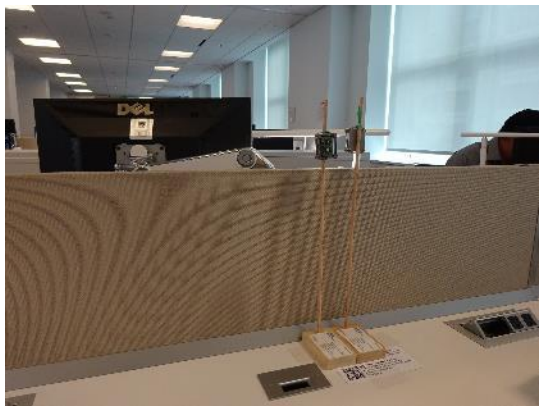


Daysimeter 121 – 1-E-4-E-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 9882 ± 8007 lux on cloudy days. The mean CS value on was 0.68 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 10903 ± 12135 lux. The mean CS value on was 0.68 ± 0.01 on sunny days.

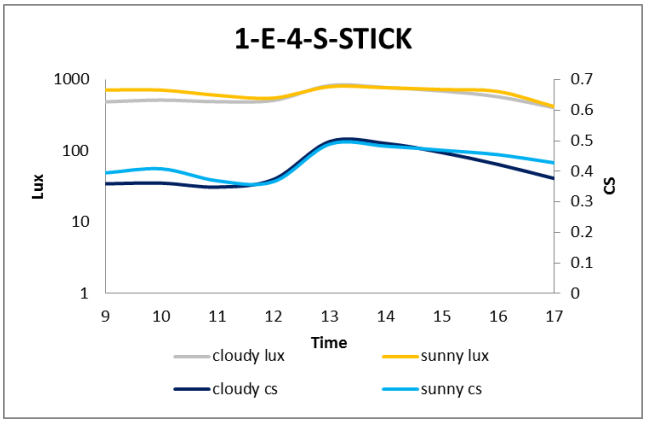
1-E-4-N-Stick



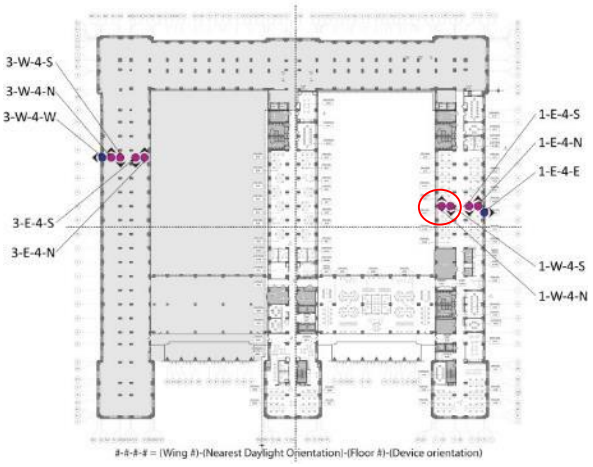
Daysimeter 230 – 1-E-4-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 539 ± 119 lux on cloudy days. The mean CS value on was 0.39 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 669 ± 108 lux. The mean CS value on was 0.43 ± 0.05 on sunny days.

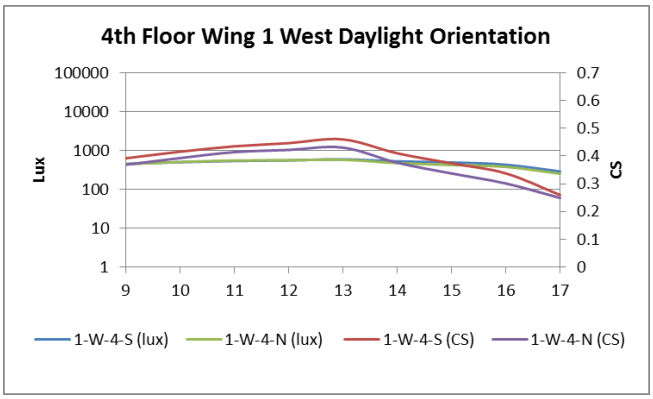


1-E-4-S-Stick



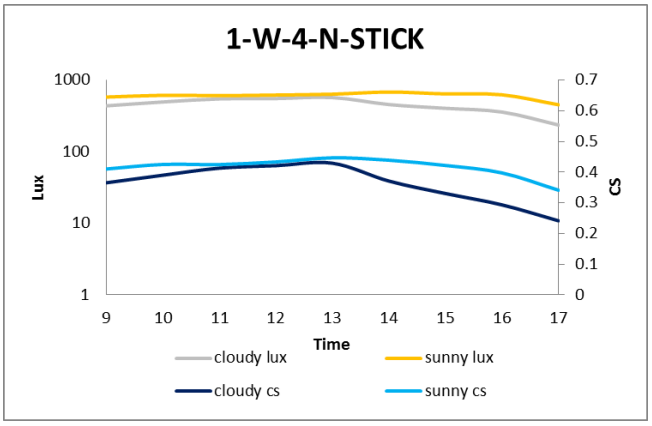
Daysimeter 232 – 1-E-4-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 590 ± 146 lux on cloudy days. The mean CS value on was 0.41 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 668 ± 120 lux. The mean CS value on was 0.43 ± 0.05 on sunny days.





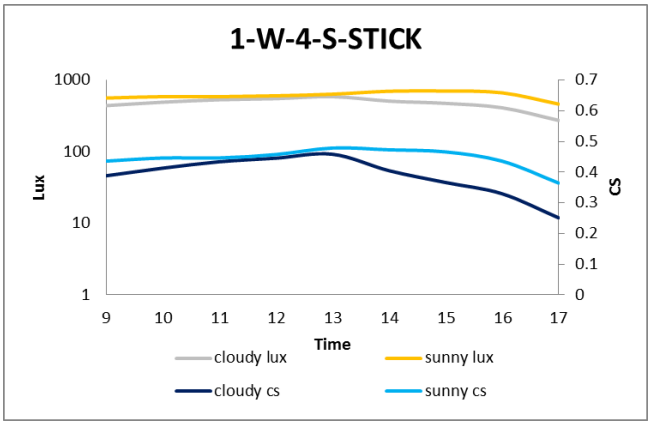
Average Lux and CS

1-W-4-N-Stick



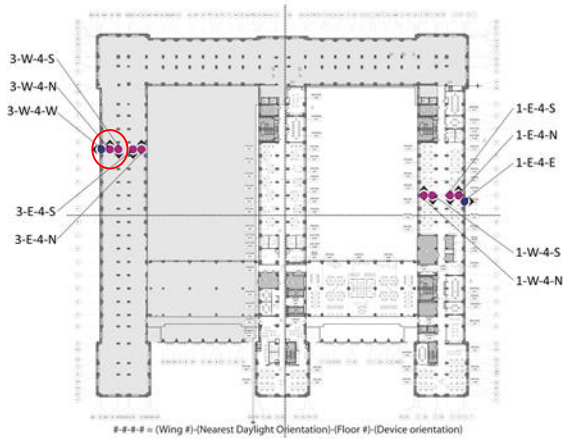
Daysimeter 231 – 1-W-4-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 452 ± 108 lux on cloudy days. The mean CS value on was 0.36 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 607 ± 64 lux. The mean CS value on was 0.42 ± 0.03 on sunny days.

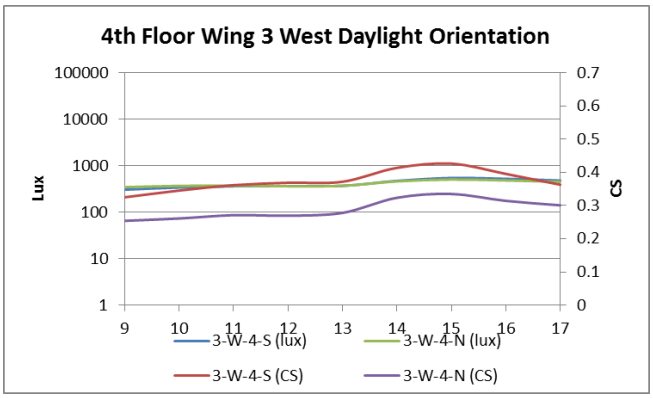
1-W-4-S-Stick



Daysimeter 233 – 1-W-4-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 475 ± 93 lux on cloudy days. The mean CS value on was 0.39 ± 0.07 on cloudy days. On sunny days mean photopic light level during working hours was 613 ± 76 lux. The mean CS value on was 0.45 ± 0.03 on sunny days.

4TH FLOOR WING 3

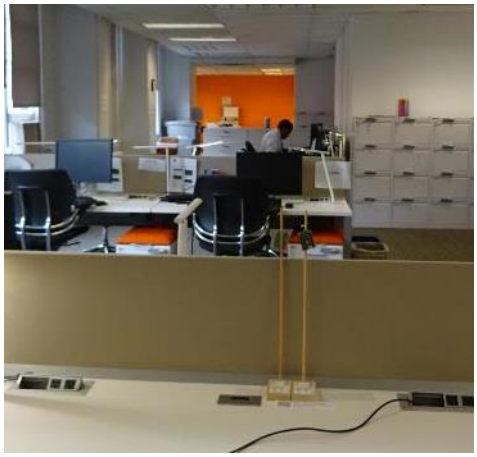




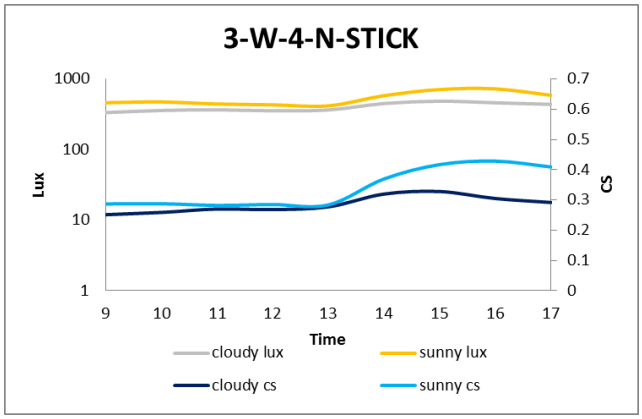
Average Lux and CS

3-W-4-W Window

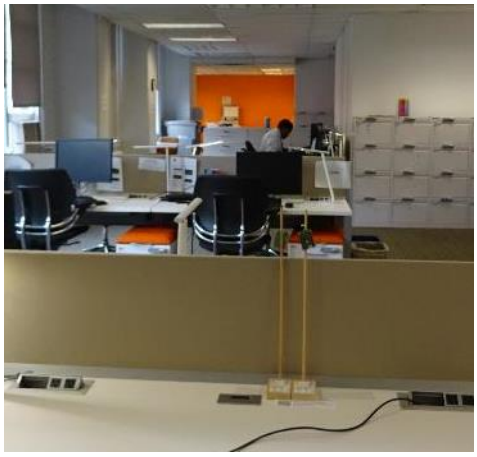
[3-W-4-W Window device failure]



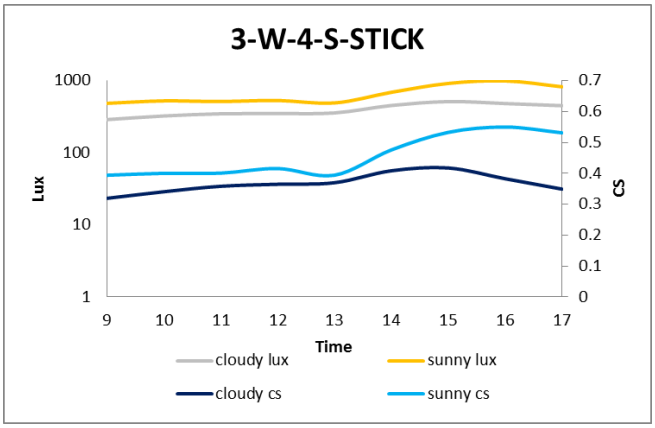
3-W-4-N-Stick



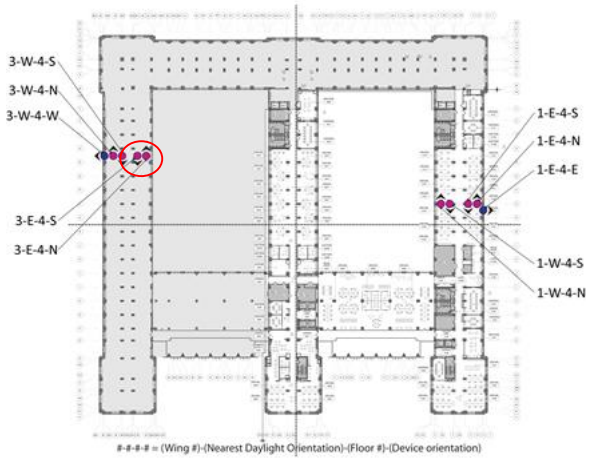
Daysimeter 222 – 3-W-4-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 402 ± 56 lux on cloudy days. The mean CS value on was 0.29 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 538 ± 120 lux. The mean CS value on was 0.34 ± 0.07 on sunny days.

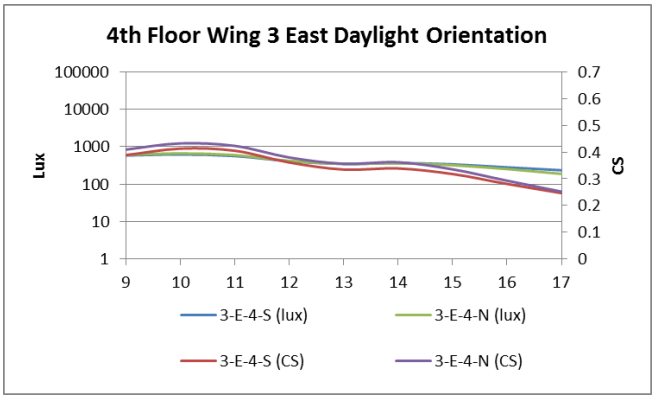


3-W-4-S-Stick



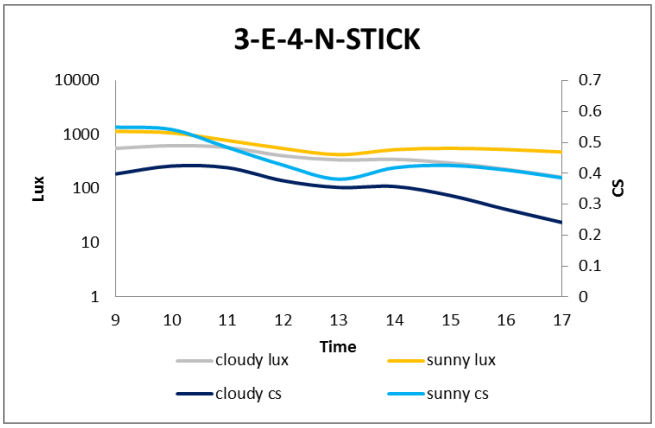
Daysimeter 229 – 3-W-4-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 397 ± 79 lux on cloudy days. The mean CS value on was 0.37 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 664 ± 200 lux. The mean CS value on was 0.46 ± 0.07 on sunny days.





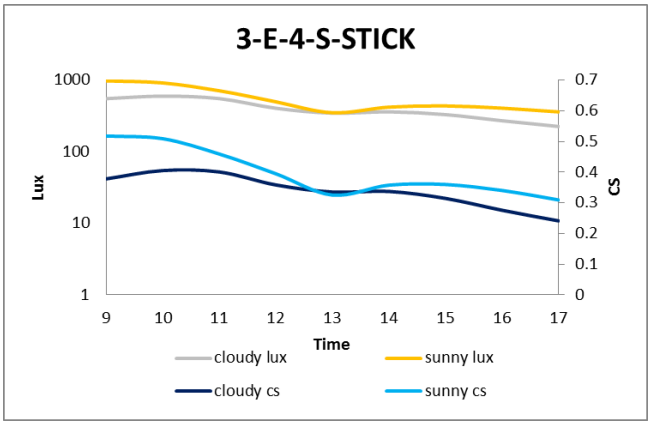
Average Lux and CS

3-E-4-N-Stick



Daysimeter 217 – 3-E-4-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 397 ± 163 lux on cloudy days. The mean CS value on was 0.35 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 680 ± 269 lux. The mean CS value on was 0.45 ± 0.06 on sunny days.

3-E-4-S-Stick

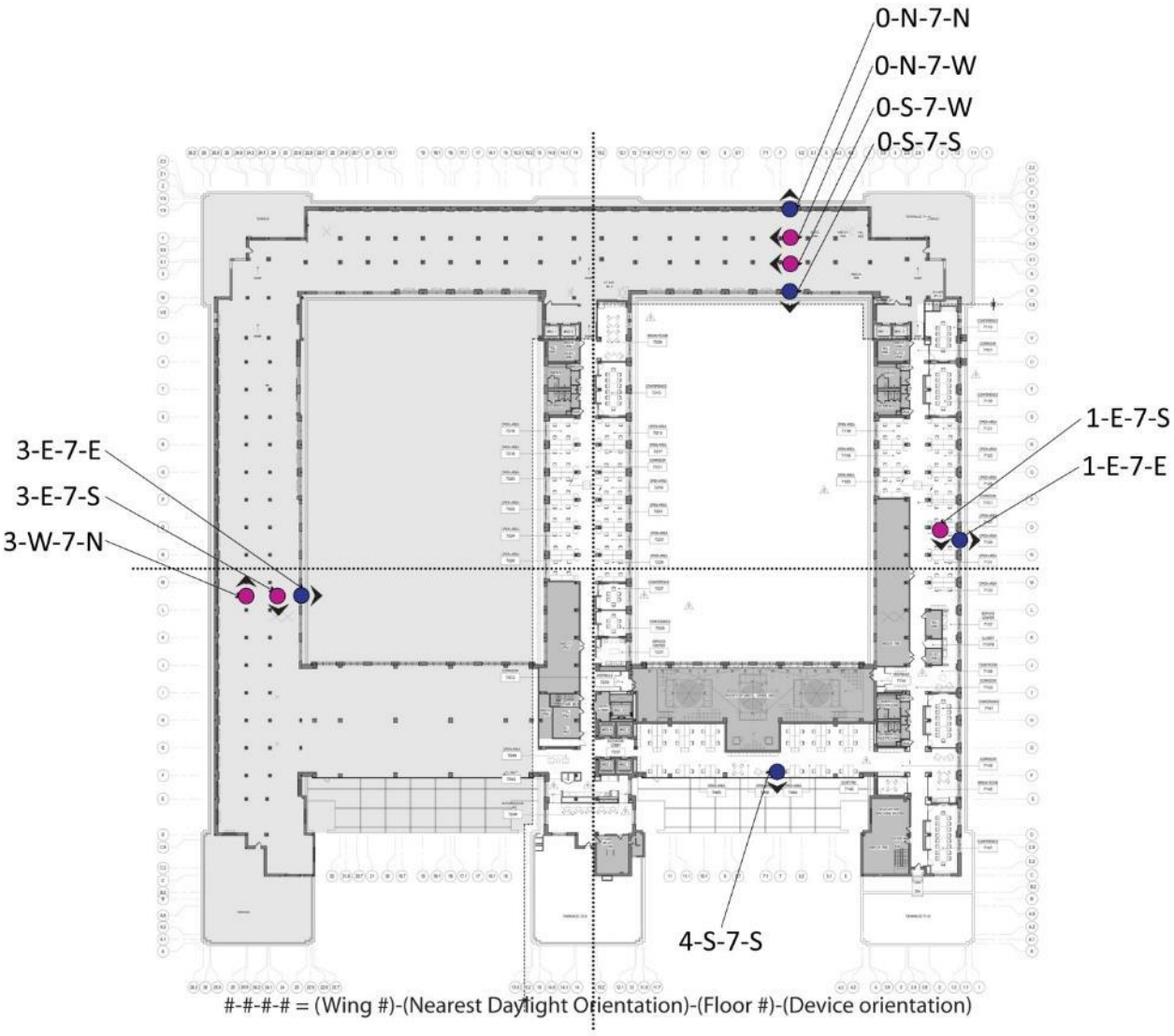


Daysimeter 212 – 3-E-4-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 405 ± 133 lux on cloudy days. The mean CS value on was 0.34 ± 0.06 on cloudy days. On sunny days mean photopic light level during working hours was 565 ± 242 lux. The mean CS value on was 0.40 ± 0.08 on sunny days.

APPENDIX J: PHOTOMETRIC DATA FOR 7TH FLOOR STATIONARY DEVICES

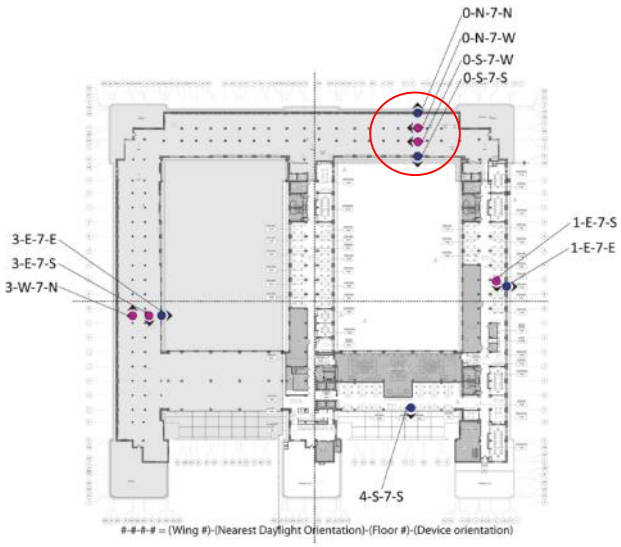
Mounted on sticks and in windows

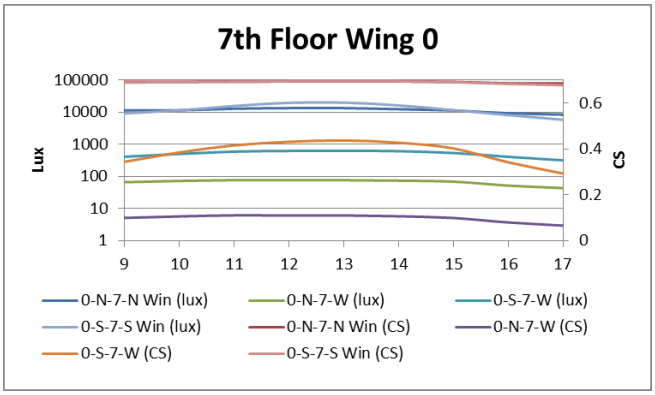
Cropped to June 15th, 2015 – July 12th, 2015 (Excluding holiday, July 3, 2015)



Location where measurements were collected.

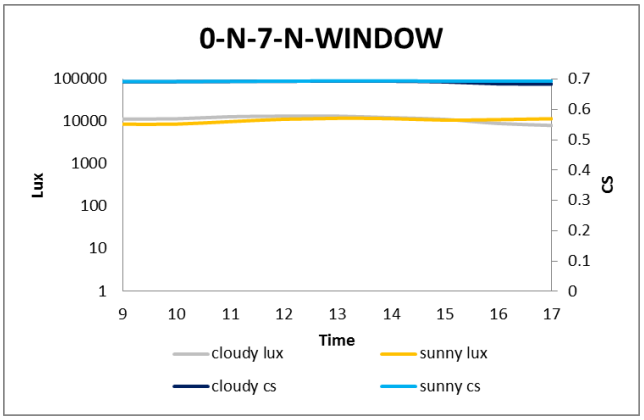
7TH FLOOR WING 0





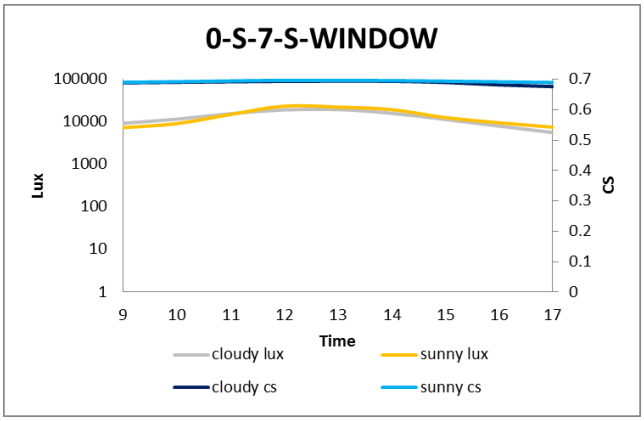
Average Lux and CS

0-N-7-N-Window



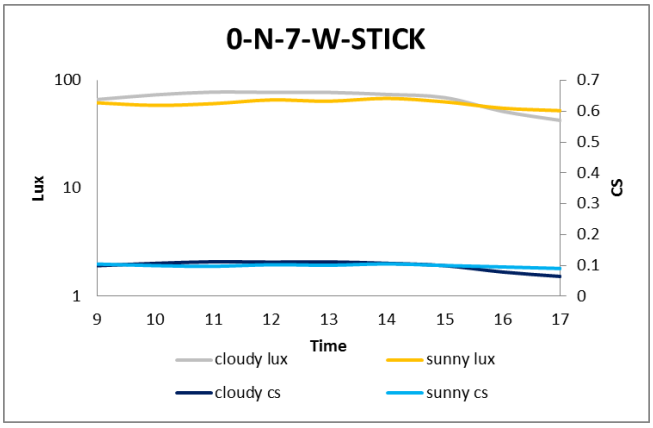
Daysimeter 005 – 0-N-7-N-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 11595 ± 1887 lux on cloudy days. The mean CS value on was 0.69 ± 0.004 on cloudy days. On sunny days mean photopic light level during working hours was 10729 ± 1263 lux. The mean CS value on was 0.69 ± 0.001 on sunny days.

0-S-7-S-Window



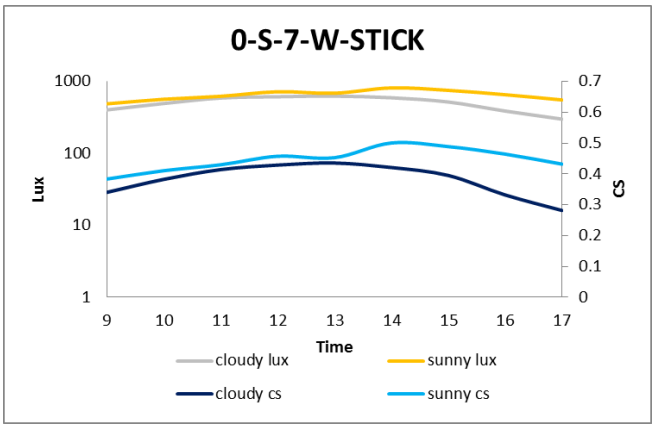
Daysimeter 002 – 0-S-7-S-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 12963 ± 4946 lux on cloudy days. The mean CS value on was 0.69 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 14098 ± 6358 lux. The mean CS value on was 0.69 ± 0.003 on sunny days.

0-N-7-W-Stick



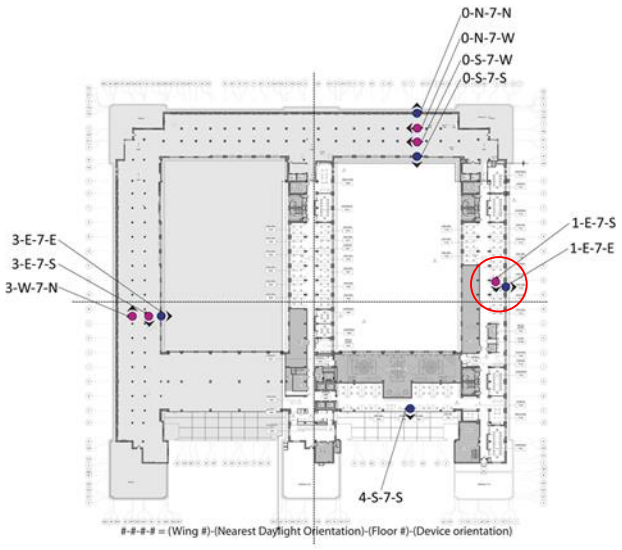
Daysimeter 161 – 0-N-7-W-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 68 ± 12 lux on cloudy days. The mean CS value on was 0.10 ± 0.02 on cloudy days. On sunny days mean photopic light level during working hours was 61 ± 5 lux. The mean CS value on was 0.10 ± 0.005 on sunny days.

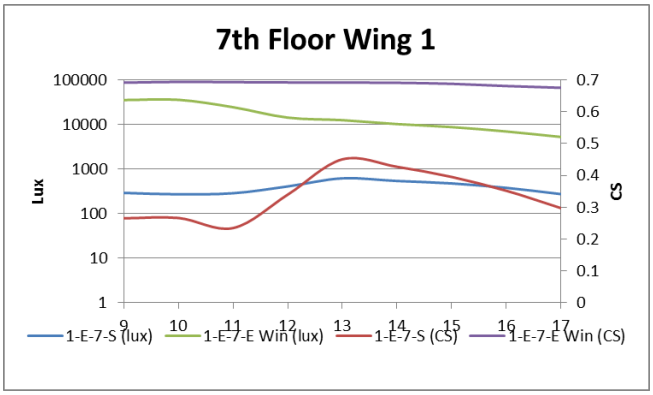
0-S-7-W-Stick



Daysimeter 250 – 0-S-7-W-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 504 ± 116 lux on cloudy days. The mean CS value on was 0.38 ± 0.05 on cloudy days. On sunny days mean photopic light level during working hours was 653 ± 104 lux. The mean CS value on was 0.45 ± 0.04 on sunny days.

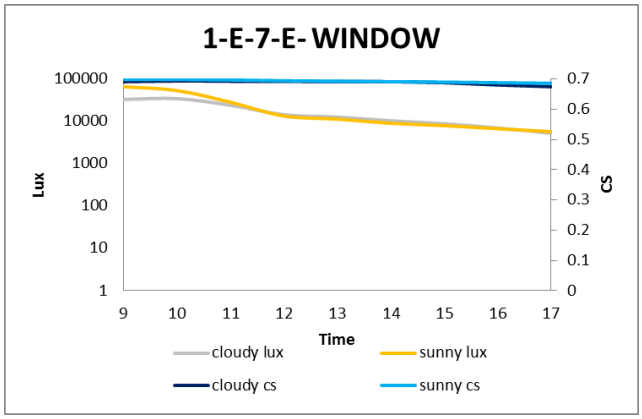
7TH FLOOR WING 1



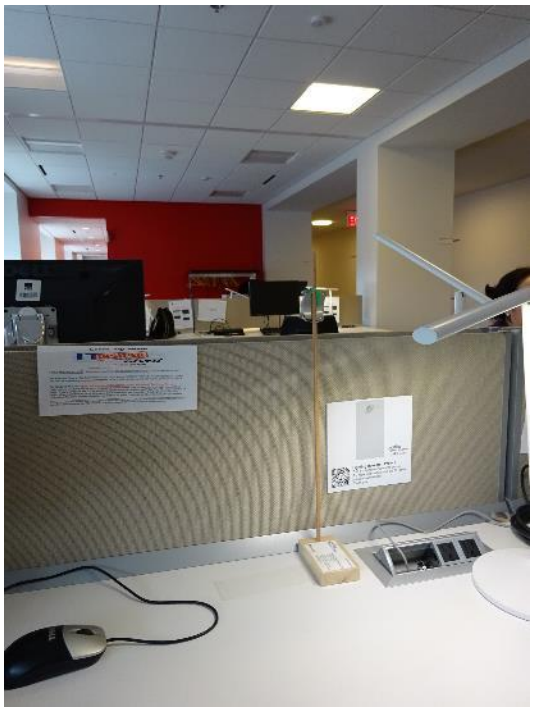


Average Lux and CS

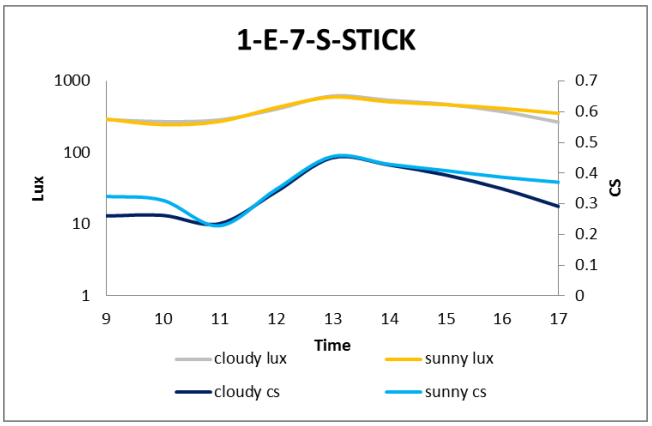
1-E-7-E-Window



Daysimeter 008 – 1-E-7-E-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 16689 ± 11118 lux on cloudy days. The mean CS value on was 0.69 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 22488 ± 22470 lux. The mean CS value on was 0.69 ± 0.005 on sunny days.

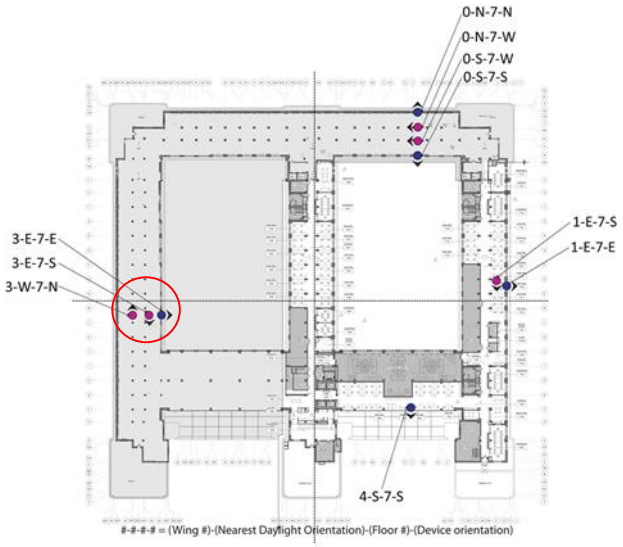


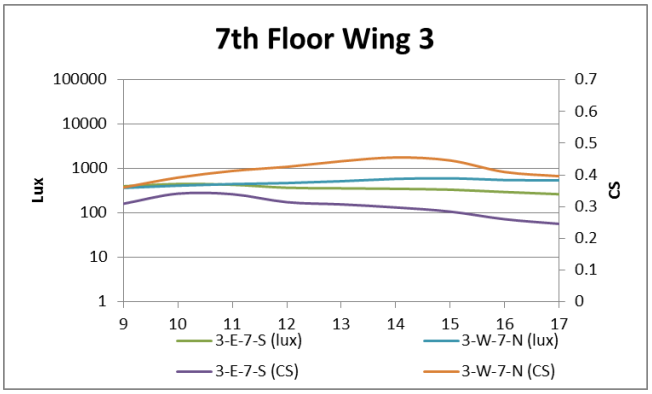
1-E-7-S-Stick



Daysimeter 159 – 1-E-7-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 393 ± 129 lux on cloudy days. The mean CS value on was 0.33 ± 0.08 on cloudy days. On sunny days mean photopic light level during working hours was 400 ± 118 lux. The mean CS value on was 0.36 ± 0.07 on sunny days.

7TH FLOOR WING 3



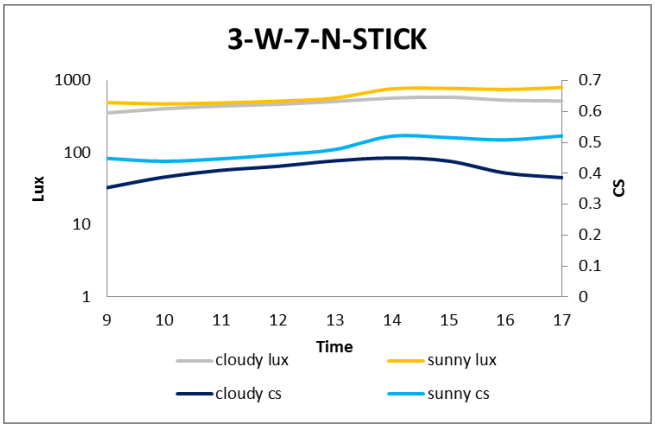


Average Lux and CS

3-E-7-E-Window

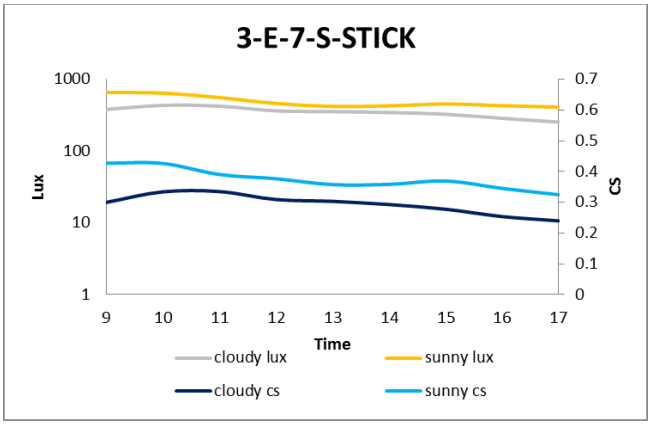
[3-W-7-E-Window, device failure]

3-W-7-N-Stick



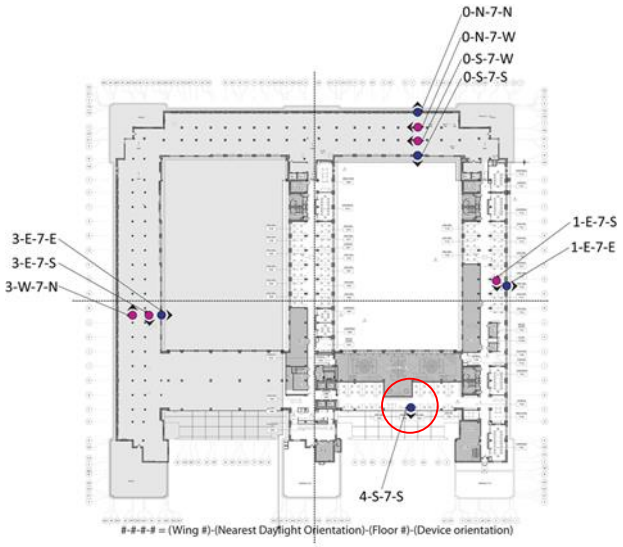
Daysimeter 163 – 3-W-7-N-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 491 ± 77 lux on cloudy days. The mean CS value on was 0.41 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 630 ± 144 lux. The mean CS value on was 0.48 ± 0.03 on sunny days.

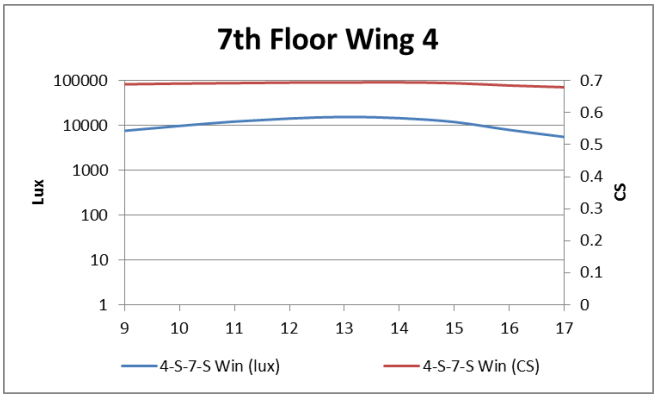
3-E-7-S-Stick



Daysimeter 134 – 3-E-7-S-Stick. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 352 ± 59 lux on cloudy days. The mean CS value on was 0.29 ± 0.03 on cloudy days. On sunny days mean photopic light level during working hours was 496 ± 98 lux. The mean CS value on was 0.38 ± 0.03 on sunny days.

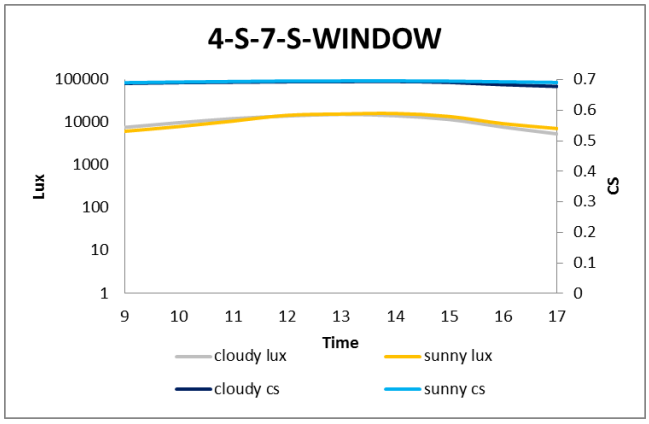
7TH FLOOR WING 4





Average Lux and CS

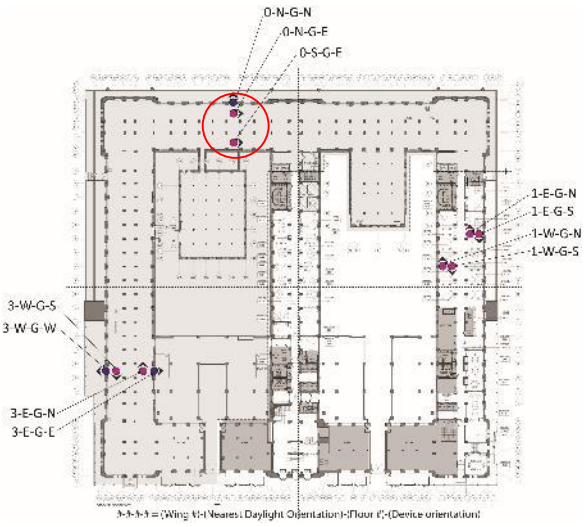
4-S-7-S-Window



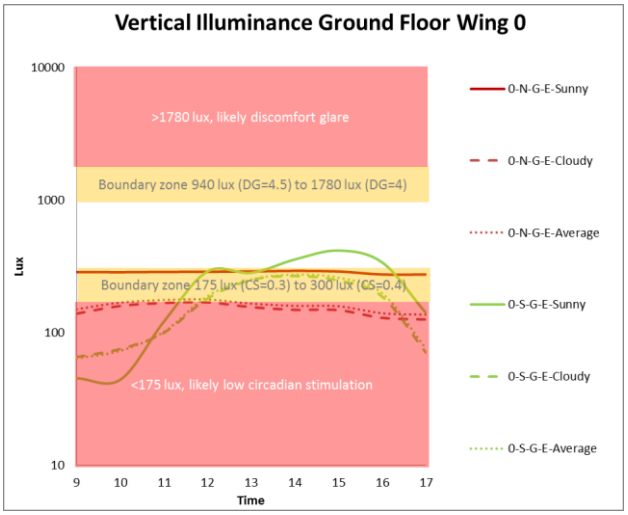
Daysimeter 162 – 4-S-7-S-Window. Mean photopic light level during working hours (08:00 am to 05:00 pm) was 11030 ± 3494 lux on cloudy days. The mean CS value on was 0.69 ± 0.01 on cloudy days. On sunny days mean photopic light level during working hours was 11401 ± 3879 lux. The mean CS value on was 0.69 ± 0.002 on sunny days.

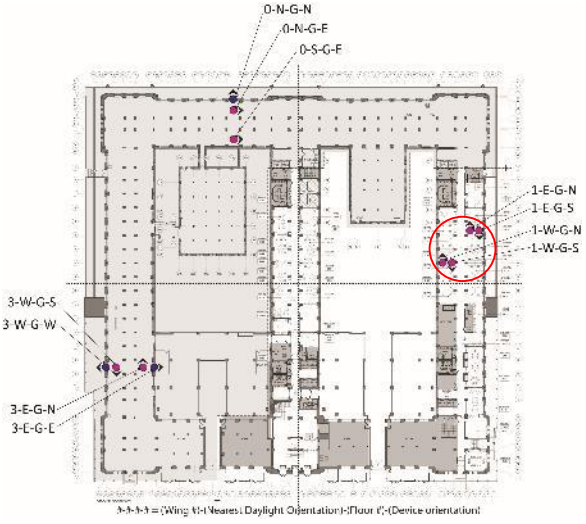
APPENDIX K: VERTICAL ILLUMINANCE FOR STICK DEVICES

GROUND FLOOR

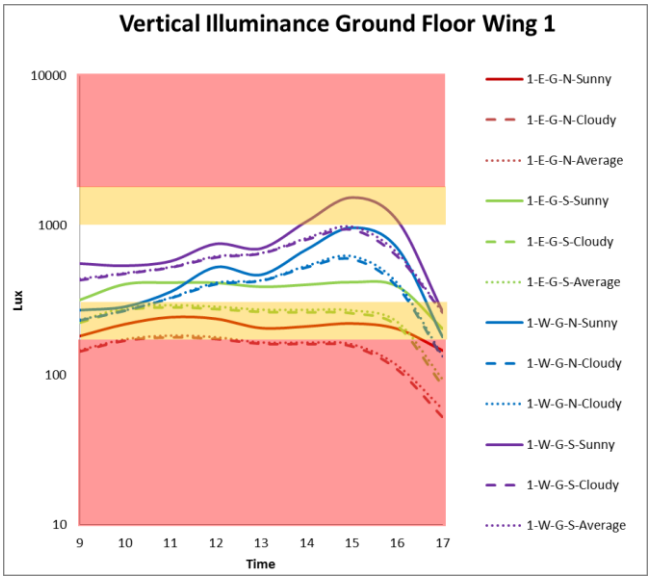


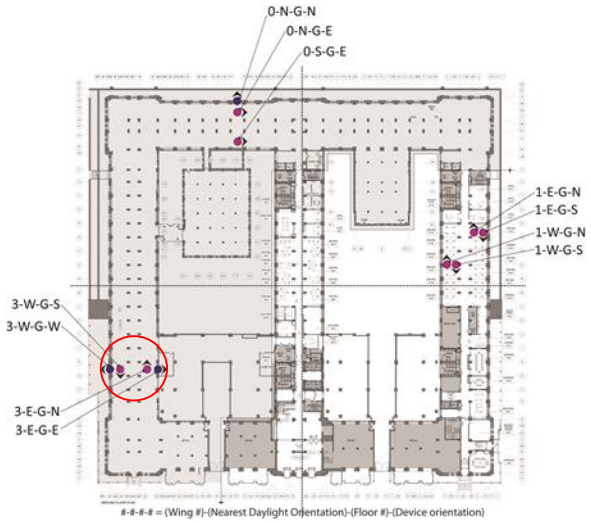
GROUND FLOOR WING 0



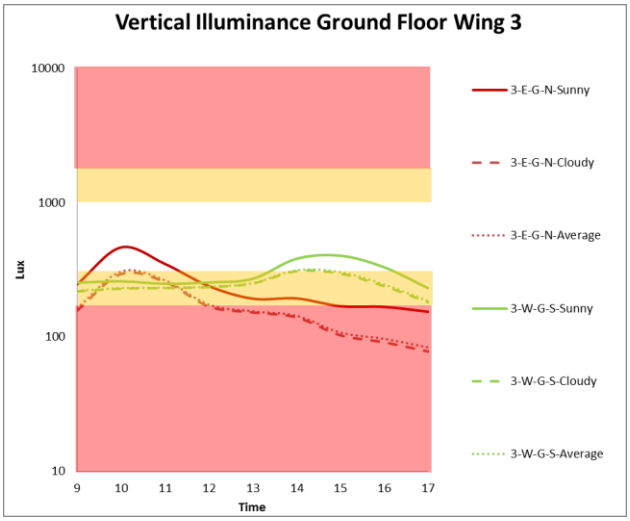


Ground Floor Wing 1

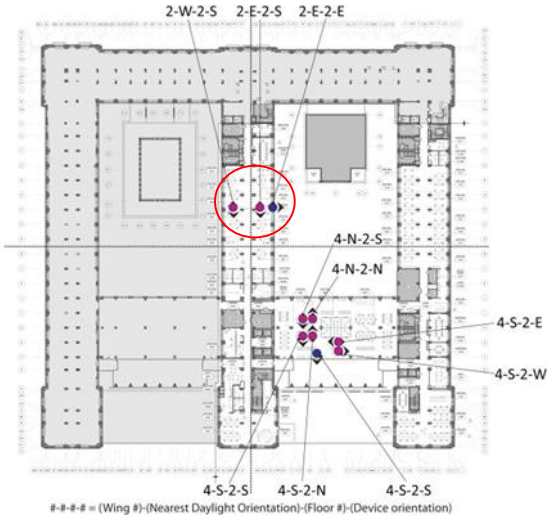




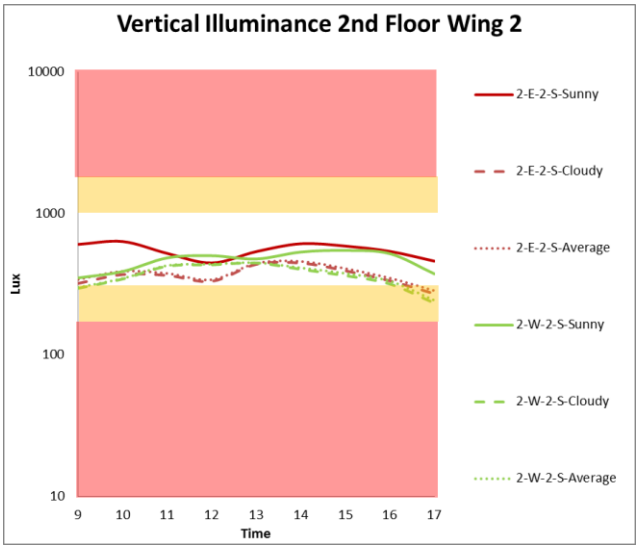
Ground Floor Wing 3

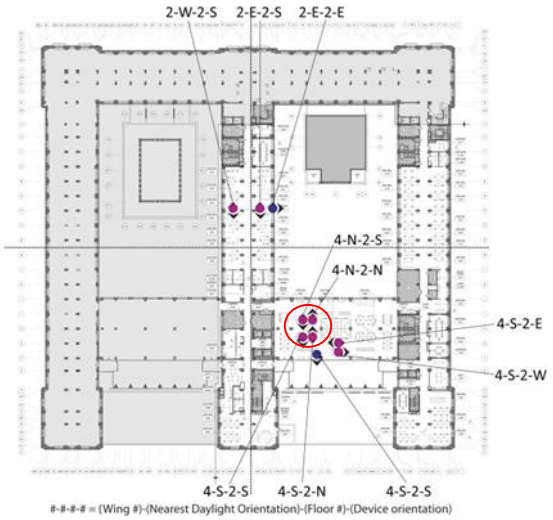


2ND FLOOR

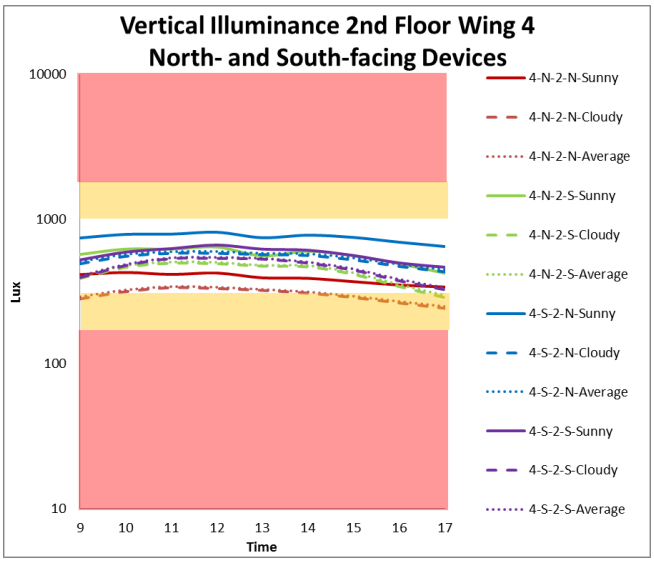


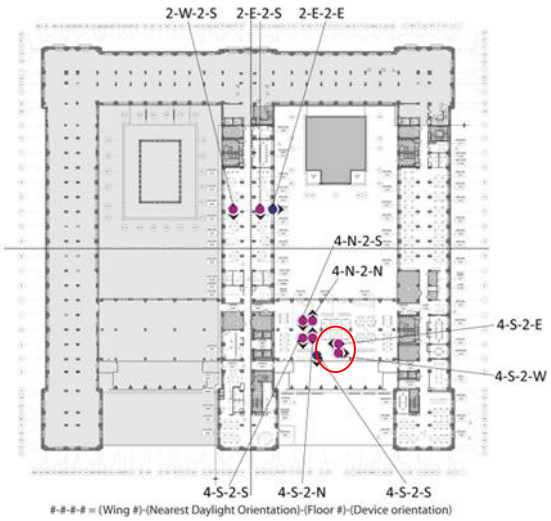
2nd Floor Wing 2



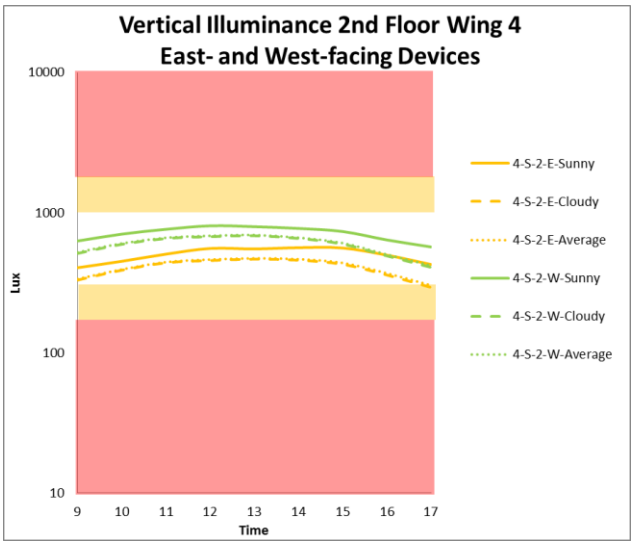


2nd Floor Wing 4 North- and South-facing Devices

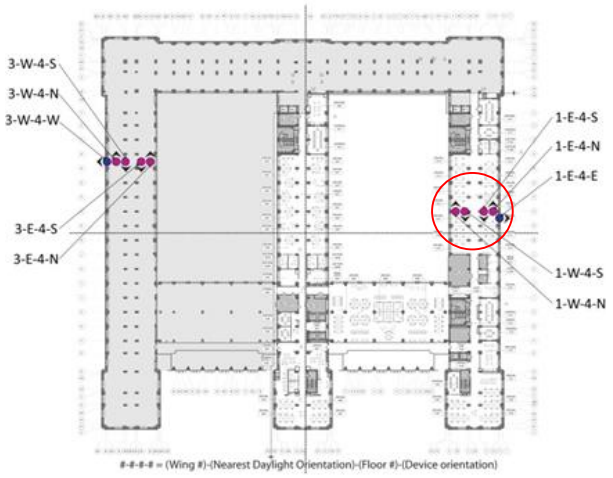




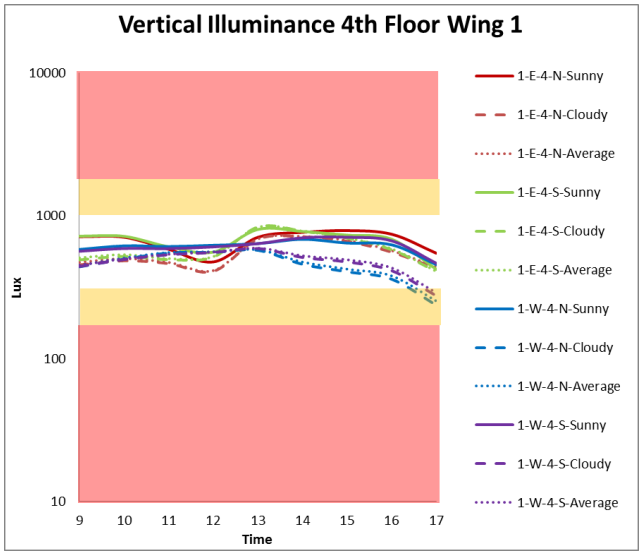
2nd Floor Wing 4 East- and West-facing Devices

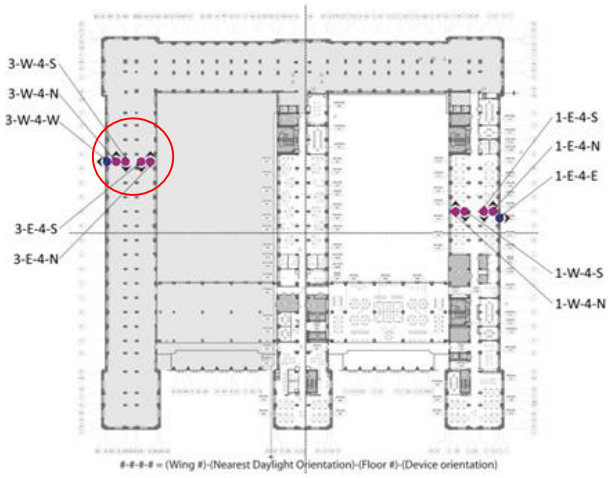


4TH FLOOR

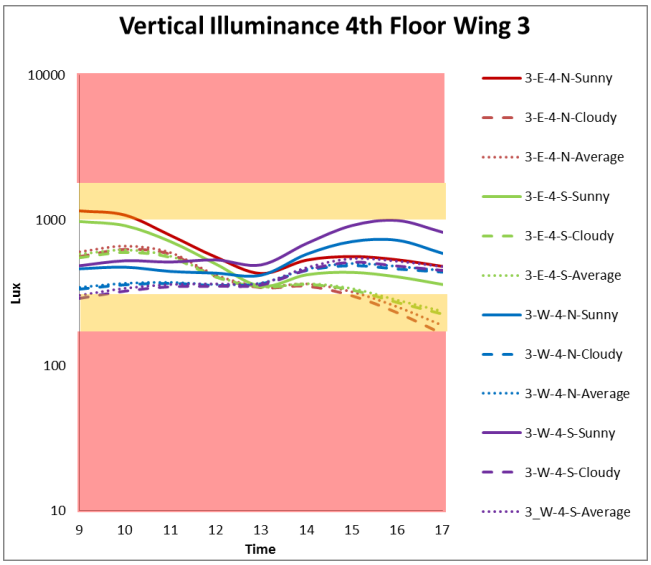


4th Floor Wing 1

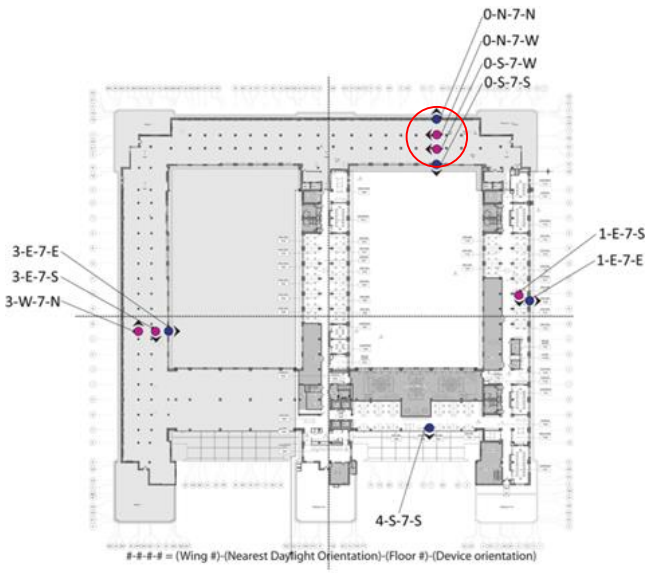




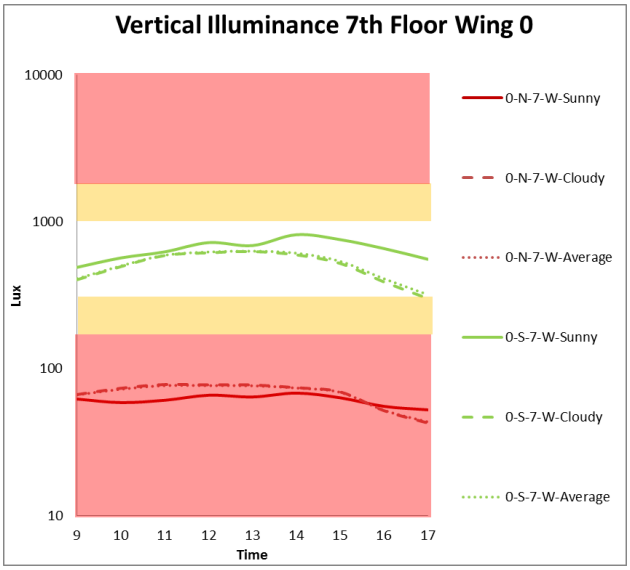
4th Floor Wing 3

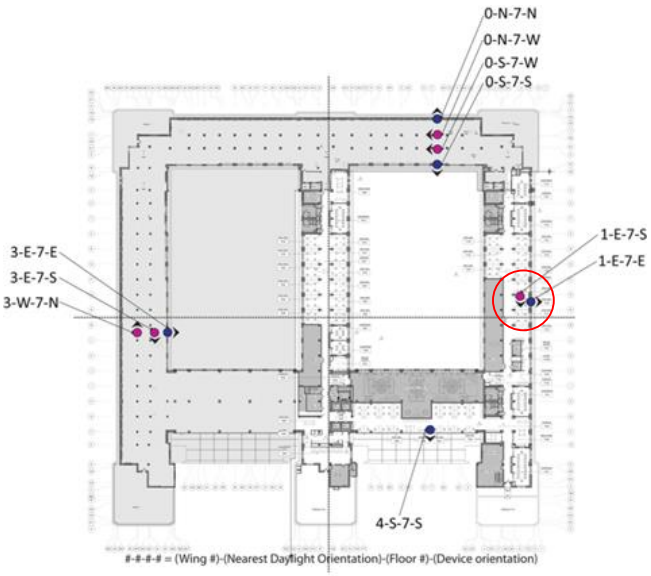


7TH FLOOR

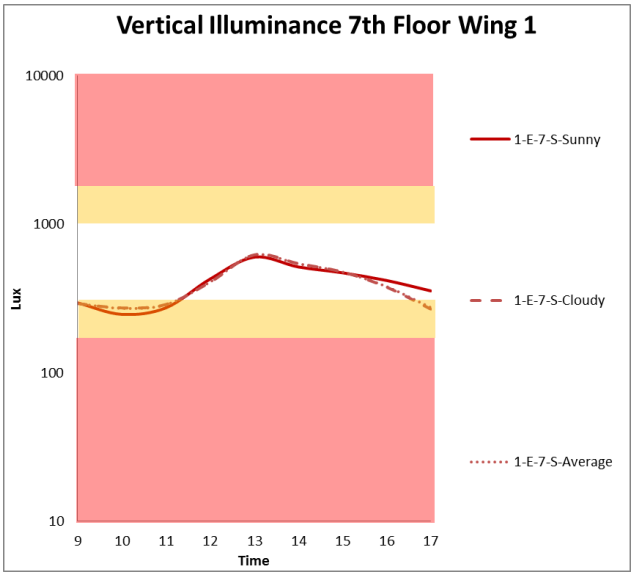


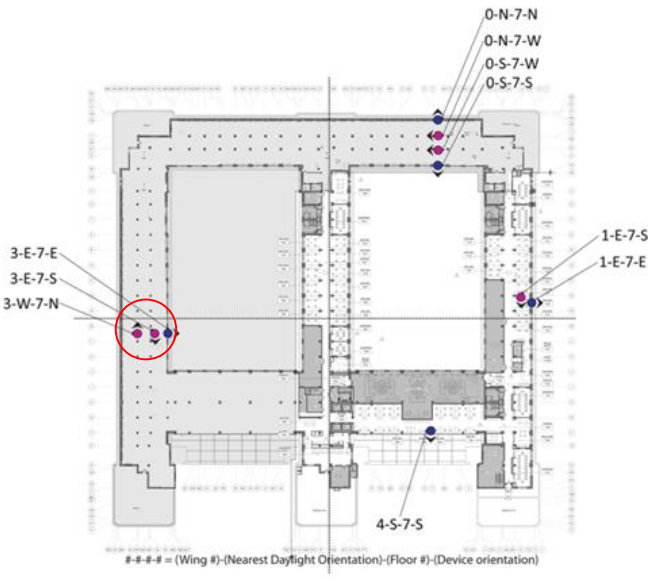
7th Floor Wing 0





7th Floor Wing 1





7th Floor Wing 3