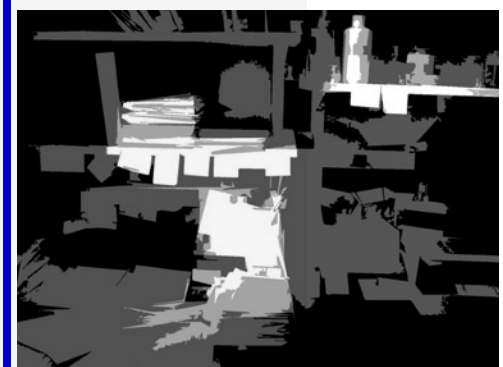
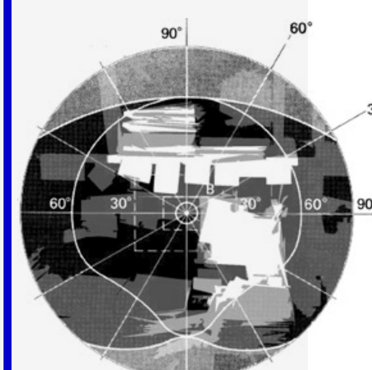
Van Nuys Medical Science Center

IUPUI Indianapolis, IN

A Study of the Lighting Conditions in the Department of Biochemestry and Molecular Biology Research Laboratories





Vital Signs VII
Center for Energy Research, Education, and Service

Ball State University
College of Architecture
and Planning
Fall 2002

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Cover Photos

Exterior photo of the Van Nuys Medical Science Center provided by Jim Hill.

Progressive analytical photos by Ryan C. Suess.

Van Nuys Medical Science Center

Lighting Study Participants

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ACKNOWLEDGEMENTS

We want to thank the personnel of the Van Nuys Medical Science Center who were always available to help us in our visits.

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LAB C: Dr. William Bosron's Laboratory

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We want to thank Jim Hill, AIA for his time and openness to our questions; giving us important background information for our research.

Ball State Center for Energy, Research / Education / Service (CERES)

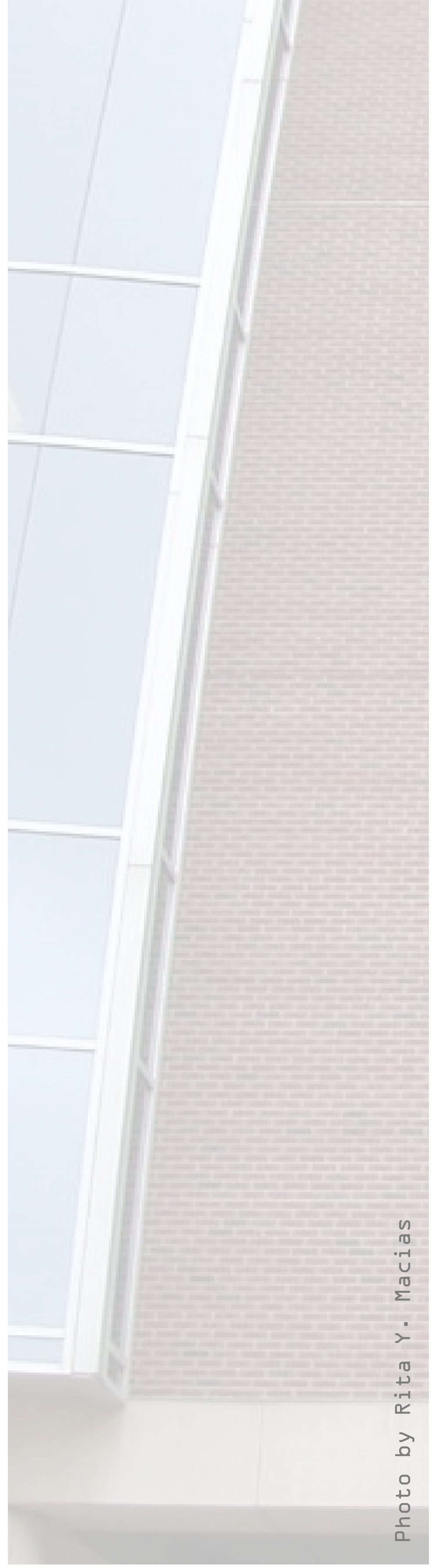
Special thanks to the CERES faculty for their assistance throughout this case study.

Robert Koester	Professor of Architecture CERES Director
Jeff Culp	CERES Operations Manager
Robert Fisher	Professor of Architecture CERES Resident Fellow

We also wish to express our thanks to Professor John Reynolds, Visiting Scholar from the University of Oregon, for his guidance in this study.


Photo by Rita Y. Macias

C O N T E N T S



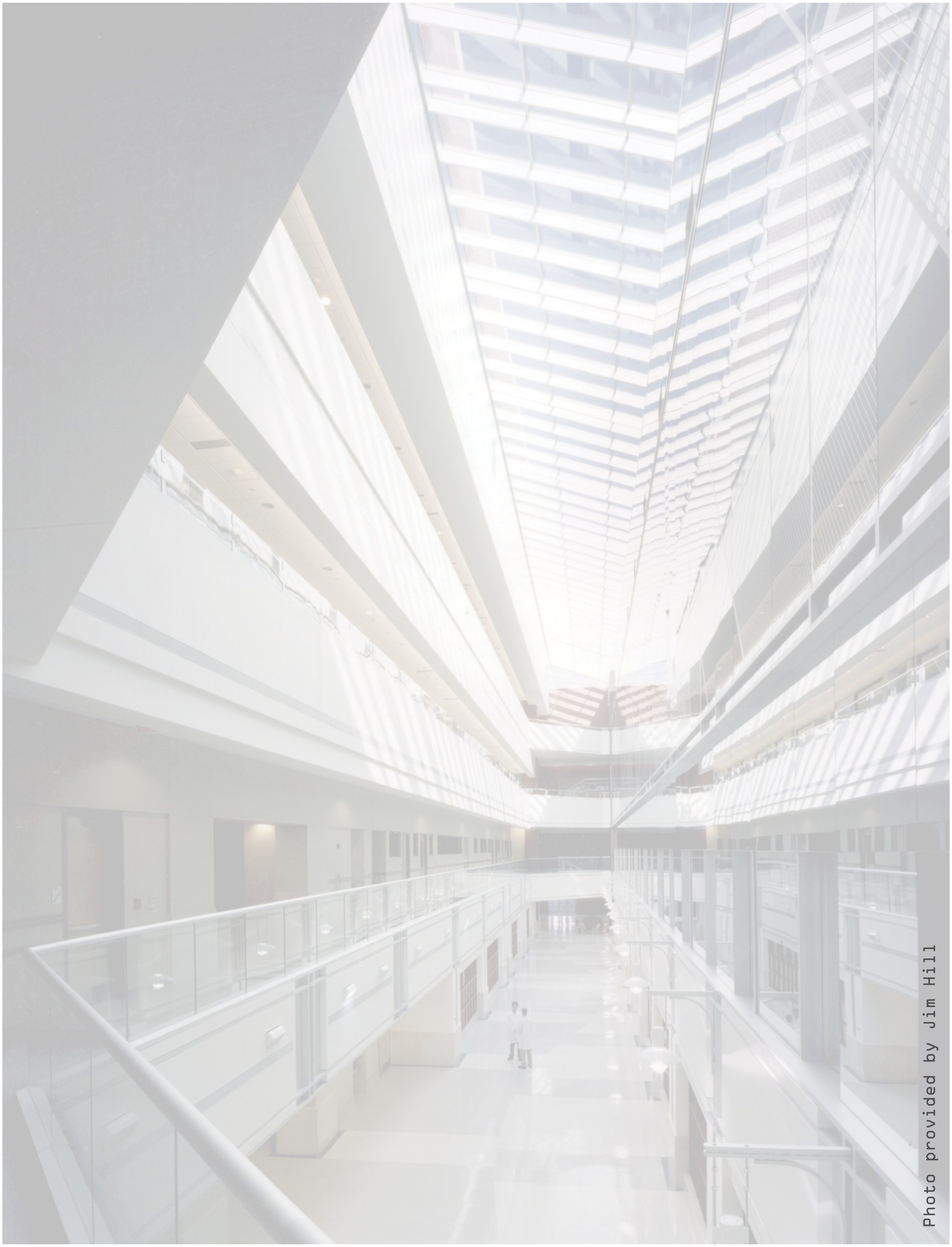


Photo provided by Jim Hill

A B S T R A C T

Photo provided by Jim Hill

This report describes a semester-long study of the artificial and natural lighting conditions in three laboratory spaces[1] in the Van Nuys Medical Science building on the IUPUI Campus in Indianapolis, Indiana.

We analyzed the lighting conditions in the laboratories to understand the effects they had on the occupants of these three labs. Conditions in the spaces change at different times of the day.

In our research we determined that the key factors for visual comfort are the ability/capability of the eyes to adjust to the conditions such as the brightness and contrast of surfaces, and the angle of reflectance of artificial and natural light off of equipment displays/screens and computer monitors in the field of view.

The light fixtures as designed are located above the occupants causing them to cast shadows onto their own work surface, which is made of a light-absorbing black Corian. In combination these two factors create a dark visual field. The large west facing windows allow the setting sun to penetrate deep into the space striking the display screens of computers and equipment creating a veiling reflection.

To evaluate these conditions in the labs we used instruments to:

- gather continuous quantitative measurements of surface illumination over a two week period.
- measure the real time instantaneous brightness levels within the occupant's visual field.

The data gathered from our investigation showed that glare on the monitors and equipment displays occurred at the stations near the windows from the light coming in through the window. We also discovered veiling reflections on computer monitors at the end of each bay within the labs caused by light from the windows and the overhead lighting where the axis of light distribution was perpendicular to the surface of the monitor.

[1] The room numbers correspond to the numbers on the construction documents provided by Jim Hill, AIA of BSA Architects.

Lab A: Dr. Mark Goebl's Laboratory (room 4071)
Lab B: Biochemistry Biotechnology Laboratory (room 4032)
Lab C: Dr. William Bosron's Laboratory (room 4023).


Photo by Ryan C. Suess

INTRODUCTION

The Vital Signs VII course, offered during the fall semester of 2002 at Ball State University, is a field-based research course focused on interior illuminance, daylight control, and occupant response. To gain a greater understanding of the course's subject matter, a comprehensive project was formulated for the course by Professor, Robert J. Koester under the auspices of the Vital Signs Project -- a national curriculum transformation initiative[2]. The Van Nuys Medical Science Center was chosen to be analyzed and investigated. Designed by BSA Architects, the addition was completed in May 1998.

Indicative phase:

This phase involves a familiarization with the building and the apparent conditions, first to identify possible areas of study, then to develop a hypothesis, and plan for its evaluation.

Investigative phase:

This phase of research consists of gathering quantitative measurements of the existing lighting conditions. Light meters were placed in the labs to measure the illumination levels at the work stations over a 2 week period. This allowed us to gather readings of various factors including the influence of cloudy, overcast and sunny weather, and the position of the lab researchers relative to their tasks. Photographs were taken of the space to understand further the conditions in the laboratories. We also talked informally with the researchers regarding the conditions in their laboratories and how these conditions affected their work. Instantaneous measurements were made to map the brightness levels within the visual field.

Diagnostic phase:

We analyzed the data collected in the investigative phase to determine if the conditions present in the labs supported our hypotheses. We determined that the light reaching the work surface was not adequate for the tasks being completed. And the location of the windows in relation to the displays of the computers and other research equipment in the labs did create conditions of glare.

Photo provided by Jim Hill

[2] The national program was developed by Cris Benton at the University of California, Berkeley and originally funded by the Energy Foundation, Pacific Gas and Electric, and the National Science Foundation.

Photo by Rita Y. Macias

HYPOTHESES

1) The artificial and natural lighting in the labs combine to create an adequately illuminated workspace that meets the recommended IES illumination levels for the specific tasks.

2) The artificial and natural lighting in the labs combine to provide glare-free conditions in the work environment.

BACKGROUND SUMMARY

Illuminance Recommendations

The Illuminating Engineering Society of North America (IESNA) has developed illumination level recommendations based on the activities taking place within a space. These recommendations are based on three factors: the age of the observer or performer of the task, the speed or accuracy required for the task, and the reflectance of the background on which the task is being performed.

Interior lighting for lobbies and atrium spaces require lower illumination levels than task-oriented spaces, such as workstations, laboratories, or operating rooms, which support tasks that require increasing levels of discrimination of finer details (in that order). Based on our assessment of the tasks performed in the labs, the IES recommendations call for between 50 and 100 footcandles (*fc*). The complete IES recommendations can be found in Appendix B.

Visual Acuity

The three components of seeing are the task, lighting conditions, and observer. There are variables affecting each of these three components. The task requirements are defined by its size, luminance, contrast, exposure time, type of object, degree of required accuracy, peripheral patterns, and whether the task is completed while stationary or in motion.

The factors that define the lighting conditions are the illumination level, disability glare, discomfort glare, luminance ratios, brightness patterns, and chromaticity. The factors from the observer include the conditions of the eyes, adaptation level, fatigue level, and subjective impressions or psychological reactions. The basic visual tasks are the perception of low contrast, fine detail, and gradations of brilliance.

Visual acuity is generally proportional to the physical size of the object being viewed; given fixed brightness, contrast, and exposure time. Also affecting visual acuity is the subtended visual angle (see figure 1.1); this factor can be adjusted by increasing or decreasing the physical distance of the object from the eye.

Foveal Vision

The central portion of the eye is composed of cones, we use these light sensitive cells to see objects in detail and in color. Relative to rods however, the cones are not very sensitive to light. This is why color perception diminishes in dim light. The remainder of the eye is composed of rods which are very sensitive to light and motion, but lack any detail.

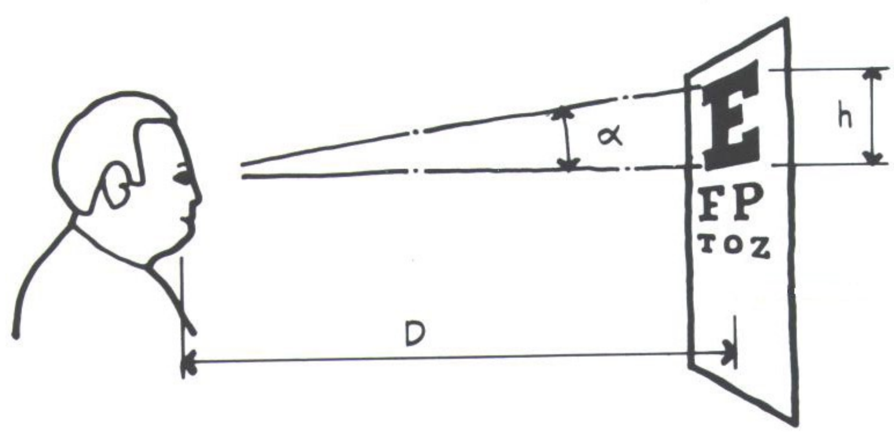


Figure 1.1
Subtended visual angle. Egan, page 10.

RESEARCH METHODOLOGY

The following methodology was used to study the lighting conditions in the research laboratories to test our hypotheses:

The initial indicative research involved a site visit in early September to familiarize ourselves with the new addition and the existing building. A guided tour was provided by John Pieper of the Department of Biochemistry and Molecular Biology. Our main objective during this visit was looking for indicators and locating problem zones within the lighting design. With the indicators in mind we then formulated a hypothesis for developing an assessment of the lighting conditions within these spaces.

After the visit, the class was divided into two teams of two people. The teams then selected which zones they would investigate. Our group chose three of the Departments research laboratories located on the 4^{th} floor. These zones were selected because of large west facing windows and the proximity of the computers and equipment to these windows. Our team was particularly interested in the effects on the occupants of direct beam light from the setting sun and the location of artificial lighting above and behind the occupants when at their work stations.

The investigative research involved gathering data with handheld instruments, i.e. light meters, to measure available illumination and luminance levels of reflections of that light from the surfaces in the labs. Photographs were used to capture instances where the shadows were cast on the work surfaces, reflected glare existed at the workstations, and veiling reflections occurred on computer monitors and the displays of other laboratory research equipment.

A final diagnostic phase of research completed the investigation of the three department laboratories, our assessment of findings and recommendations are to be handed over to Mary Harden and hopefully steps will be taken to improve the lighting conditions in the research laboratories.

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INDICATIVE PHASE
first visit

We made the first visit to the Van Nuys Medical Science Building on the IUPUI Campus on September 17, 2002. The purpose of this visit was to become familiar with the facilities and identify potential areas for research.

We were introduced to Mary Harden Business Manager of the Biochemistry and Molecular Biology Department, our contact for visits. The spaces that were to be studied were shown to us including the large atrium that separates the existing building from the addition. We were also shown three labs and their support spaces located in the addition, and one lab along with its support spaces located in the existing building.

In the Atrium, the new portion of the building is taller and the glazing at the top slopes down to the east to the roof of the original building (see figure 2.1). At the ground floor of the building, hanging lights are attached to the eastern wall similar to a street setting (figure 2.2). There are also lights attached to the east wall and both walls at the ends of the atrium similar to flood lights that shine down (figure 1.3). Notice the light located in the vestibule and the two spots reflecting off of the glass of the vestibule back to the camera. These lights are on all day regardless of how much natural light enters the atrium. When looking up, the 'flood lights' were so bright that even at 1:00 pm on a mostly clear day, they caused an uncomfortable direct glare. However, they are located above the normal sight line; i.e. one has to look up for them to sense the glare.

Sitting in the seating area on the 4th floor, the light coming from the glazing above makes it difficult to see the contents on the screen of a handheld computer. The sitting spaces on every floor except for the top floor are located under the sitting space for the floor above. In this shadow, the lighting level was noticeably lower than the atrium itself which was quite bright when the sun was not shining directly into the space. In general, the atrium was a comfortably lit space.

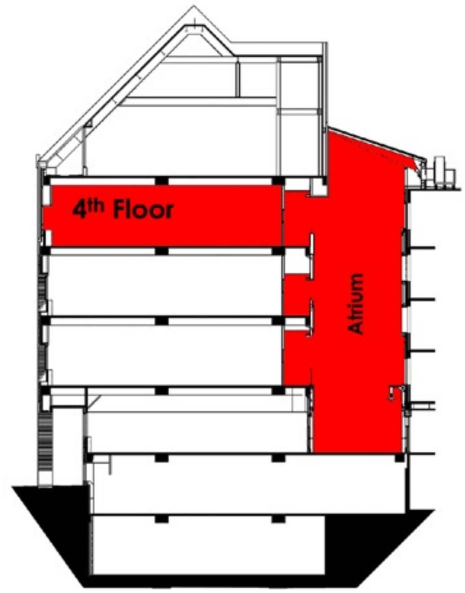


Figure 2.1
Building Section, Van Nuys Medical Science Center.

Figure 2.2 (above)
Photo of the atrium streetscape.
Figure 2.3 (left)
Photo of the flood lights in the atrium.

In Lab A, upon entering the space one of the first things noted were the computers and their proximity to the windows. From inspecting we noted that it was difficult to read a computer screen even when sunlight was not shining directly on the screen, especially with laptop computers. The second thing noticed, was the work surface. The lights overhead were somewhat behind the occupant casting a shadow of the occupant onto the work surface. The shelves above cast shadows onto the walls and the work surface further creating poor conditions at the work surface. Similar conditions occurred in the other labs in the new part of the building.

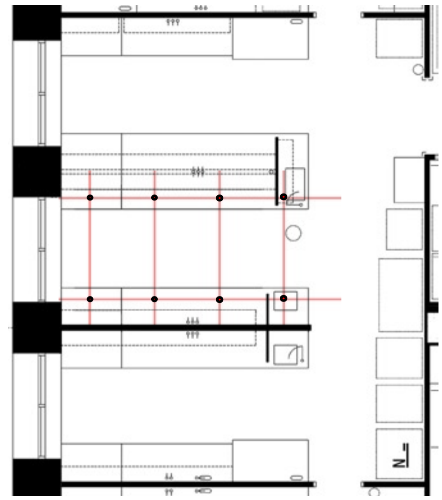
Lab B had more occupants and consequently more computers in the lab. The counter/workstation at the window is set 8 inches below the standard 36 inch tall counter. Computers are located throughout the space with the majority of the laptop computers placed right next to the window (see figure 2.5).

Lab C is located on the southwest corner of the building. Direct beam light from the sun also interferes with computer monitors and instrument displays from late morning to sunset. The workstation near the windows of each counter is also lower than the rest of the counter as in lab B. Also in this lab the shelves are over flowing with supply materials further adding to the shadows cast on the work surface from the lighting. All of the lights inside the laboratory have been replaced with different types of bulbs. This resulted in several different colors of light in the lab.

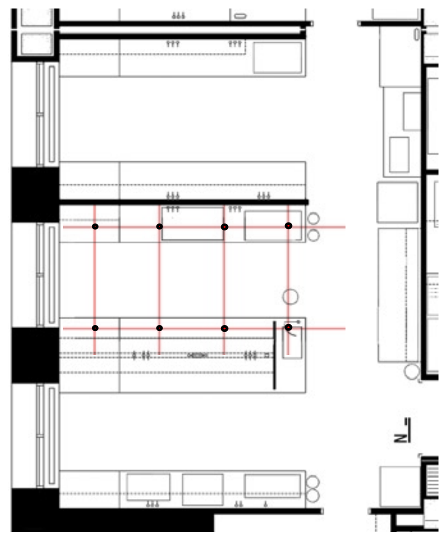
Figure 2.4 (above)
Fourth floor plan, Van Nuys Medical Science Center.

Figure 2.5 (right)
Illustrates the conditions in labs. Note the lower work surface and the proximity of the laptop to the window.

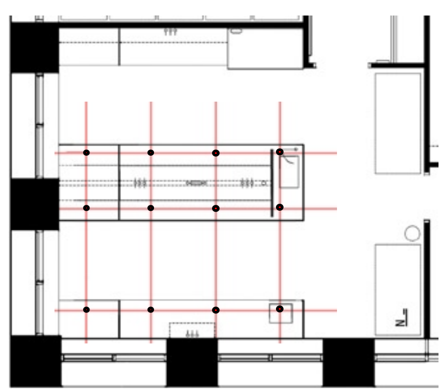
During the second visit we inventoried the finishings and equipment in the space (see box below) and observed the electrical lighting. We focused on our own visual comfort and took photographs illustrating the conditions in the labs. Two different scenarios exist in the three labs that we analyzed. Labs A and B had only West facing windows while Lab C had South facing windows as well as West facing windows. To record the patterns in the labs the spaces were broken down according to the grid as shown on the floor plans (figure 3.1). Hobo™ and Stowaway™ Data loggers (see Appendix C) were placed on the work surfaces on a grid to record the illumination levels every 15 minutes over a two week period in the labs. We were trying to determine the pattern of illumination intensity that existed in each lab and how the pattern is affected by time of day and weather conditions. We wanted to know how daylight affected the overall conditions in the labs. Specifically we wanted to see how much the illumination levels increased when the setting sun penetrated into the labs and how far into the labs the illumination levels were affected. We were also curious if the lights in the labs were turned off when the labs were not occupied.



Lab A



Lab B



Lab C

Figure 3.1

Inventory

The following is an inventory made through observing the three department Labs on the 4th floor of the Van Nuys medical Science Center. Though the layout varies, a fit-out standard applies to each of the labs and presumably in all of the new labs in the addition.

Casework:

Light tan wood base cabinets with wood doors
Light tan wood wall w/ frosted glazing panel doors
Tan metal without a partition
Black work surface

Finishes:

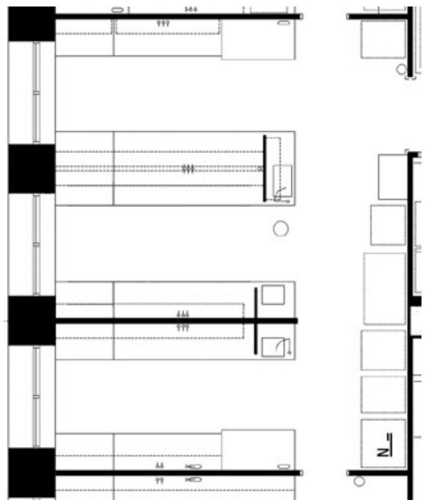
Floor – White tile
Walls – White drywall
Ceilings – White acoustical tile ceiling

Glazing:

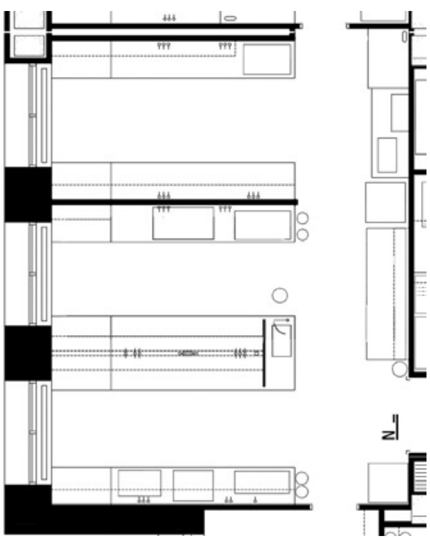
7'-0" wide x 5'-5" tall, tinted glazing flush with ceiling
Interior blinds

Lighting Fixtures:

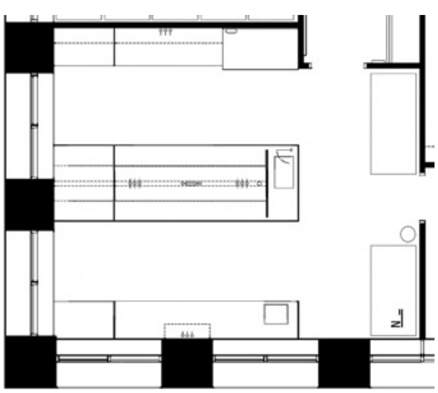
1x4 recessed ceiling fixtures (2 lamps ea.)



Lab A



Lab B



Lab C

Figure 3.2

Hypothesis Part I

The intent of this part of the research was to test how the actual illumination levels in the labs compare to the recommended IES standards. The plan to collect data involved certain assumptions that were made to utilize the instruments efficiently and minimize inconvenience to the occupants.

Assumptions:

The first assumption was that the light levels in the west windows in lab A & lab B are similar, so only one Hobo™ data logger was place in the west window of lab A. The light from the south windows might affect the readings in the west window, so a separate data logger was used for the west window of lab C.

The second assumption was that labs A and B have similar light level patterns. This allowed us to accommodate for the higher occupancy level in lab B. The number of instruments placed in this lab was reduced because of limited counter space due to the number of occupants and quantity of computers and equipment. The amount of open counter space in lab A accommodated the placement of data loggers systematically without interfering in the tasks of the occupants.

The third assumption accounts for the congestion in Lab C; instruments could not be placed on an exact grid to collect data, variations between 6 and 12 inches were assumed to not be significant enough for illumination pattern detection inside the labs.

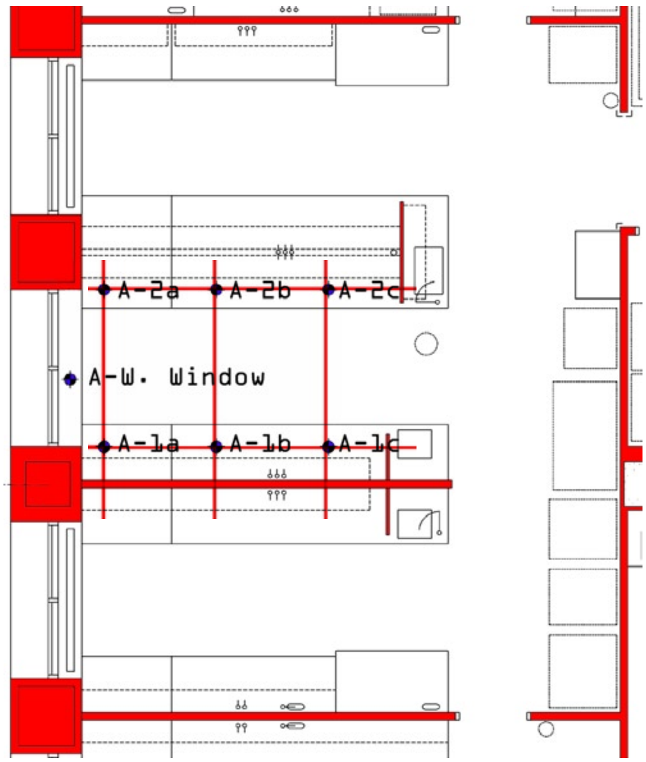
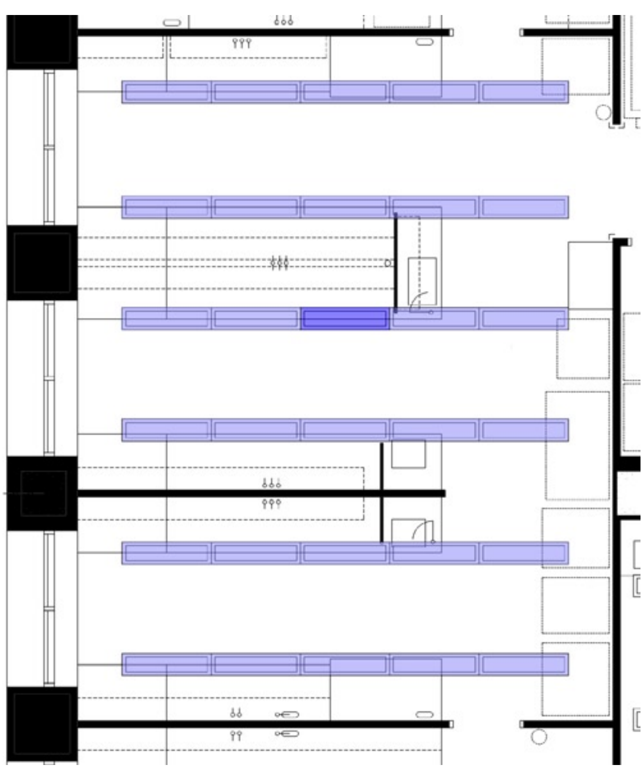


Figure 3.3 Lab A Data logger layout



Data collection:

The center bay of labs A and B were chosen to see how the solid walls with cabinets affected the illumination levels compared to the conditions created by the shelves without a partition to visually separate it from the adjacent bay.

In lab A, a Hobo™ data logger was placed in the west facing window. Six Stowaway™ data loggers were placed 12 inches from the edge of the work surface down the length of two work stations of the center bay; perpendicular to the west facing windows (see figure 3.3). The first data logger for each counter was placed one foot from the west facing wall, and the other two data loggers for each counter were placed at 5ft intervals. Figure 3.4 shows the lay-out of the fixtures within Lab A. Also indicated are the lamp types within the fixtures as of 11/27/02.

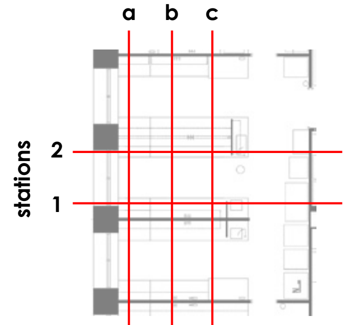


Figure 3.4
Lab A reference grid.

Figure 3.5
Lab A Fixture layout & lamp types (all lamps are T8's):

Sylvania E32W Octron 4100°K

GE 32W 3500°K

Lab B, three Stowaway™ data loggers were placed as close as possible to the grid established in lab A to verify if the illumination levels at specific points in this lab were the same as those in lab A (see figure 3.5). The two data loggers placed near the west facing wall are 8 inches below the standard lab work surface. A fourth Stowaway™ was placed across the circulation path, adjacent to the interior (east) wall of the lab. This data logger was placed on top of a computer, 18 inch above the level of the other data loggers in the lab. Figure 3.6 shows the layout of the fixtures within Lab B and the lamp types within the fixtures as of 11/27/02.

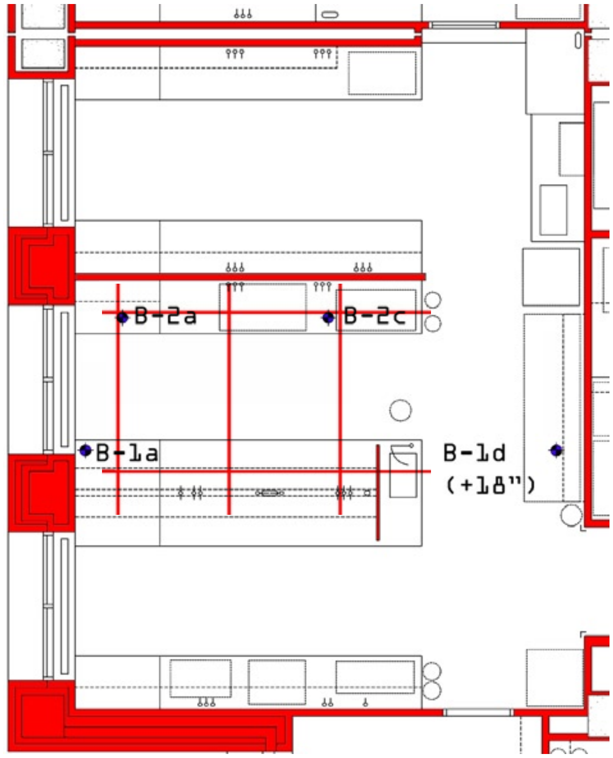


Figure 3.6 Lab B Data logger layout

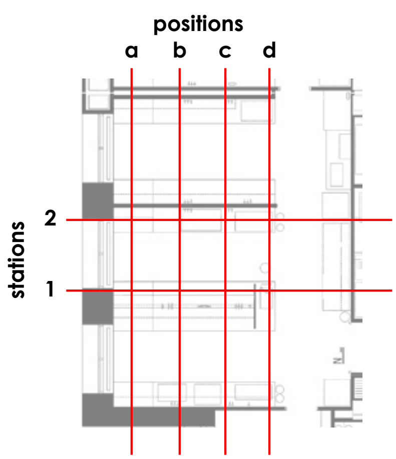
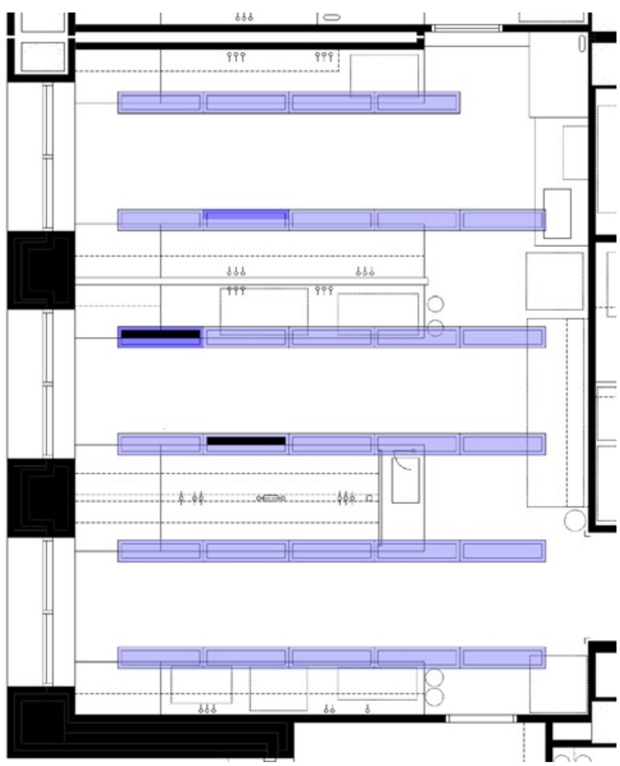


Figure 3.7
Lab B reference grid.

Figure 3.8
Lab B Fixture layout & lamp types (all lamps are T8's):

- Phillips TL80 E 3500°K
- GE 32W 3500°K
- Burnt out bulb



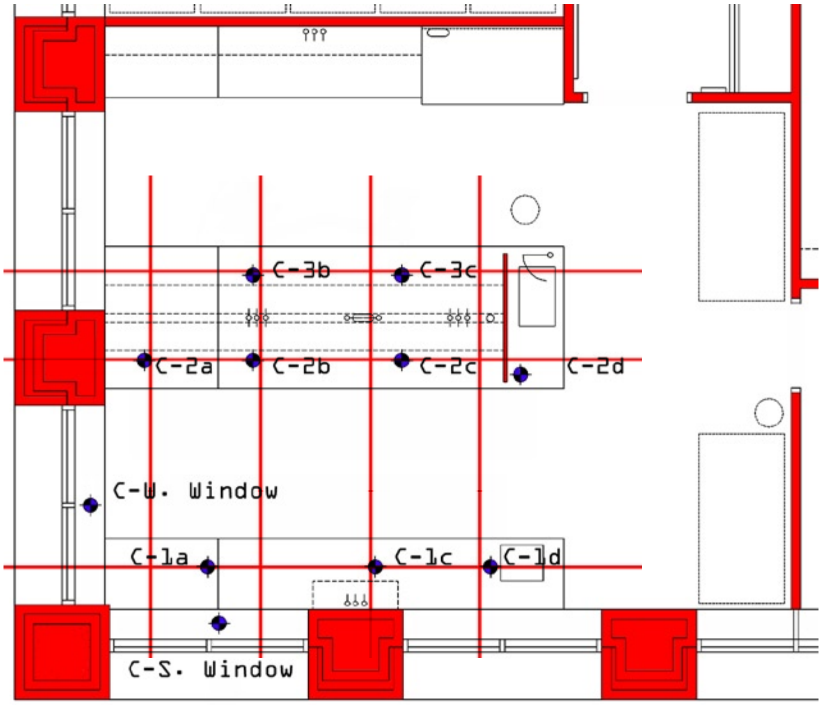
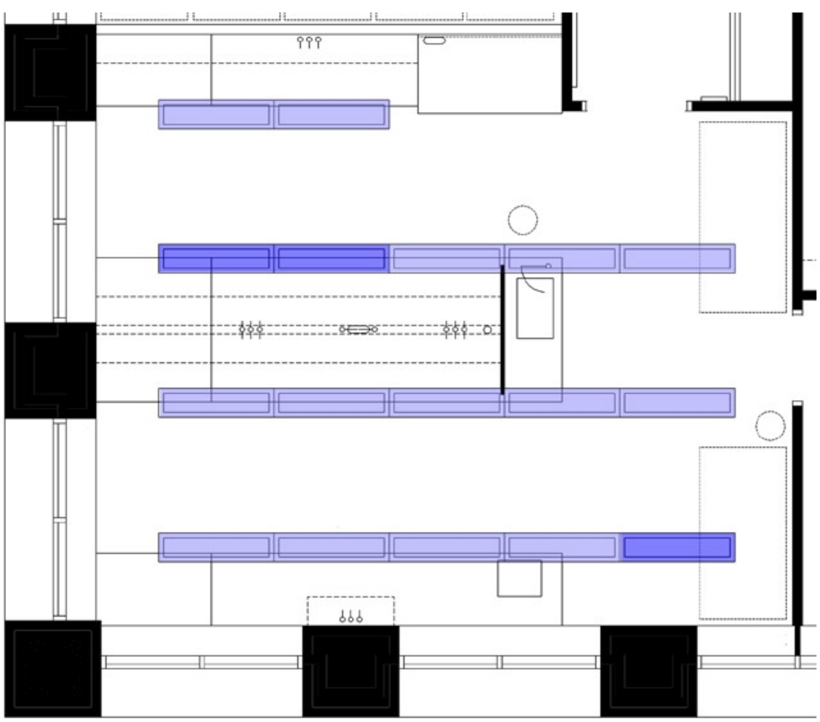


Figure 3.9 Lab C Data logger layout

Lab C, one Hobo™ data logger was placed in a west facing window and a second one was placed in a south facing window (see figure 3.7). Nine Stowaway™ data loggers were placed in this lab as close to the established reference grid from Lab A as possible in order to establish overall light patterns as well as sectional lighting levels perpendicular to the both the west and south facing glazing in Lab C. Figure 3.8 shows the layout of the fixtures within Lab C and the lamp types within the fixtures as of 11/27/02.



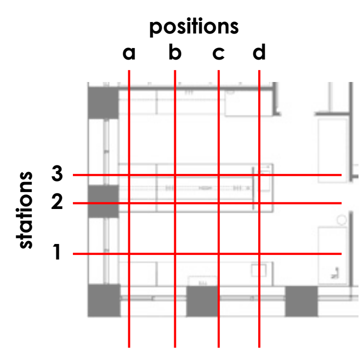


Figure 3.10
Lab C reference grid.

Figure 3.11
Lab C Fixture layout & lamp types (all lamps are T8's):

Phillips TL80 E 3500°K

GE 32W 3500°K

Hypothesis Part II

This portion of the research intended to quantify the lighting conditions within the visual field of the occupants at their workstations.

Grayscale / Visual Field Mapping

Visual field maps were constructed using a thorough understanding of the anatomy of the eye and the field of vision. The foveal vision lies within only 1° of the 180° field of view. Photos of the visual fields at some of the workstations were taken with a digital camera; this is the base image (figure 3.12). With the aid of Photoshop, the image complexity was then reduced to four scales of gray (figure 3.13) to simplify and identify hotspots located in the field of view. In order to properly and accurately take and record luminance values the manipulated gray scale images were reduce to edge maps (figure 3.14).

The eyes acute ability to distinguish fine detail is achieved when the ratio between the immediate background and the central task is between 1:1 and 4:1. The near surround lies within 60° of the field of vision and allows for contrast ratios of 10:1. While the 120° far surround, which accounts for the rest of the visual field, allows for contrast ratios of 100:1.

Data collection:

With the field maps as guides a Minolta LS-100 Spot luminance meter was used to record the values at 5 stations; two in Lab A, one in Lab B, and two in Lab C.

Figure 3.12
Example base image.

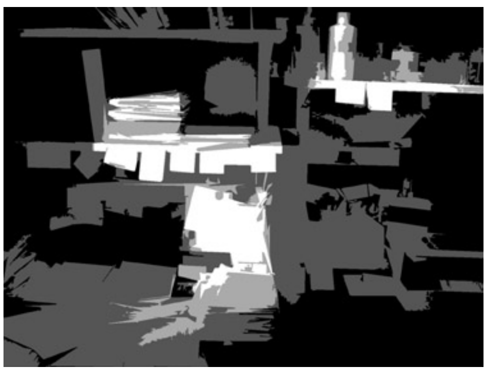


Figure 3.13
Example tone image.

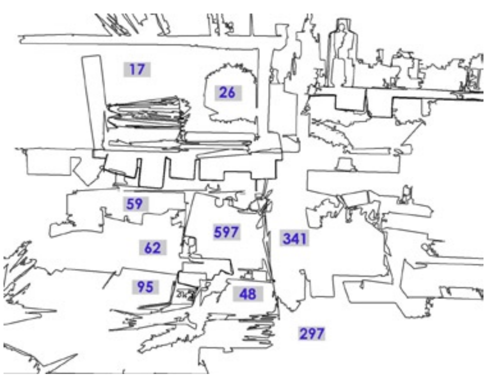


Figure 3.14
Example edge map with spot luminance readings.

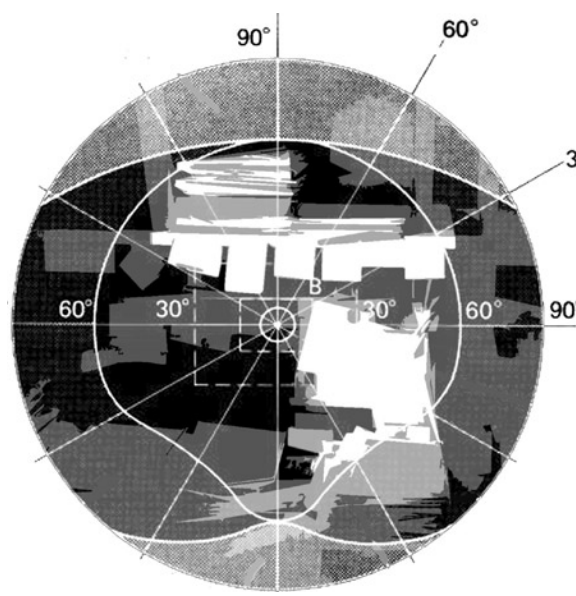


Figure 3.15 (right)
Example foveal vision overlay.

DIAGNOSTIC PHASE

FIRST HYPOTHESIS

A pattern Similar to Lab A occurs in Lab B, confirming our assumption that the lighting conditions within the two labs are similar. The graphs show that the pattern of light levels at station 2a and 2c in Lab A are similar to those of station 2a and 2c in Lab B (figure 4.1 and 4.2). For Lab B, it will be assumed that the illuminance patterns are the same as the illuminance patterns in Lab A. This should hold true for the remainder of the labs along the length of the building except for the Labs at the southwest corner of the building (Lab C).

LONG TERM PATTERN ANALYSIS

The results from the data loggers indicate that the lighting levels in the labs do not behave as anticipated. The light levels actually increase as the distance from the windows increases. We attribute this to the fact that at the end of the counter, additional light from the fixtures of the adjacent bays are reaching the workstation. The work station in the middle receives light from the current bay only. The work station closest to the windows receives the least amount of light because the line of fixtures stops 18 inches from the wall, giving light only from one direction.

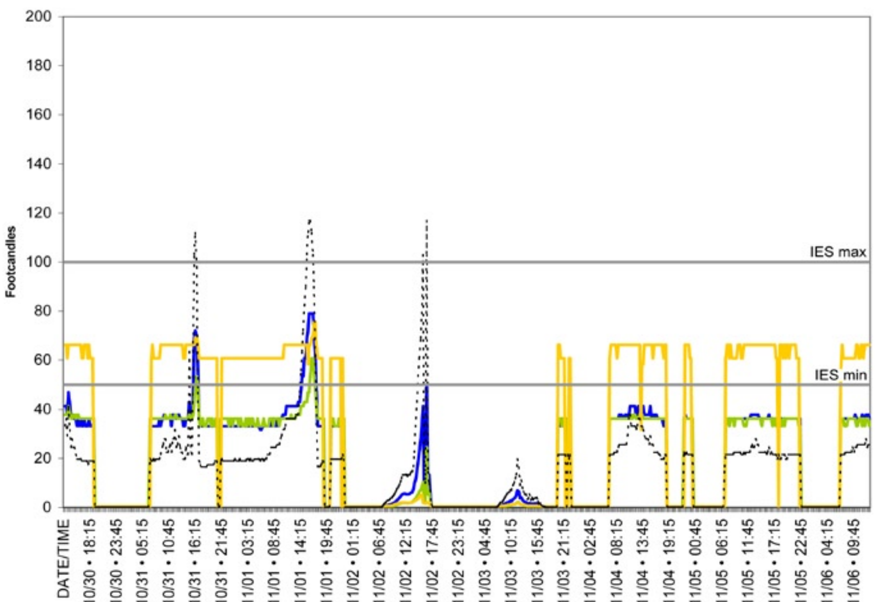


Figure 4.1
7 Day illuminance level graph for Lab A counter 2.

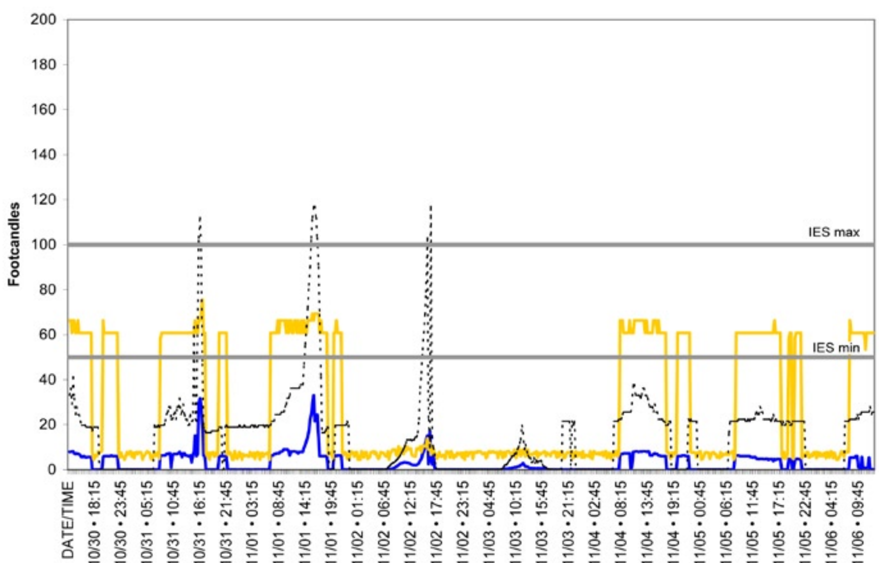


Figure 4.2
7 Day illuminance level graph for Lab B counter 2.

Illuminance pattern analysis of Lab A

The first week of data was excellent for study. Thursday Friday and Saturday were sunny days and the rest of the week was cloudy. The lights were turned off for the weekend giving us the illuminance levels for natural lighting only. The three peaks indicate where direct beam sunlight entered the space in the evening. The plateaus indicate the levels of artificial light in the lab. Notice that the station at the interior end of the counter (A 2c) is considerably higher than the other three. This is because the lines of fixtures for each bay extended into the circulation aisle along the interior wall of the lab (see figure 4.4).

Station C on counter 2 recorded the highest sustained illumination levels; the only one to remain above the minimum IES recommended levels. At 120 *fc*, the levels exceed the maximum IES recommendations when the setting sun enters the space. Illumination levels at station A and B exceed the minimum IES recommended levels when the setting sun enters the lab in the evening; occurring for only 3 hours of the work day.

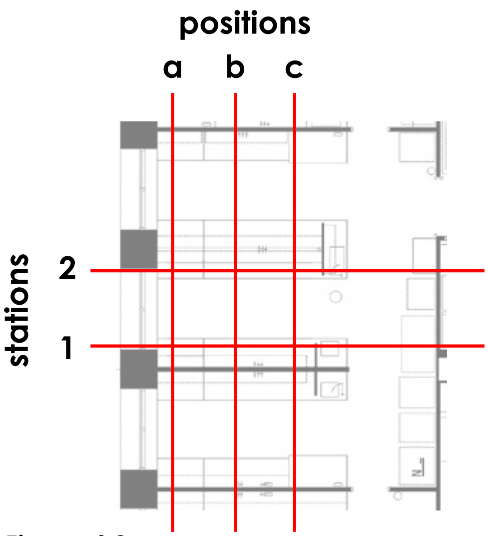


Figure 4.3
Lab A reference grid.

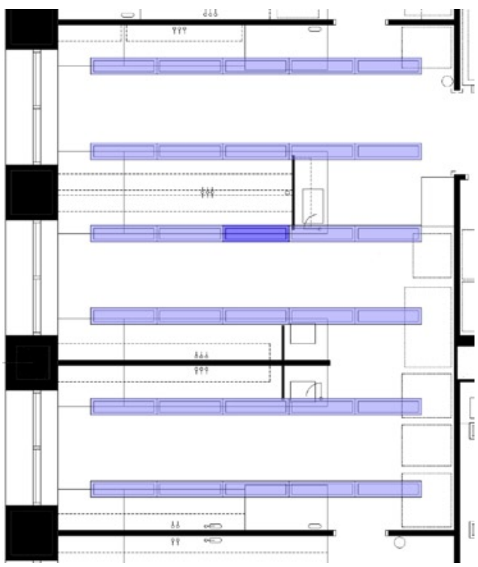


Figure 4.4
Lab A fixture Layout.

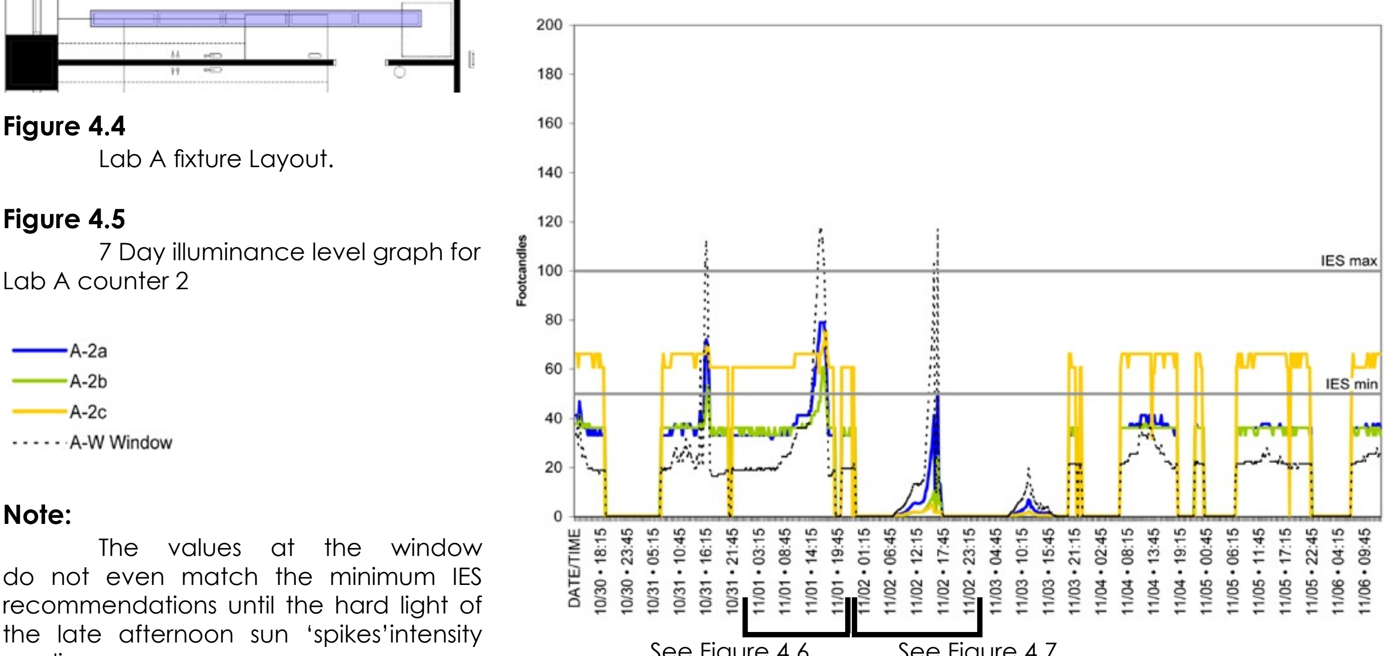
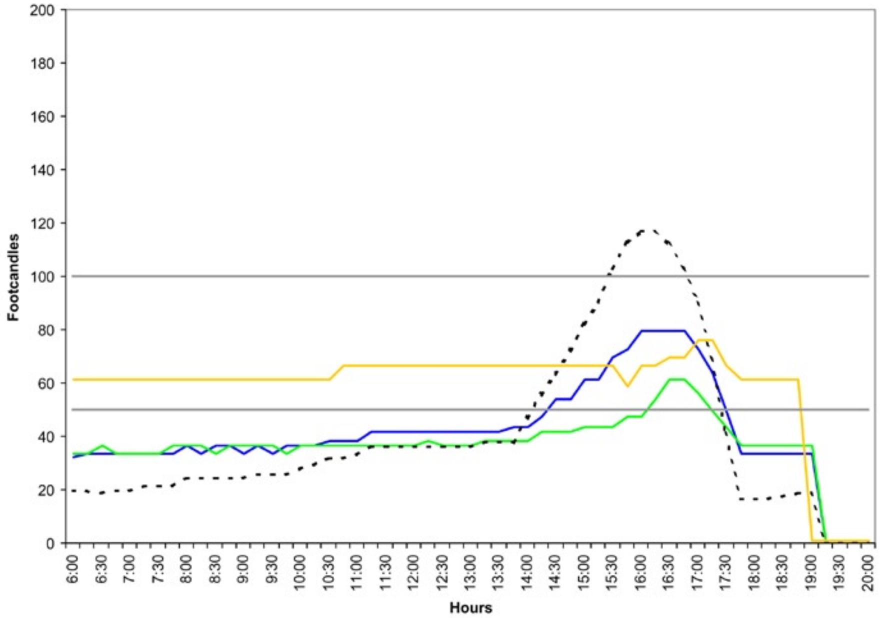


Figure 4.5
7 Day illuminance level graph for Lab A counter 2

Note:
The values at the window do not even match the minimum IES recommendations until the hard light of the late afternoon sun 'spikes'intensity readings.



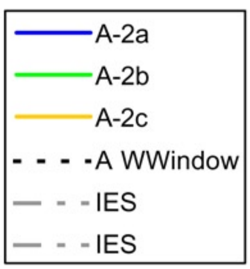
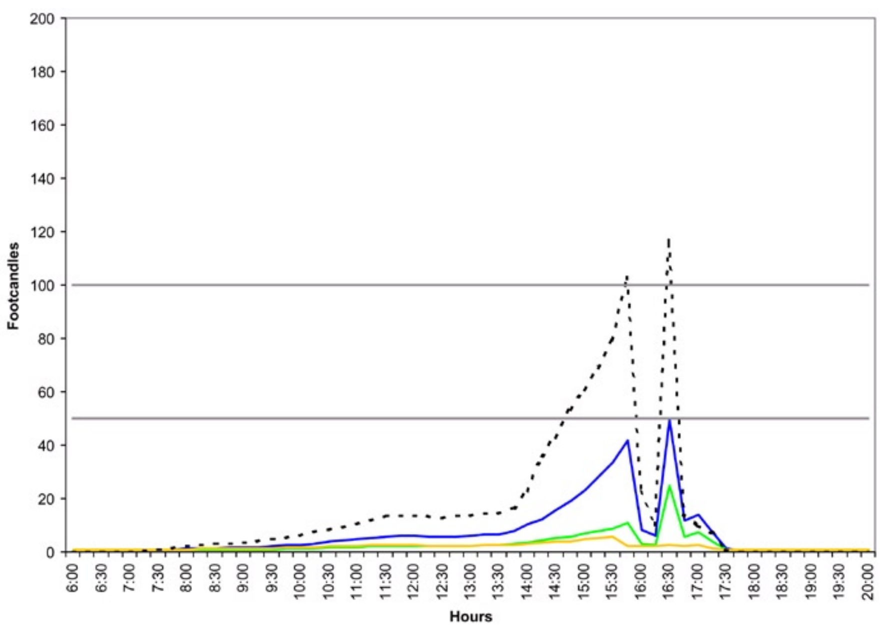


Figure 4.6 (above)
1 Day illuminance level graph for Lab A counter 2 (**November 1**).

Figure 4.7 (below)
1 Day illuminance level graph for Lab A counter 2 (**November 2**).

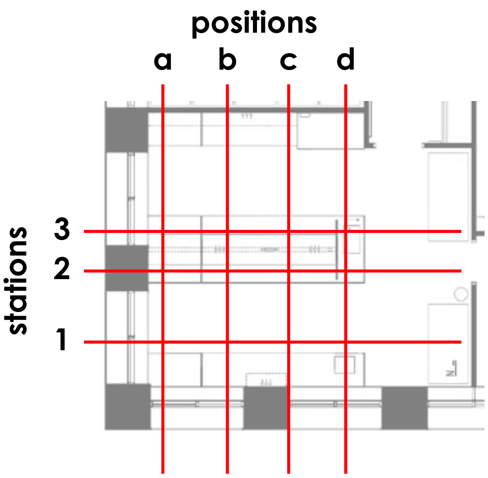


November 1st:

The lights are on for an extended period of time on this day presumably due to a particular test being run that night. A look at the week long data (figure 4.5) indicates lab use the entire night before except for a short period of time where the lights were turned off. The levels drop again while the lab is unoccupied and rise again when the occupants return to continue work.

November 2nd:

This graph isolates the contribution from natural light to the overall scheme of the lab. We presume that a cloud caused the unexpected drop in illumination on Saturday November 2nd because all of the data loggers on the counter were affected. As expected the illuminance levels decrease as the distance of the room increases. The amount of light from the window does not contribute a significant amount of light to accommodate the decrease in artificial light levels.



Illuminance pattern analysis of Lab C

Similar to Lab A, the data loggers recorded a peak in the evening caused by the setting sun. The peek is higher in this lab (152 *fc*) due to south facing windows as well. Station D (located at the circulation path in the lab) recorded the highest constant illuminance levels while Station A recorded the lowest levels. The highest level was recorded at station B, 189 *fc* on Friday and 152 *fc* on Saturday. Both instances exceed the illuminance levels recorded by the data logger placed in the west window. On Friday all stations show illuminations above the IES recommended minimum except for station 'b'.

To see the graphs of the remaining data for the labs, turn to Appendix C.

Figure 4.8
Lab A reference grid.

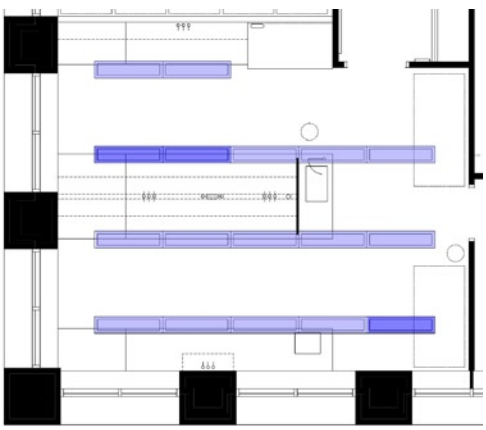
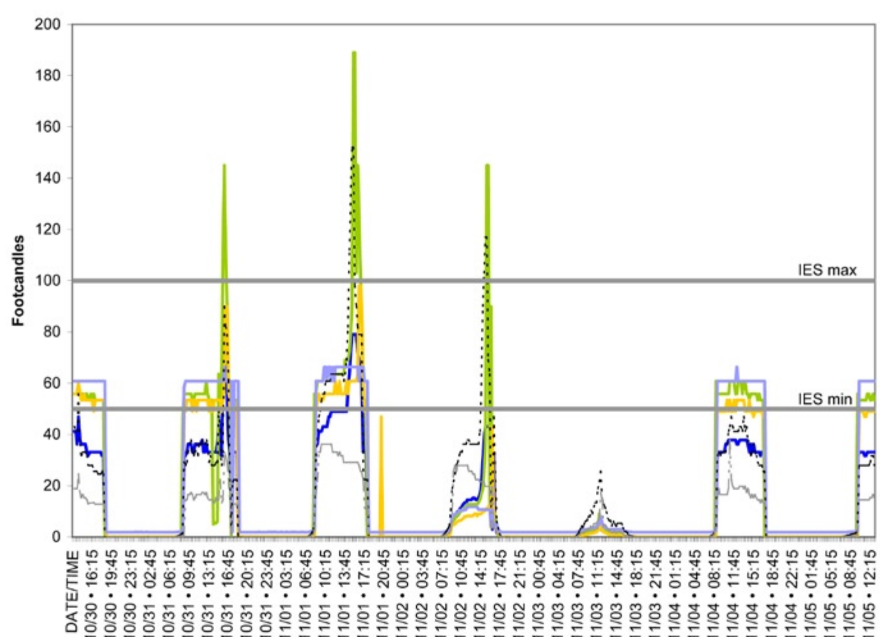
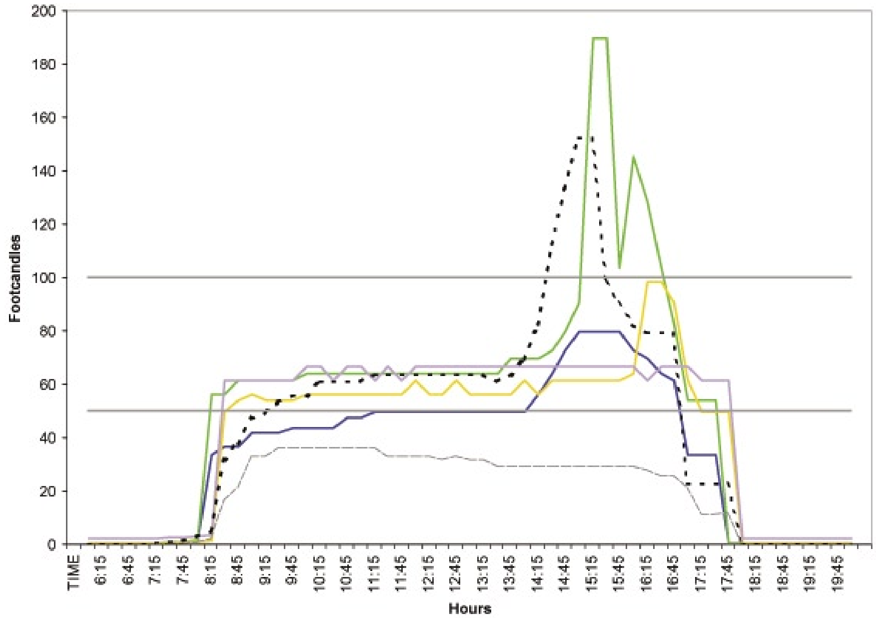


Figure 4.9
Lab C fixture layout.

Figure 4.10
7 Day illuminance level graph for Lab C counter 2.





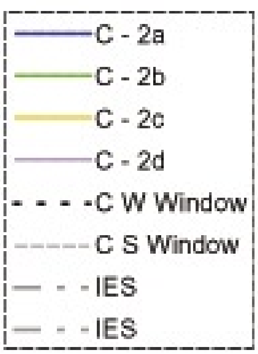
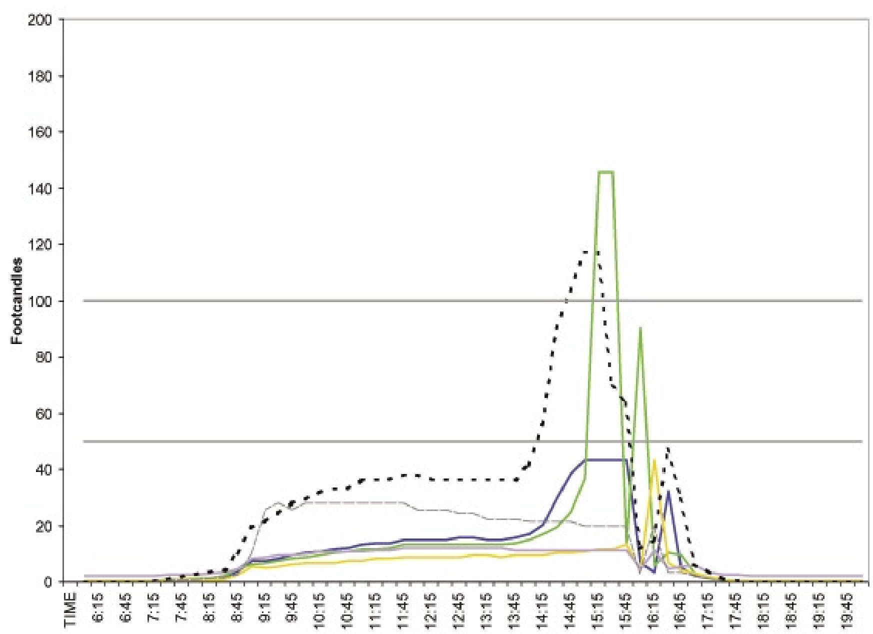


Figure 4.11 (above)

1 Day illuminance level graph for Lab C counter 2 (**November 1**).

Figure 4.12 (below)

1 Day illuminance level graph for Lab C counter 2 (**November 2**).



November 1st:

The lights are on for the expected length of time on this day. A look at the week long data indicates no deviation for an expected work day. Position 'a' at station 2 was lower and had less variation than position 'b'. This is due to the lower work surface at this position and the placement of a computer monitor at this position. Direct beam light from the sun did not strike position 'a'. The double peak at position b was probably cause by obstruction of the data logger by the occupants.

November 2nd:

This graph isolates the contribution from natural light to the overall scheme of the lab. We presume that a cloud caused the unexpected drop in illumination on Saturday November 2nd because all of the data loggers on the counter were affected. As expected the illuminance levels decrease as the distance of the room increases. The amount of light from the window does not contribute a significant amount of light to accommodate the decrease in artificial light levels; except for the behavior at station 'a' as indicated above.

Section Line Graph

The section line graphs represent a cross-section of the illumination levels through the labs perpendicular to the windows. The different lines represent four times during the course of the day. First in the morning, at 11:00 and one in the evening at 19:00 and the two points in the afternoon where the highest illuminance levels were recorded, 15:30 and 16:30.

The IES recommended minimum and maximum are represented in the graph to establish scale.

Lab A

The November 1st graph shows how the light inside the lab is coming in from the window but the artificial illumination is below the IES recommendations. Position C is the exception since added light comes from the adjacent bays where the lines of fixtures extend into the circulation path. The levels at all of the stations exceed the minimum recommended level once the setting sun begins to enter into the lab.

The November 2nd graph shows just how the daylight is coming through the window and is decreasing as the distance from the window increases.

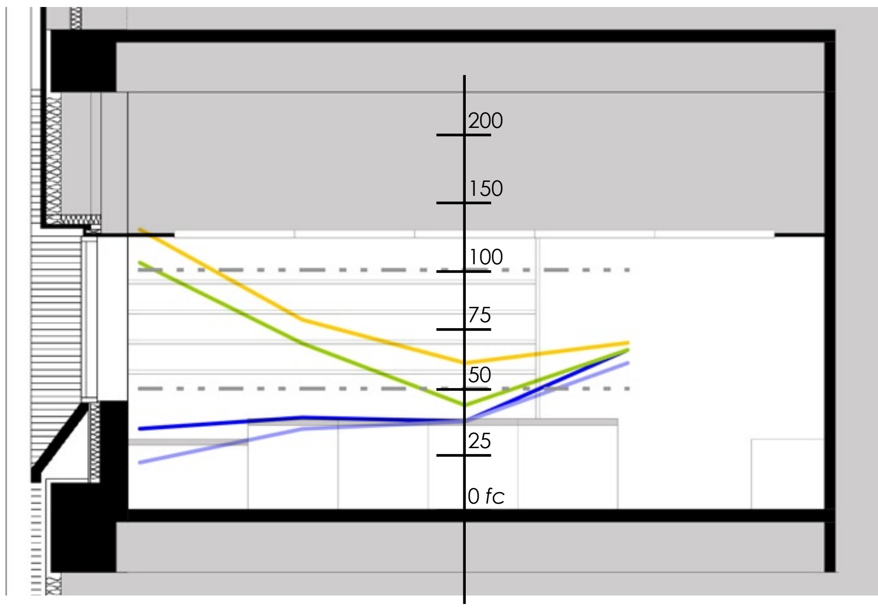


Figure 4.13
Nov. 1st, 2002, section illuminance line graph for Lab A counter 2.

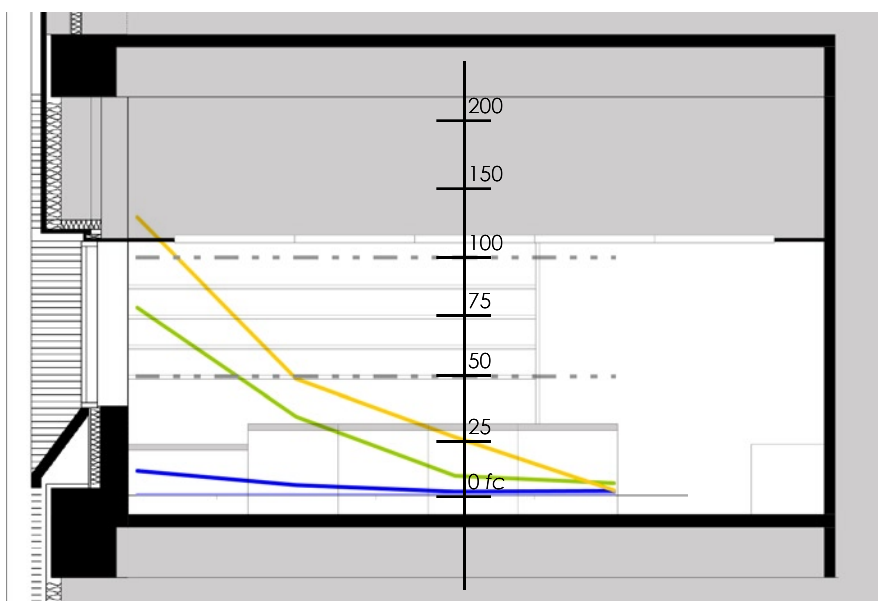


Figure 4.14
Nov. 2nd, 2002, section illuminance line graph for Lab A counter 2.

Lab C

For Lab C we studied the counter in the same way as for Lab A. We chose to show the data according to the grid we established in the other labs as a way to show the general behavior in the room. Due to the placement of instruments in this lab, the data loggers were not able to be placed exactly on the grid as the graphics seem to represent.

Compared to the graph for Lab A, we observed there is a peak in the middle due to light from the west window coming through. The overall illuminance levels are higher in Lab C; easily falling within the IES recommendations on November 1st.

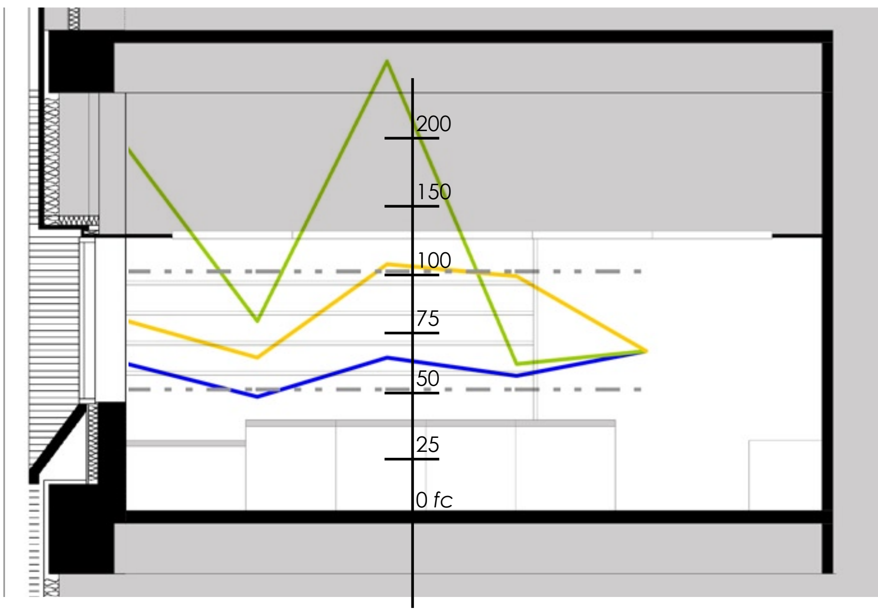


Figure 4.15
Nov. 1st, 2002, section illuminance line graph for Lab C counter 2.

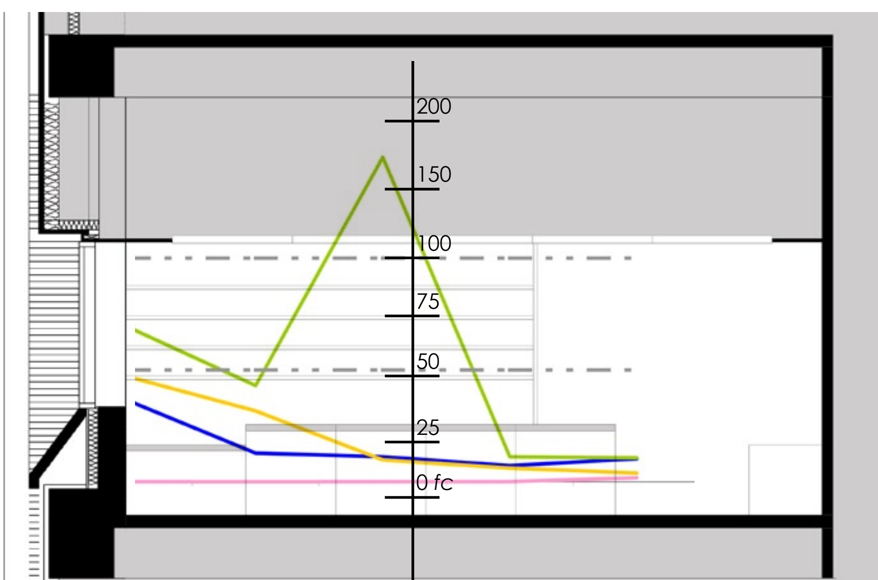
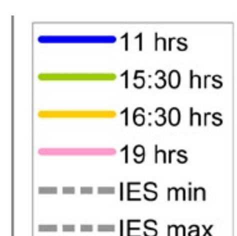


Figure 4.16
Nov. 2nd, 2002, section illuminance line graph for Lab C counter 2.



3D Illuminance Models of Lab C

These graphs were used to visualize the illumination levels in the lab generated by the natural light from the west and the south directions. The values in the grid for positions without instruments were estimated to avoid deformities in the plot caused by placing a zero in the space.

Figure 4.13 shows how the artificial lighting illuminates the space with little natural light. Without direct beam illumination from the sun, the pattern from the previous labs holds true, the illuminance levels increase farther from the west facing windows. This condition does not seem to exist in relation to the south facing window; the light levels seem to be level unless direct beam sunlight is entering the space.

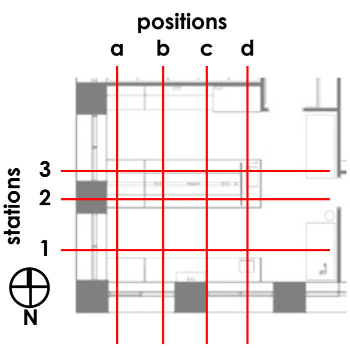
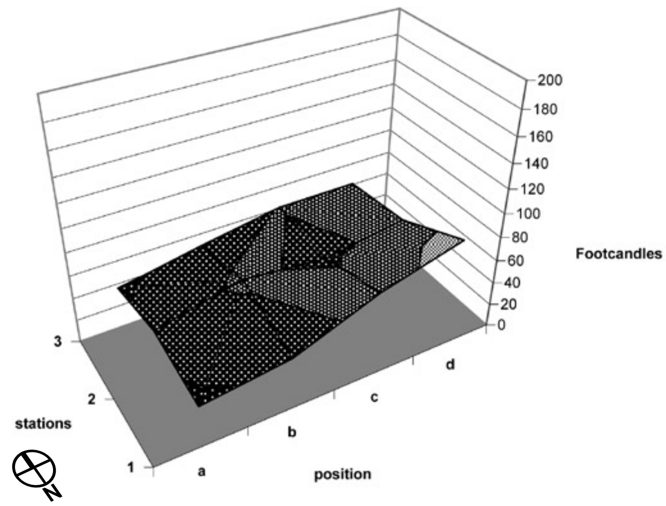
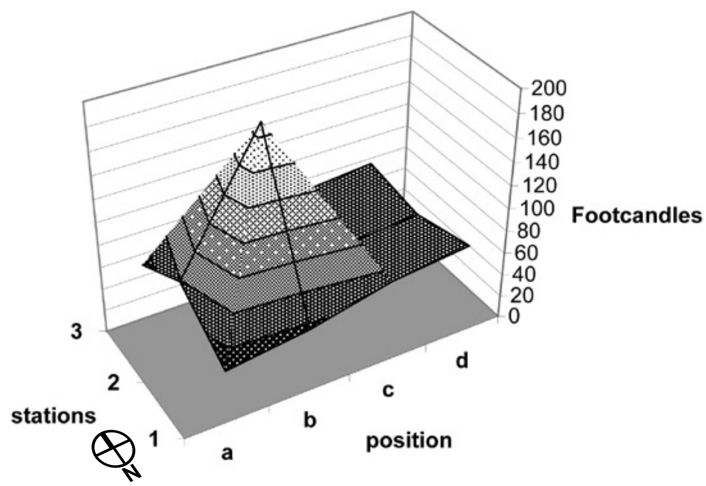


Figure 4.17 (above)
Lab C reference grid





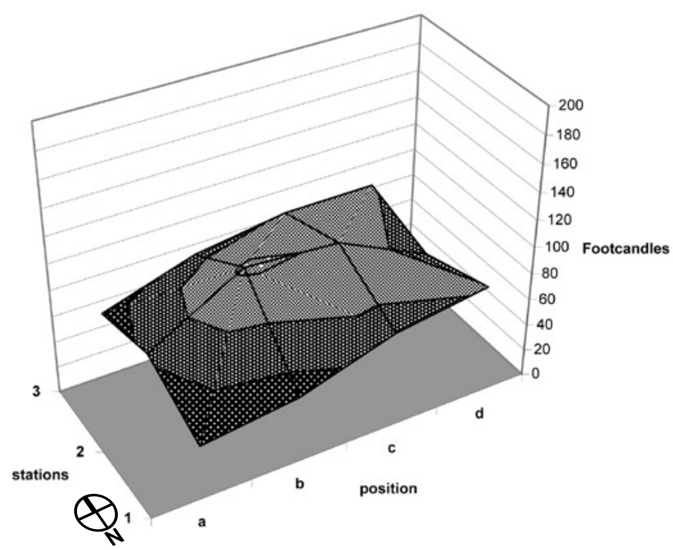
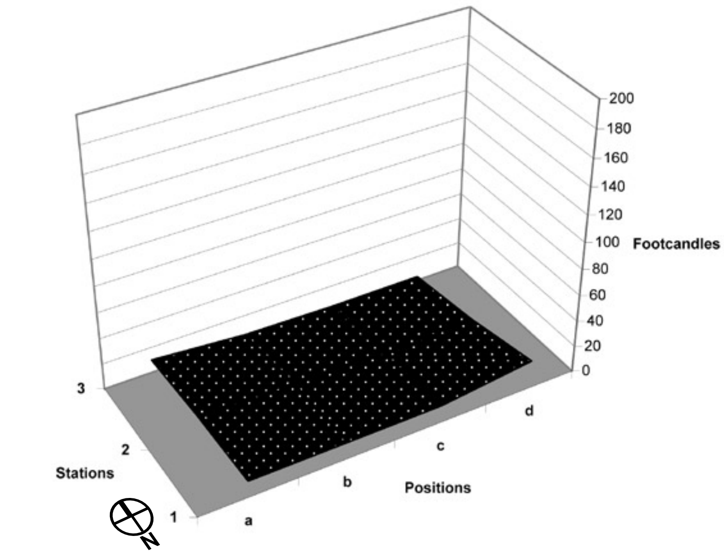


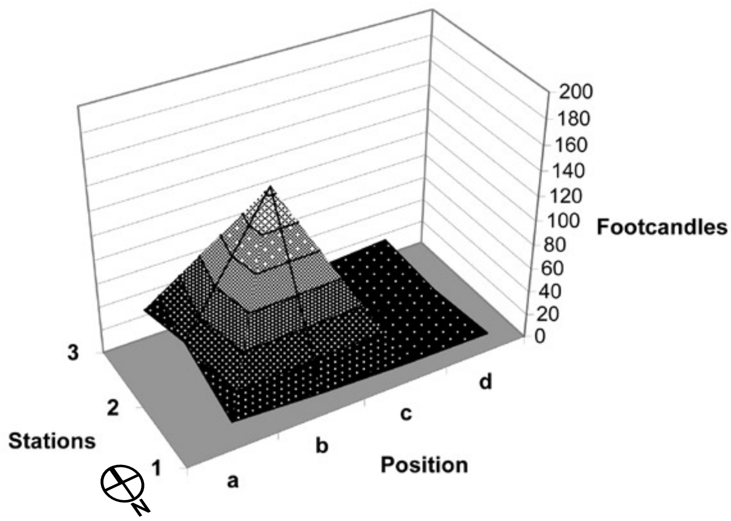
Figure 4.18 (top)
11:00 Nov. 1st, 2002, 3D

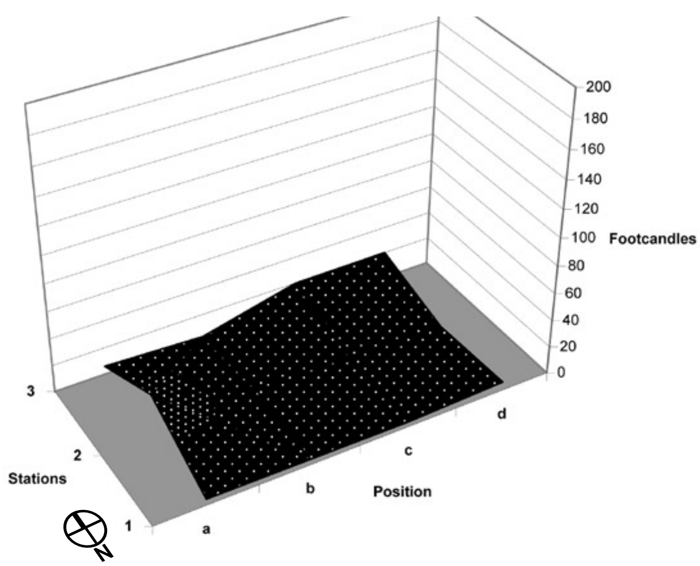
Figure 4.19 (middle)
15:30 Nov. 1st, 2002, 3D

Figure 4.20 (bottom)
16:30 Nov. 1st, 2002, 3D

These graphs show how drastically the illuminance levels increase at the first station of the second counter. Figure 4.18 shows the illuminance levels for the space on a clear day during the week with the artificial light contributing. Figure 4.21 shows the same conditions on a clear day during the weekend when the artificial lights are turned off.







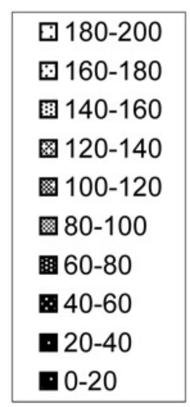


Figure 4.21
Key for 3D Illuminance graphs

Figure 4.22 (top)
11:00 Nov. 2nd, 2002, 3D

Figure 4.23 (middle)
15:30 Nov. 2nd, 2002, 3D

Figure 4.24 (bottom)
16:30 Nov. 2nd, 2002, 3D

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Lab A Foveal Vision Analysis 1

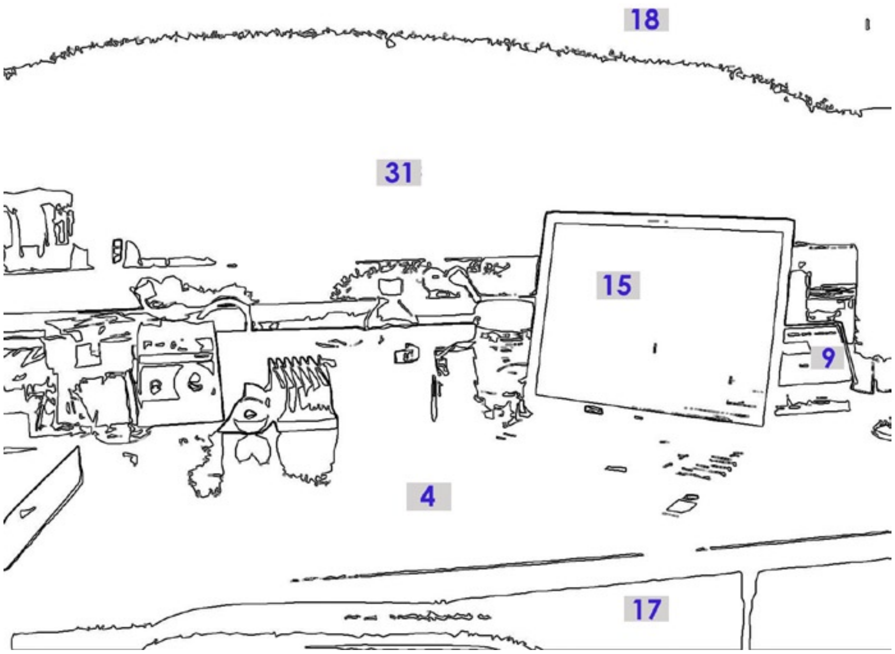


Figure 4.25
Lab A study 1 edge map.

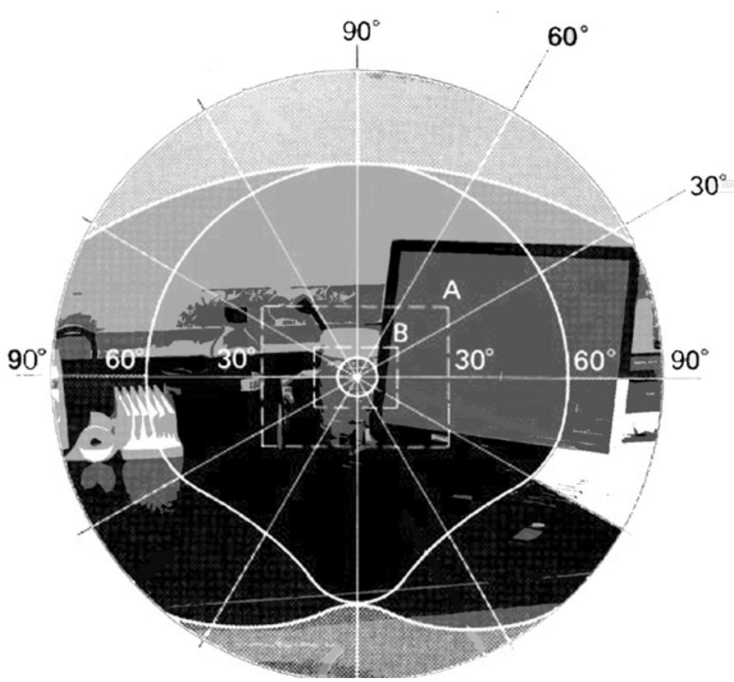


Figure 4.26
Lab A study 1 foveal overlay.

Figure 4.27 Base image

Figure 4.28 Tones

That greatest difference (approx. 8:1) occurs between brightness of the wall (31 *fl*) and the brightness of the countertop (4 *fl*). The luminance levels from the screen of the laptop computer are about half those of the wall behind it and are almost the same as the part of the wall behind which is in the shadow of the wall-mounted cabinets. Including the full peripheral space brightness ratios remain within the recommended maximum of 10: 1 for highly precise visual tasks. See Appendix F for more information regarding lighting ratios for specific situations.

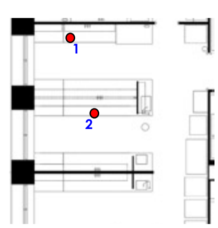


Figure 4.29
Lab A foveal study locations.

Lab A Foveal Vision Analysis 2

Figure 4.32 Base image

Figure 4.33 Tones

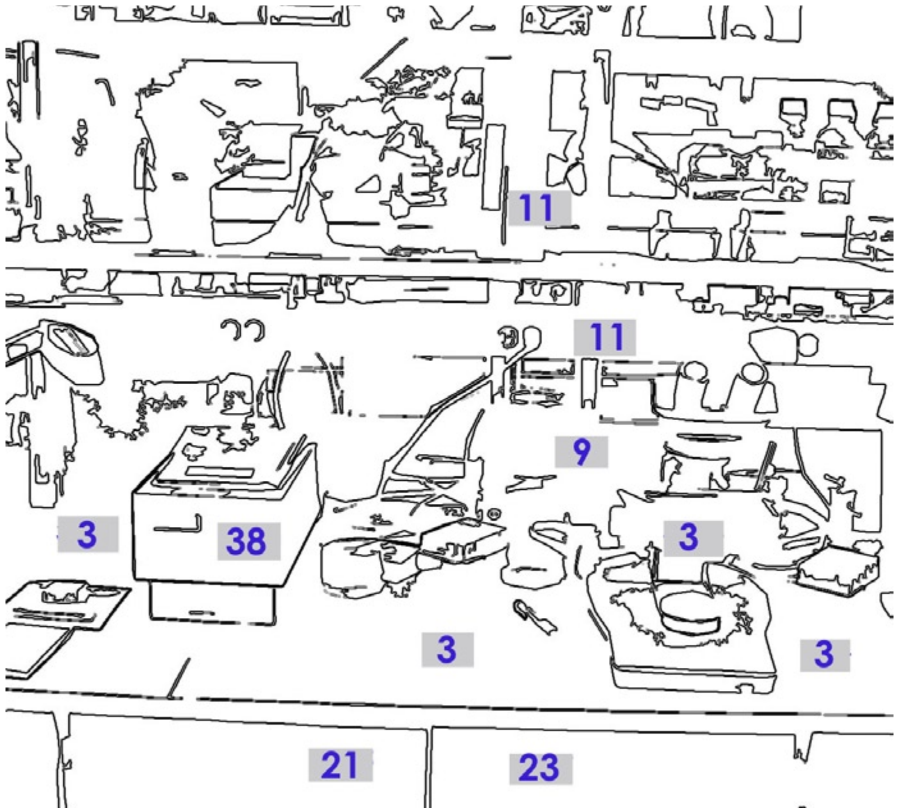


Figure 4.30
Lab B study 2 edge map.

The second analysis in lab A shows low differentiation in luminance levels from various surfaces at this work station as well. The greatest difference (approx. 13:1) occurs between the countertop (3 *fl*) and the light colored plastic casing of the instrument on the counter slightly to the left (38 *fl*). This does not cause a problem however because the bright spot is not bright enough at this ratio to cause disruption in the eyes perception. In general, the entire work space remains within the optimal ratio 4:1. See Appendix F for more information regarding lighting ratios for specific situations.

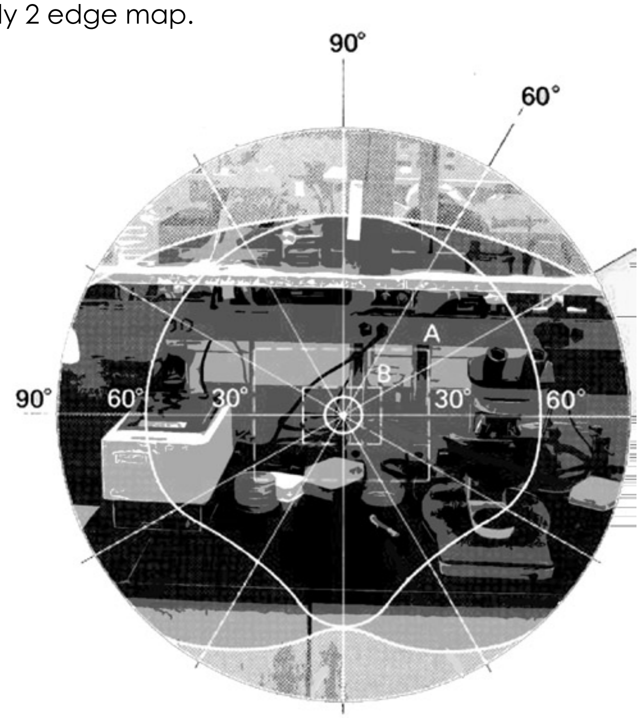


Figure 4.31
Lab B study 2 foveal overlay.

Lab B Foveal Vision Analysis

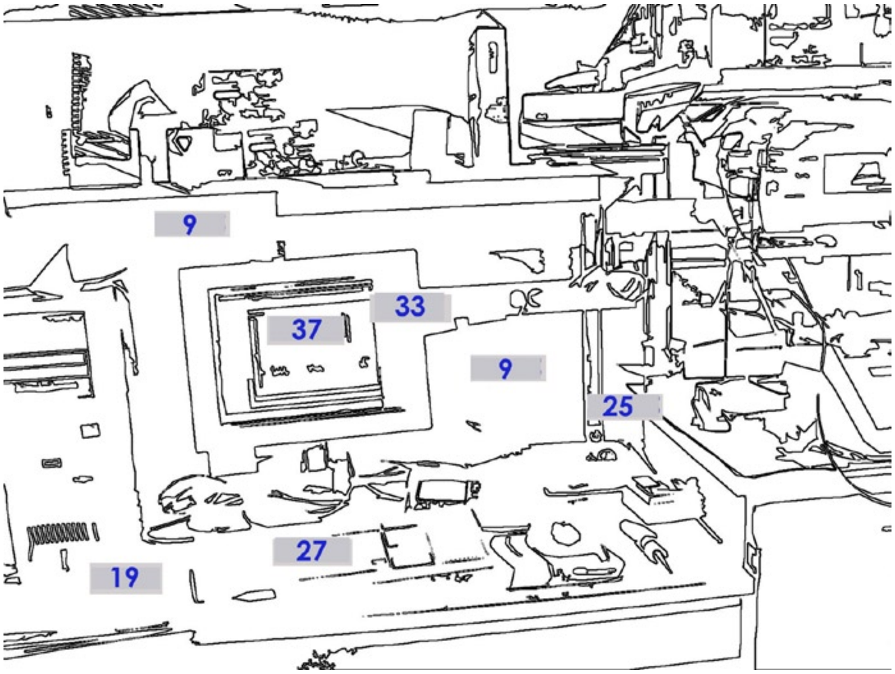


Figure 4.34
Lab B study edge map.

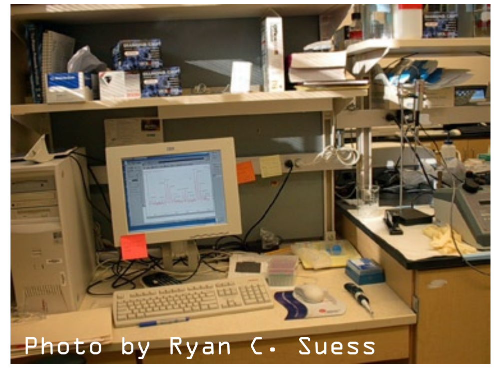


Figure 4.36 Base image

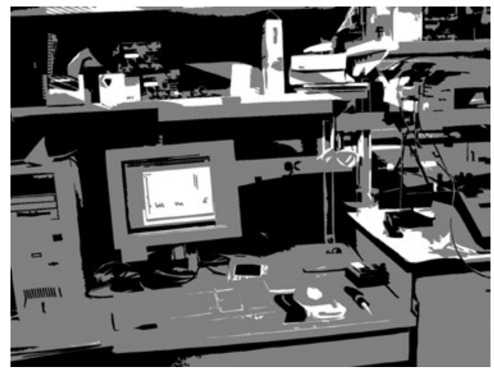


Figure 4.37 Tones

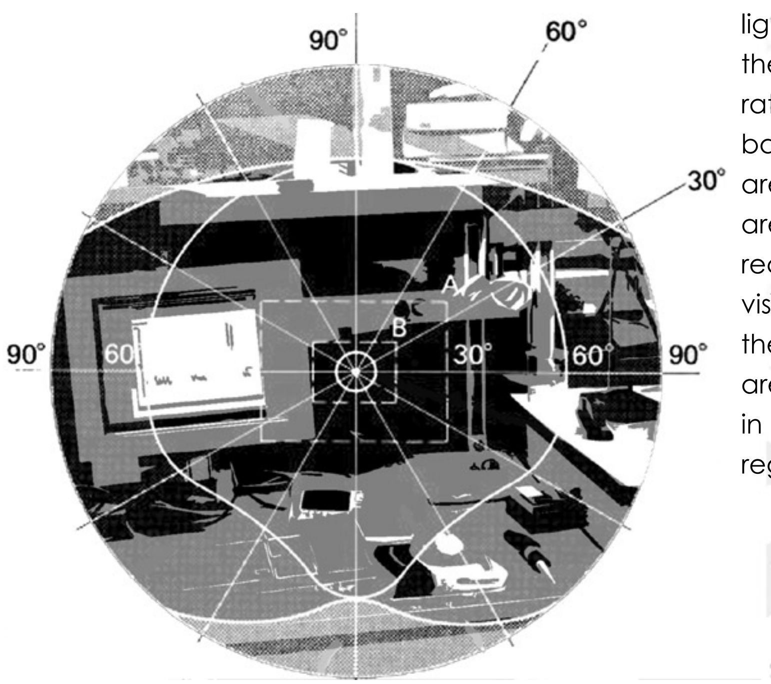


Figure 4.35
Lab B study foveal overlay.

This work station has high variations in luminance with the sun entering directly into the space. However, the surface of the counter is a light color similar to that of the shelving units and the computer case, maintaining a low differential ratio between the central task and the peripheral background. The hot spots that occur on the shelf are approximately 50° outside the foveal vision area. In general the entire work space is within the recommended 10:1 maximum for highly precise visual tasks. With a largely uniform coloration of the surfaces within this station, the luminance levels are higher overall than at the other work stations in the lab. See Appendix F for more information regarding lighting ratios for specific situations.

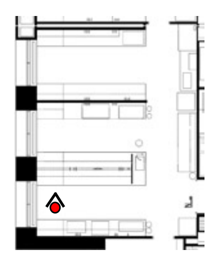


Figure 4.38
Lab B foveal study location.

Lab C Foveal Vision Analysis 1

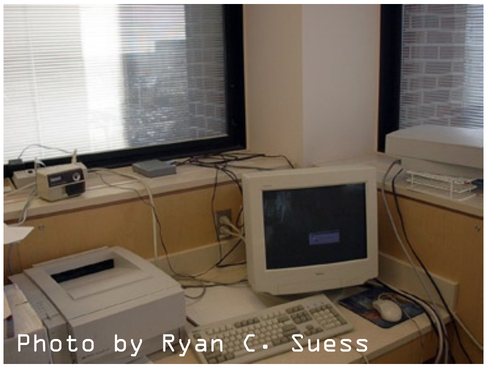


Figure 4.41 Base image

Figure 4.42 Tones

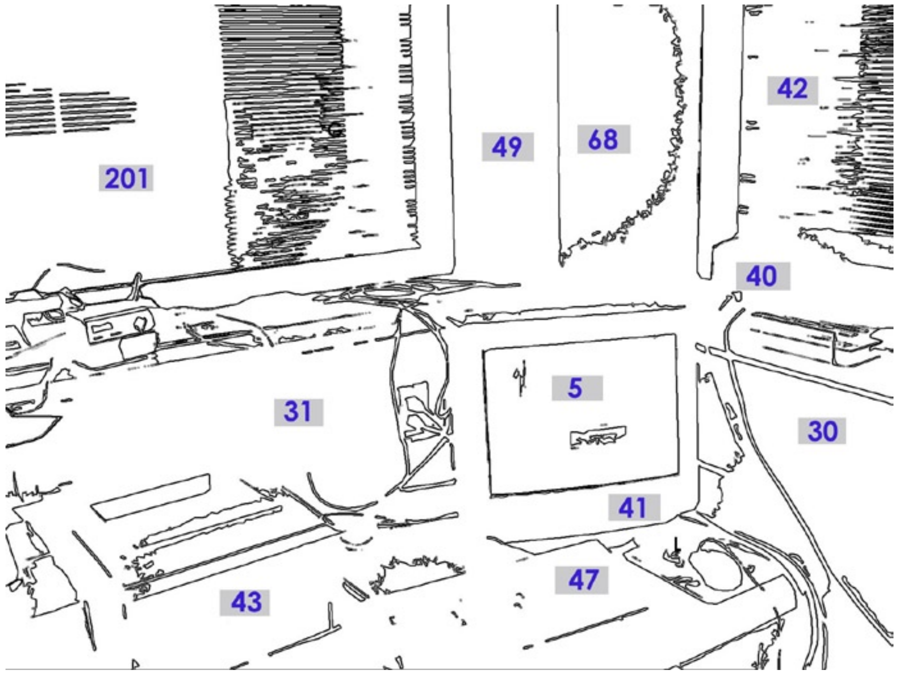
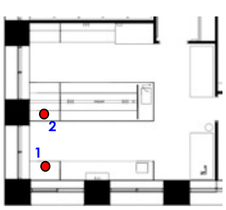


Figure 4.39
Lab C study 1 edge map.

The greatest difference (40:1) occurs between the computer screen (5 fl) and the window behind it (201 fl). When seated at this space the there is a difference of brightness within 40° of the central task of 40:1. At 20:1, there is a 20% in visual acuity. See Appendix F for more information regarding lighting ratios for specific situations.

Another situation in this space is the direct glare from the sun in the evening that comes in through the window to the right of the space. The blinds in the window are there to negate this problem, but access to the control limits the occupant's manipulation of the blinds.

Figure 4.43
Lab C foveal study locations.



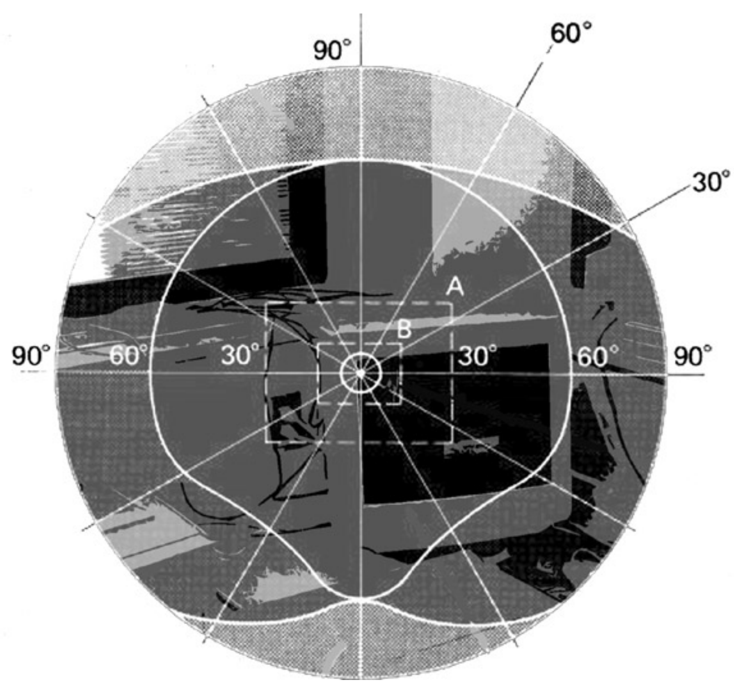


Figure 4.40
Lab C study 1 foveal overlay.

Lab C Foveal Vision Analysis 2

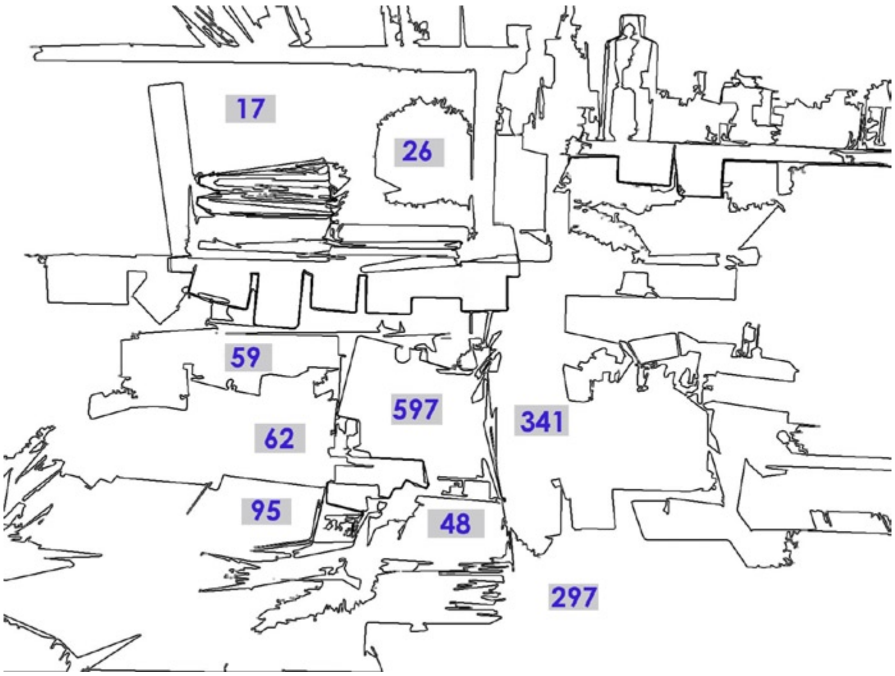


Figure 4.44
Lab C study 2 edge map.

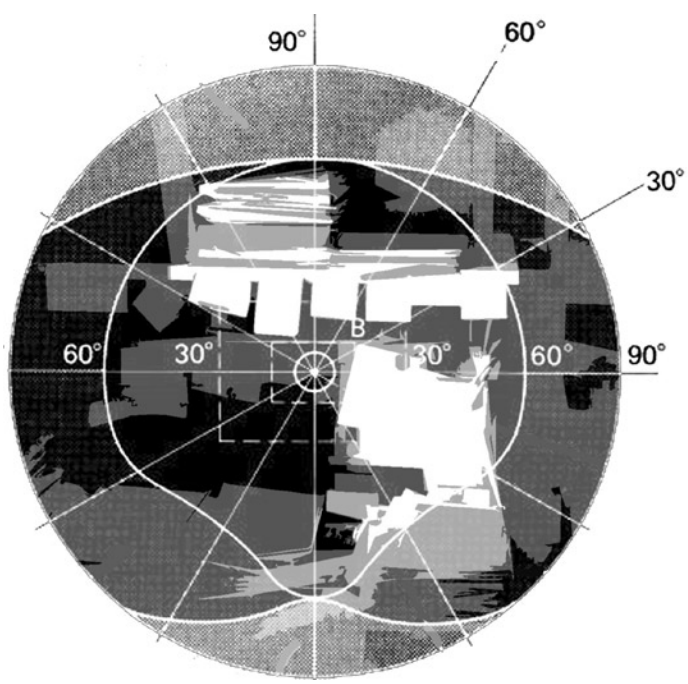


Figure 4.45
Lab C study 2 foveal overlay.

Figure 4.46 Base image

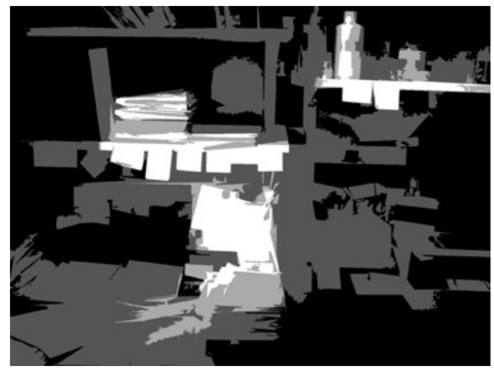


Figure 4.47 Tones

This station had the most extreme luminance variations of all the spaces in the labs we examined. When the setting sun penetrates into the space it creates hot spots on the various pieces of paper and materials at the station. The work surface varies from 48 *fl* to 95 *fl* (approx. 2:1). The back drop to the work space is full of hot spots with the highest being 597 *fl*. This creates a difference between 6:1 and 12:1. Looking at the original picture, it appears that there are greater ratios than those captured by the equipment. These hotspots are especially bright and are well within the 40° cone of vision and exceed the recommended 10:1 maximum difference. See Appendix F for more information regarding lighting ratios for specific situations.

Veiling Reflections

In lab A, the light from the west facing windows cause glare on the computer displays when placed near or angled towards the windows. The laptop display in figure 4.48 shows how the screen is affected. A laptop computer may be easily moved to remove this condition, but in a space with such a large amount of light, ambient conditions can affect the readability of the display.

In Lab C this computer was placed at the end of the bay with the screen facing the west windows. Not only is there a problem with the light from the window, but the overhead lights as well. This monitor is off, but would be rather difficult read.

In figure 4.44, the strong direct beam light reflecting off the surfaces at the work station creates veiling on the screen of the desktop computer. The computer was relocated to this space because it was completely unusable when it was placed in the station behind the user. Placed there, the sunlight would directly strike the display of the monitor making it very difficult to read.

Figure 4.48
Light from the window veiling the display of a laptop computer in Lab A.

Figure 4.49
reflected glare from the window and overhead lights veiling the display of a desktop computer in Lab C.

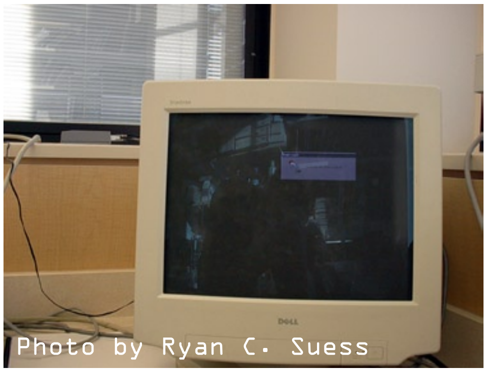


Figure 4.50
Reflected light from the station behind veiling the display of a desktop computer in Lab C.

Occupant Survey

The survey was divided into two parts and distributed by Mary Harden to the occupants of all the labs in the building. The first 16 questions pertained to the investigations being coordinated by the other Vital Signs VII team. Questions 17-21 pertained to our investigation. Of all the surveys distributed, 32 were returned. Only 19 of the 32 respondents worked in the labs and replied to our questions. Only 16 of the 19 that worked in the labs worked near the windows.

The questions and the results are as follows:

17. Is the lighting in the labs comfortable for the tasks that your perform at the lab stations?
    12 (86%) responded yes
    2 (14%) responded no

18. Is it difficult to perform tasks on a computer at your desk?
    2 (10%) responded yes
    18 (90%) responded no

19. Do you require supplemental lighting in order to perform tasks as your desk?
    6 (32%) responded yes
    13 (68%) responded no

20. Are there conditions of glare at:

- lab stations?	3 yes
- desks?	4 yes
- computer screens?	5 yes

21. How often are the blinds over the windows of the lab spaces open?

- always	5 (36%)
- frequently	5 (36%)
- sometimes	2 (14%)
- seldom	0 (0%)
- never	2 (14%)
- N/A	1

The responses by the occupants reflect a positive opinion of the lighting condition in the labs. This conflicts with some of the findings of our study but this was not unexpected. The occupants have not experienced optimal conditions before. Instead they compare the conditions of the new spaces with those of the existing building which are considerably worse than the addition.

A complete copy of the survey can be found in Appendix E.

Photo by Ryan C. Suess

CONCLUSION

Photo by Rita Y. Macias

Hypothesis I

The artificial and natural lighting in the labs combine to create an adequately illuminated workspace that meets the recommended IES illumination levels for the specific tasks.

Based on the data collected in the investigative phase (p. 11) and analyzed in the diagnostic phase (p.17), this hypothesis is false. In many instances the lighting levels were below the IES recommendations at the work stations. The lighting levels were within the recommendations in the circulation spaces, however. This is the opposite of how the lighting in the space should perform.

See page 37 for recommendations to solve these problems.

Hypothesis II

The artificial and natural lighting in the labs combine to provide glare free conditions in the work environment.

The conclusions derived from the indicative phase (p. 9), the investigative phase (p.11), and the diagnostic phase (p.17) proves this hypothesis to be false. The large windows allow a lot of light into the spaces without enough control from window treatments. The direct beam penetration causes glare on computer monitors and equipment displays as well as luminance hot spots on the surfaces of the work stations. Though in labs A and B, the levels do not exceed the maximum ratio of 10:1; they are outside the optimal range between 1:1 and 4:1.

See page 37 for recommendations to solve these problems.

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RECOMMENDATIONS

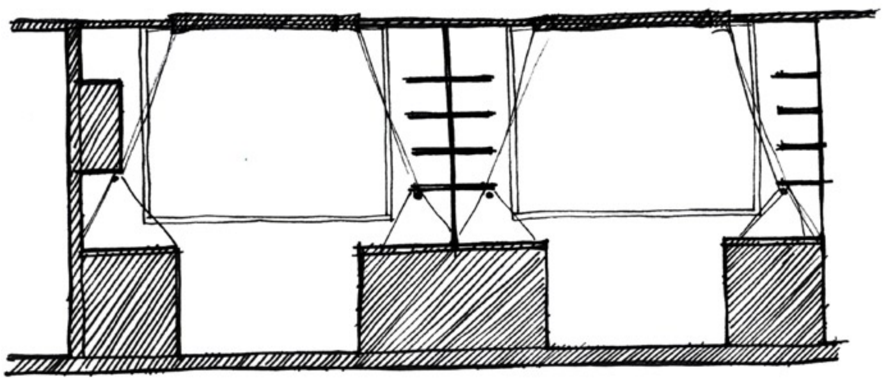

Figure 6.1
Bay Section with new overhead lighting configuration and task lighting.

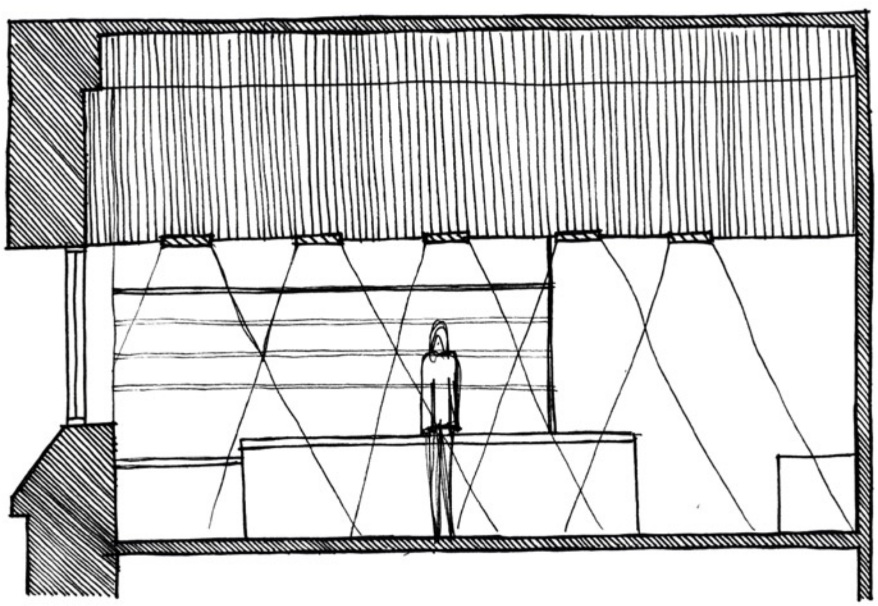

Figure 6.2
Lab Section with new overhead lighting configuration.

Install Task Lighting

For the desks and counters, we suggest the installation of task lighting under the wall cabinets/shelves (fig. 6.1). Task lighting will be helpful while working on the countertop, but will not be very beneficial to workstations where the occupants will be using computers.

Lighting Reconfiguration

Rearrange the lighting configuration to run north-south or perpendicular to the counters. This will maximize the illumination pattern of the fixtures used. See figure 6.1 and 6.2.

Upgrade Lamp

The black counters desired to resist stains absorb a lot of the light in the labs. Replacing the current fixtures with higher rated lamps will increase the ambient lighting levels in the lab. Brighter fixtures could reduce or negate the need for task lighting with the rearrangement of the general lighting in the space. It is also recommended that when bulbs are replaced, that the replacement matches the bulbs in place. Ideally, when a bulb needs replaced they all are to maintain the quality of lighting in the space.

Reducing Glare

To diminish the glare in the in the labs, the recommendation is to install shading devices in the west windows of the labs which would still allow natural light to contribute to the lighting design but would diffuse the harsh light from the setting sun.

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APPENDIX A

Interview with Jim Hill, of BSA Design.
(Via conference call)
Thursday, October 2nd, 2002

RE: Van Nuys Medical Science Center

The building is an addition to an old University Building from 1950´s on the IUPUI Campus. Jim Hill of BSA Design was the Lead Architect for the Van Nuys Medical Science Center. BSA Design provided architectural, MEP engineering and lab planning design services for the project.

The pre-design phase programme was developed jointly between the University Architect and the IU School of Medicine. The actual users of the research spaces also provided input during the programming phase.

The design work started in 1992 with the initial ideas solving the problem of joining the two buildings, but due to budget delays and the inclusion of the State Department of Health laboratories, the project did not really get going until April 1996. The construction was completed in May 1998, adding approximately 167,000 gross square feet to the old existing building, providing the work space essential for labs and their own offices, as well as a location for the State Board of Health labs. The final cost of the building it was $34 million dollars.

The connection was dealt with by placing an atrium between the buildings. The atrium, a 20 foot wide space on a north south axis, functions as an interior street; preserving a preexisting circulation path on the IUPUI campus. Balconies serve as the circulation on the upper floors.

A mirror wall replaced the façade of the old building to open up the narrow atrium. At the same time the mirror wall hides the different floor to floor heights between the buildings, which resulted in the third floor being skipped in the addition to avoid confusion.

The original design called for a glass curtain wall to separate the laboratories from the Atrium. Due to sensitive research and the occupants need for as much wall space as possible, a solid wall with high windows separates the atrium and the offices for the research labs.

The labs are generic and modular. The design was based on the programme module prescribed by the administration to give every one the same layout in which to conduct their research.

The utilities are run horizontally through the walls, instead of through the floor and each work station can be separately turned on or off as needed. The mechanical systems and the utilities in the new labs required a floor to floor height almost 5 feet greater than the existing building. Direct lighting was used in the laboratories to control the ceiling heights. Indirect lighting would have added another 18 inches to each floor of the building. The large windows were not designed for the purpose of adding natural light to the labs, but rather were requested by the occupants for a connection to the outside while spending long hours in the labs.

The labs in the building do not have automated lighting controls at the request of the researchers due to the odd hours often required by their research. The exception to this is the Laboratory Animal Facility located on the lower level, which utilizes an electronic lighting control system for the animal housing rooms. This system allows a researcher to automatically turn lights on and off to create the desired diurnal cycle on a room-by-room basis.

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Background

In order to understand lighting design, we need to explain how light works:

The Illuminating Engineering Society of North America (IESNA) defines light as visually evaluated radiant energy. Put more simply, it is a form of energy that allows us to see. If considered as a wave, it has a frequency and a wavelength. The part of the electromagnetic radiation spectrum which can be perceived by the human eye is known as the visible spectrum. The visible portion ranges from blue light at 475 nanometers (nm), through green, yellow, orange, red and violet light at 725 nm. White light is the combination of all the wavelengths (fig. B-1).

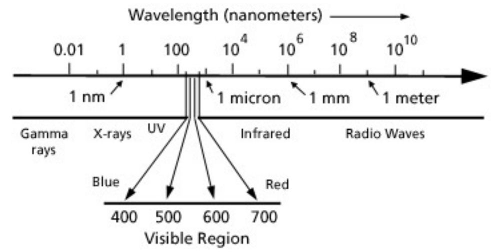


Figure B.1
The visible spectrum.

Lighting design is possible because light is predictable, i.e., it obeys certain laws and exhibits certain fixed characteristics.

The eye

There are two aspects to the way the human eye perceives light:

- Biophysical aspect - relating to the eye and how it functions
- Internal interpretation of the physical input - how the brain translates the data sent to it by the eye.

The biophysical aspect is what we can measure with instruments and the one we can explain. We can define terms to understand eye activity, like ‘perception’, ‘color’, ‘glare’, ‘transmission’, ‘reflection’, ‘refraction’, ‘absorption’, and more.

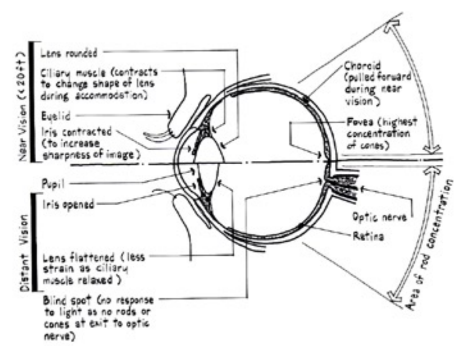


Figure B.2
The parts of the human eye.

The eye is formed of parts, such as:

The lens -	a focusing device.
The iris -	a variable aperture which controls the amount of light admitted to the eye.
The retina -	a sensing surface composed of nerve pickups called rods and cones. The rods, which sense the presence or absence of light, in black and white, and the cones, which sense colors in relation to one another.

(fig. B-2)

Luminous transmittance

The luminous transmittance or reflectance of a material is what the eye actually perceives.

The transmitted light passes through the material completely or partially, in the first case the material is transparent, in the second material is translucent.

Refraction occurs when light is bent moving from one material

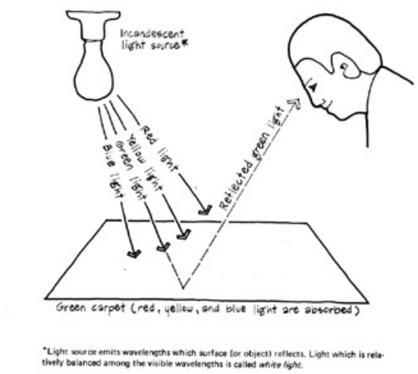


Figure B.3
Reflection and Absorption.

to another, such as from air to glass or from air to water. Materials have different indices of refraction.

Reflectance is the fraction of light falling on the surface which returns from it.

(fig. B-3)

Direct and Diffuse Light

Direct light is the light which comes directly from the sun on a sunny day. It's a strong light that creates very sharp shadows. Inside a building direct light is analogous to the light of the projector or from a drafting lamp.

Diffuse light is the kind of light experienced on an overcast day. Because the light is coming from all directions there are no distinct shadows. In a building, it's similar to a ceiling full of fluorescent lights, where the idea is to light the entire area.

Illumination or Illuminance

…is the light energy arriving at a real surface The unit of measure is *fc*.

Luminance

Luminance is the luminous flux density leaving a projected surface in a particular direction, and its unit of measure is the *fl*.

An object is perceived because light coming from it enters the eye. The impression received is one of object brightness, and this sensation depends on the object luminance and on the state of adaptation of the eye.

Contrast

When we see a surface, we are sensing the luminance of that surface, but the way we see the surface infers things about it by the variation of the luminance.

As example, if a surface has words printed on it in black ink, the luminance of that surface varies based on the variation in the reflectance of the surface and the black ink; this is called contrast.

The eye is astoundingly adaptive in range. It can adjust from levels below 1 foot-candle, to levels over 10,000 foot-candles in moments. When the change for the eye is too rapid, or most of the background is dark but one spot is intensely bright, this extreme contrast is known as glare.

Glare

There are two types of glare:

- when the eye has adapted to an environment and this changes, and

- when the eye has adapted to an environment and a source of light appears much brighter than anything else within the field of view.

(fig. B-4)

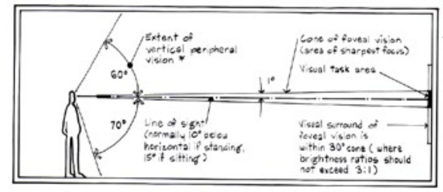


Figure B.4
Vision Angles.

Daylight

It is the natural light provide by the sun, the most abundant, and most desirable form of lighting available. It comes in the form of beam light and sky vault light.

Windows provide visual contact with the outside, and the daylight coming through them provides a bright pleasant ambience. Daylight also provides good modeling of shadows, minimal veiling reflections and excellent vertical surface illumination (fig. B-5).

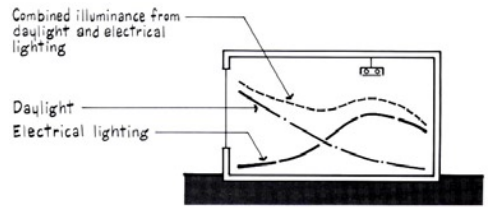


Figure B.5
Integration of Daylight and Artificial Light.

The most prominent characteristic is its variability. The level of exterior illumination, at a particular place and time, depends on:

- Solar altitude, which can be determined if latitude, date, and time of day are given.

- Weather conditions.

- Effect of local terrain, the natural and man made obstructions and reflections.

(fig. B-6)

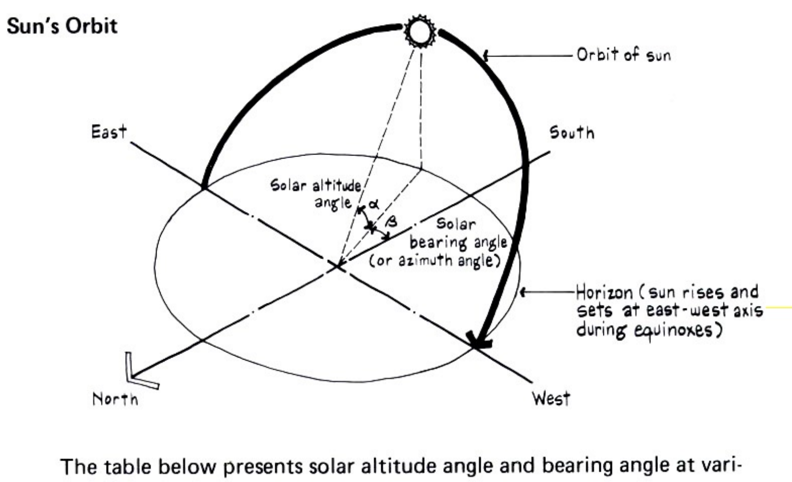


Figure B.6
Position of the Sun.

I E S N A

Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors.

Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors

Type of Activity	*Illuminance Category*	*Ranges of Illuminances*	
		Lux	*Footcandles*
General lighting throughout spaces			
Public spaces with dark surroundings	A	20–30–50	2–3–5
Simple orientation for short temporary visits	B	50–75–100	5–7.5–10
Working spaces where visual tasks are only occasionally performed	C	100–150–200	10–15–20
Illuminance on task			
Performance of visual tasks of high contrast or large size	D	200–300–500	20–30–50
Performance of visual tasks of medium contrast or small size	E	500–750–1000	50–75–100
Performance of visual tasks of low contrast or very small size	F	1000–1500–2000	100–150–200
Illuminance on task, obtained by a combination of general and local (supplementary) lighting			
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000–3000–5000	200–300–500
Performance of very prolonged and exacting visual tasks	H	5000–7500–10000	500–750–1000
Performance of very special visual tasks of extremely low contrast and small size	I	10000–15000–20000	1000–1500–2000

Courtesy of Illuminating Engineering Society of North America.

APPENDIX C

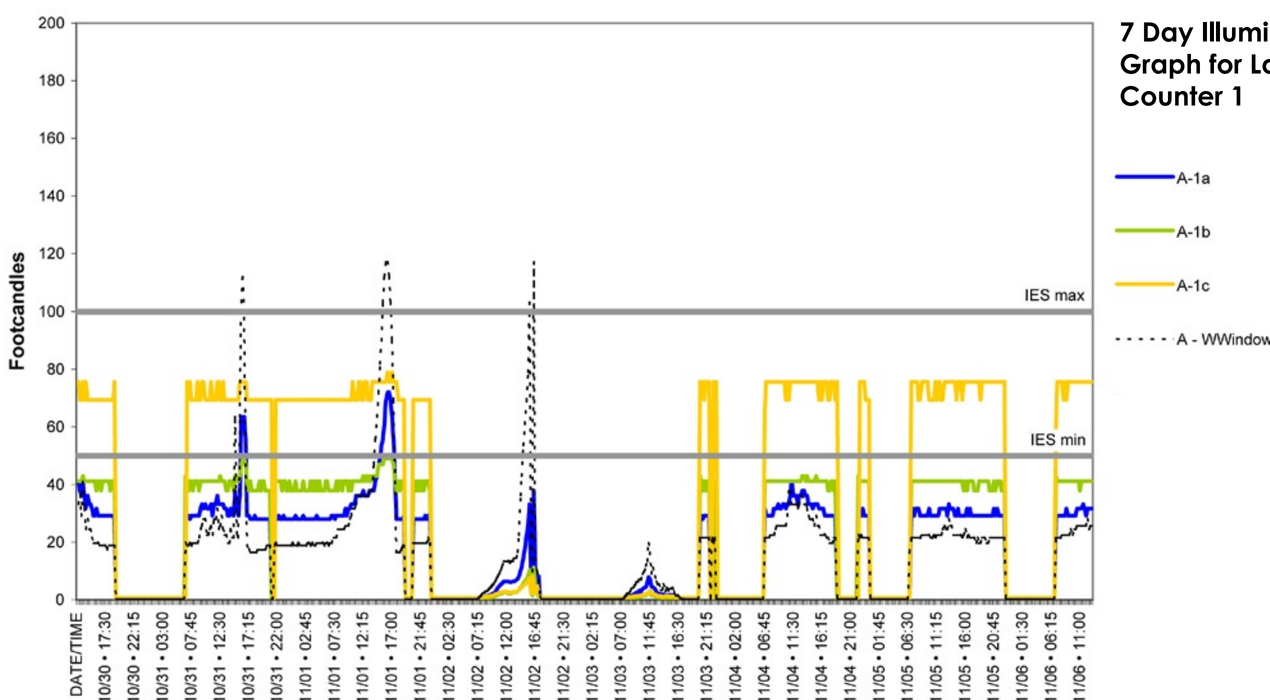
WEEK 1
October 30th through November 5th, 2002.

10.30.02	Wednesday	cloudy
10.31.02	Thursday	cloudy
11.01.02	Friday	sunny
11.02.02	Saturday	partially cloudy
11.03.02	Sunday	light rain
11.04.02	Monday	cloudy
11.05.02	Tuesday	light rain

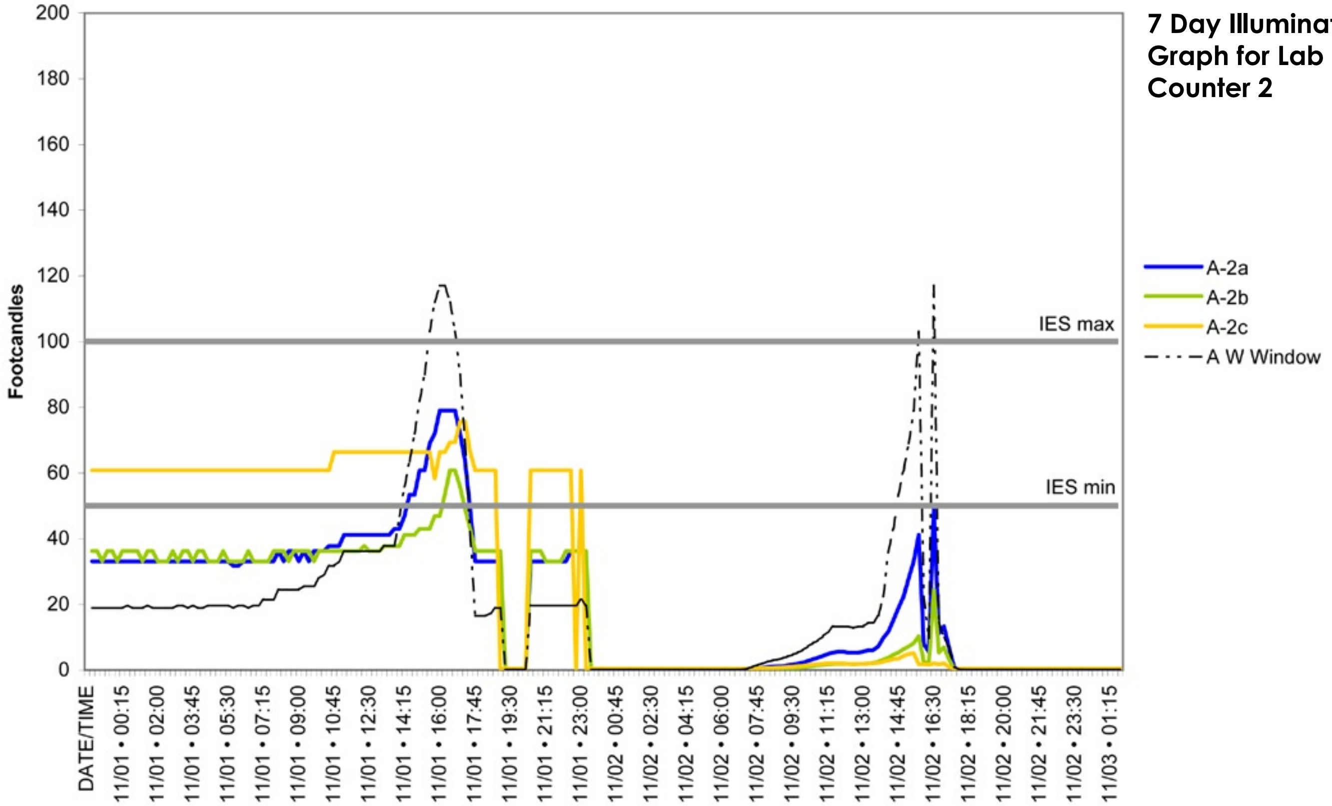
WEEK 2
November 6th through 13th, 2002.

11.06.02	Wednesday	cloudy
11.07.02	Thursday	sunny
11.08.02	Friday	partially cloudy
11.09.02	Saturday	cloudy
11.10.02	Sunday	rainy
11.11.02	Monday	cloudy
11.12.02	Tuesday	cloudy
11.13.02	Wednesday	sunny

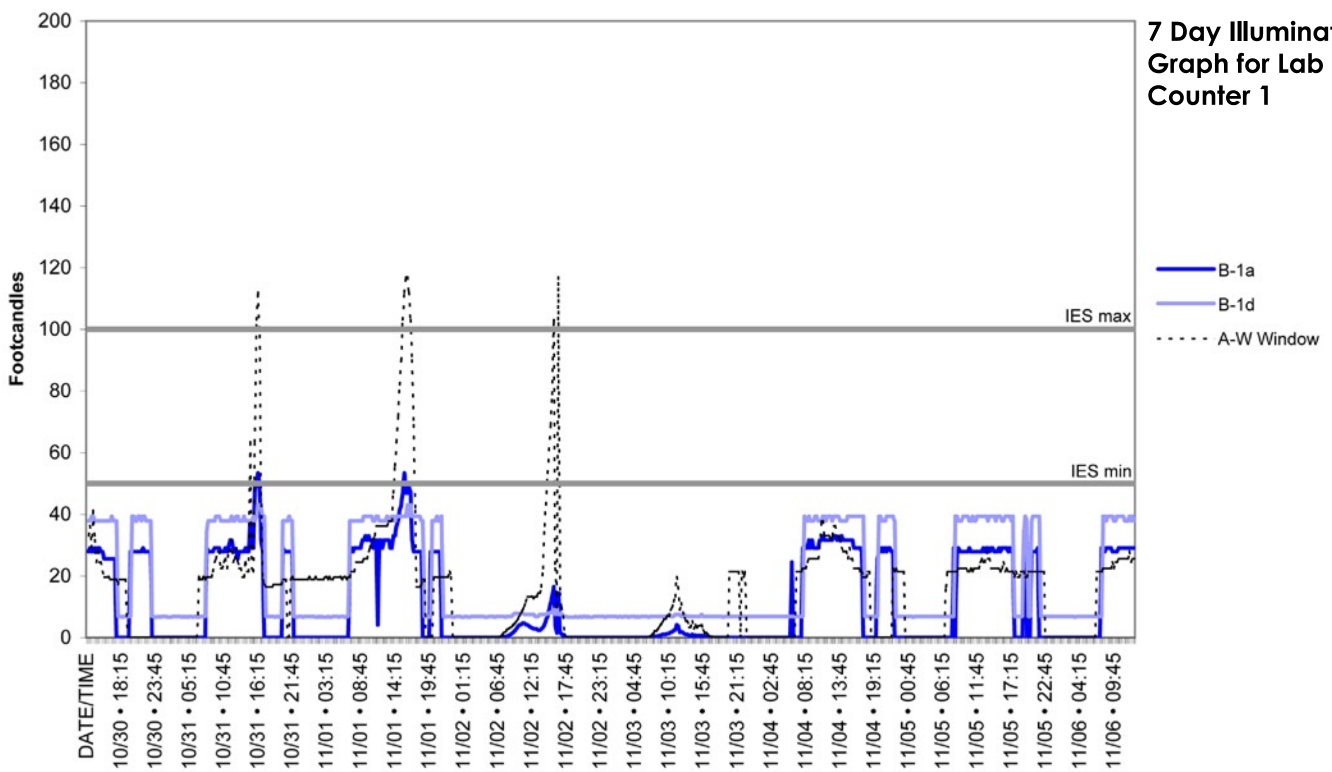
Figure C.1
This table shows the weather conditions over the two week period that the data loggers were in place in the Labs. The weather data was obtained from www.weather.com.



7 Day Illumination Graph for Lab A Counter 1

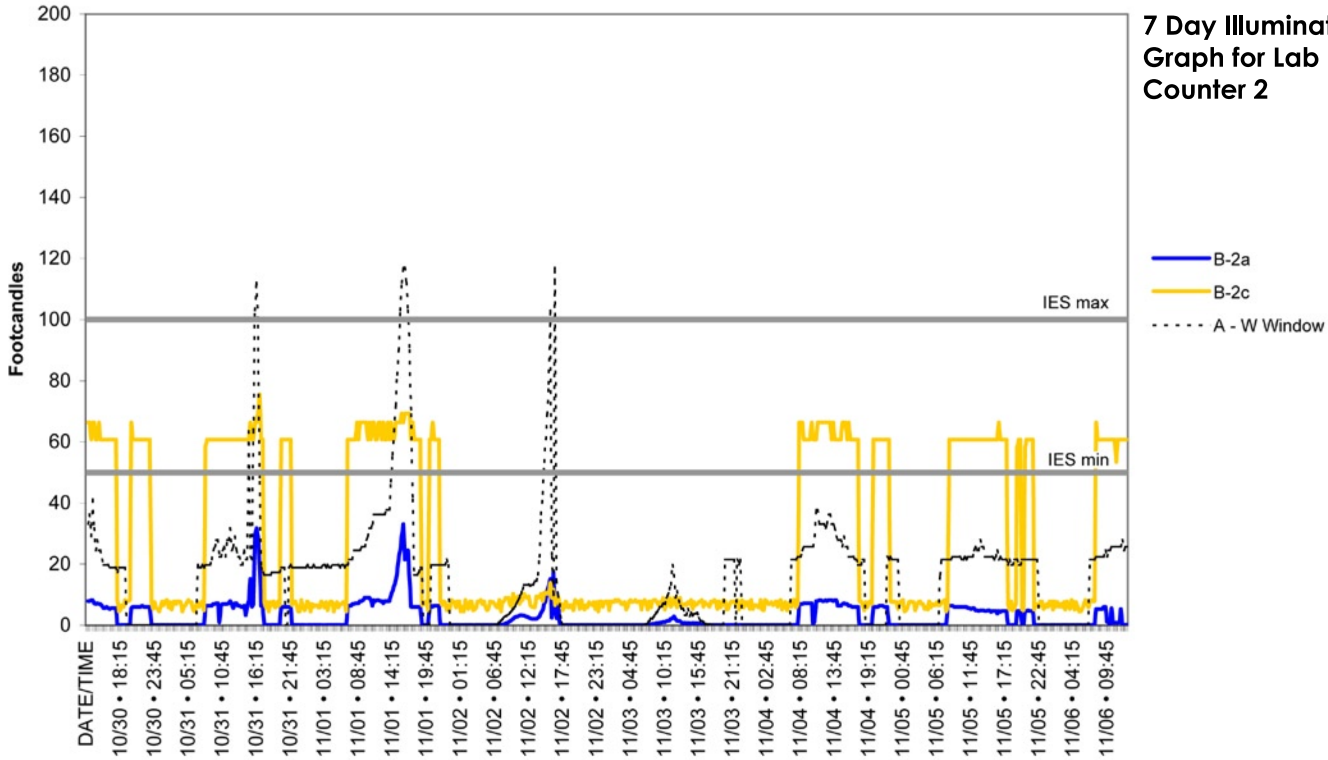


7 Day Illumination Graph for Lab A Counter 2

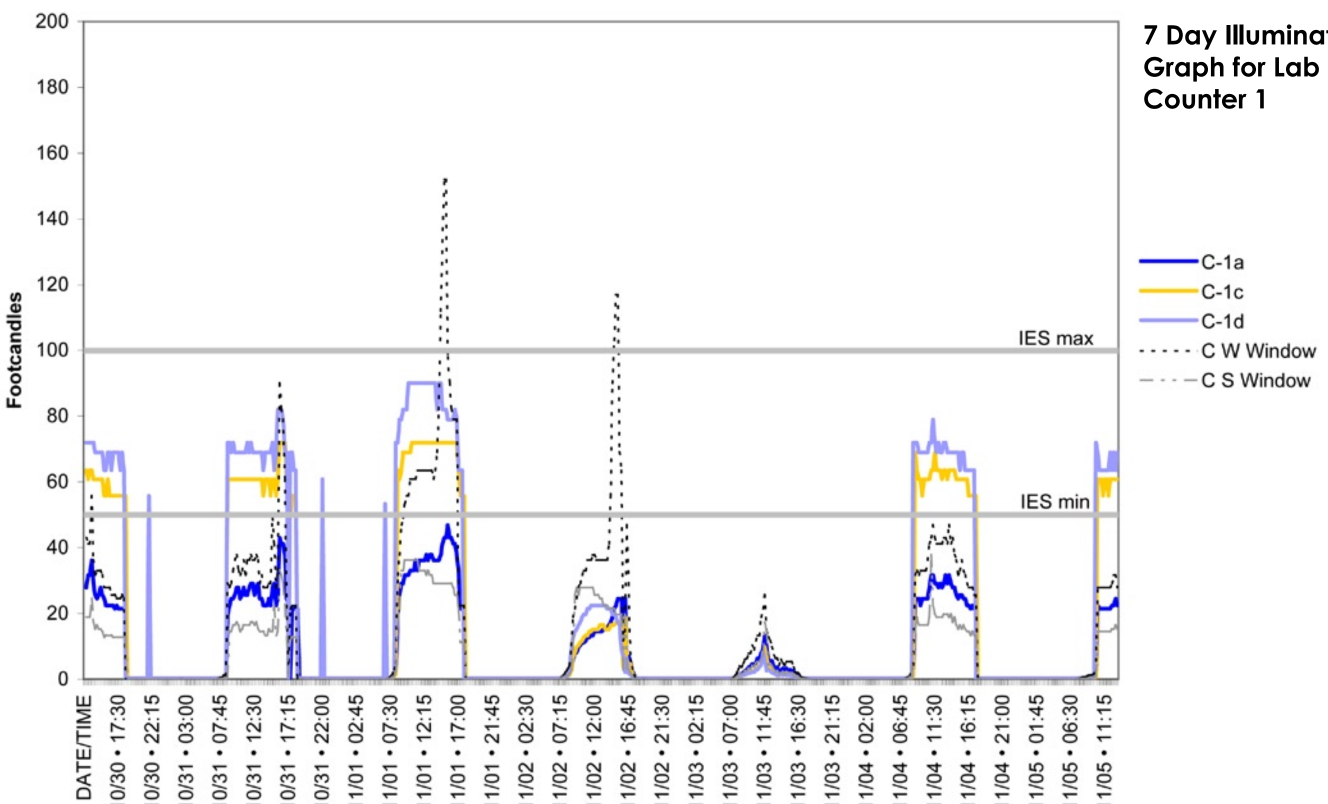


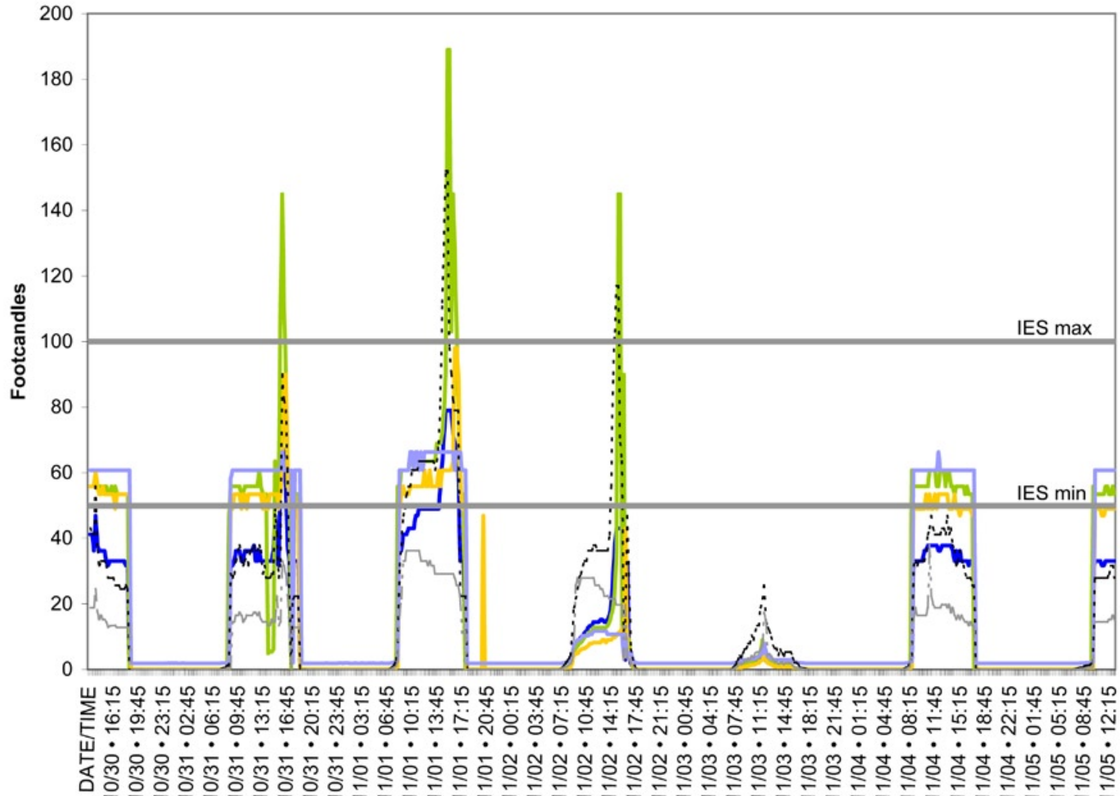
7 Day Illumination Graph for Lab B Counter 1

7 Day Illumination Graph for Lab B Counter 2

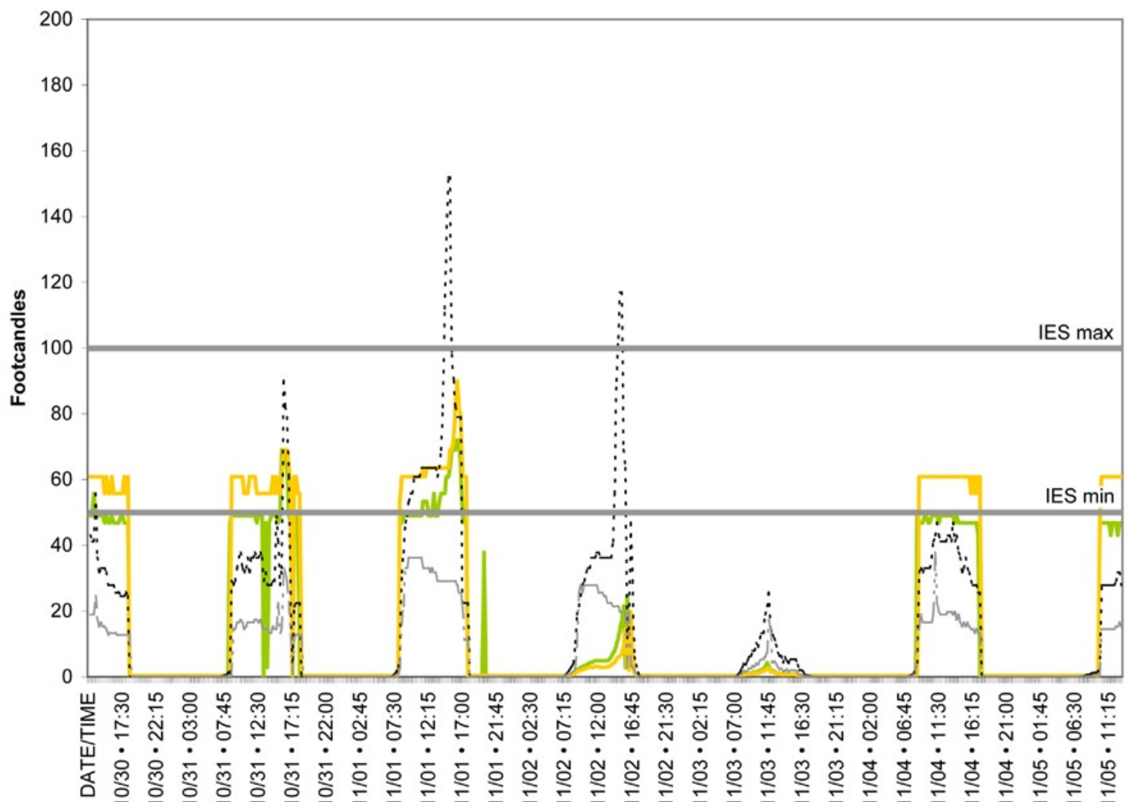


7 Day Illumination Graph for Lab C Counter 1

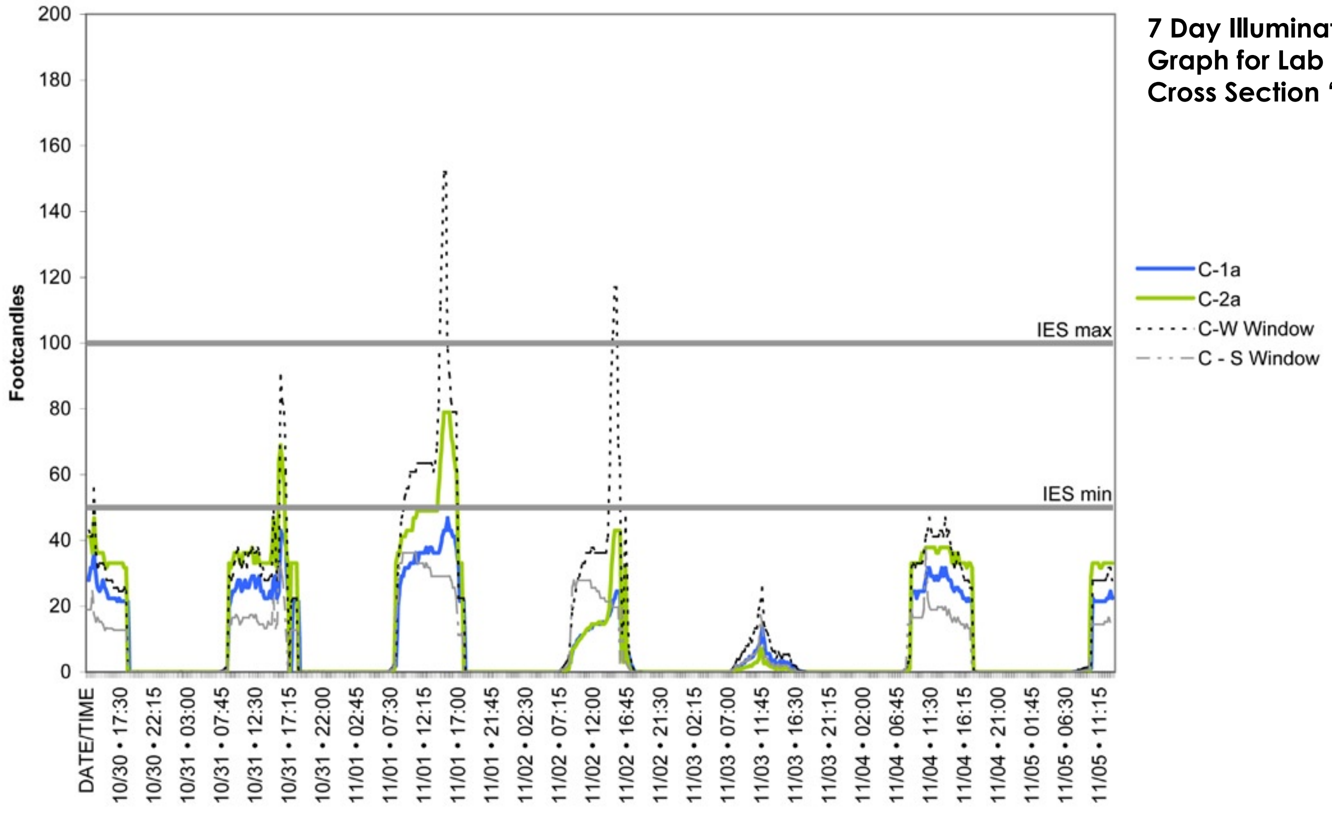




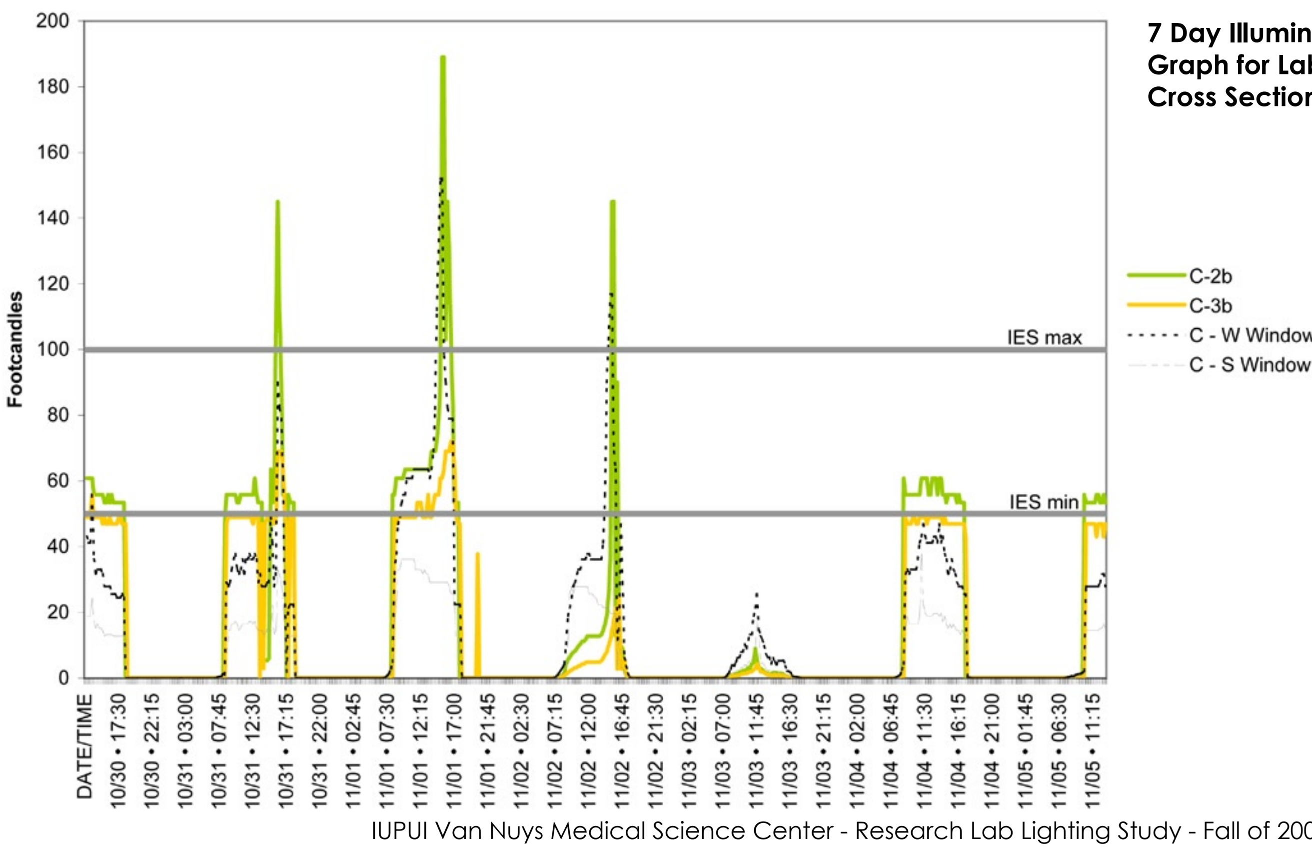
7 Day Illumination Graph for Lab C Counter 2



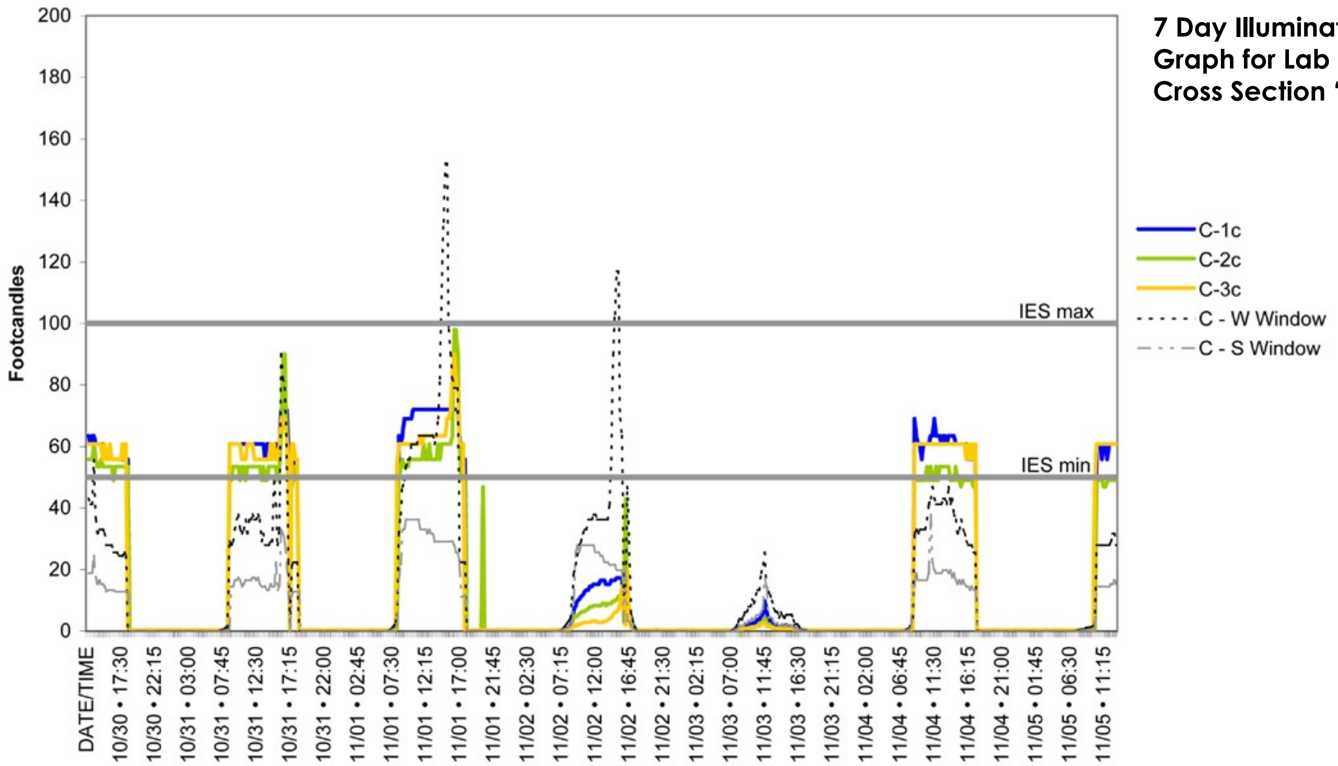
7 Day Illumination Graph for Lab C Counter 3



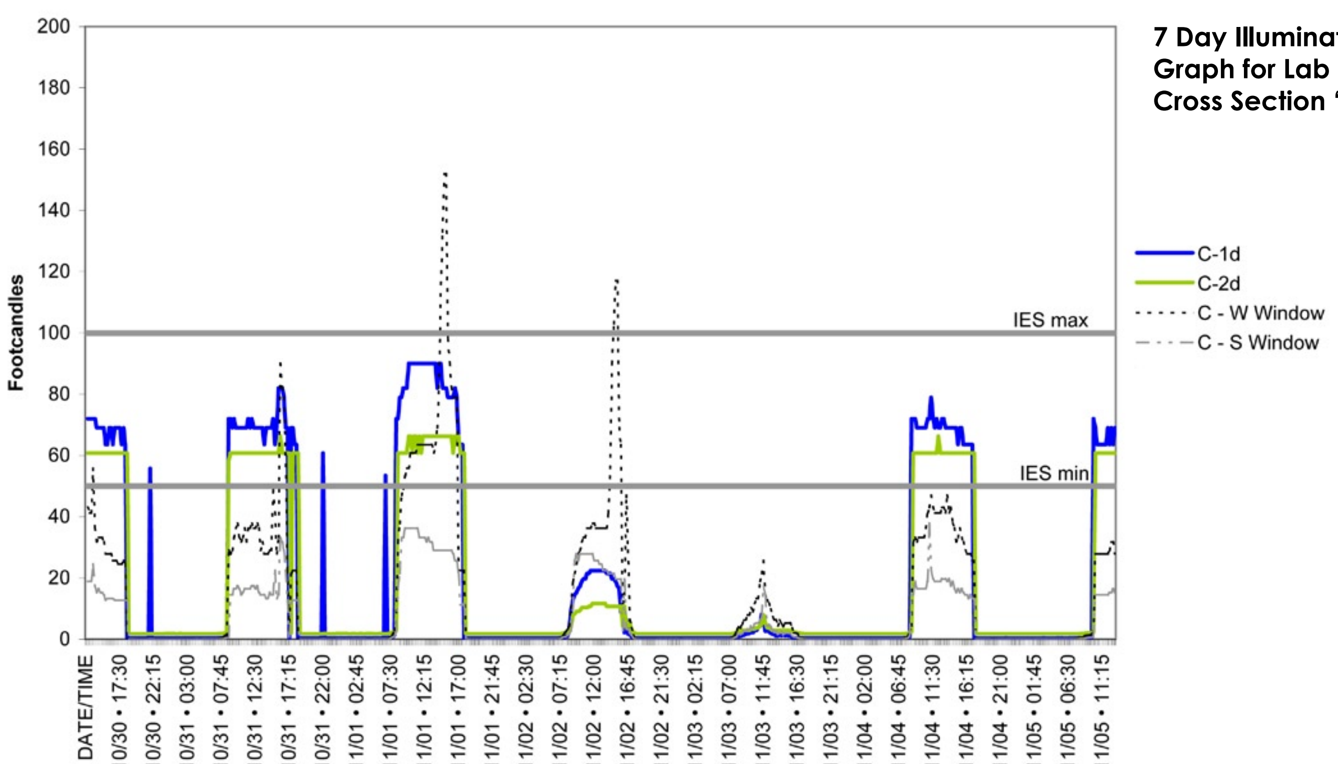
7 Day Illumination Graph for Lab C Cross Section 'a'



7 Day Illumination Graph for Lab C Cross Section 'b'

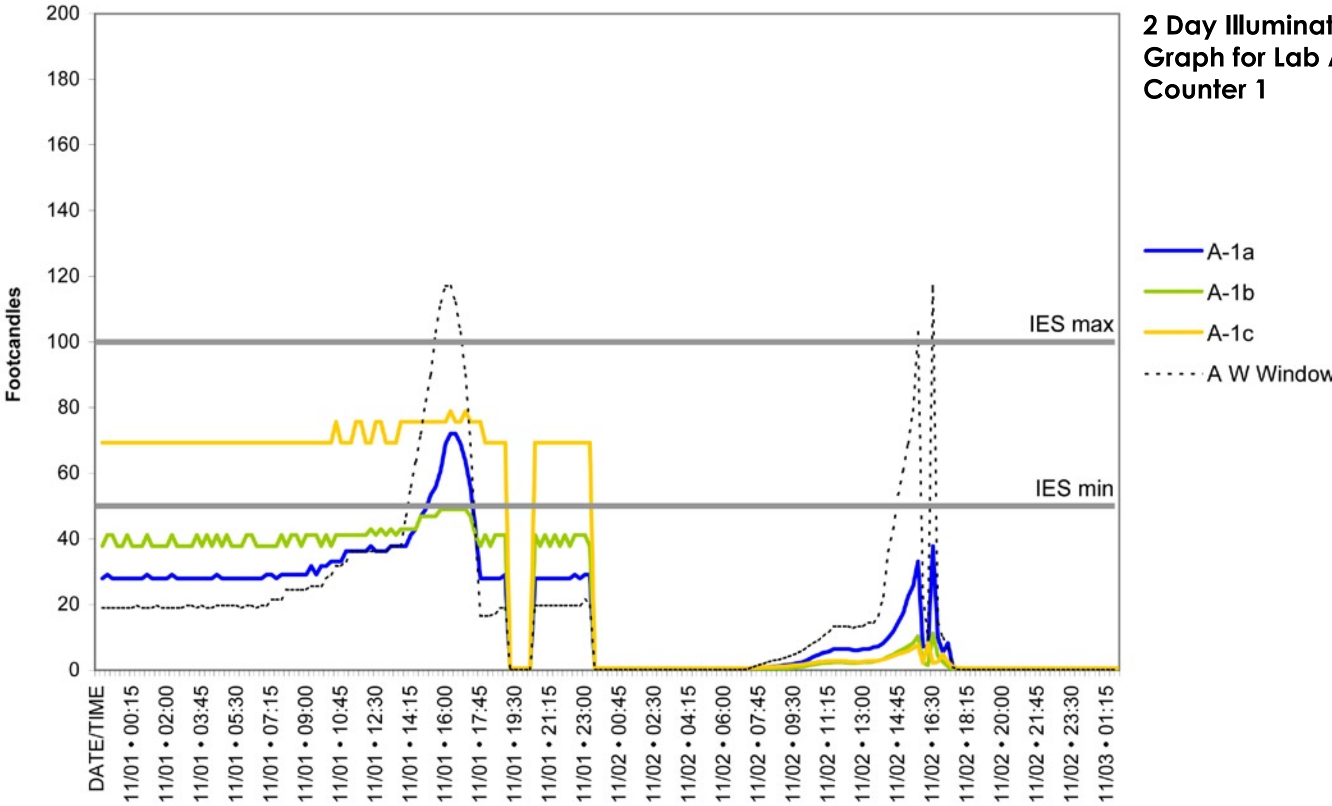


7 Day Illumination Graph for Lab C Cross Section 'c'

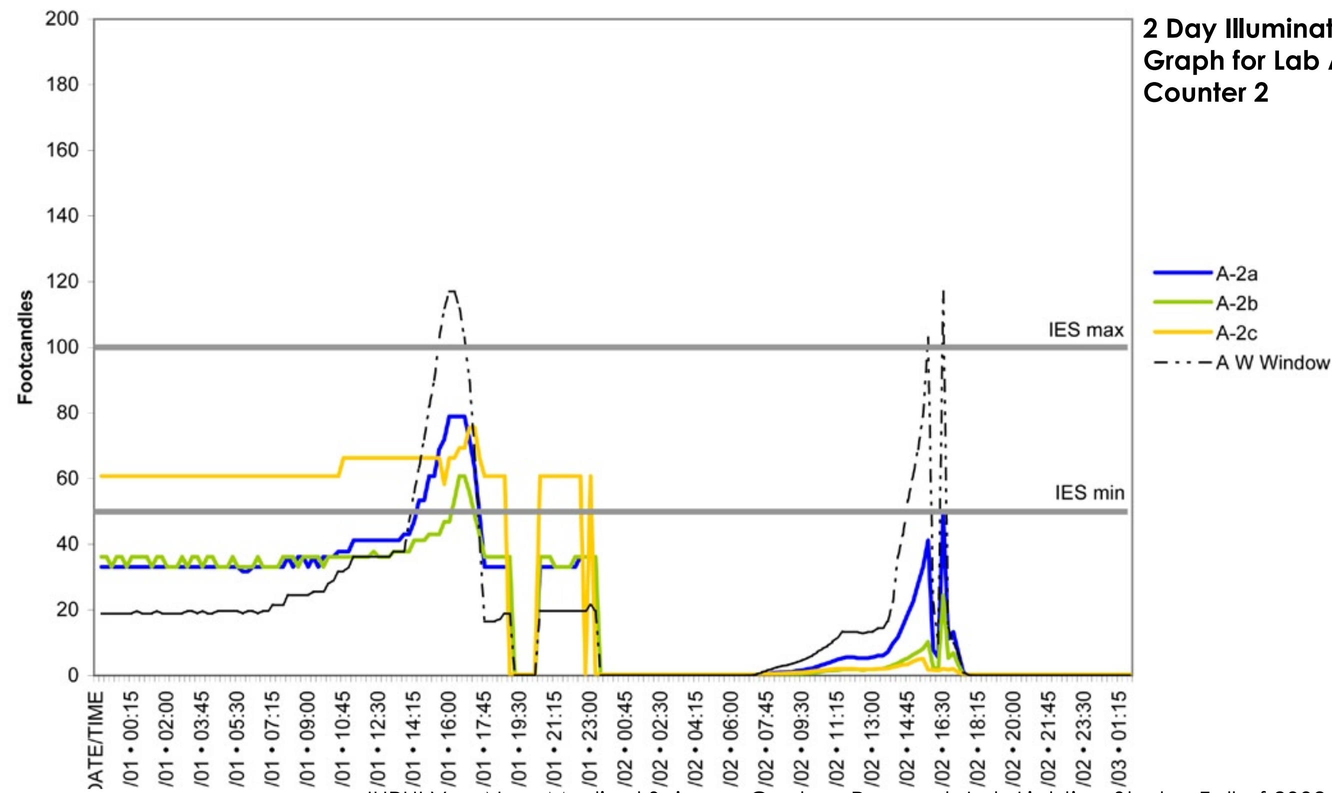


7 Day Illumination Graph for Lab C Cross Section 'd'

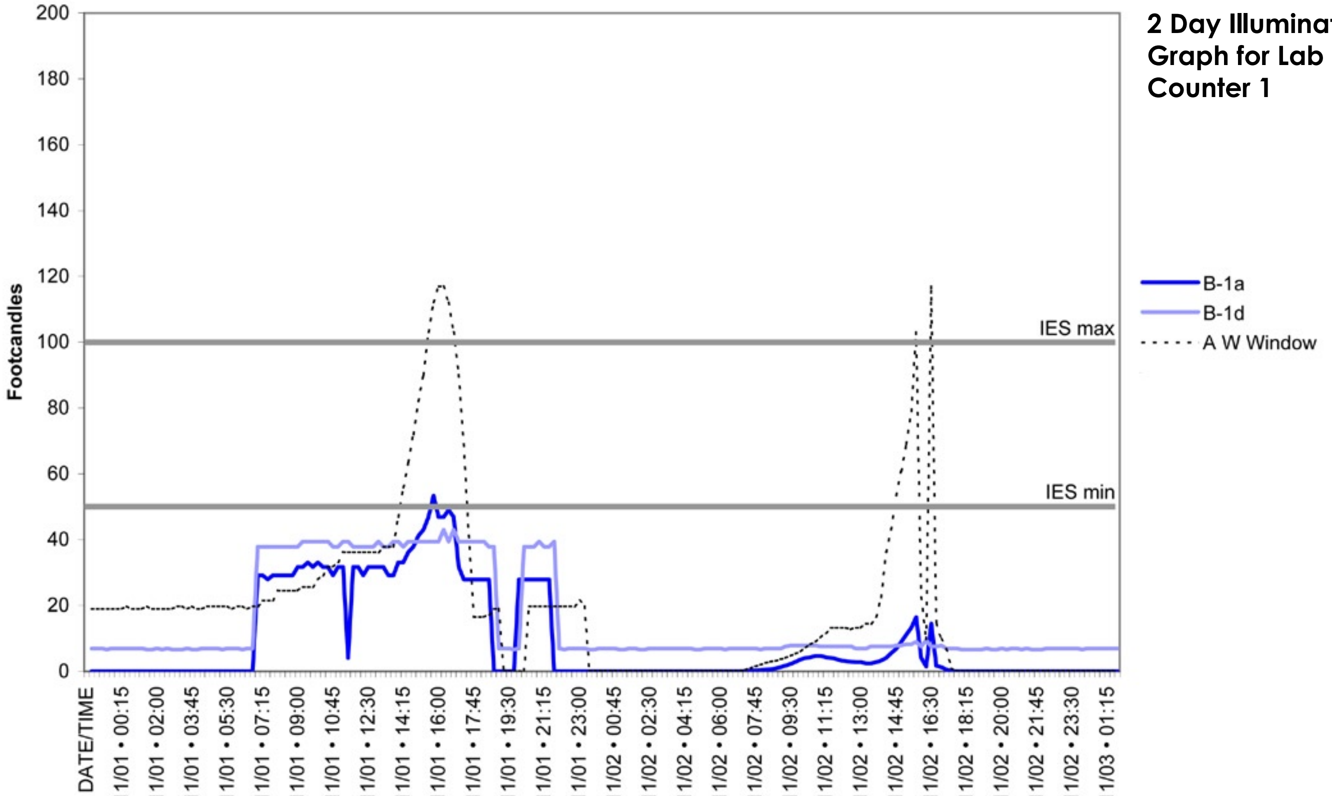
2 Day Illumination Graph for Lab A Counter 1



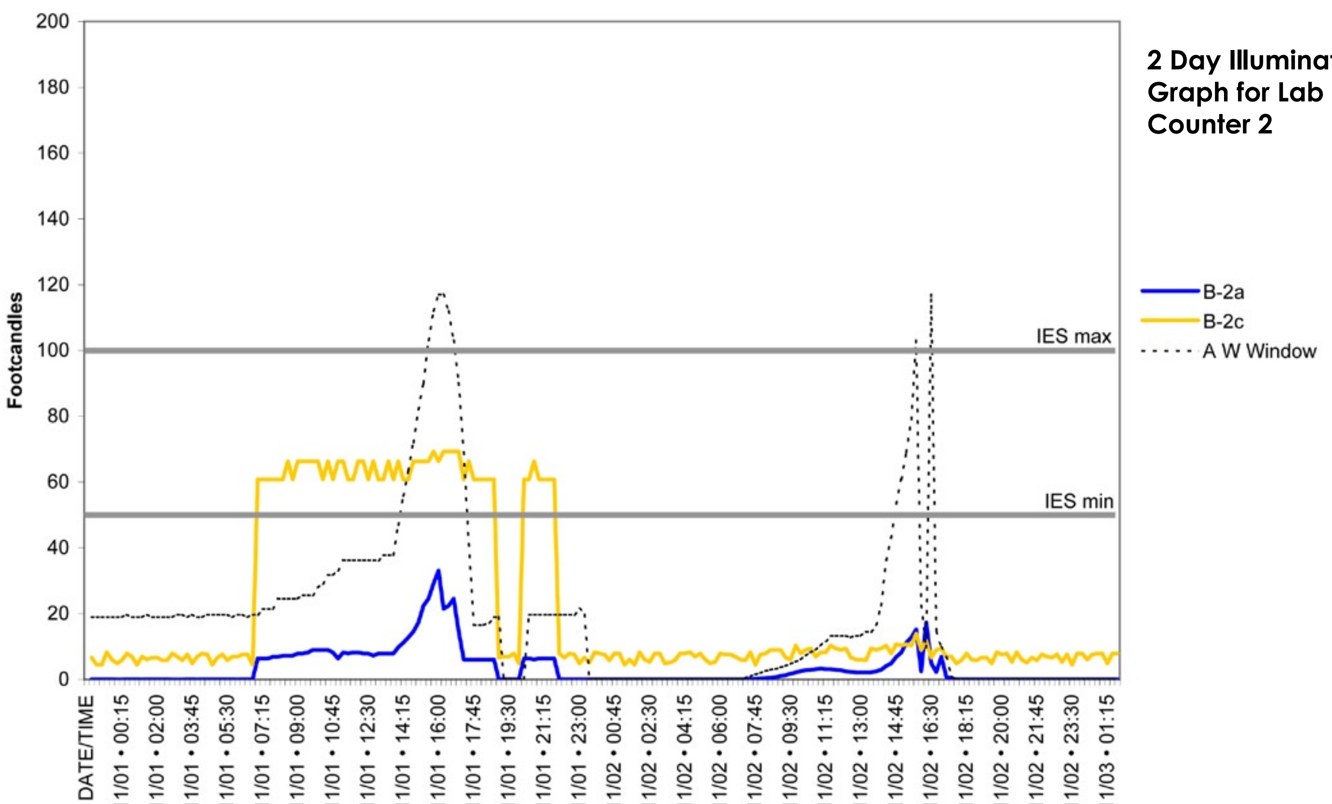
2 Day Illumination Graph for Lab A Counter 2



2 Day Illumination Graph for Lab B Counter 1



2 Day Illumination Graph for Lab B Counter 2



- GE
  - Range: 1-10,000*fc*
  - Precision:
    - w/o cap: 2*fc*
    - w/ cap: 200*fc*
  - Accuracy: 10-15%
  - Cosine Corrected
  - Color Corrected
- Silvania
  - Range: 0-2000*fc*
  - Precision: 1*fc*
  - Accuracy: ±5%
  - Cosine corrected
  - Color corrected
- Minolta LS-100
  - Range: 0.01-100,000*fc*
  - Precision: 0.01*fc*
  - Accuracy: 0.01%
  - Cosine corrected
  - Color corrected
- Luminance Spot Meter
  - Range: 0.001-87-530*fc*
  - Precision: 0.001*fc*
  - Accuracy: ±2%
  - Cosine corrected (within 1° FOV)
  - Color corrected
- Stowaway
  - Range: 0.001-1,000*fc*
  - Precision: 0.001*fc*
  - Accuracy: 5%
  - Partially cosine corrected
  - Color correction:
    - Incandescent multiplied by 1
    - Daylight multiplied by 6
    - Fluorescent multiplied by 12
- Hobo
  - Range: 0.01-15,000*fc*
  - Precision: 0.01*fc*
  - Accuracy: 5%
  - Partially cosine corrected
  - Color correction: same as Stowaway

Figure C.1 - Sylvania OSRAM instantaneous light meter.

Figure C.2 - Hobo and Stowaway light intensity loggers. Collection of data over time.

Figure C.3 - Minolta LS-100 direct reading narrow-angle, spot-type liminance meter.

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Survey Questionnaire

Van Nuys Medical Science Building Lighting Questionnaire

1. What tasks do you normally perform in your office? (check all that apply)
   - ☐ Reading ☐ Group Work
   - ☐ Writing ☐ Meetings
   - ☐ Computer Tasks ☐ Other____
2. Is it difficult to perform any of these tasks due to the lighting conditions in your office? Y N
   If so, which tasks present difficulty?
3. How many hours per day do you typically spend in your office performing these tasks? _______hrs/day
4. Do you find it necessary to take periodic breaks in order to rest you eyes? Y N
5. Do you use supplemental or additional lighting in order to perform some tasks? Y N
6. What types of tasks require supplemental lighting?
7. At what hour of the day do you typically turn the lights in your office on?
8. At what hour of the day do you typically turn them off?
9. Is it possible for you to perform tasks within your office with the lights turned off? Y N
10. Do you find it difficult to read glossy print material in your office with the lights on? Y N
11. Do you find it difficult to read a computer screen in your office with the lights on? Y N
12. Do you find it difficult to read glossy print material in your office with the lights off? Y N
13. Do you find it difficult to read a computer screen in your office with the lights off? Y N
14. Do you feel that the windows in your office compromise your privacy? Y N
15. Rate the comfort of the light entering through the windows: (circle one)
    Very Comfortable Comfortable No Opinion Uncomfortable Very Uncomfortable
16. Are the windows in your office distracting? (circle one)
    No Opinion Somewhat Distracting Distracting Very Distracting
17. Is the lighting in the labs comfortable for the tasks that you perform at lab stations? Y N
18. Is it difficult to perform tasks on a computer at your desk? Y N
19. Do you require supplemental lighting in order to perform tasks at your desk? Y N
20. Are there conditions of glare at: (circle all that apply)
    Lab Stations Desks Computer Screens
21. How often are the blinds into your lab space open?
    Always Frequently Sometimes Seldom Never

Interior Illuminance / Daylight Control / Occupants' Response Ball State University Vital Signs Class

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Excessive Brightness and Glare

While brightness and brightness contrast are basic in visual communication, excessive contrast or excessive background brightness can disrupt the ability of the eye to perceive fine detail. These glare conditions can temporarily cripple vision by destroying the observer's ability to adequately perceive a task, an obstruction, an object or a space.

Glare is generally corrected by reducing or dimming the source luminance; by using baffles, louvers, or diffusers to reduce excessive luminaire brightness; by relocating the source outside of the normal visual field; and by reducing the reflectance characteristics of excessively bright surfaces.

Brightness Tolerance as a Function of Area

In estimating and evaluating brightness tolerance, there is a fundamental relationship between *brightness intensity* and *area of brightness;* affecting the actual quantitative limits of visual comfort.

A small area of brightness may be tolerable while a large area of the same brightness may be intolerable. Large-area luminous elements (luminous ceilings, walls, and windows walls) require particular attention to accurate brightness control. Because these elements consume a relatively large portion of the normal visual field, they exert a more significant brightness influence and must function within more restrictive tolerances. A small glare source can be buffered by increasing the brightness of the background against which the source is viewed. Luminous elements which are sources of moderate discomfort and distraction in a low brightness environment may be quite innocuous in brighter surroundings because the contrast is reduced and the eye tends to adapt itself to the higher brightness background. An example of this would be the impact of the headlight of a car during the day versus at night.

Brightness Tolerance as a Function of Location

As a corollary to the relationship between intensity and area of brightness, the negative influence of a glare source depends upon its location in the normal field of view and its proximity to the central foveal area of the eye. Figure D.1 illustrates typical average brightness levels that can be tolerated in different portions of the peripheral field of view. (Maximum brightness of relatively small highlighted areas can be tolerated as high as three times the *average* brightness shown.) While these tolerances will vary somewhat with the state of adaptation of the occupant's eye, this diagram indicates that there must be increasing restriction of general brightness as the area in question approaches the center of the visual field.

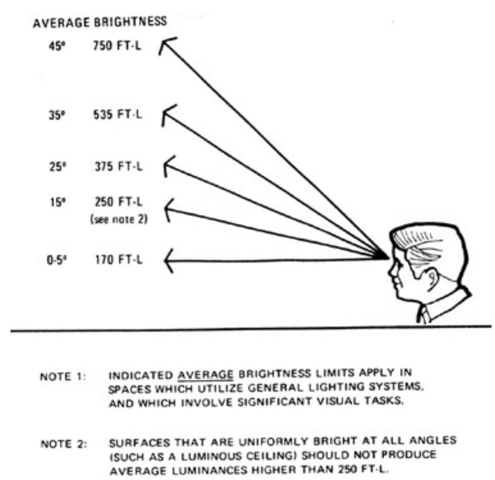

Figure D.1
Limits of visual comfort (location).
Flynn, page 25.

These studies help to explain why brightness levels that are considered acceptable for luminous ceilings are found to be excessive for luminous wall areas. Wall areas must function within more restrictive tolerances because they represent a more dominant influence in the normal visual field.

Adaptation and Surrounding Brightness

The subjective impression of visual comfort also depends on the brightness relationship between the task surface and its surroundings. Facing a window with a view of a bright overcast sky can make reading a book extremely difficult because of the effects of background glare. Equally difficult is reading a brightly illuminated book when the surroundings are in darkness.

In spaces where sustained visual work is involved (such as offices, classrooms, industrial areas, etc.), brightness relationships within the normal field of view should be controlled to allow the eye to adapt to an overall environmental brightness near the brightness of the task itself. In this way, the *shock effect* of high environmental contrast, as well as the strain of continual readaption, can be minimized.

In areas designed for prolonged work; research and experience have indicated the necessity for lighting the ceiling and walls as well, to avoid uncomfortable or fatiguing working conditions produced by excessive contrast. For comfortable seeing over a long periods of time, the general brightness of surfaces immediately surrounding the task should not differ appreciably from that of the task itself. For work areas, it is generally recommended that spatial brightness average no less than 1/10 and no more than 10 times the average brightness of the task.

Effect of Spatial Context

Brightness in the peripheral areas surrounding a specific, localized task center has an important effect on the ability to distinguish fine task detail (visual acuity). Optimum acuity is achieved when the general brightness difference between the central task (foveal vision) and the immediate spatial background (peripheral vision) is between 1:1 and 4:1, with the task area tending to be slightly brighter than the background. An increase in this ratio to 250:1 (task brighter) will produce a reduction in acuity of approximately 10%; while for a bright task seen against a totally dark background, acuity is reduced approximately 20%.

As a general rule, when highly precise visual performance is required, spatial brightness differences exceeding 10:1 should be kept well outside of the more central 40° visual cone.

Even more significant differences in acuity occur when the spatial background is brighter than the task (i.e., the task detail approaches a silhouette condition). A relatively moderate 1:20 ratio (background is brighter) will produce a reduction in acuity of approximately 20% - and these reductions multiply rapidly as the background intensity increases.

Task Contrast

For maximum perception of *detail* associated with the visual task, maximum contrast is desirable. In the immediate task area, the eye perceives detail through a sequence of quick eye movements that use foveal vision to scan the boundaries separating areas of different brightness and color. For example, white ink on white paper is imperceptible, while black ink on white paper provides contrast sufficient for the eye to separate the significant form and detail from the local background. For detail to be clearly definable against a background there must be contrast between the two; and acuity improves as contrast increases.

The eye also perceives detail through *color contrast*. Red ink is perceptible against its complementary color of green, even if both the red detail and the green background involve the same luminance. In practice most task contrast involves both brightness and color.

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[end of report]