W. D. Richards Elementary School

Columbus, Indiana

A Study of the Lighting Conditions in the Music Instruction Space

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

Ball State University
College of Architecture and Planning
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Cover Photo

Exterior photo of W. D. Richards Elementary School by Joshua E. Inman

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Mrs. Ercell Cody
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Bartholomew Consolidated School Corporation
Mrs. Debbie Turner
Music Teacher
Richard's Elementary School
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Photo by Joshua E. Inman

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W.D. Richards Elementary School

Main entrance showing the character of the roof monitors and skylights protruding through the roof plane.
[photo looking East-Northeast]

Photo by Joshua E. Inman

Abstract

This document describes a semester-long study of the natural and artificial lighting conditions in the Music Instruction room at the W. D. Richards Elementary School located in Columbus, Indiana.

During the study we analyzed the different lighting systems within the Music Instruction room to understand the effects of the daylighting design used throughout the building. In our research we wanted to determine how successfully an east-facing roof monitor could illuminate a typical classroom as measured against the recommendations of the Illuminating Engineering Society of North America (IES). We further sought to determine whether the east-facing roof monitors resulted in any visual discomfort during the day due to glare caused by excessive brightness and high contrast on the surfaces in the classrooms such as chalkboards, television monitors and other teaching tools.

To evaluate the conditions in the space and to measure contrast ratios within the user's visual field, we used instruments to gather quantitative measurements of illumination over a one week period.

After analyzing the data we found that the natural light within the Music Instruction room was not an adequate source of light to support the tasks being preformed. However, there is not a need for all of the fluorescent and incandescent lights to be on at one time. We also found that incandescent light reflecting from laminated wall displays causes glare and visual discomfort for the occupants.

W.D. Richards Elementary School

Side exterior view showing the character and sawtooth pattern of the roof monitors.
[photo looking North-Northeast]

Photo by Joshua E. Inman

Introduction

The Vital Signs program is administered by the Center for Energy Research/Education/Service (CERES) at Ball State University in Muncie, Indiana. Developed in 1995, the course focuses on developing environmental assessments of various architectural buildings throughout the region.[1] The case study chosen for the fall semester of 2003 was the W. D. Richards Elementary School located in Columbus, Indiana. The school was designed by Edward Larrabee Barnes and completed in 1964. An addition designed by Lee / Timchula Architects was completed in 1997.[2]

Illumination Background [3]

According to the Vital Signs VIII manual,[3] light is defined as the part of the electromagnetic radiation spectrum that can be perceived by the human eye. The visible spectrum ranges from blue light (475 nanometers), through green, yellow, orange, red, and violet light (725 nanometers). When all of these wavelengths are viewed together we see white light. Light obeys certain laws and has fixed characteristics that make it predictable; this makes the design of lighting possible.

For a further explanation of light and how we perceive it see Appendix A.

The Illuminating Engineering Society (IES) developed a set of standards for illuminating areas based on the activities taking place within them. Activities within the Music Instruction room fall into the category for *performance of visual task of high contrast*. Tasks such as reading music or song books, viewing a video, and reading from the blackboard require a certain amount of light. The IES recommends between 20 and 50 foot candles (fc) for the high contrast category.

The complete IES table of recommendations can be found in Appendix B.

Indicative Phase

The first phase of our research involved an initial visit to the building to familiarize ourselves with the lighting conditions. After a brief examination of the areas we chose to evaluate the Music Instruction room.

Investigative Phase

This second phase of our research consisted of gathering information and quantitative measurements of the lighting conditions within the room. We set up light meters and illumination data loggers, in the Music Instruction room and recorded the illumination levels over a period of one week. We also recorded digital images of the space to be used for mapping the brightness levels within the visual field. During our visits we talked with the primary user of the room, the music teacher, Mrs. Debbie Turner. She discussed with us the problems she faces with the lighting during different seasons and gave us an idea of her typical lighting strategy during school hours from 8:10 a.m. to 2:40 p.m.

Diagnostic Phase

The last phase of this study was devoted to analyzing the data we collected in the previous phase. We found that the daylight reaching the users' task area met the recommended IES standards (20-50 foot candles). We also found that the incandescent lighting system created reflected glare within the users' visual field.

Skylight Detail

Exterior view showing the detailed view of the construction of the main roof monitor. [photo looking North]

[1] **CERES,** *CERES at Ball State University*. www.bsu.edu/ceres. (accessed, December 8, 2003)

[2] **W.D. Richards,** *W.D. Richards Elementary.* www.bcsc.k12.in.us/schools/richards/index. (accessed, December 8, 2003)

[3] **Schiler**, Marc E., and Shweta A. Japee. ***Interior Illuminance, Daylight Controls and Occupant Response***.

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Research Methodology

We used the following three-phase research methodology to study the lighting conditions in the Music Instruction room to test our hypothesis:

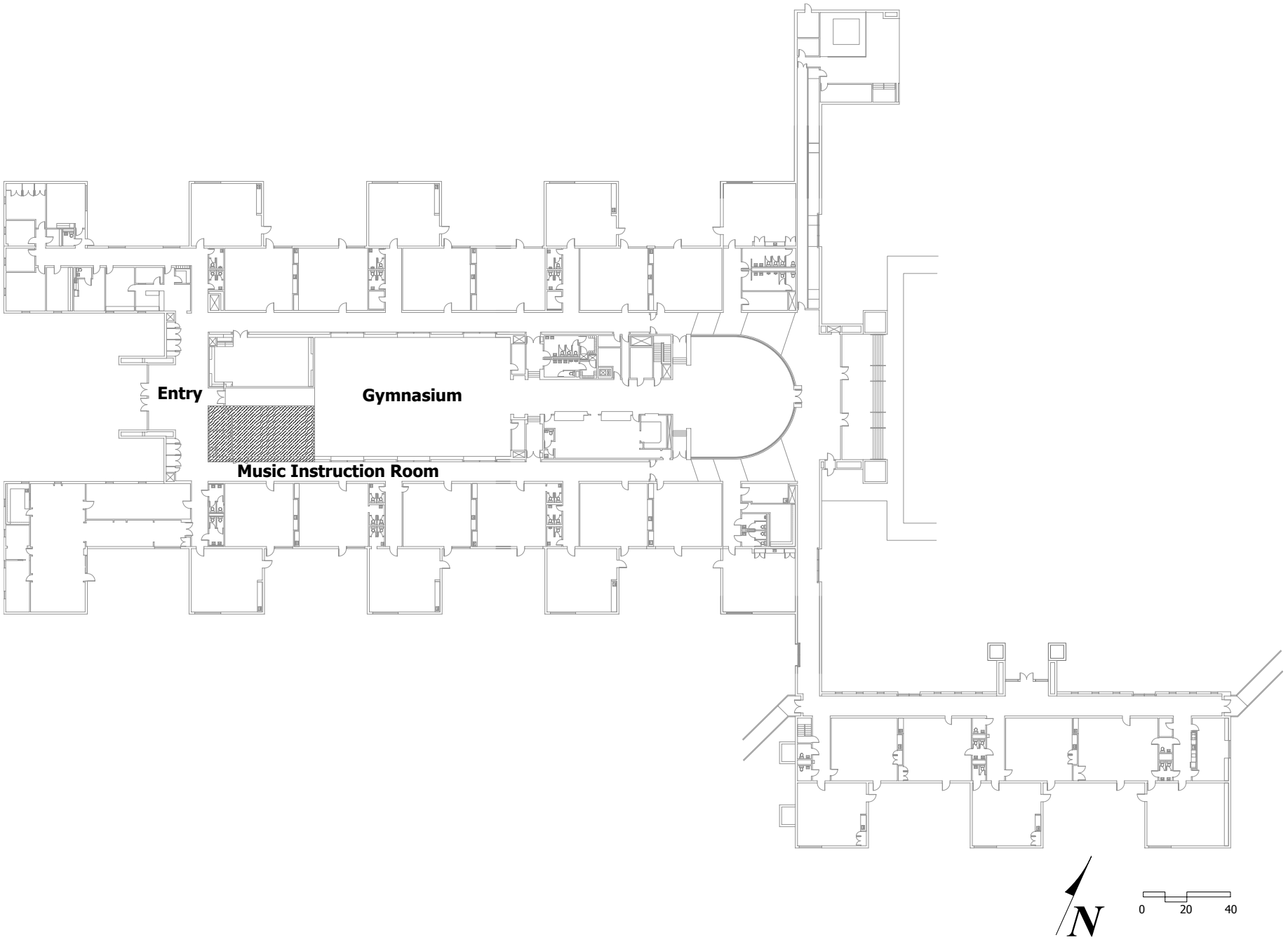
The *indicative* research phase involved a visit to the school in mid-September to familiarize ourselves with the different spaces in the school and to begin to understand how the lighting system worked. A short tour was conducted by Mrs. Ercell Cody, Principal and we were able then to explore the building at our leisure in order to identify indicators and problem zones within the lighting design we wanted to test. Once the indicators were identified, we formulated a hypothesis for developing an assessment of the lighting conditions within a chosen space.

Following the visit, each of the four teams selected a space they intended to investigate. Our team chose the Music Instruction room located to the southwest of the Gymnasium. We were interested in the quantity and quality of natural light brought in through the roof monitor and its success or failure in providing the recommended level of light for the space. Our team was also particularly interested in the reflection of light into the space by the angled ceiling as well as the north, west, and south walls.

The *investigative* research phase involved gathering data with handheld instruments, such as light meters and luminance guns, to measure the available illumination and luminance levels throughout the space. Digital photographs were taken to capture the illumination patterns in the space. Glare and hot spots were also identified using these photographs.

The *diagnostic* research phase completed the investigation of the Music Instruction room. Measurements of lighting conditions were gathered using illumination data loggers, and illumination quantities taken over a specified length of time were analyzed.

Finally, findings and recommendations to improve the lighting conditions of the space were developed. These recommendations are to be turned over to Mrs. Cody in hopes that necessary steps may be taken to improve the conditions in the space.


Entry
Gymnasium
Music Instruction Room
N
0
20
40

Indicative Research

Our first visit to W. D. Richards Elementary School in Columbus, Indiana took place on September 9, 2003. The purpose of the visit was to begin to familiarize ourselves with the building. During this visit we began identifying spaces we might like to research.

We met with Mrs. Ercell Cody, Principal of Richards Elementary who, during the course of the project, was our contact for information and the coordinator for our site visits. We were allowed to explore the building freely to make our observations.

Most classrooms and the gymnasium are naturally lit by northeast facing roof monitors. The section [Figure 2.2] on the following page shows an east to west cut through the Music Instruction room. This section is typical for most of the classrooms within the building. We talked with several of the teachers to get a better idea of how the building lighting systems function. Most had similar complaints about harsh morning light coming in through the overhead monitors. In other areas of the building the complaints only pertained to certain times of the year. Spring and Fall produce some issues of comfort with brighter light creating glare in the rooms. This is particularly bothersome if the glare is reflected off the blackboard on the west wall. The monitors are all equipped with a shading device. We found that some teachers prefer to keep the shades closed at all times and make use of the fluorescent light as a substitute.

In the Music Instruction space we were interested in the amount of natural light that was hitting the west wall in the back of the room. There was a large contrast of light between the east front wall where the blackboard is and the back west wall. We were also intrigued by the number of different lighting systems that were in the room. The incandescent track lights were operated on several different switches and the two fluorescent light banks were each on their own switch allowing for a multitude of lighting options.

Hypothesis:

The artificial and natural lighting in the music instruction room combine to create an illumination level that meets the recommended Illuminating Engineering Society (IES) illumination levels for the specified tasks.

Figure 2.1
Richards Elementary Floor Plan

The Music Instruction room is denoted with hatching pattern.
Plan courtesy: Mr. Tom Allen

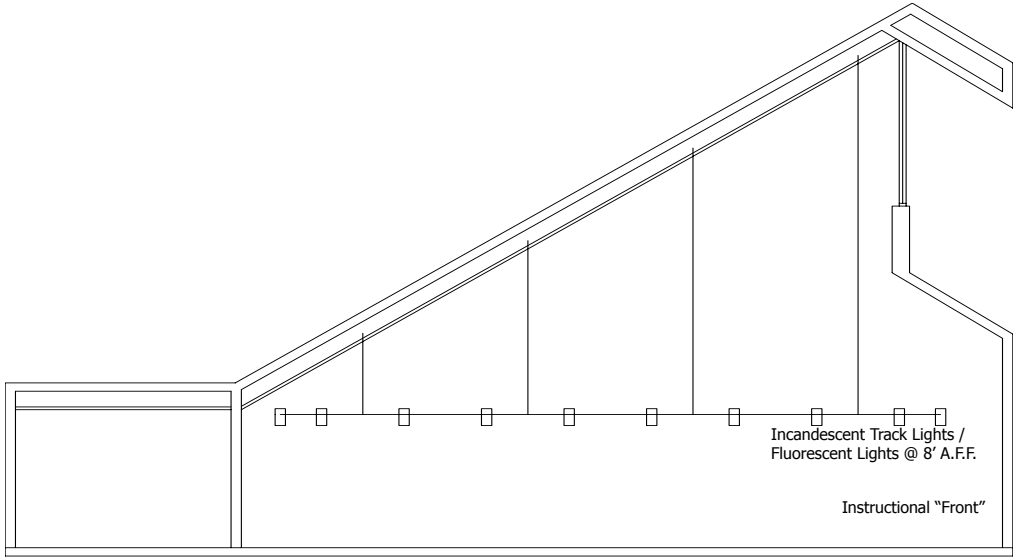
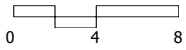


Figure 2.2
Music Instruction Room Section



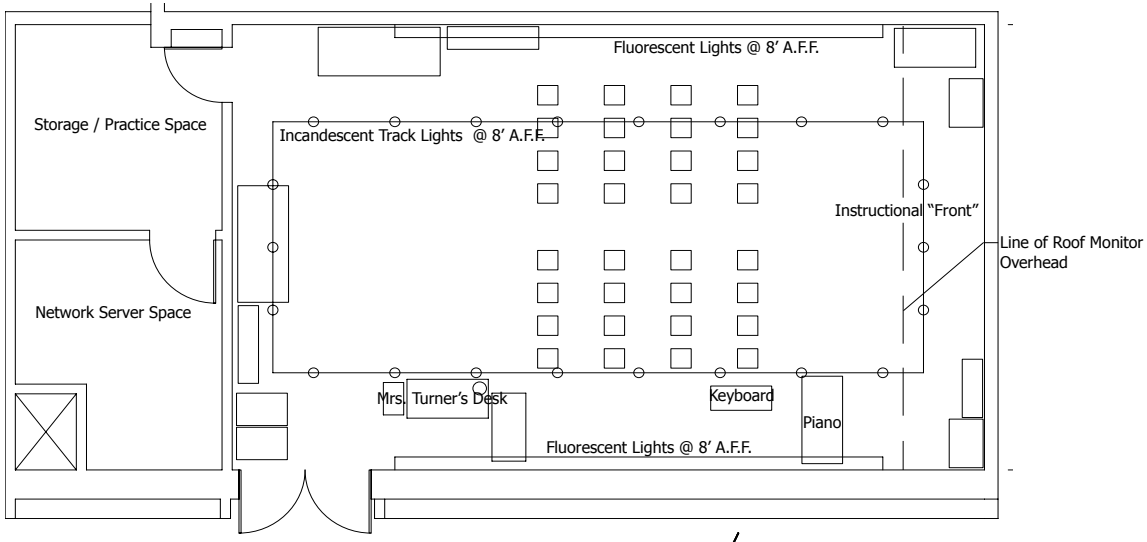
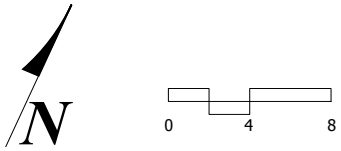


Figure 2.3
Music Instruction Room Floor Plan



Investigative Research

On November 12, 2003 we made a second visit to the site. This visit was used to gather information and take measurements in the Music Instruction room. We spent some time photographing the space. The images we took were used for the foveal vision analysis (see pages 24-27). We also took an inventory of the finishes and the furnishings within the space.

Inventory

Table 3.1

Finishes:	
Walls	Painted (off-white satin) gypsum
Ceiling	2 x 2 white acoustic ceiling tiles
Floor	Sage green institutional carpet
Furniture: (There is no fixed funiture)	
File cabinets	Painted (40% cool gray or tan enamel) aluminum
Desk	Wood veneer surface with painted (black enamel) aluminum base
Tables	Wood veneer 12' tables (covered with white matte finish tablecloths)
Chairs	Molded (navy blue) plastic on polished aluminum frames
Book shelves	Painted (40% cool gray or tan enamel) aluminum
Equipment:	
Piano	Stained wood upright piano
Keyboard	Plastic (black matte)
Computer	Dell (Black) monitors
Television (ceiling mounted)	(Black) monitor
Glazing:	
Roof Monitor	Clear, East-facing glass
Small window in west wall to practice room	Clear glass

This information was gathered through our observation of the Music Instruction room.

Evaluating the Hypothesis

The intent of the investigative research was to test the actual illumination levels in the Music Instruction room against the recommended IES standards. Plans were made prior to the visit in order to efficiently utilize the available instruments and time as well as to minimize the inconvenience to the users of the room.

Assumptions

During the planning process we made certain assumptions about the space and our instruments.

The first assumption dealt with our plan to position the illumination data loggers. We assumed that the nature of activities within the music instruction room would limit our ability to place instruments in certain positions. The result was a plan to place the instruments as far from the walls as possible without placing them in the way of daily activities.

A subsequent assumption was made during the November 12th visit that variations in placement between 6 and 18 inches would not be significant enough to alter illumination quantity measurements in the music room. Bearing this second assumption in mind, we attempted to place our Stowaways further from the wall rather than nearer, if at all possible.

The intent of data collection during the investigative phase was to gather both instantaneous illumination and long term illumination quantities within the Music Instruction room.

Data Collection

To gain a better understanding of the general lighting conditions in the Music Instruction room, we took instantaneous illumination measurements using a G.E. Illumination Meter (see Appendix D for instrument abilities and limitations).

We sectioned the room off in 4 foot increments and took measurements at a height of 30 inches above the floor plane. The 4 foot increments aligned with the spacing of the incandescent track lighting thus allowing us constant reference points as we recorded our measurements. The height was derived from the theoretical task surface of the students using the room.

We were interested in the illumination quantities over different parts of the day which corresponded to the different classes using the room. Measurements were taken at 8 a.m., just minutes prior to Mrs. Turners first class of the day. A second measurement was taken at 11 a.m. following the final morning class. The third measurement was taken at 1:00 p.m. prior to the first afternoon class.

See Figures 4.8 and 4.9 for more details on the instantaneous measurements.

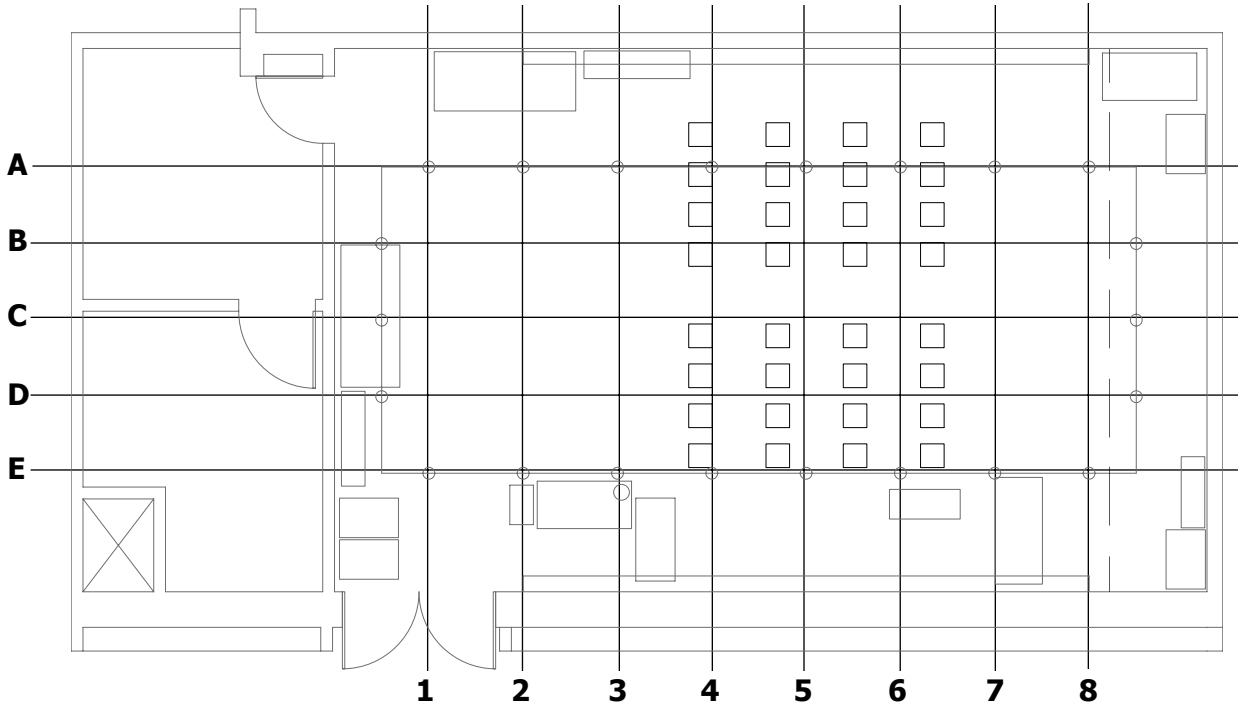


Figure 3.1
Reference Plan - Locations for Measurement of Instantaneous Illumination Quantities

Data Collection
Illumination over Time

Following the intantaneous illumination measurements we wanted to observe the illumination quantities over a week-long time period to see if the daily measurements matched the intantaneous. We set up six Stowaway Illumination Data Loggers around the room taking a measurement every 5 minutes from midnight Thursday, November 13 through 6:00 a.m. Wednesday, November 19.

We sectioned the room off into thirds measuring the west third, central third, and east third of the Music Instruction room. One set of instruments was placed near the north wall, the other near the south wall in order to measure any differences in reflected illumination due to the east-facing roof monitor.

We were able to isolate the fluorescent lighting on Thursday morning, the incandescent lighting on Friday morning, and the natural lighting over the weekend. These isolated measurements allowed us to develop more accurate representations of the contribution from each light source.

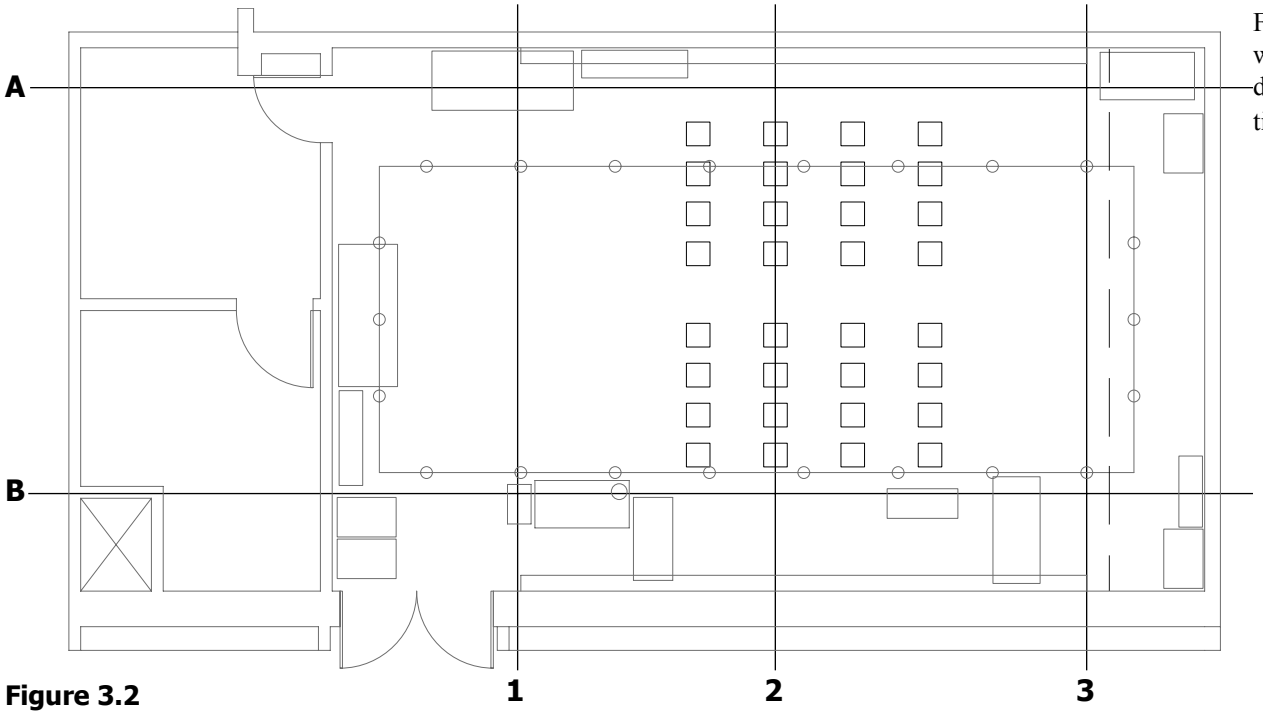


Figure 3.2
Reference Plan - Locations for Measurement of Illumination Quantities over Time

This phase of our diagnostic research sought to quantify the lighting conditions within the visual field of Mrs. Turner and her students.

Visual Field Mapping

Visual field maps were constructed utilizing an understanding of how the human eye works. The foveal vision falls within only the central 2° of the 180° field of view. Within the foveal vision, modest contrast ratios ranging from 1:1 to 4:1 allow the eye to distinguish fine detail. The near field falls within 60° of the line of sight, and the eye can accommodate contrast ratios as great as 10:1. In the far surround, or the remaining 120° of the visual field, the eye can accommodate contrast ratios approaching 100:1.[1]

Visual field maps were developed by first taking a digital photograph from beyond the visual field. This image became the base image [Figure 3.4]. Using Adobe Photoshop, the base image was reduced to eight tones of gray [Figure 3.5] to simplify the image's complexity. The tone image permitted ease of spot luminance measurements as well as providing quickly identifiable hot spots. The tone image was then manipulated into an edge map [Figure 3.6]. Luminance measurements were recorded on the edges images. Finally, foveal overlay images [Figure 3.3] were created by "moving forward" in the space photograph and placing a foveal overlay on the image at the location of an individual chair. The resulting overlay allowed us to determine whether luminance ratios exceeded acceptable contrast ratios and to identify and quantify potential glare problems.

Quantifying the Data

Using the visual field maps as our guides, we used the Minolta LS-100 Spot luminance meter to obtain the luminance values from various locations throughout the space. These locations included the instructors field of view, the individual students field of view from within the typical seating arrangement, and from the reading/performance area at the west end of the room looking towards the instructional end (east) and toward the roof monitors (up and south).

[1] **Stein**, Benjamin, John S. Reynolds. ***Mechanical and Electrical Equipment for Building***.

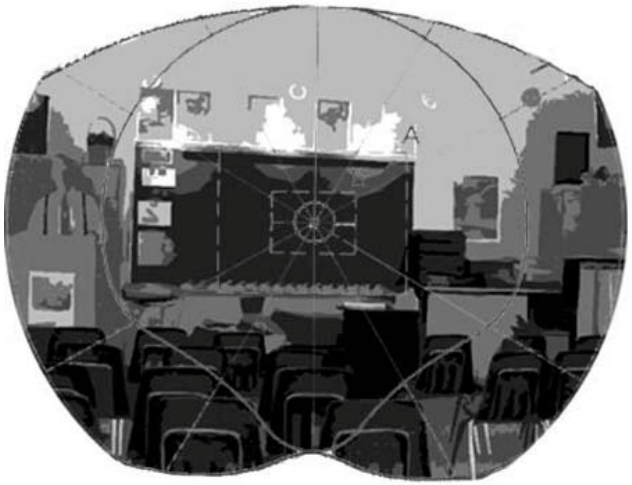


Figure 3.3 Example Image of Binocular Overlay

Figure 3.4 Example Base Image

Figure 3.5 Example Tone Image

Figure 3.6 Example Edges Image

Photo by Joshua E. Inman

Diagnostic Research

The data collected from the Stowaway Illuminance data loggers indicate that while the light in the Music Instruction space does meet the IES recommended minimum standard, it does so differently than anticipated. We anticipated higher illumination levels toward the western end of the room as the light could enter the roof monitors from the east and could penetrate all the way to the west wall. We also anticipated the additional light reflecting off of the west wall would cause that end of the room to maintain a higher illuminance.

Both our instantaneous measurements and our measurments over time indicated that, in fact, there is a higher level of illumination toward the west end of the Music Instruction room. The diagnostic analysis discusses further the quanities of illumination throughout the room. We also analyzed the contrast patterns around the space and found that there were few points of visual discomfort within the room.

Composite Assumption

Figure 4.2 represents the composite measurements from the all six of the illumination data loggers. Discrepancies between the illumination levels were assumed to be due in part to the varied distance of the instruments from the north or south walls. The data represented also take into account the multipliers for color correction (see Appendix D). See Appendix C for the individual components of the composite graph.

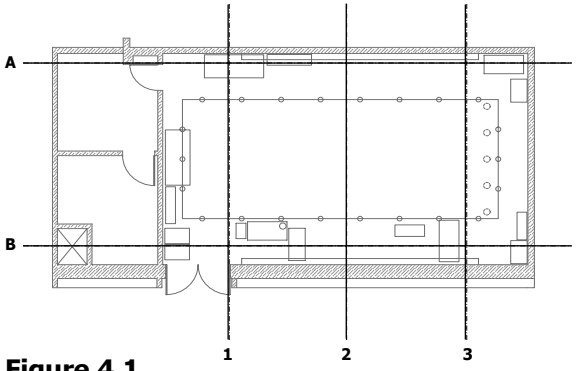


Figure 4.1
Reference Plan
Illumination Quantities over Time

Source of Glare

The glare from the incandescent accent lights was noticed during the indicative visit to Richards Elementary and led to the decision to investigate the lighting design in the Music Instruction room.

[Photo looking East from the student seats]

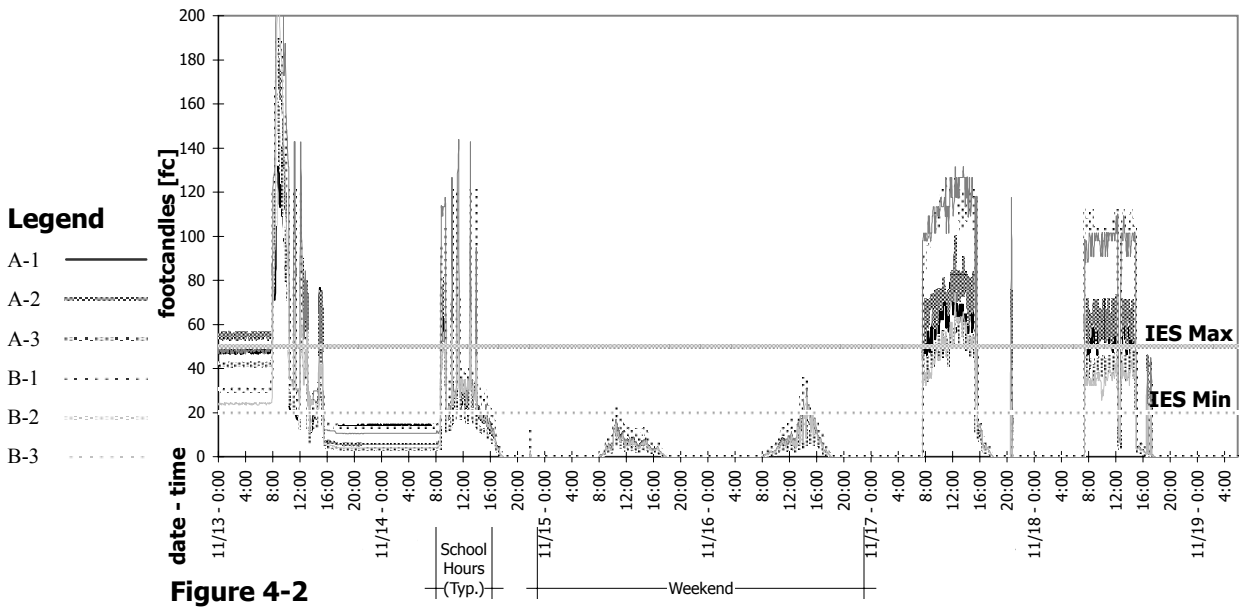


Figure 4-2
7 Day Composite

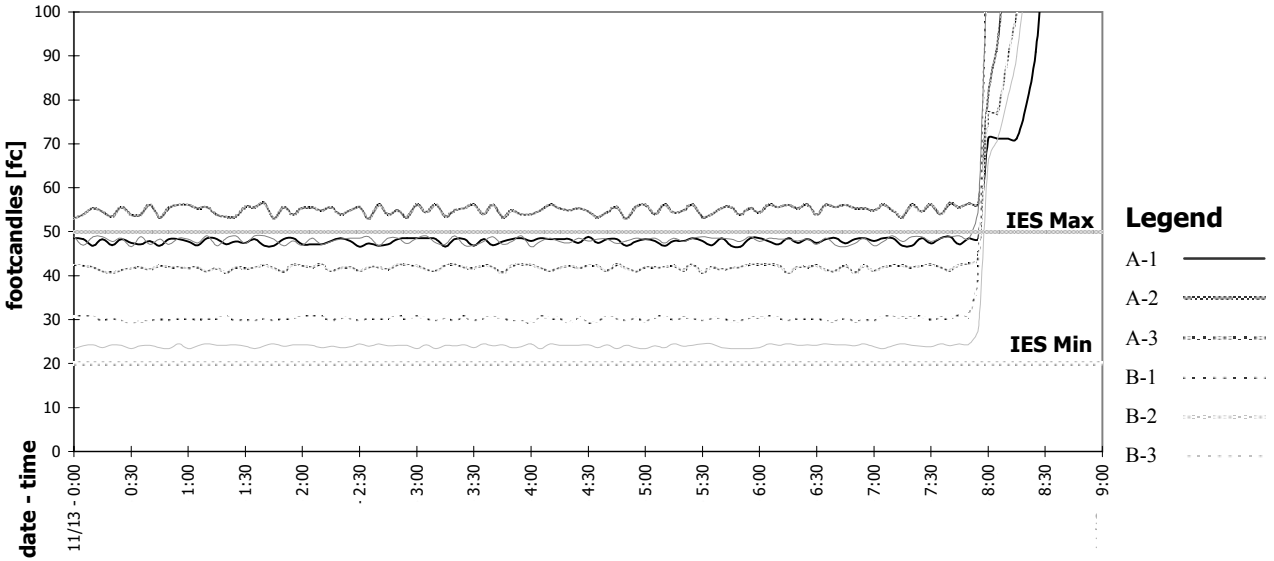


Figure 4.3
1 Day Isolated Fluorescent Composite

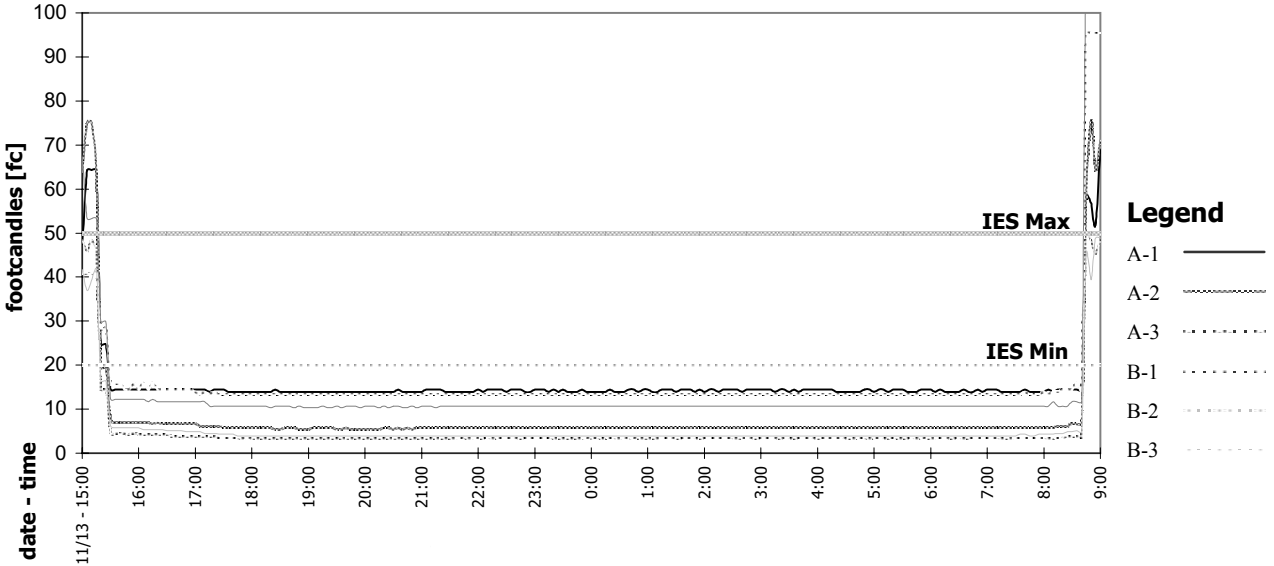


Figure 4.4
1 Day Isolated Incandescent Composite

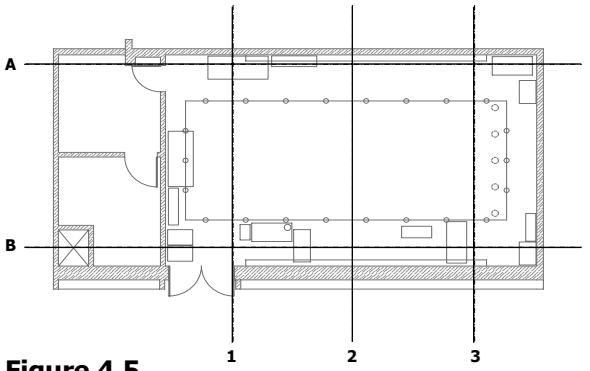


Figure 4.5
Reference Plan
Illumination Quantities over Time

Components of Composite Illumination Patterns

In order to accurately represent the contributors of illumination levels in the Music Instruction room, it was necessary to isolate each light source during the course of our data gathering.

Figure 4.3 represents the isolation of the fluorescent light overnight on November 13. The readings show that the fluorescent lights alone are able to meet minimum IES recommendations for the room.

Figure 4.4 represents the isolation of the incandescent light overnight on November 14. The readings show that the incandescent lights fail to meet the minimum IES recommendation of 20 fc. However, the incandescents are utilized as a complimentary light source rather than the primary source for the room. The main purpose for the incandescents is to highlight different displays and task locations around the room.

Figure 4.7 represents the isolation of natural light on November 15. Conditions were overcast both November 15 and 16 when these values were isolated. The data indicated that natural light is able to provide the minimum IES recommended illumination only during a brief period during the late morning.

See Appendix C for the individual components of the composite graphs.

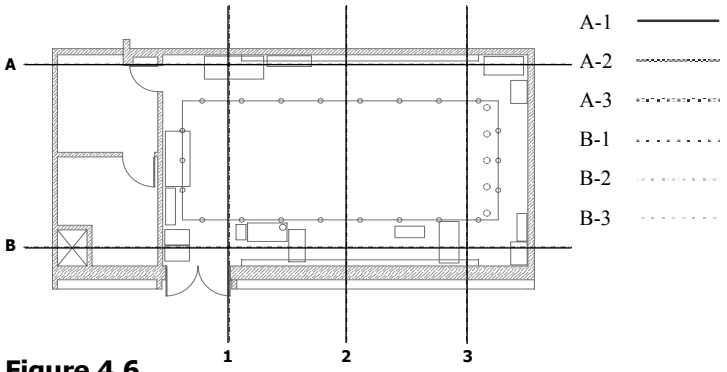


Figure 4.6
Reference Plan
Illumination Quantities over Time

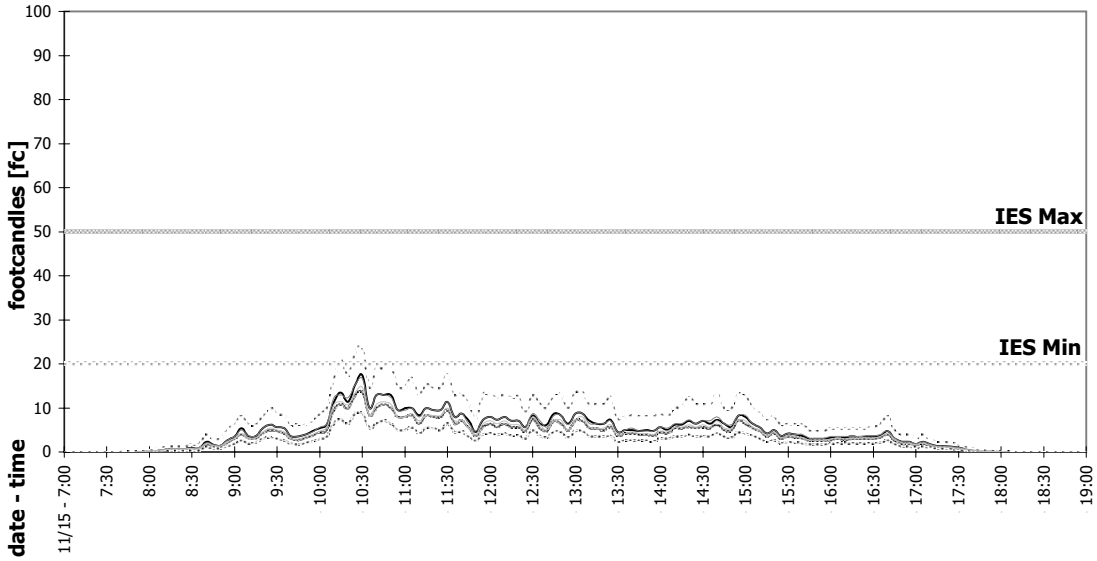


Figure 4.7
1 Day Isolated Natural Composite (Overcast Conditions)

Instantaneous Illumination Quantities

The results of the instantaneous illumination measurements were not as we had anticipated. We anticipated a "mountain of light" similar to Figure 4.12. We assumed the light would enter in through the east-facing skylight and reflect off the west wall and into the space. Thus, we expected to see the highest illumination levels closest to the west wall and a diminishing illumination moving toward the east.

The 8:00 a.m. measurement [Figure 4.8] indicated that during the winter months, the first class does not gain any natural light as the sun has not yet broken the horizon.

The 1:00 p.m. measurement [Figure 4.12] follows our assumption closely. However, the 12:00 noon measurement [Figure 4.11] showed the higher illumination levels occurring closer to the center of the Music Instruction room.

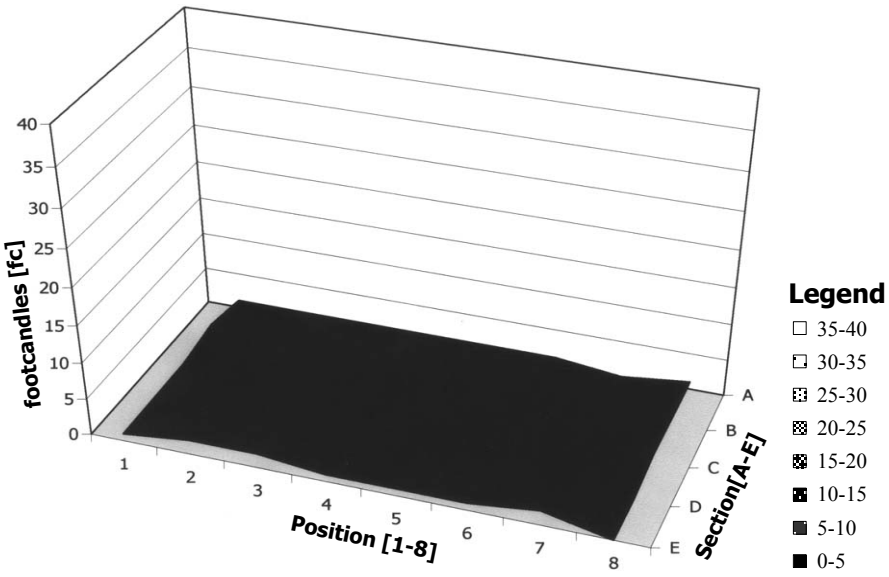


Figure 4.8
Instantaneous "Mountain of Light" (8:00 a.m.)

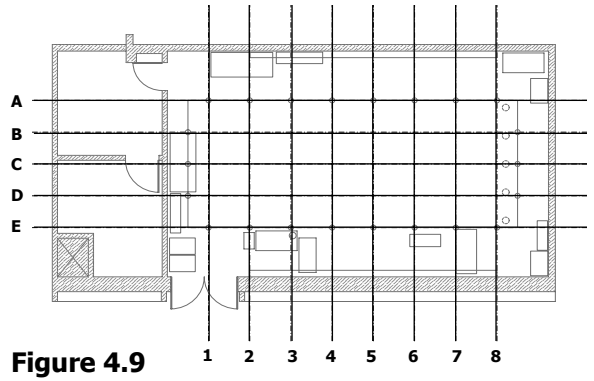


Figure 4.9
Reference Plan
Instantaneous Illumination

We also noticed a slight increase in the illumination levels toward the north wall [sections A and B] common to both measurements.

We decided to measure the illumination of the room over the next week to determine which model more accurately represented the general lighting performance of the room. The arrangement of illumination data loggers was determined in order to allow analysis of west, central, and eastern positions as well as the north versus south sides of the room. (See Figure 4.15 for arrangement of illumination data loggers.)

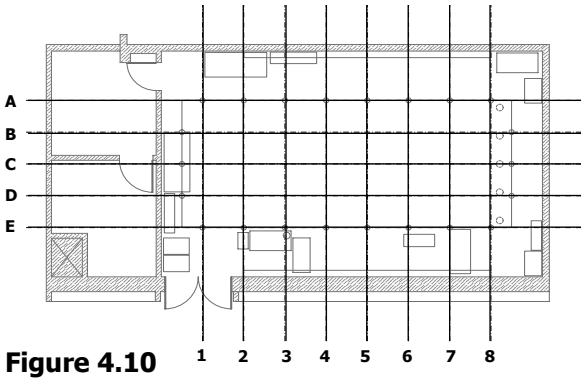


Figure 4.10
Reference Plan
Instantaneous Illumination

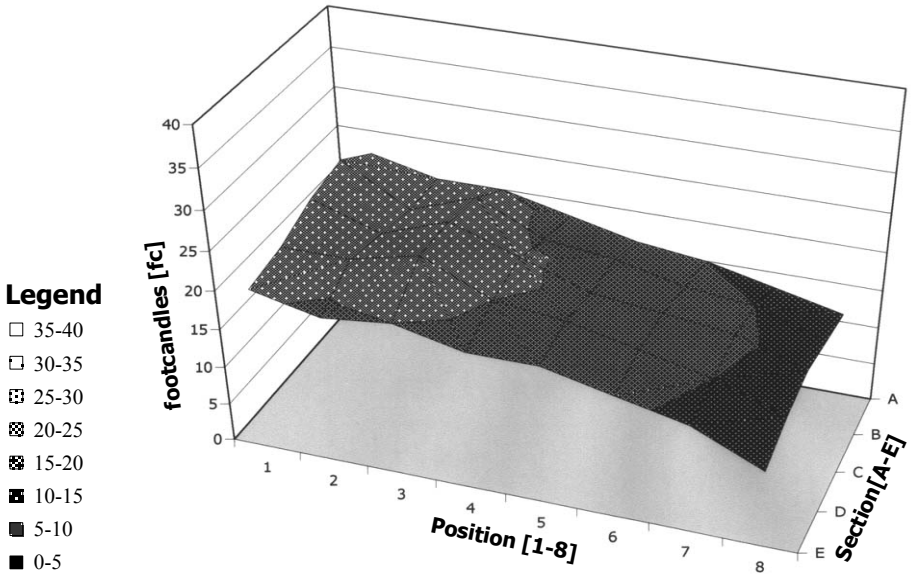


Figure 4.11
Instantaneous "Mountain of Light" (12:00 noon)

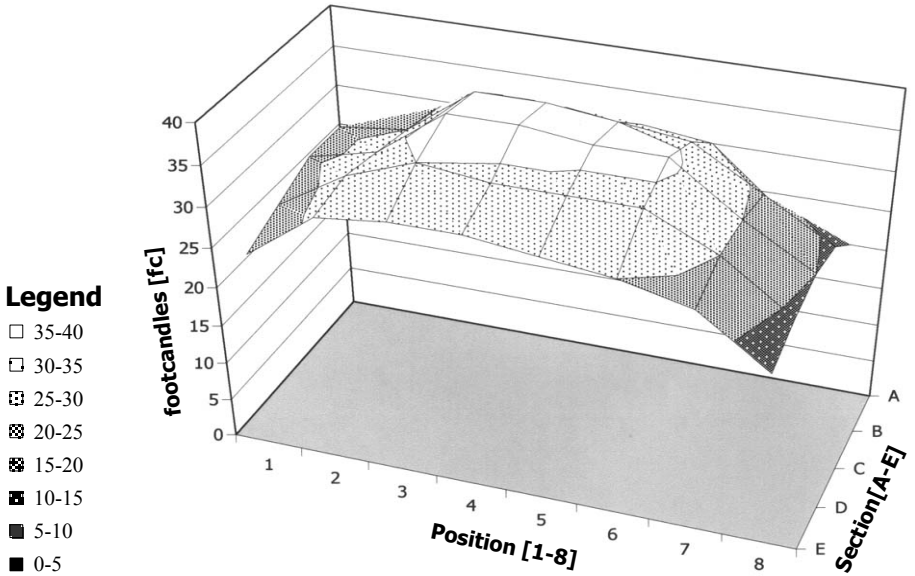


Figure 4.12
Instantaneous "Mountain of Light" (1:00 p.m.)

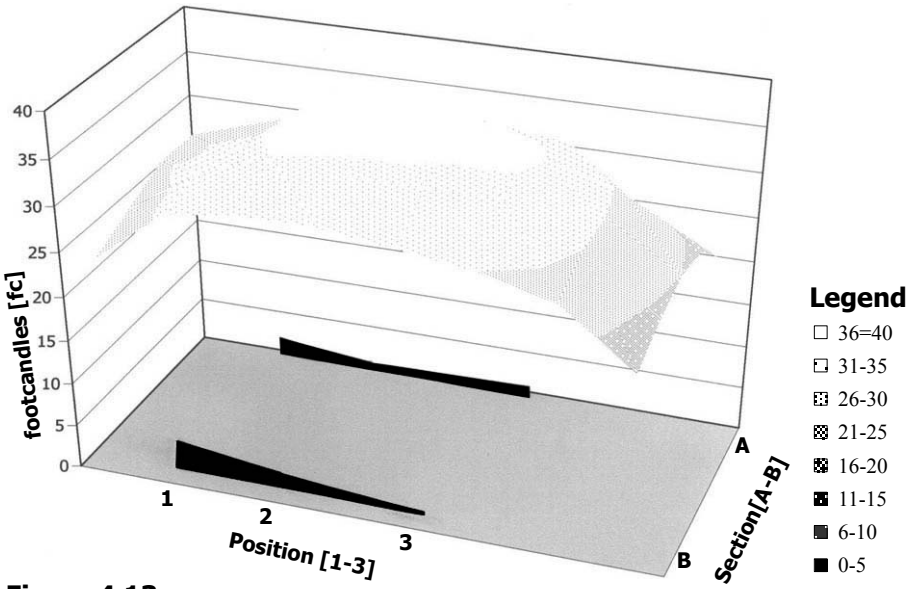


Figure 4.13
Extracted "Mountain of Light" (9:00 a.m.)

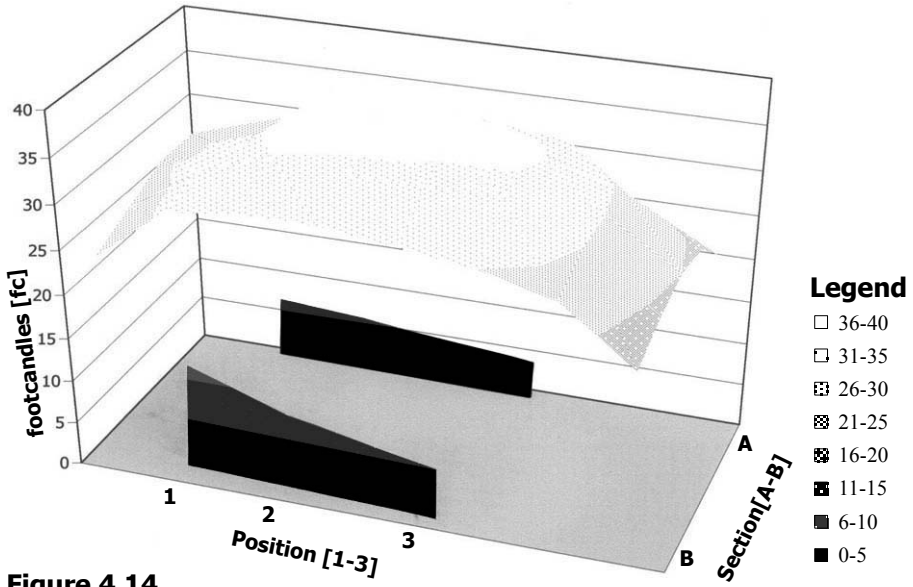


Figure 4.14
Extracted "Mountain of Light" (11:00 a.m.)

Extracted Illumination Quantities

We decided to investigate our findings further by examining instantaneous points from the long term illumination readings. We created instantaneous illumination patterns using the November 16 readings. The 2 hour increments provided a representation of different class meetings throughout the day.

The 9:00 a.m. measurement [Figure 4.13] indicates that very little illumination is present in the room. We presume that the overcast conditions for the day greatly lowered the morning readings.

The 11:00 a.m. measurement [Figure 4.14] indicated illumination levels toward the west end of the room higher than the 9:00 a.m. readings. However, the measured illumination levels still remained below the recommended IES minimum of 20 fc.

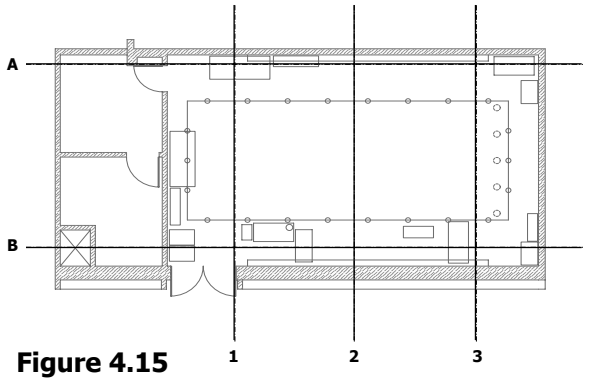


Figure 4.15
Reference Plan
Illumination Quantities over Time

The 1:00 p.m. measurement [Figure 4.17] matched the 11:00 a.m. reading very closely. The illumination levels still did not meet the recommended IES minimum. We also noticed a higher illumination level in the southwest portion of the room. This contradicted our assumption that the illumination levels would be greater on the north side of the room.

The 3:00 p.m. measurement [Figure 4.18] followed more closely what had been measured with the light meter [Figures 4.11 and 4.12]. The center section of the room had a higher level of illumination than the east or west ends. We also noticed a slight increase in the illumination levels toward the south wall.

The 3:00 p.m. rmeasurement was the closest instant to meeting the minimum recommended IES illumination levels for November 16.

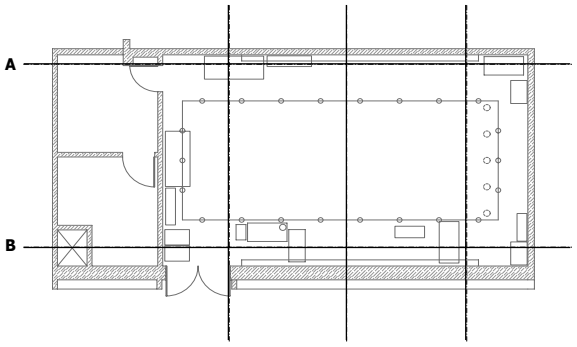


Figure 4.16
Reference Plan
Illumination Quantities over Time

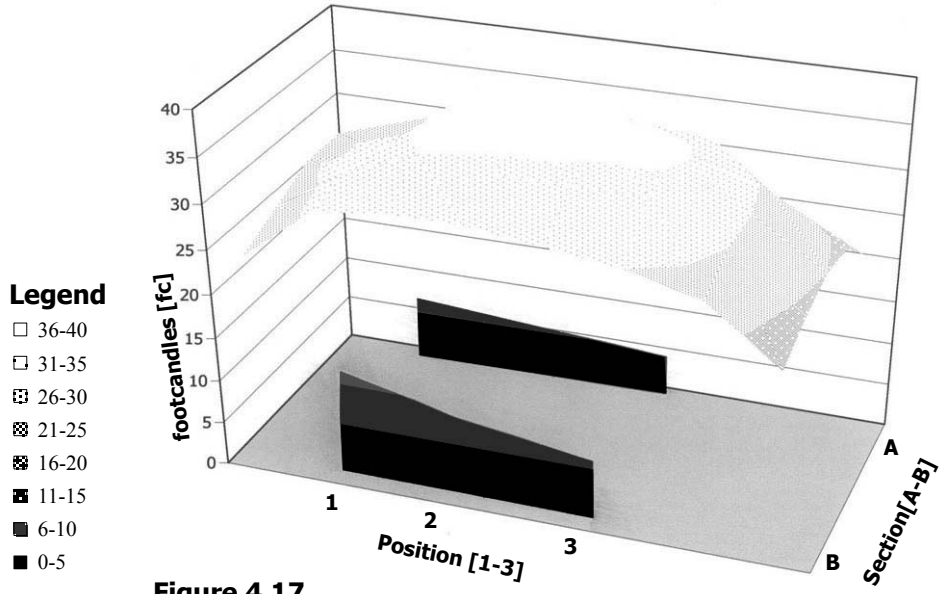


Figure 4.17
Extracted "Mountain of Light" (1:00 p.m.)

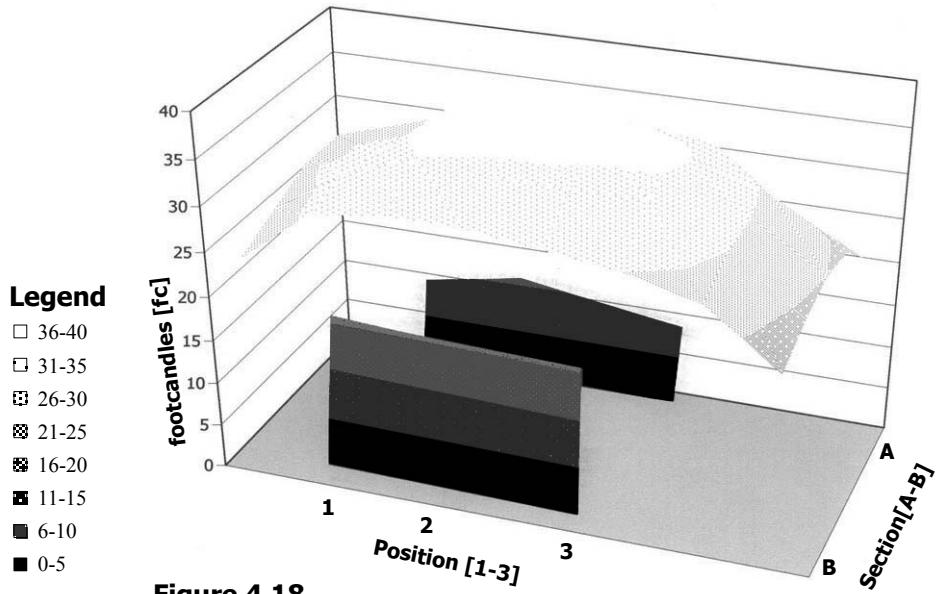


Figure 4.18
Extracted "Mountain of Light" (3:00 p.m.)

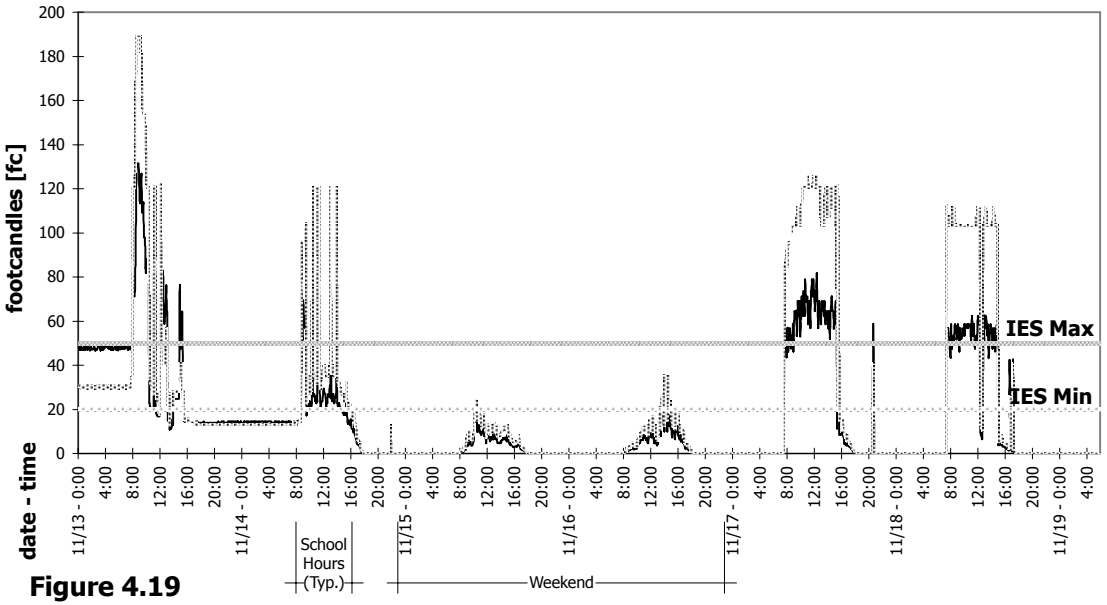


Figure 4.19
7 Day West Composite (Section 1)

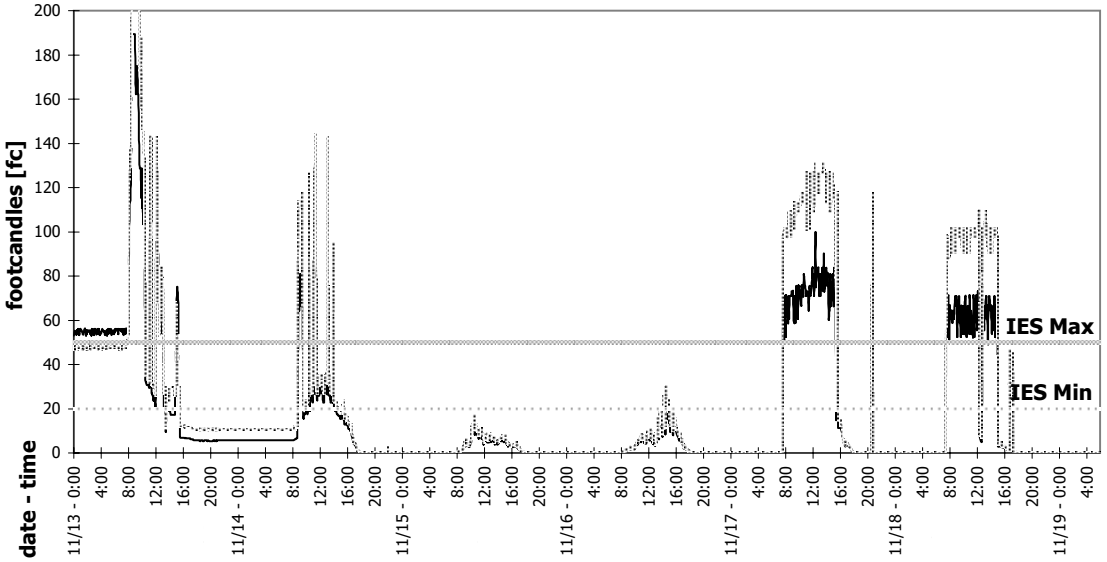


Figure 4.20
7 Day Central Composite (Section 2)

7 Day Cross-Section Illumination Quantities

The measurements taken by the illuminance data loggers indicated that the pattern seen in the 12:00 noon measurement [Figure 4.11] is the general pattern in the Music Instruction room. When the west composite [Figure 4.19] and central composite [Figure 4.20] graphs are compared, the measurements are consistently higher across the central position.

We presume that the light entering the roof monitors does strike the west wall and reflect back toward the eastern end of the space as we originally assumed. However, much of the entering light is deflected off the angled ceiling resulting in a higher illuminance level toward the center of the room. While the light enters at a steep enough angle to be reflected into the center of the room, the angle of incidence is still too sharp to reflect any considerable amount of light into the eastern portion of the room.

The measurements show that a combination of lighting systems was used during instructional periods that often exceeded the maximum IES recommendations for illumination of the room, during the 8:00 a.m. to 4:00 p.m. class time.

See Appendix C for the individual components of the composite graphs.

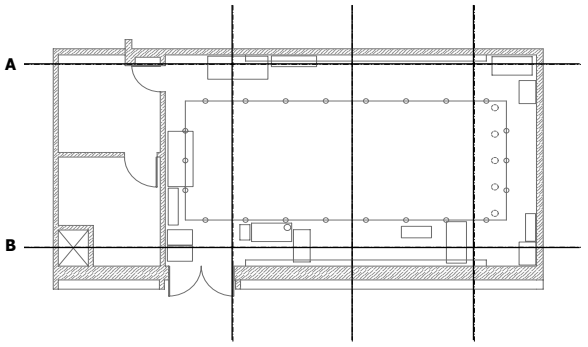


Figure 4.21
Reference Plan
Illumination Quantities over Time

7 Day North and South Illumination Quantities

The measurements taken by the illuminance data loggers also indicated that the pattern seen in which the north side of the room had slightly higher illumination levels indeed occurred as the general pattern in the Music Instruction room. When the north composite [Figure 4.23] and south composite [Figure 4.24] graphs are compared, the measurements are consistently higher across the northern section.

We presume that the light entering the roof monitors strikes the north wall and reflects into the northern portion of the room. This would account for the apparent brightness being greater on the north vertical surface when compared to the south vertical surface.

The measurements show that a combination of lighting systems was used during instructional periods that often exceeded the maximum IES recommendations for illumination of the room.

See Appendix C for the individual components of the composite graphs.

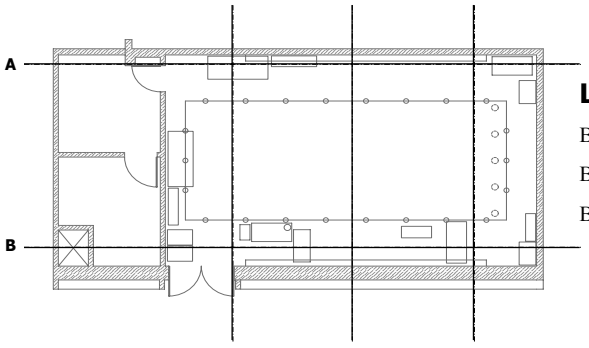


Figure 4.22
Reference Plan
Illumination Quantities over Time

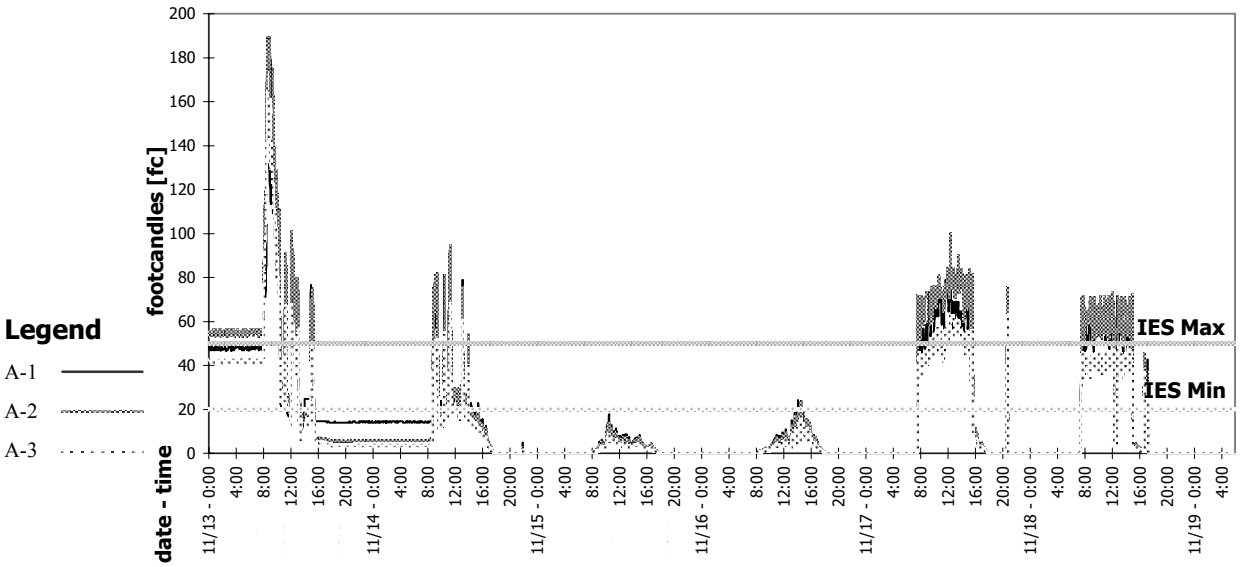


Figure 4.23
7 Day North Composite (Section A)

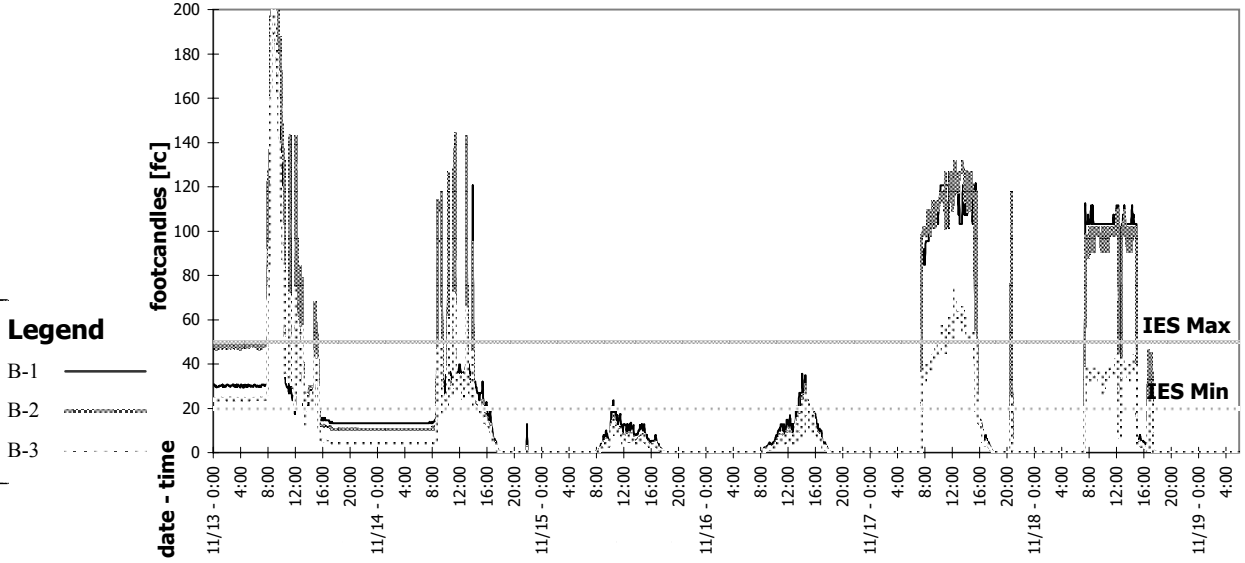


Figure 4.24
7 Day South Composite (Section B)

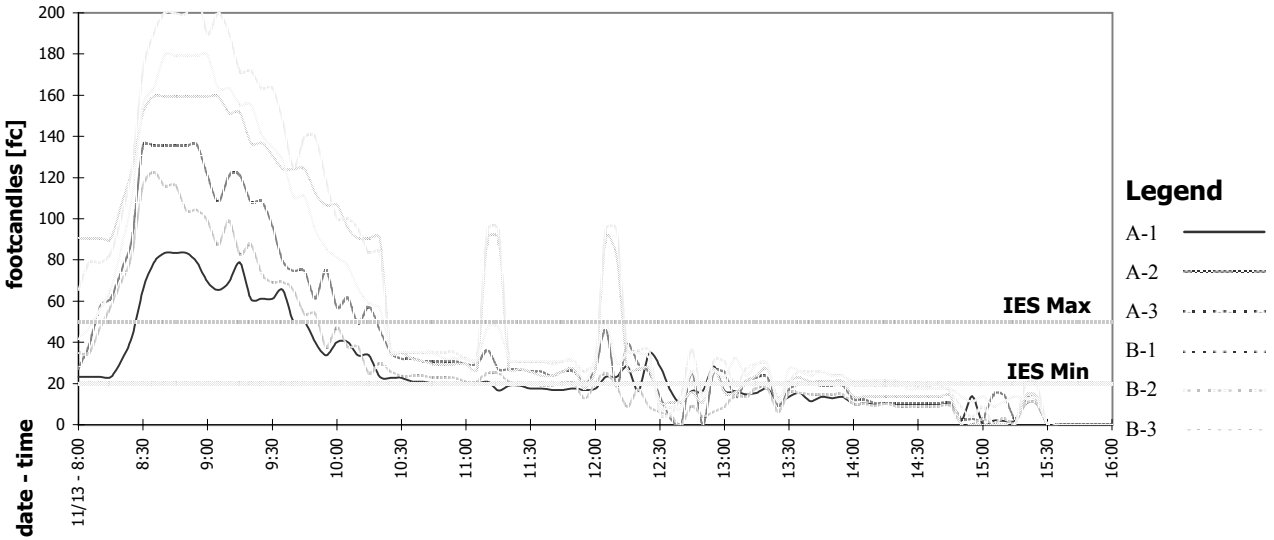


Figure 4.25
1 Day Composite (Sunny Conditions)

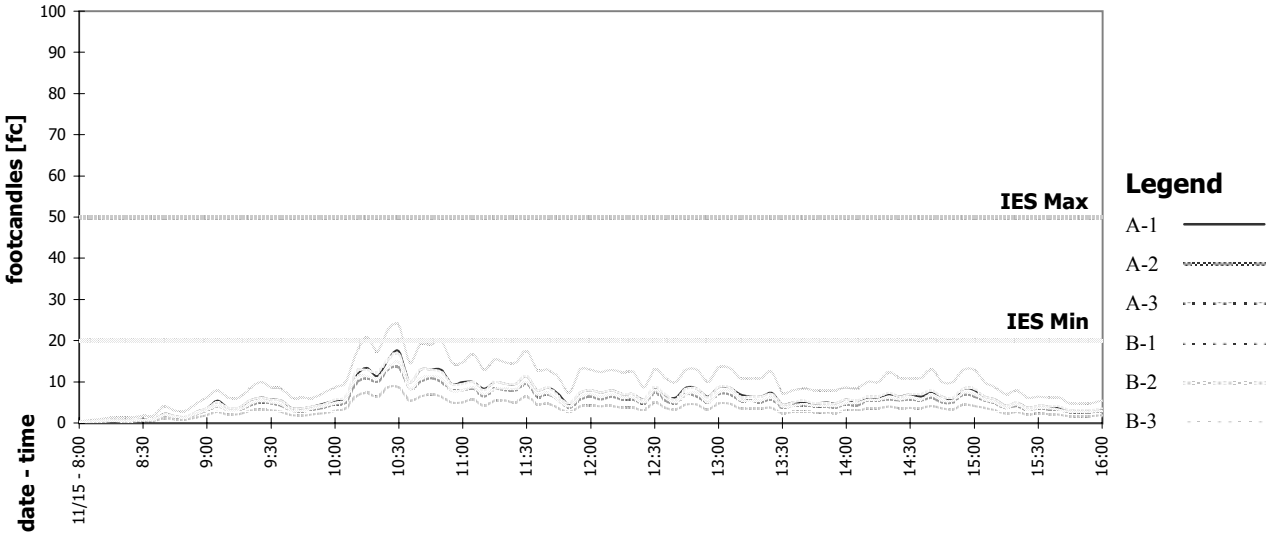


Figure 4.26
1 Day Composite (Overcast Conditions)

Short Term Natural Illumination Quantities (Overcast v. Sunny Conditions)

After finding that fluorescent light could meet the minimum IES recommendations but that the incandescents light and natural light (for overcast conditions) did not, we analyzed the measurements taken the morning of November 13 to find out if natural light for sunny conditions could meet the minimum IES recommendations.

We were able to remove the fluorescent and incandescent light portions of the measurements based on the isolation measurements made [Figures 4.23 and 4.24]. The resulting measurement was the natural light component of the composite.

We found that under sunny conditions, the natural light far exceeded the IES recommendations. Measurements show a brief period when we presume direct daylight penetrated the space shortly after 8:00 a.m. However, during the afternoon hours, measurements indicated that natural light was no longer meeting the minimum IES recommendations.
Note: we presume that conditions may have changed from sunny to partly or mostly cloudy as indicated by hourly weather reports at www.weather.com.

See Appendix C for the individual components of the composite graphs.

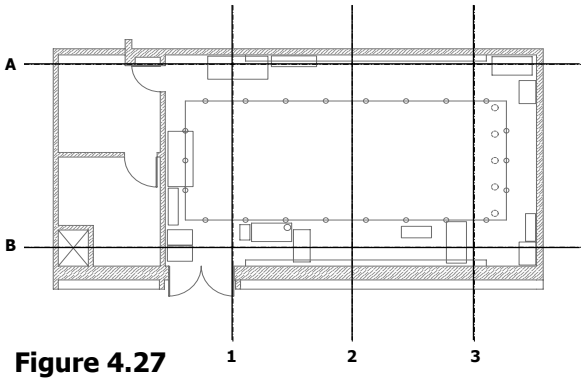


Figure 4.27
Reference Plan
Illumination Quantities over Time

Glare Analysis

The indicative phase revealed that several conditions of glare existed in the Music Instruction room. The common problem we observed was direct reflection from laminated wall displays [Figures 4.29 and 4.30] spotlighted by the incandescent lights. Many of these displays where out of the direct foveal field, but still within the general field of vision causing visual discomfort.

The incandescent task lamp on the instructor's desk was also a source of direct glare [Figure 4.28]. However, the arrangement of the room was such that the lamp was out of the foveal vision of the students during instructional periods. This source also became negligible if the fluorescent lighting was turned on as the contrast ratio fell well within recommended levels.

The major glare problems observed were resolved prior to instructional periods and produced little distraction to the users.

Figure 4.30 Laminated Display Glare

Figure 4.29 Reflected glare from incandescent lighting upon laminated graphics

Figure 4.28 Desk lamp is a source glare on a cloudy morning

Figure 4.31 East Wall w/ Artificial Lights Base Image

Figure 4.32 East Wall w/ Artificial Lights Tones Image

Foveal Vision Analysis - East Wall with Artificial Lights

This foveal analysis is used to evaluate the conditions most often utilized in this space. The fluorescent lighting is on as are some of the incandescent lights. The greatest contrast [50:1] occurs between the board and the reflected light from the incandescent spot lights above. The fluorescent light provides a contrast ratio near 4:1, however, these lights are beyond the field of view for the students using the space. The contrast between the walls, the blackboard, and the piano area are such that visual comfort is not compromised.

With the two exceptions mentioned above, the space brightness ratios remain within the recommended maximum of 40:1. See Appendix B for more information regarding luminance ratios for specific situations.

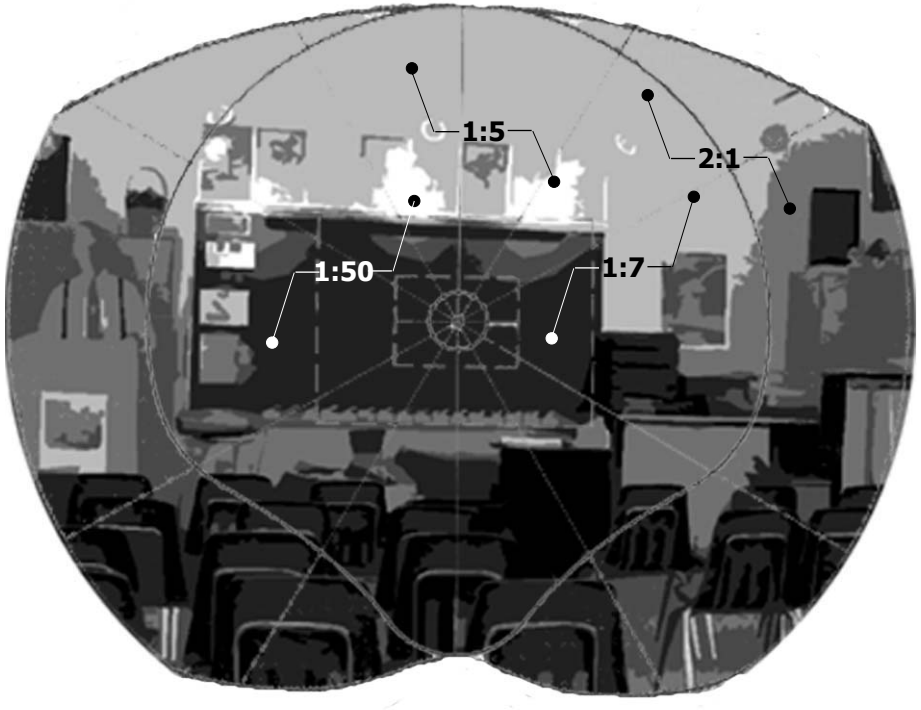


Figure 4.33 East Wall w/ Artificial Lights Binocular Overlay Image

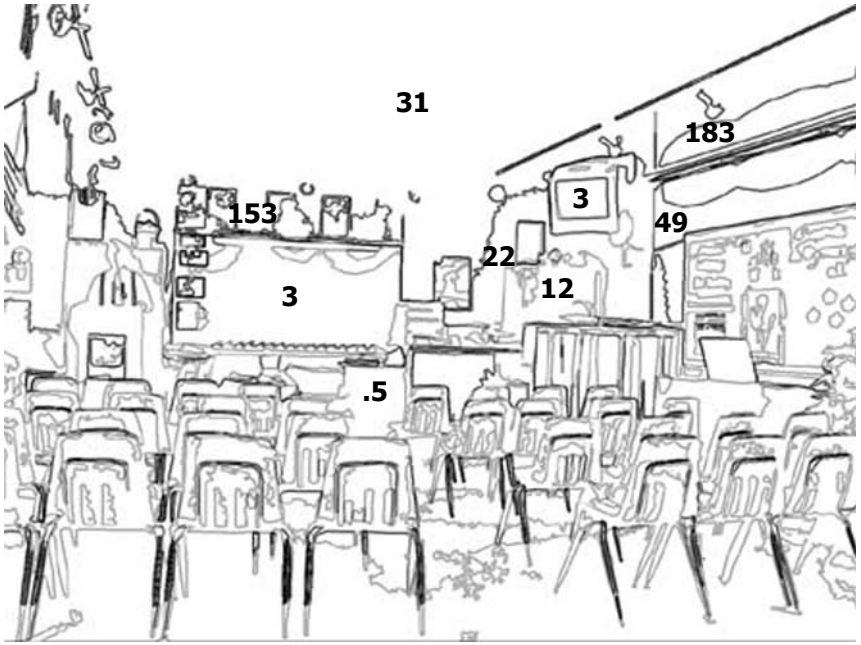


Figure 4.34 East Wall w/ Artificial Lights Edges Image

Foveal Vision Analysis - East Wall

This foveal analysis is used to evaluate the space as it utilizes only the natural light system. The monitor shades are fully open to allow for maximum lighting. The greatest contrast occurs between the blackboard and the wall surrounding it [8:1]. The vertical surfaces to the west end of the room vary such that there is very seldom greater than a 2:1 ratio. The ratio across the space (from beneath the light monitor to the black board) is only 50:1, well within the 100:1 ratio that defines the 120° visual field.

The space brightness ratios remain well below the recommended maximum of 40:1. In fact, the ratios are so low in some instances that we wonder if lack of contrast becomes a problem for the student from time to time. See Appendix B for more information regarding luminance ratios for specific situations.

Figure 4.36 East Wall Base Image

Figure 4.37 East Wall Tones Image

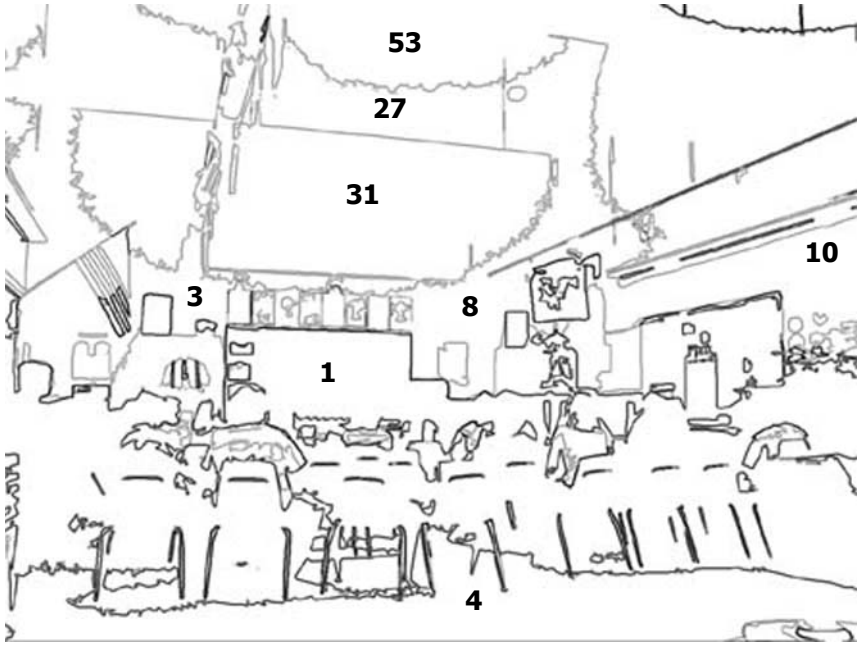


Figure 4.35 East Wall Edges Image

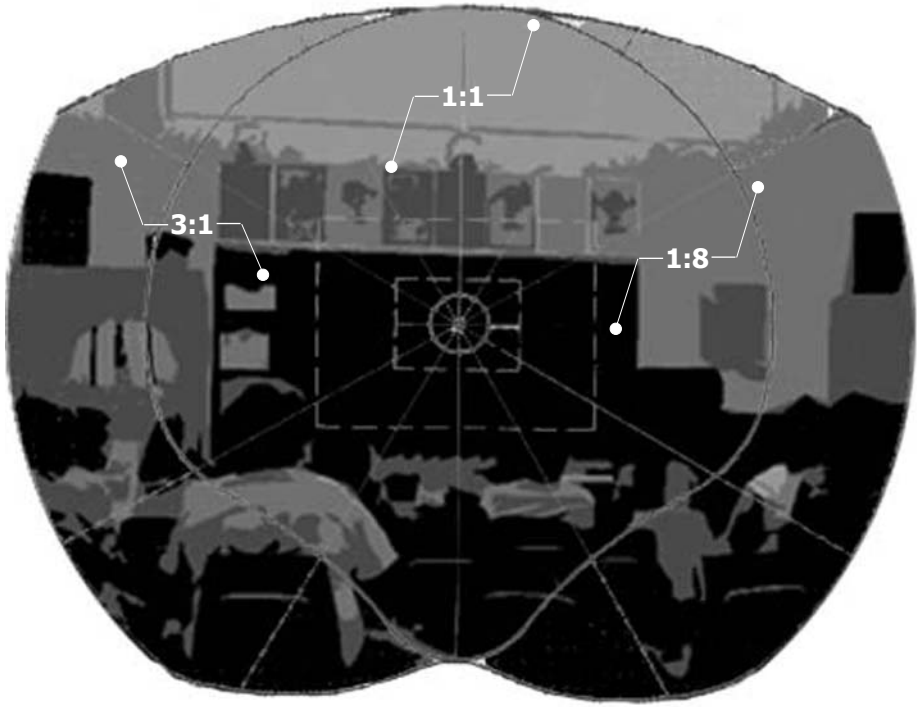


Figure 4.38 East Wall Binocular Overlay Image

Figure 4.39 South Wall Base Image

Figure 4.40 South Wall Tones Image

Foveal Vision Analysis - South Wall

This foveal analysis is used to evaluate the vertical south wall as natural light is reflected into the space. The skylight shades are fully open to allow for maximum lighting. The greatest contrast [55:1] occurs across the upper regions of the space beyond the typical field of view. As the focus moves back down towards the instruction level, the ratios become as low as 2.5:1 which is well within the recommendations for all aspects of the visual field.

For practical purposes, the contrast ratios near the skylight windows can be discarded. The users of the space do not focus attention toward this area. We noticed it sometimes became the area where a distracted or daydreaming student focused their attention. By not providing a minimum level of visual comfort in this area, the design may be able to help redirect focus back down to the instructor and the task at hand. See Appendix B for more information regarding luminance ratios for specific situations.

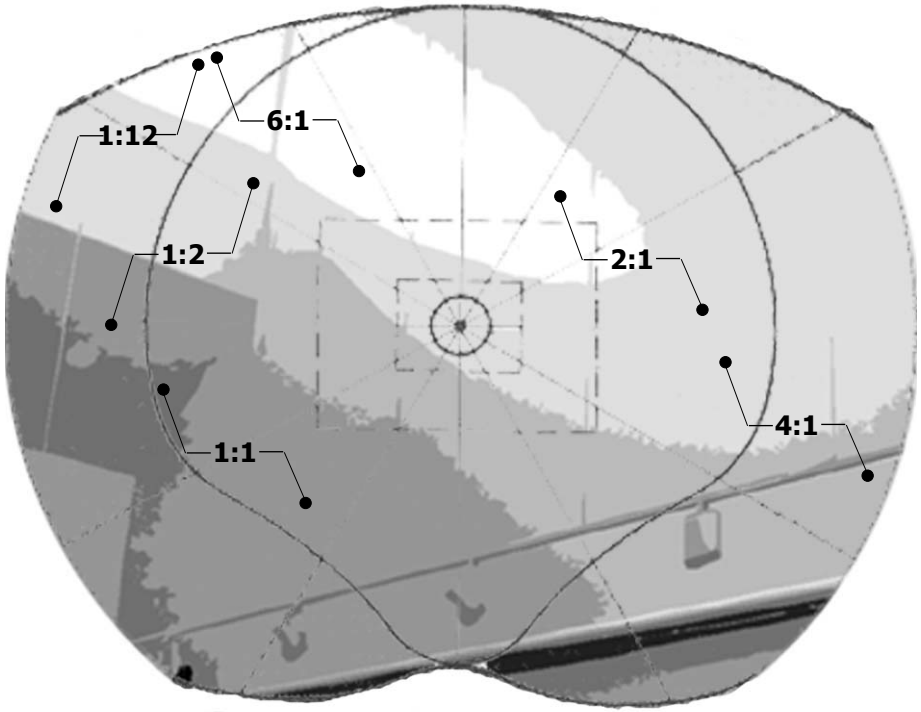


Figure 4.41 South Wall Binocular Overlay Image

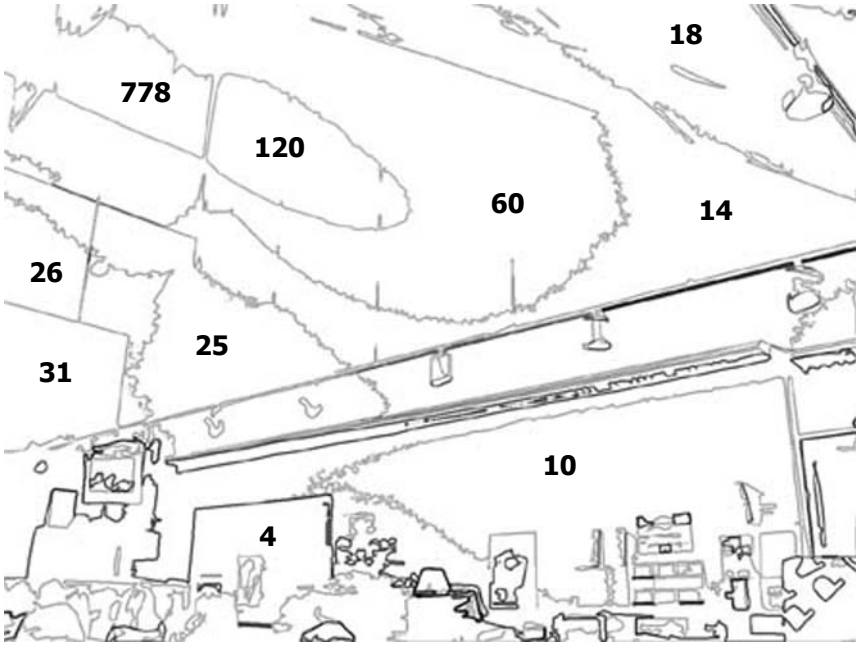


Figure 4.42 South Wall Edges Image

Foveal Vision Analysis - West Wall

This foveal analysis is used to evaluate the west wall of the space as it utilizes only the natural light system. The monitor shades are fully open to allow for maximum lighting. Generally ratios across the wall remained close to a 1:1 or 2:1 ratio. The door [28:1] and window [14:1] into the practice room created the largest contrast ratios.

Again, the contrast ratios fall within the recommended 40:1 maximum ratio. However, the contrast between the wall and the darker door and window could become a source of visual discomfort for the users if the foveal field was directed to the area for extended periods of time. Similarly, the continuity across the wall, while meeting the recommendations, may not provide enough contrast for the eye to distinguish fine details. See Appendix B for more information regarding luminance ratios for specific situations.

Figure 4.44 West Wall Base Image

Figure 4.45 West Wall Tones Image

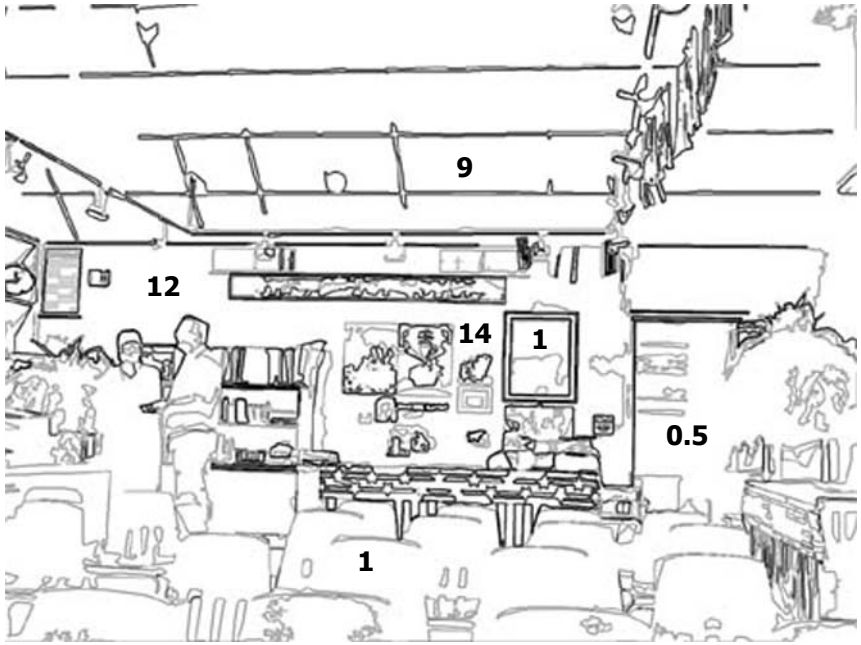


Figure 4.43 West Wall Edges Image

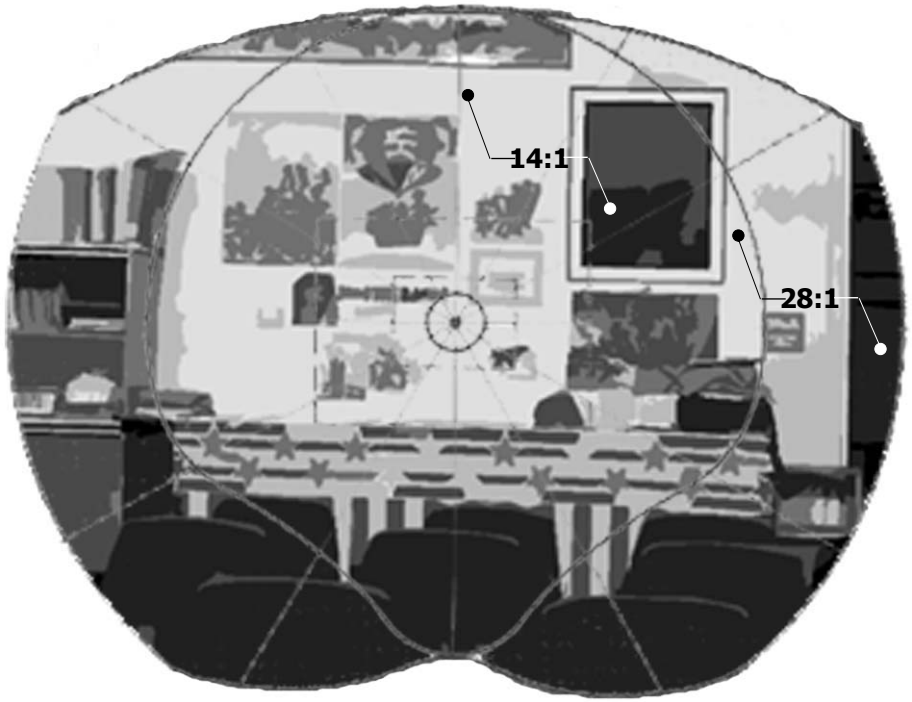


Figure 4.46 West Wall Binocular Overlay Image

Photo by Erin J. McCloskey

Conclusions

Hypothesis

Based upon the findings presented in the previous sections, our hypothesis has proven true. The natural and artificial light indeed combine to illuminate the music instruction room in accordance with the IES recommendations.

The fluorescent lighting alone met the IES recommendation [20-50fc] for the space. In some instances, the fluorescent lighting exceeded the maximum illumination needed. The Incandescent lights were found to contribute only minimally to the overall illumination of the space. The natural light alone was unable to meet the minimum recommended illumination [20fc] for all but a short period during the middle of the day under overcast skies. Conversely, the illumination levels were well above the recommended levels under sunny conditions.

Lighting Quality

While the quantity of light objectively meets recommendations, the quality of the lighting becomes a subjective discourse. We found that the fluorescent lights alone created a "cold" space. The addition of the natural light softened the space. When natural light was the only source of illumination, general visual comfort was not an issue. While the measurements indicated the illumination levels were below the recommended standards, the quality of the light allowed the user to successfully complete the task despite that fact.

User Controls

We also found that the design of the lighting system included a range of control systems. The incandescent track lights were operated on six different switches and the two fluorescent light banks were each on their own switch. These controls are very successful in allowing the user to adapt the light in the space to their needs. More encouraging, was that the controls were utilized as they were intended in the design. We were able to observe several different variations of the lighting systems. Observation also showed that user experience with the system and its controls, as well as the ease of use, maximized the success of the lighting system in the Music Instruction room.

As a final observation we note that the students showed a keen understanding of the lighting design and how it could be controlled to provide maximum comfort in their education. On several occasions, we noted that a student (or students) would suggest a control change that would enhance the lighting in the space for their current task. The lighting design in the W.D. Richards Elementary School thus became another educational experience for the students.

User Comfort

The variety of user controls help to make the Music Instruction room a successful learning environment for Mrs. Turner and her students.

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Recommendations

Many of the issues and problems that our research uncovered already have a user controlled device that can resolve the issue. The success or failure in the lighting of the Music Instruction room often lies in the hands of the users controlling the systems.

Immediate Responses

Our immediate recommendations address the reflective glare produced by the incandescent lights.

One solution is to raise the incandescent lighting system. By raising the entire system, the angle of incidence is more shallow and the light would be reflected at a more shallow angle decreasing the chances of interrupting the visual comfort of the students. Raising the system also lowers the density of the illumination falling on the target surfaces.

A simpler solution would be to redirect the incandescent fixtures. Through a process of experimentation, each incandescent that causes visual discomfort through reflection could be redirected until the reflected glare is eliminated from the visual field of the seated students. While tedious and time-consuming, this solution results in less expenditure of money and an increase in visual comfort for the students.

Considerations in Future Designs

While Richards Elementary can successfully serve as a model for future day lit school designs, we offer some suggestions that will improve the performance of those future designs:

Future day lit designs must consider the orientation of the skylights. Richards' skylights open to the eastern sky. While this provides a high quantity of natural light, the users are often faced with intense morning glare during the beginning and final months of every school year. By turning the skylights northward, two problems will be nearly eliminated. First, the natural light will remain more constant throughout the day and the year. Secondly, northern facing skylights will eliminate many of the instances of direct sun penetrating into the space and creating the problematic reflective glare mentioned by the users.

The success of Richards' design lies, in part, to the number of controls offered to the users of the building. Users have the option of using fluorescent lights and/or any combination of four independently controlled sets of incandescent spot lights. Similarly, every room with a skylight has the option to close the shading devices for the skylight window. Additionally, using dimming controls (automatic or preferably manual) would allow even greater flexibility in how the spaces can be lit for the numerous needs within the educational environment.

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Appendix A

Background [1]

To begin to understand lighting design, one must understand how light works.

The Illuminating Engineering Society of North America [IES] defines light as visually evaluated radiant energy or, more simply, a form of energy that permits us to see. Light may also be considered as a wave, therefore having both a frequency and a wavelength. The visible spectrum is the portion of the electromagnetic spectrum that can be perceived by the human eye. This visible portion ranges from blue light at 475 nanometers (nm), through green, yellow, orange, red, and into violet light around 725 nm. White light is a combination of all visible wavelengths.

[Figure. A-1]

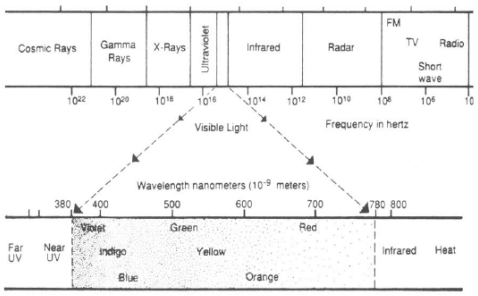


Figure A.1 Electromagnetic Spectrum
Visible light falls between 380 and 780 nm.

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

The Human Eye [2]

There are two aspects to visual perception by the human eye:

biophysical aspect - relating to the human eye an how it works

internal interpretation – relating to the manner in which the brain translates the data it receives from the eye.

The internal interpretation aspect requires a great deal of interpretation; the biophysical aspects can be measured, quantified and can thus be explained.

The eye consists of three main parts:

The lens	a focusing device ranging from 2 inches to infinity
The iris	a device controlling the amount of light admitted to the eye
The retina	a device composed of nerve pickups called rods (sensing the presence or absence of light in black and white) and cones (sensing colors in relation to each other)

[Figure. A-2]

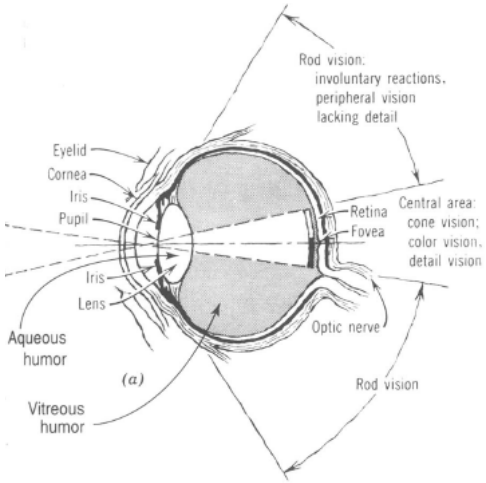


Figure A.2 The Human Eye
The eye operates on similar optic principles to a camera. The fovea, the center of focus, is an area the size of a pin head and contains 100,000 cone cells.

Luminous Transmittance [1,2]

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

All light striking a surface is either transmitted, reflected, or absorbed. Transmitted light passes through the material either completely (transparent) or partially (translucent). Refraction occurs when light is bent passing from one material to another (such as water to air or air to glass). All materials have different indices of refraction. Reflection is the portion of light falling onto a surface which returns from it.

[Figure. A-3]

Direct and Diffuse Light [2]

Direct light is the kind of light which comes directly form the sun on a sunny day. The light is strong and creates sharp shadows. Inside a building, direct light is analogous to the light from a projector or from a drafting lamp.

Diffuse light is the kind of light experienced on an overcast day. The light comes from all directions and there are no distinct shadows. In a building, this is analogous to a ceiling full of fluorescent lights, or a white ceiling lit by coves around the sides.

Illumination [2]

Illumination is the quantity of light energy arriving at a real surface and is measured in foot candles (fc).

Luminance [2]

Luminance is the luminous flux density (luminous energy or light) leaving a surface in a particular direction and is measured in footlamberts (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 [2]

When we see a surface, we are sensing the luminance of that surface. The way we see the surface, infer things about it, or read things from it is by the variation in the luminance.

As an example, if a surface has words printed on it in black ink, then 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. It is only damaged when the change is too rapid, or most of the background is dark, but one spot is intensely bright. Such extreme contrasts are known as glare.

Glare [2]

There are two types of glare:

when the eye has adapted to an environment and the environment changes and

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

[Figure A-4]

Daylight [1]

Daylight is the natural light provided by the sun. It is the most desirable and most abundant source of light available. It falls as both beam light and as sky vault light.

Daylight is an amenity. Windows provide visual contact with the outside, and the resultant daylight provides a bright, pleasant, airy ambience. Daylight also provides good modelling shadows, minimal veiling reflections, and excellent vertical surface illumination.

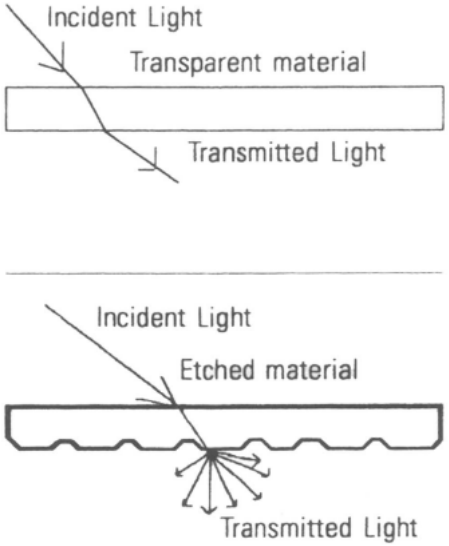
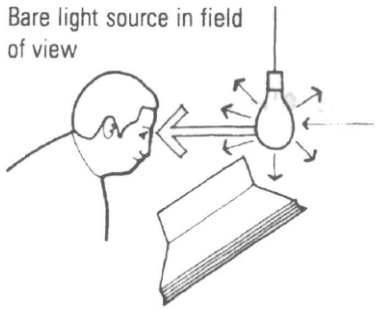
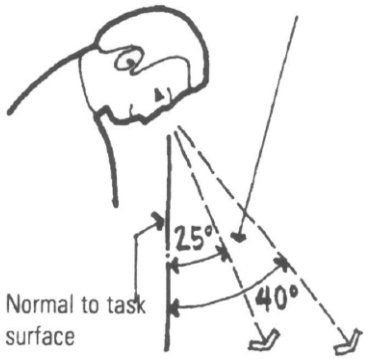


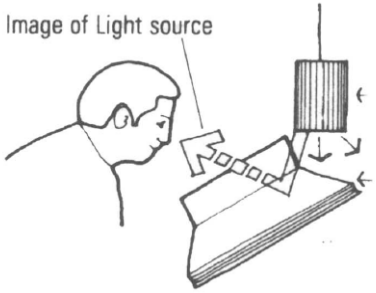
Figure A.3 Transmission and Refraction
Transmitted light (upper) passes through a material. Refraction (lower) occurs when light is bent moving from one material to another.



Direct Glare



Veiling Reflections



Reflected Glare

Figure A.4 Glare
Visual comfort limits for glare depend on the relationship of brightness and size of the source, position of the object in the visual field and the eye adaptation of the viewer.

The most prominent characteristic of daylight 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.
effects of local terrain, the natural and man-made obstructions and reflections.

[1]**Stein**, Benjamin, John S Reynolds. ***Mechanical and Electrical Equipment for Building***.
[2]**Schiler**, Marc E., and Shweta A. Japee. ***Interior Illuminance, Daylight Controls and Occupant Response***.

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Appendix B

Illumination Categories and Illuminance Values for Types of Activities in Interiors[1]

[Table B-1]

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

Source: Courtesy of Illuminating Engineering Society of North America [IESNA]

Recommended Maximum Luminance Ratios [1]

[Table B-1]

Note: To achieve a comfortable brightness balance, it is desirable to limit luminance ratios between areas of *appreciable size* as seen from normal viewing positions as follows:

1 to one third	Between task and adjacent surroundings
1 to one tenth	Between task and more remote darker surfaces
1 to 10	Between task and more remote lighter surfaces
20 to 1	Between luminaires (or fenestration) and surfaces adjacent to them
40 to 1	Anywhere within the normal field of view

These ratios are recommended as maximums; reductions are generally beneficial.

[1] **Stein**, Benjamin, John S Reynolds. ***Mechanical and Electrical Equipment for Building***.

Appendix C

Weather Conditions[1]

Week of November 12th through 19th

11_12_03	Wednesday	Cloudy/Partly Cloudy
11_13_03	Thursday	Sunny/Partly Sunny
11_14_03	Friday	Partly Cloudy
11_15_03	Saturday	Cloudy
11_16_03	Sunday	Cloudy
11_17_03	Monday	Foggy/Rainy
11_18_03	Tuesday	Cloudy
11_19_03	Wednesday	Partly Cloudy

Additional visits

11_26_03	Wednesday	Partly Cloudy/Sunny

[1]**Weather.com** ***The Weather Channel Online.*** www.weather.com

7 Day Illumination Graph
All sources Composite
[Figure C.1]

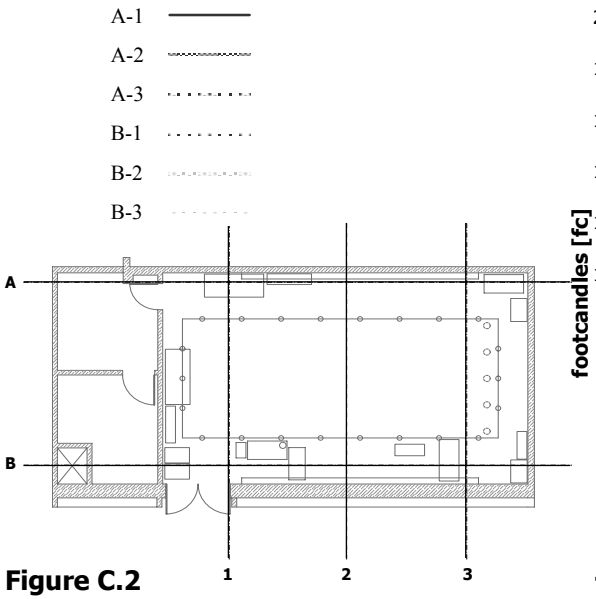
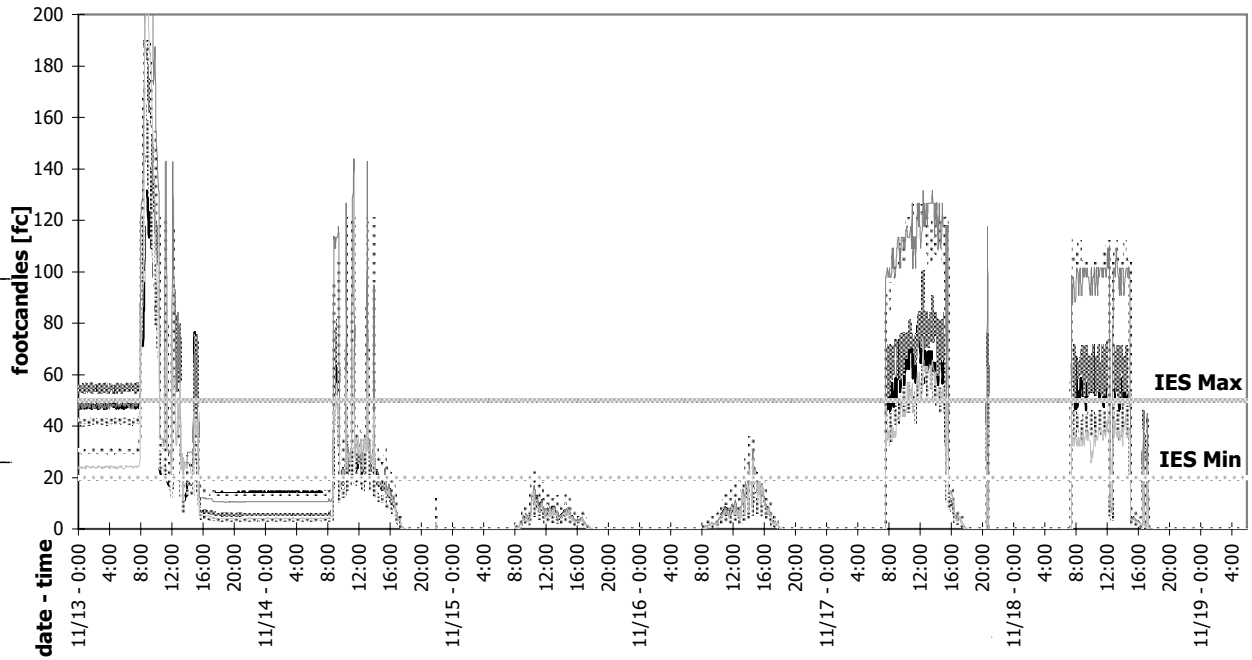
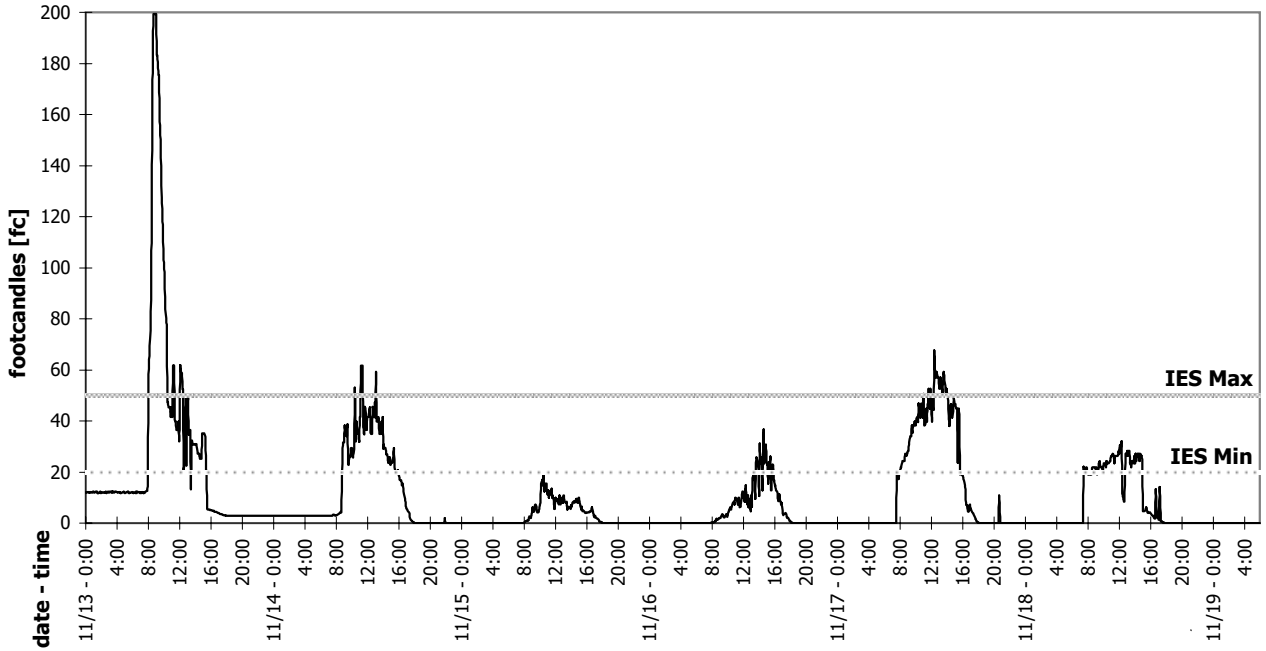


Figure C.2
Reference Plan
Illumination Quantities over Time

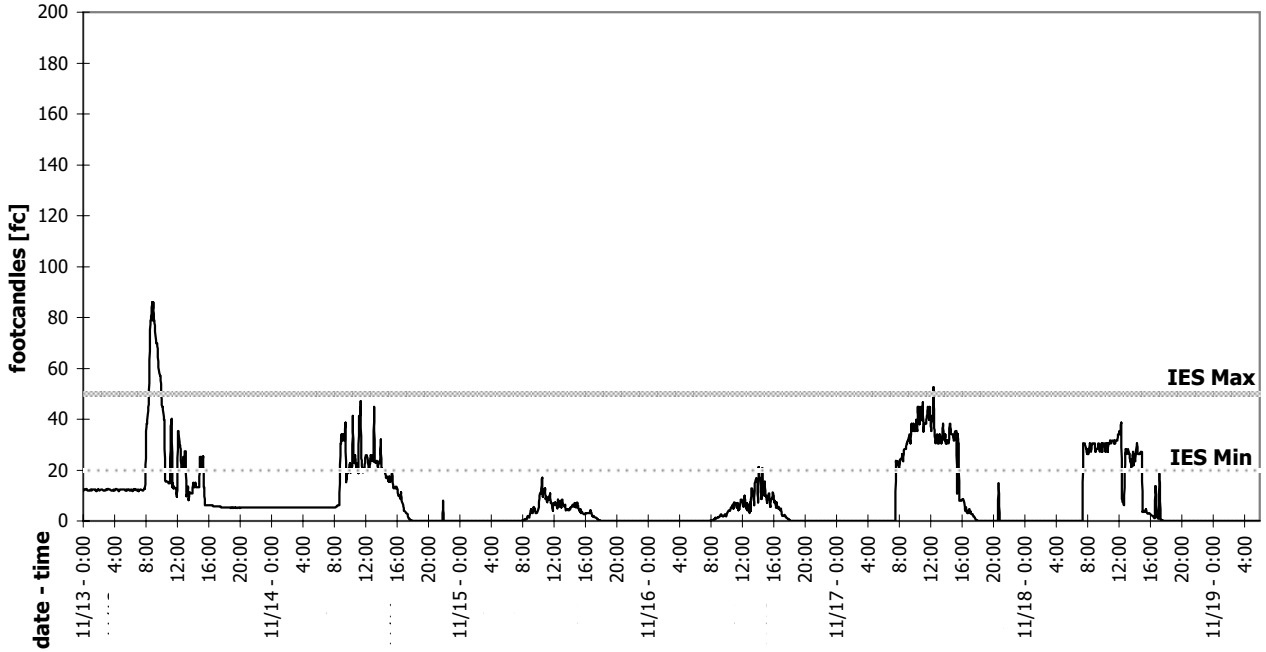
Stowaway Data Logger Illumination Quantities





7 Day Illumination Graph
Above Lighting Level [8ft AFF]
Reference A,1 [NWC]

[Figure C.3]



7 Day Illumination Graph
Above Lighting Level [8ft AFF]
Reference B,2 [SCC]

[Figure C.4]

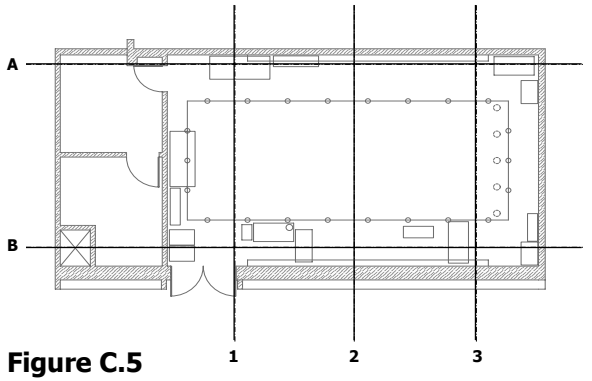
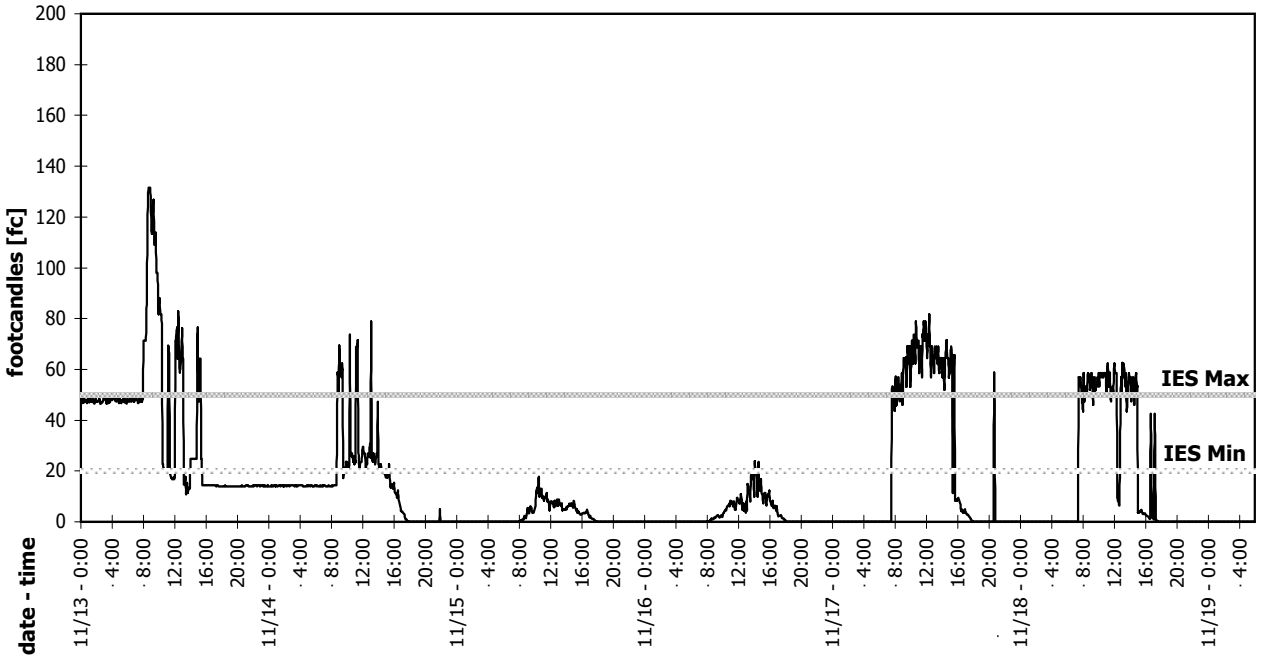


Figure C.5
Reference Plan
Illumination Quantities over Time

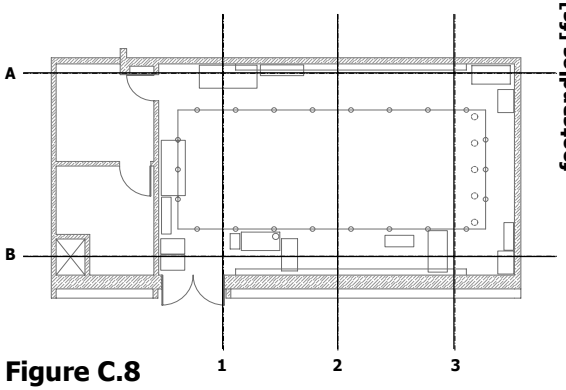
7 Day Illumination Graph
Reference A,1 [NW]

[Figure C.6]



7 Day Illumination Graph
Reference B,1 [SW]

[Figure C.7]



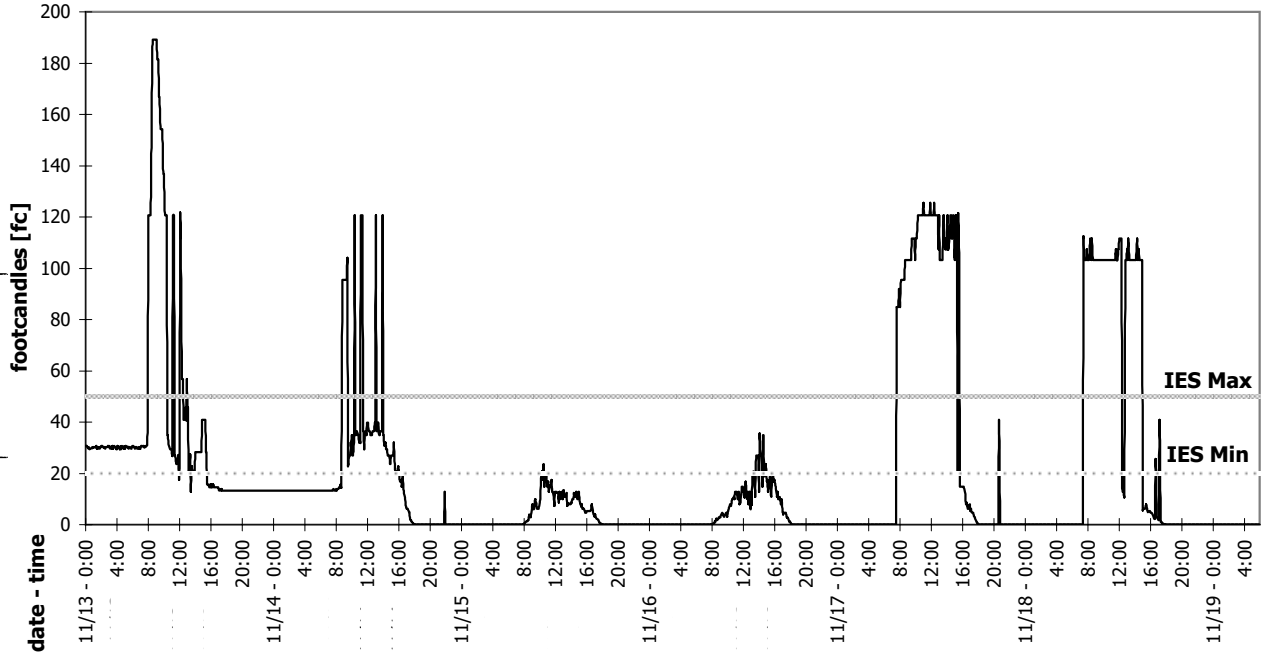
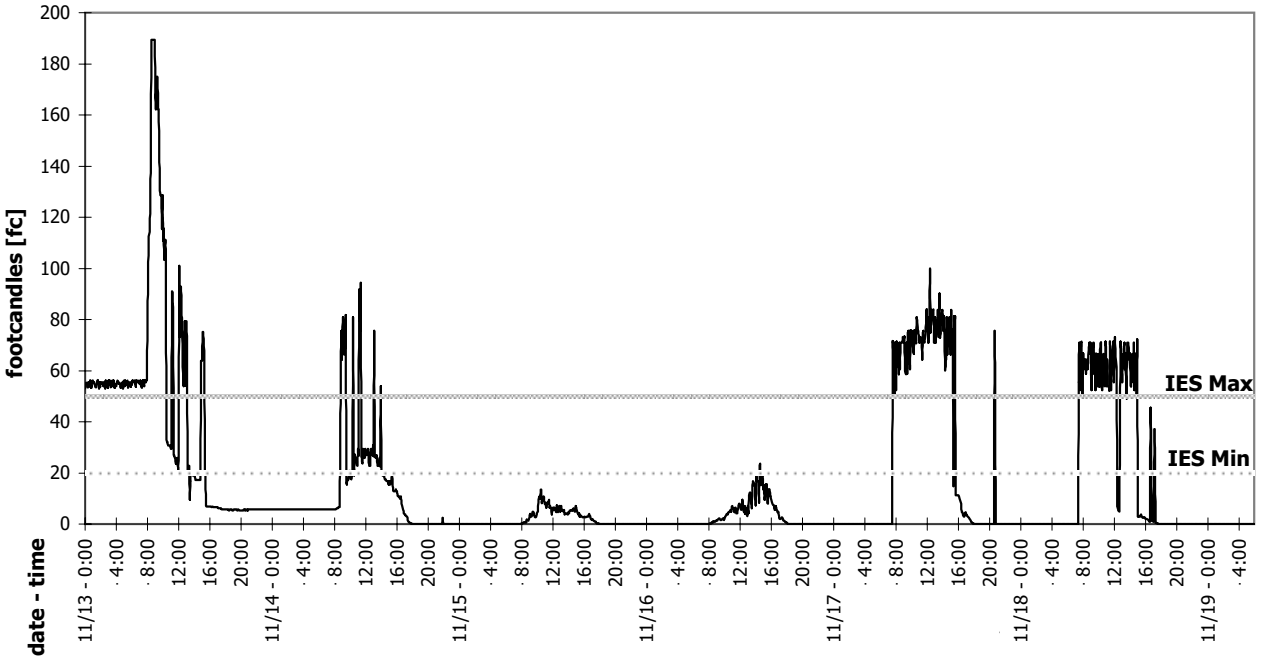
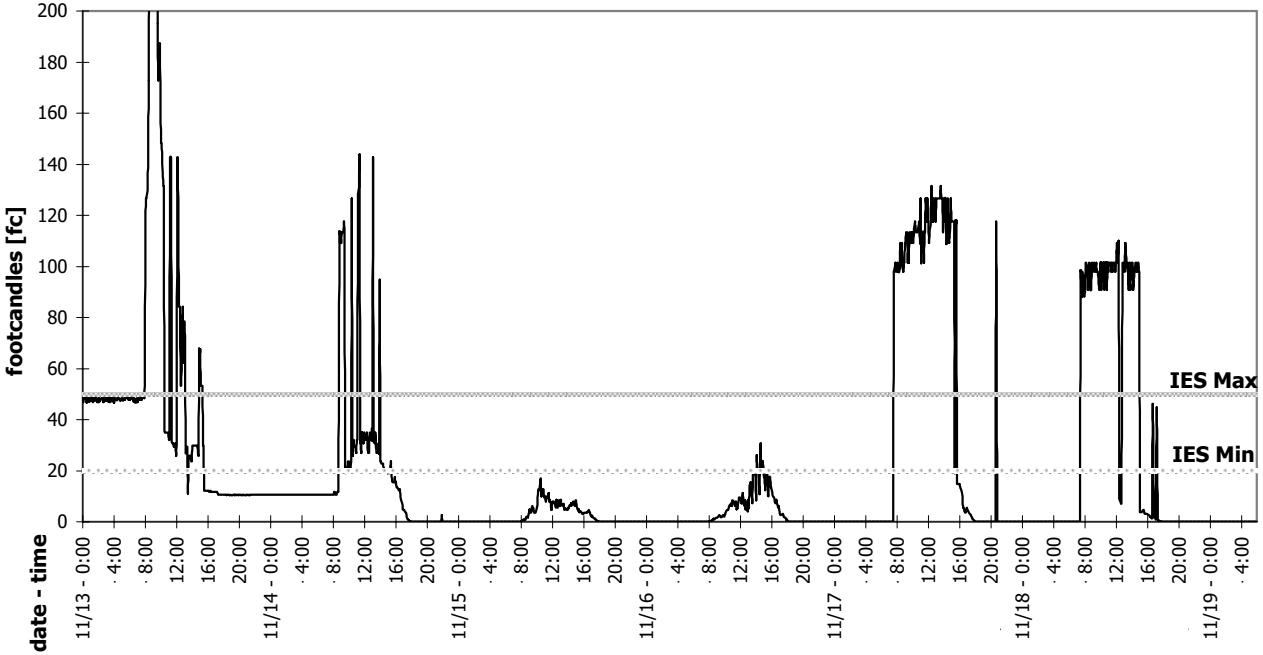


Figure C.8
Reference Plan
Illumination Quantities over Time



7 Day Illumination Graph
Reference A,2 [NC]
[Figure C.9]



7 Day Illumination Graph
Reference B,2 [SC]
[Figure C.10]

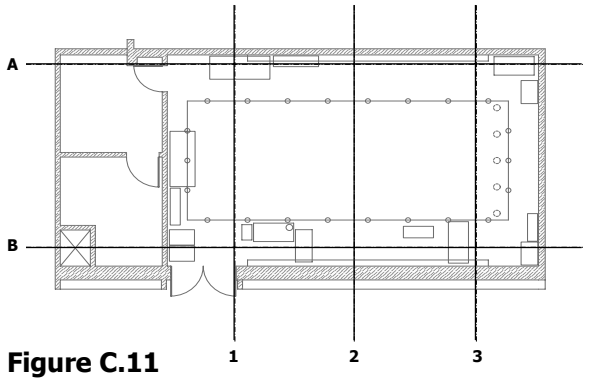
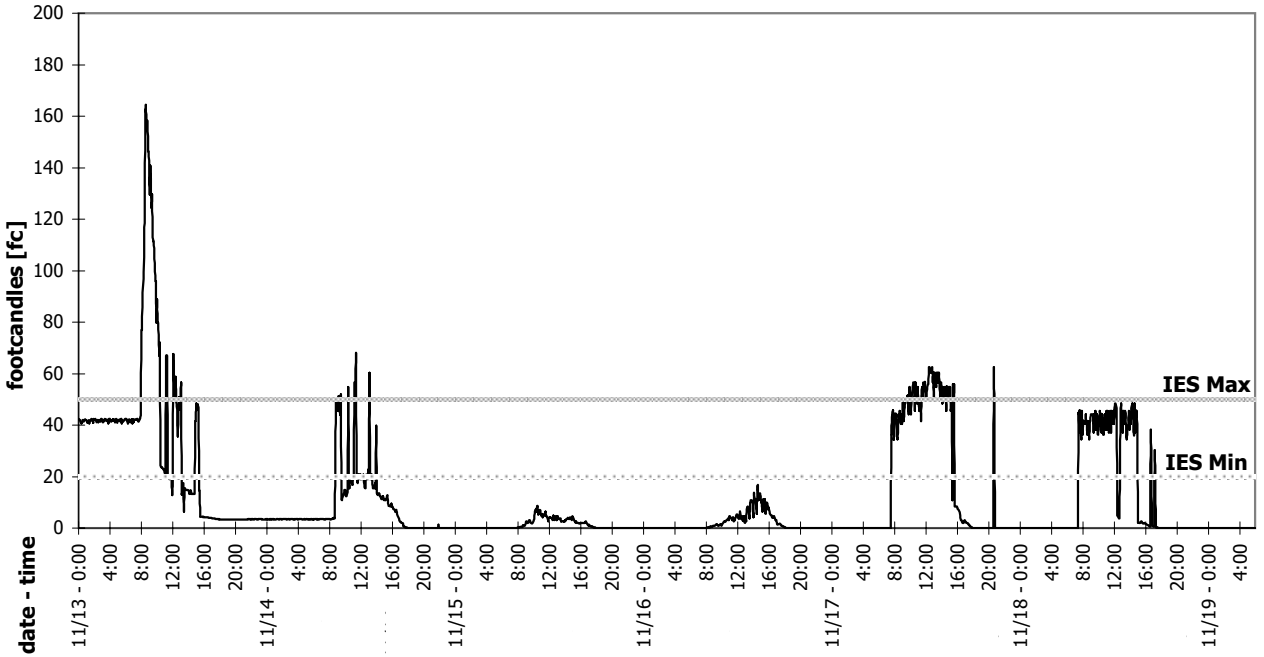


Figure C.11
Reference Plan
Illumination Quantities over Time

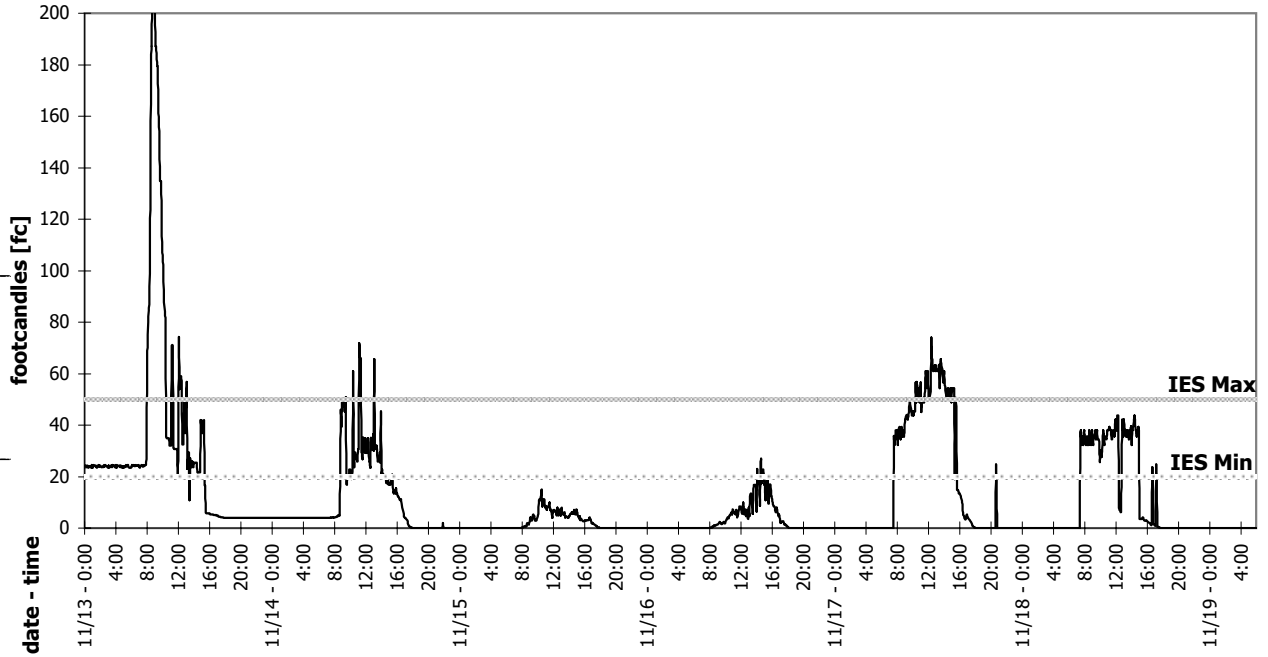
7 Day Illumination Graph
Reference A,3 [NE]

[Figure C.12]



7 Day Illumination Graph
Reference B,3 [SE]

[Figure C.13]



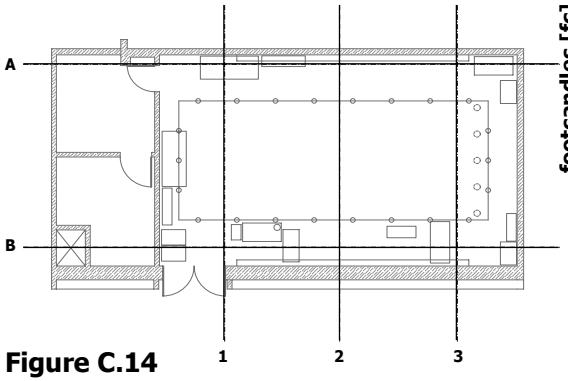
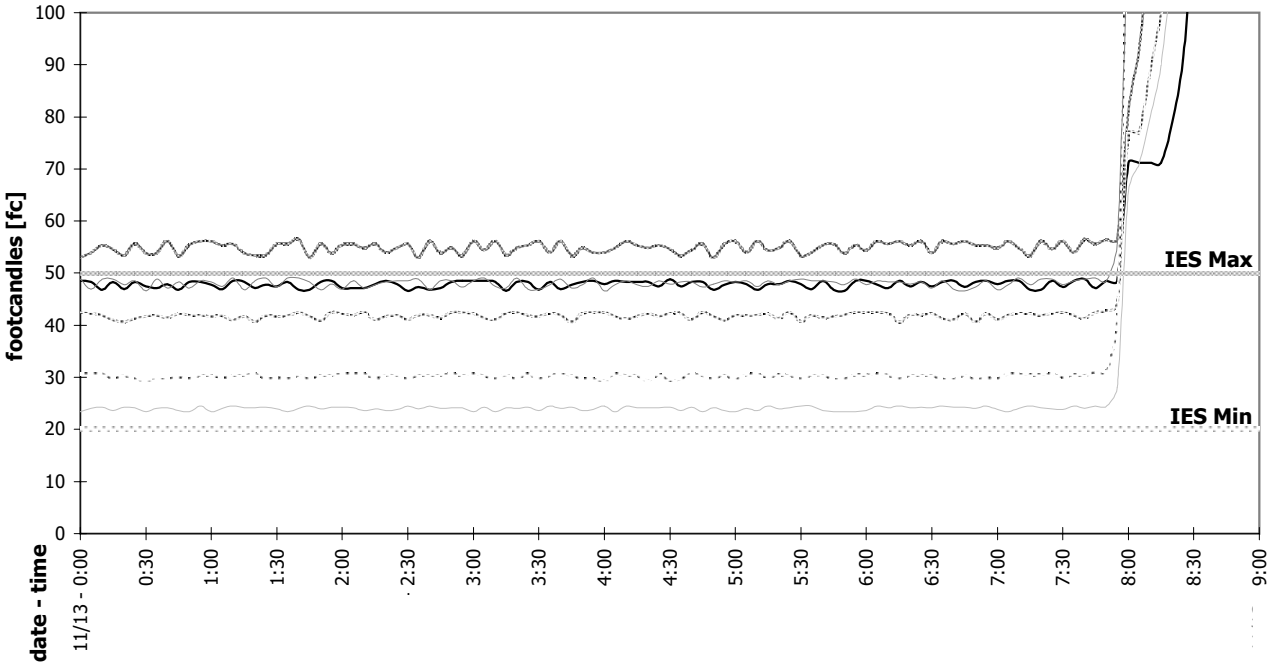


Figure C.14
Reference Plan
Illumination Quantities over Time

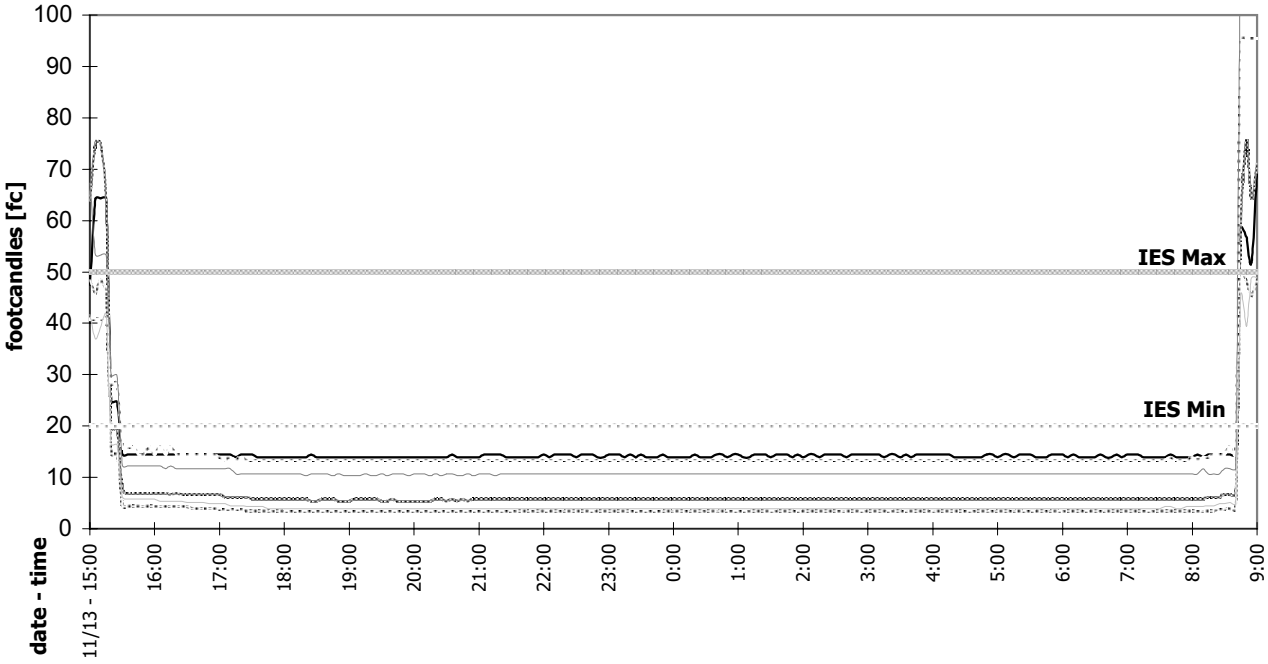


1 Day Illumination Graph
Fluorescent Light Composite

[Figure C.15]

Legend

A-1
A-2
A-3
B-1
B-2
B-3



1 Day Illumination Graph
Incandescent Light Composite

[Figure C.16]

Legend

A-1
A-2
A-3
B-1
B-2
B-3

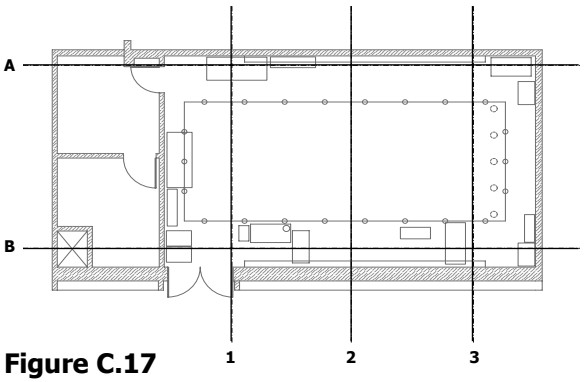


Figure C.17
Reference Plan
Illumination Quantities over Time

Appendix D

Figure D.1 G.E. Light Meter

Figure D.2 Minolta LS-100 Spot Luminance Meter

Figure D.3 Stowaway Illumination Data Logger

G.E. Light Meter [Figure D.1]

Range		0-10,000 fc
Precision	w/o cap	2 fc
	w/ cap	200 fc
Accuracy		10-15%
		Cosine Corrected
		Color Corrected

Silvania Light Meter

Range	0-2,000 fc
Precision	1 fc
Accuracy	±5%
	Cosine Corrected
	Color Corrected

Minolta LS-100 [Figure D.2]

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 (w/in 1º FOV)
	Color Corrected

Stowaway Illumination Data Logger

[Figure D.3]

Range	0.001-1,000 fc
Precision	0.001 fc
Accuracy	5%
	Part. Cosine Corrected
Color Correction	Incandescent multiplied by 1
	Daylight multiplied by 6
	Fluorescent multiplied by 12

Hobo Illumination Data Logger

Range	0.01-15,000 fc
Precision	0.01 fc
Accuracy	5%
	Part. Cosine Corrected
Color Correction	Incandescent Multiplied by 1
	Daylight multiplied by 6
	Fluorescent multiplied by 12

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[end of report]