ME 523 Final Project – Analysis of Natural and Artificial Lighting in Classroom

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Abstract

In this study the measured light distribution in a classroom is compared to the estimated distribution computed with lighting analysis software. Results indicate that the classroom receives adequate daylight, and also provides sufficient artificial light levels. Controls are in place to provide mixed lighting when needed.

A comparison of the measured daylighting factors reveals some significant error in the Ecotect model used to predict daylighting. This may be due to shortcomings of the model coupled with the fact that experimental data was only available for a sunny day. The Visual Basic model used for artificial lighting showed close agreement with measured results.

Introduction

History of Lighting in Schools

Shattuck Hall was originally built in 1915 as an elementary school, and has since been purchased by Portland State University and undergone some interior renovations. Despite many changes in the school, the original windows are still in place. Like most buildings constructed before widespread installation of air conditioning in the late 1950's, Shattuck was designed to provide adequate natural light levels and ventilation throughout the building. Once air conditioning became prevalent there was no longer a need for windows to provide ventilation, and their poor thermal performance made them even less attractive. Designers began transitioning to buildings with less window coverage and more internal areas. At the same time, educational theorists preferred large open spaces where a flexible learning environment was promoted (Heschong 2000).

In recent years the benefits of daylighting have become well known, and modern windows allow for energy efficient performance despite higher window coverage. As such, many new building are being designed with daylighting in mind. Since lighting represents a large portion of a building's electric use, a well designed building with good daylighting can result in significant energy savings. Additional benefits are seen in reduced energy consumption for cooling, since daylighting introduces less heat into the building than the equivalent electric lighting. A final economic benefit is that the reduction in light use results in less maintenance cost for bulb and ballast replacement (Benya 2001).

Typical Classroom Lighting Recommendations

Lighting is important in academic areas to provide an appropriate environment for student comfort and learning. Following are some standards for lighting in classrooms (Christine 2004):

1) Daylighting should be designed to exclude penetration of direct sun
2) Contrast between light and dark areas should be minimized. An 'average to minimum' brightness ratio of less than 4:1 is recommended, along with a 'maximum to minimum' ratio less than 8:1.
3) Daylight levels should provide 50 to 250 foot-candles at 30 inches above the floor.
4) Artificial lighting should provide 30 foot-candles at 30 inches above the floor for general classrooms. Science and art rooms should be illuminated to 50 foot-candles.

Relationship between lighting and student performance

Numerous studies have been conducted showing a strong correlation between daylighting in schools and student performance. One of the largest studies looked at 2,000 classrooms in 3 school districts. Using multivariate regression analysis, availability of daylighting was correlated to student performance on standardized tests in both math and reading. The study showed that in one California school district students with the most access to daylight progressed

20% faster on math tests and 26% faster on reading tests, compared to students in rooms with the least daylight. Improvements ranging from 7-13% were seen in the other two school districts. (Heschong 2002). Another study conducted in North Carolina, showed a performance increase of 5-14% between students in schools designed for daylighting versus traditional schools (Nicklas 1997).

While these studies demonstrate the possible link between daylight availability and student performance, it has also been suggested that performance is linked to providing each student with optimal light levels, which may differ from student to student. Student preferences for either bright or dim light levels should be accommodated to increase performance. This can be done by providing classroom areas with different lighting and encouraging students to study in the areas they find most comfortable. (Dunn 1985).

Daylight Modeling

Lighting design, and especially daylighting, involves the consideration of numerous parameters, some of which may be in conflict with each other or other aspects of a building's design. In recent years, a lot of architects have started to use modeling software to analyze these complex lighting designs.

One of the most commonly used software packages is 'Autodesk Ecotect'. Ecotect provides a number of tools for building design and analysis. Daylighting is calculated using the Building Research Establishment (BRE) Split-Flux method. This method is based on the assumption that there are three separate components of light that reach any point inside a building: Sky Component (SC), Externally Reflected Component (ERC), and Internally Reflected Component (IRC). The daylight factor is simply the sum of each of these three components. To be a useful design tool, daylight factor values are generally calculated using a standard overcast sky illuminance in order to represent a worst-case design condition (Autodesk Ecotect 2010).

'Visual Basic Edition' is a second software package that was used in this study for artificial light modeling. Visual Basic is designed to quickly develop simple interior lighting layouts where uniform horizontal illumination is the primary objective. Visual Basic uses the Lumen Method for all of its calculations (Acuity 2006). This method accounts for light directly from the luminaires, along with reflected light off of interior surfaces. Calculations are based on an empty interior, uniform surface characteristics, and perfectly diffuse reflectance (Rea 2000).

Method and Procedure

Daylight Measurements

Daylighting was measured in Shattuck Hall, room 211. This is a typical example of a classroom on the North side of the building, with 5 windows lining the North wall. Daylight was measured in-line with each window, at 5 points. See the schematic in Figure 1 for details. Measurements were made using an Extech HD450 Photosensor. All measurements were made at a height of 2.5 ft. The photosensor was mounted to a tripod, which ensured consistent height and levelness for each measurement.

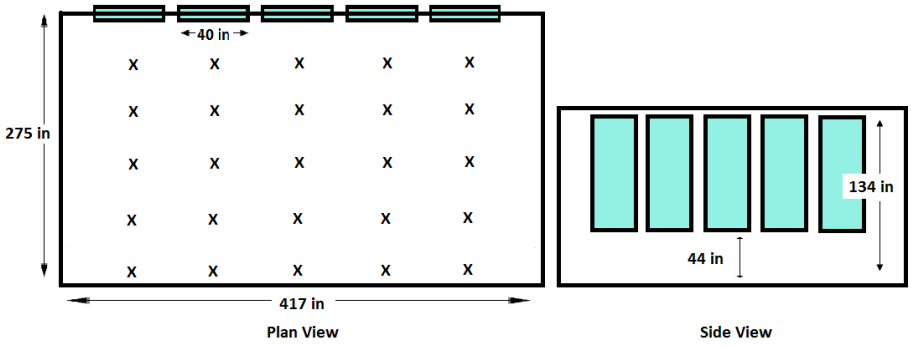

Figure 1: Shattuck Hall Room 211 window position and general layout. Measurements were taken at locations marked with an X.

Measurements were taken on Saturday 3/6/2010, starting at 12:45 PM. In addition to measuring interior illuminance levels, the exterior illuminance was also measured just outside of the central window. Interior values were then normalized to the exterior values, calculating the Daylight Factor: Daylight Factor (%) = Indoor Illuminance/Outdoor Illuminance. Daylight factor provides a more useful value for illuminance comparison, since testing cannot be performed under all environmental conditions (Lechner 2008).

Artificial Light Measurements

Artificial light levels were also measured in Shattuck Hall, room 211. These measurements were taken after dark (3/8/2010 at 7:00PM) so that there was no contribution of natural light to the measured values. Measurements were taken at the same 25 points shown in Figure 1 using the same equipment. Two illumination scenarios were tested:
a. All Lights On – In this scenario, all of the luminaires were turned on (refer to Figure 2 for luminaire distribution). This is representative of the lighting that would be used at night.
b. Wall Lights On – In this scenario, only the luminaires along the South wall (opposite the windows) and the East wall task lighting were turned on. This is representative of a common lighting scenario where artificial lighting is required to supplement daylight that does not provide adequate illuminate through the full depth of the room.

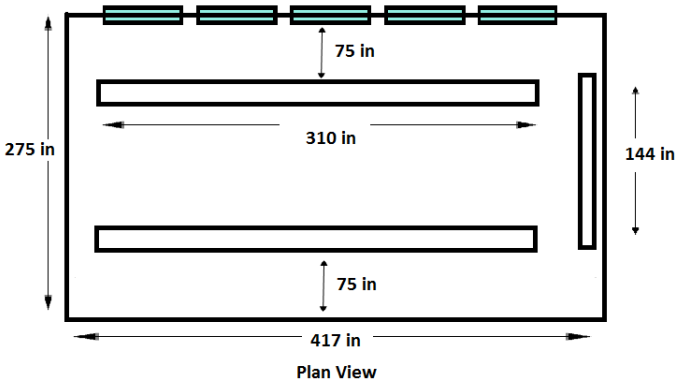

Figure 2: Shattuck Hall Room 211 luminaire placement. The long luminaires provide primary lighting for the room, while a short task light on the East wall provides illumination for the white board.

Ecotect Model for Daylighting

Autodesk Ecotect was used to calculate the daylight factor in Shattuck Hall room 211. The geometry depicted in Figure 1 was used. Additionally, the following input parameters were selected:

Grid: horizontal work plane, 600mm above the floor
Design sky: 7025 lux (Use Tregenza formula), Overcast
Window Cleanliness: Average (x 0.9)

'Visual' Model for Interior Lighting

'Visual Basic Edition' was used to calculate the illuminance due to artificial lighting. The geometry shown in Figures 1 and 2 was used, although only the two primary luminaires could be modeled due to software limitations. Since the exact luminaires installed in Shattuck Hall were unknown at the time of modeling, luminaires with similar characteristics and luminance were selected. An arrangement with two rows of four luminaires each was modeled to replicate the actual arrangement. The following input parameters were used:

Surface Reflectance: "Standard Commercial" - Ceiling 80%, walls 50%, Floor 20%
Luminaire Selection: "Peerless Ice Tray Indirect/Direct Rectangular"
CU Value: 0.57
Lamps per Luminaire: 2
Lumens per Lamp: 4000

Results

Daylighting

The average horizontal daylight measured outside the North facing classroom window was 425 foot-candle. The average measured illuminance was 55 foot-candles (FC), with a maximum of 96 FC and a minimum of 33 FC. The contour plot in Figure 3 shows that 2/3 of the measured area is illuminated at 45-96 FC. The other 1/3 is illuminated at 30-45 FC. The measured results indicate that the primary task areas within this classroom are illuminated to a minimum of 50 FC, which meets typical classroom design requirements (Christine 2004).The rest part of the room need artificial light to compensate. The calculated daylight factors range from 8% to 22%. This is greater than the recommended minimum for classrooms of 2% (Lechner 2008). Additionally, the average to minimum brightness ratio is 1.7 and the maximum to minimum ratio is 2.9. Both values are within the recommended range (Christine 2004).

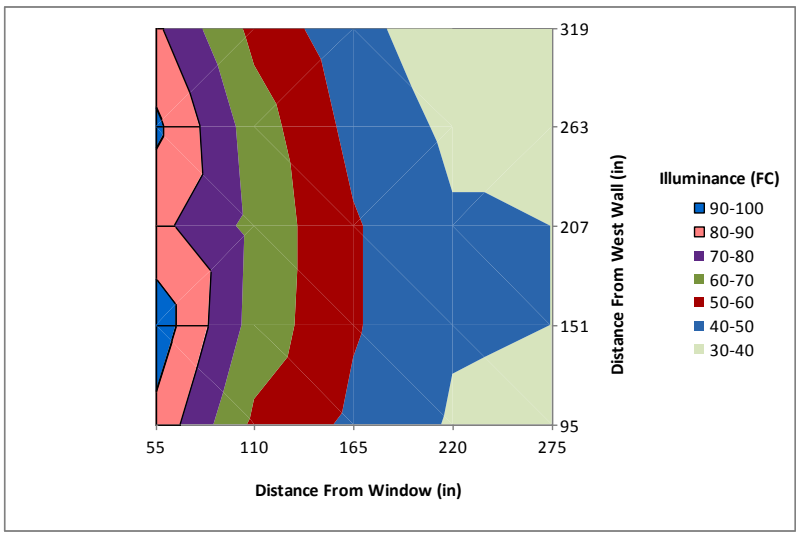

Figure 3: Measured illuminance due to daylight in classroom.

In addition to measured values, Ecotect software was used to calculate daylighting in the classroom. The model calculated an average daylight factor of 1.63%, with a maximum of 5.3 % and a minimum of 0.3%. Figure 4 shows the software calculated light distribution. Although the software shows a similar light distribution to the measured values, the magnitude of the modeled daylight factor is more than 400% lower.

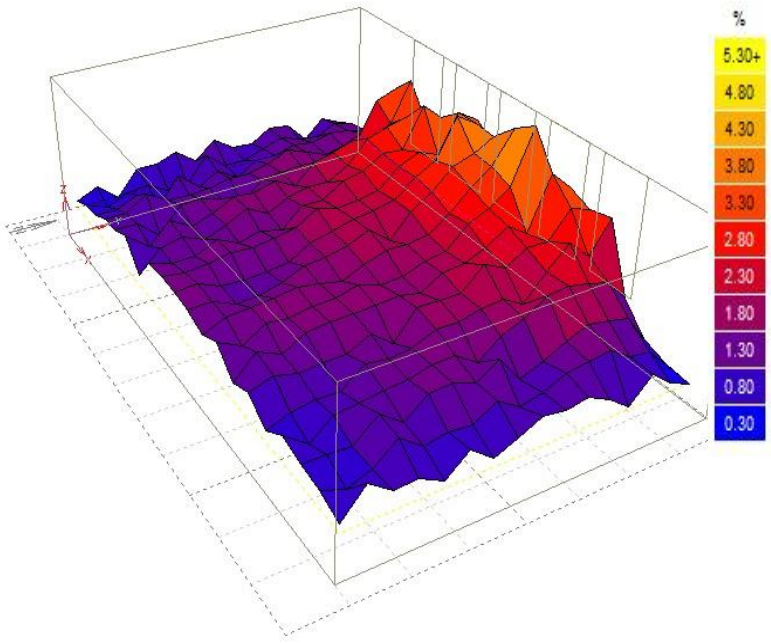

Figure 4: Ecotect model results showing daylight factor calculated for overcast conditions.

It is clear that the Ecotect model produced an inaccurate estimate of the measured illuminance levels. It should be noted that Ecotect calculates daylight factors using a standard overcast sky illuminance, while experimental data was collected on a sunny day. This means that the model does not account for different sun positions, the influence of direct sunlight, or reflected sunlight from other buildings or surfaces. In the case of Shattuck Hall, there is another building located approximately 50 ft to the north that was not modeled. The building has a glass and metal façade with a relatively high solar reflectance.

Another possible source of error in the experimental results is the measurement of outdoor illuminance. This was measured outside the 2nd floor classroom window by extending a photosensor out the window. The measured

illuminance may have been artificially low due to some shading from the building and nearby trees. An underestimate of the outdoor illuminance means that calculated daylight factors may be higher than actual levels.

Artificial Lighting

Artificial light levels in the classroom were measured with all three luminaires turned on. The average measured illuminance is 34 foot-candles (FC), with a maximum of 42 FC and a minimum of 20 FC. The contour plot in Figure 5 shows that the majority of the measured area is illuminated at 30-42 FC. A small region on the perimeter of the room is illuminated at 20-30 FC. The measured results indicate that the primary task areas within this classroom (desk tops) are illuminated to a minimum of 30 FC. This is consistent with the recommended illuminance levels published by the IESNA (Rea 2000) of 30 FC for reading an 8-10 point font and writing with a #2 pencil. Additionally, the brightness ratio of 42/20 = 2.1 is well within the IESNA recommended brightness ratio for classrooms of less than 5.0 (Rea 2000).

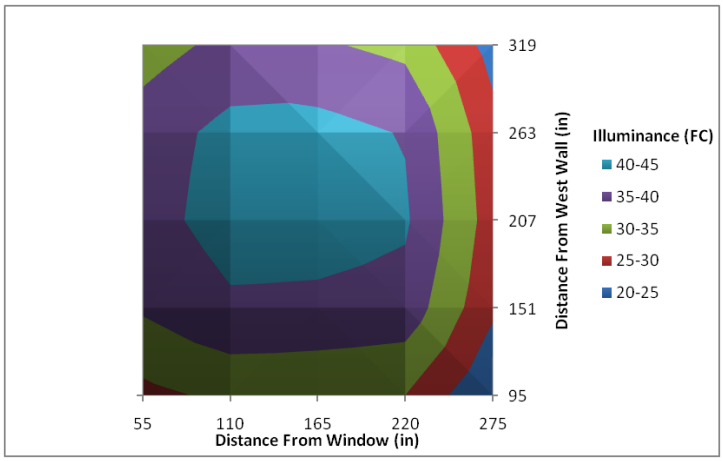

Figure 5: Measured illuminance of classroom with full artificial light conditions.

Light levels were also measured with only the luminaires along the South wall and East wall task lighting turned on. In this scenario the average measured illuminance is 19 FC, with a maximum of 34 FC and a minimum of 5 FC. The contour plot in Figure6 shows this scenario. If you picture Figure 6 plotted on top of its mirror image, you will achieve lighting roughly equivalent to figure 5. This illustrates the additive nature of illuminance. The lighting in this room was designed with automatic controls to turn on each set of luminaires independently as natural light levels fluctuate. You can imagine an overcast day or late evening scenario where daylight is adequately illuminating the North side of the room with the distribution shown in Figure 3, while the South wall luminaires are providing the illuminance shown in Figure 6. The total illumination would be the sum of each light source, and is expected to provide the requisite 30 FC on all primary task areas.

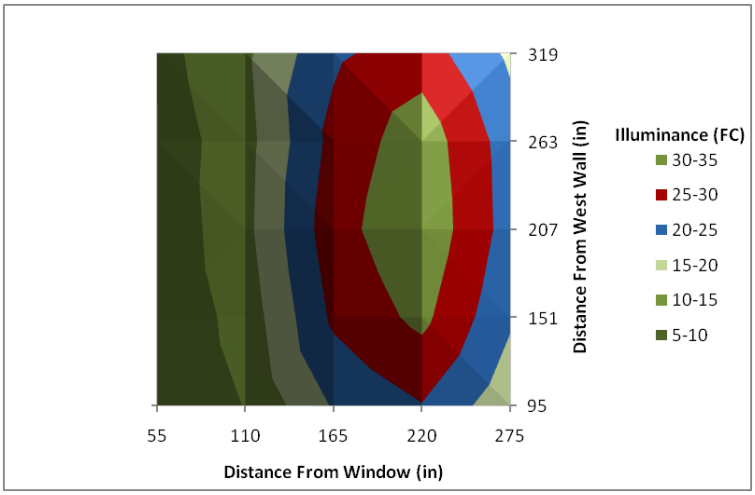

Figure 6: Measured Illuminance of classroom with only the luminaires on the South wall and East wall task lighting turned on.

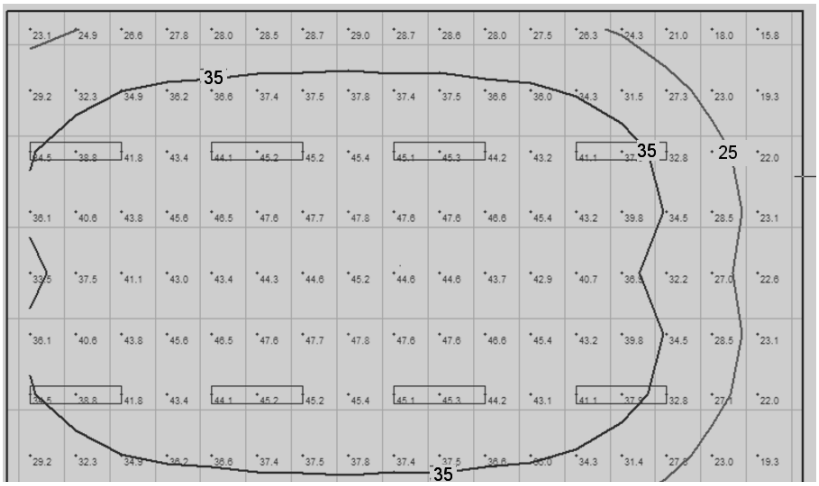

Figure 7: Classroom illuminance levels modeled with Visual Basic software.

In addition to measuring actual light levels in the classroom, a model was developed with Visual Basic software. The software calculates an average illuminance of 36 FC, with a maximum of 48 FC and a minimum of 16 FC. Figure 7 shows the software calculated light distribution. The software shows a similar light distribution to the measured values. Some lower illuminance levels are seen on the East wall, which is likely because the East wall task lighting was not modeled. Based on these results it appears that Visual Basic provides an accurate model

of illuminance levels given the proper input parameters. It should be noted that the model for a square classroom with a simple luminaire distribution is likely to produce better results than a more geometrically complex room or unusual lighting strategy.

Conclusions

This study confirms that Shattuck Hall room 211 receives adequate daylight, and thus provides comfortable illumination that should foster a productive learning environment. Although only room 211 was measured, it's expected that the light distribution in 211 is similar to other classrooms on the north side of Shattuck hall, while south side rooms will receive more light. Therefore, all classrooms appear to receive adequate natural light. Artificial light levels are also appropriate, and controls are in place to provide mixed lighting when needed.

A comparison of the measured daylighting factors reveals some significant error in the Ecotect model used to predict daylighting. This may be due to shortcomings of the model coupled with the fact that experimental data was only available for a sunny day. Future research should be conducted to better understand the factors that contributed to this discrepancy.

The Visual Basic model used for artificial lighting showed close agreement with measured results. This confirms that Visual Basic is a valuable tool for lighting designers, at least when used to model conditions similar to this test. Models with more complex geometry or lighting design should be studied further before Visual Basic is trusted as an accurate modeler for all lighting scenarios.

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