



11 | Incorporation of Daylighting in Classrooms

AE Lighting & Electrical Breadth

11.1 Introduction

The second environmental aspect to be discussed in detail that helps students perform better is having a substantial amount of natural light in the classrooms. According to the Northeast Energy Efficiency Partnerships (NEEP), “Good lighting promotes better learning. Today’s schools must provide a stimulating environment where children will learn best. High quality light improves students’ moods, behavior, concentration, and therefore their learning¹⁸.” There are two large windows in every classroom of the school that may be able to provide an adequate amount of daylight to institute daylighting practices; however this natural light will not result in any energy savings as long as the lights are still turned on. Therefore, adding daylighting photosensors that trigger some of the lights to shut off in the classrooms will allow the natural light to benefit students as well as reduce the electricity consumption.

11.2 Problem Statement

The current lighting used in the classrooms is intended to be on all day, which is costly and reduces the benefits of natural light that enters through the windows. Students’ performance improves when an increased amount of natural daylight is used to light the classrooms. Daylighting practices will be implemented in the classrooms. An adequate amount of light will need to penetrate the classrooms in order to utilize daylighting techniques.

11.3 Goal

The goal of this analysis is to determine if daylighting is possible with the current room layout and lighting configuration. If the current design is found to be inadequate for daylighting techniques, a redesign of the room and lighting layout will be done and the daylighting reassessed. This research will also focus on energy savings, and therefore cost savings, and construction impacts. The pros and cons of adding occupancy sensors to the classrooms will be investigated.

11.4 Methodology

1. Research daylighting techniques and the benefits of using these techniques in schools.
2. Meet with AE Lighting/Electrical faculty to obtain advice and guidance.
3. Use computer programs to run daylighting calculations on the current room configuration.
4. Redesign the room configuration and lighting layout.
5. Run daylight calculations and test assumptions with the new room layout.

¹⁸ *Classroom Lighting Know How* found at http://www.designlights.org/downloads/classroom_guide.pdf



6. Compare the results from each lighting test. Determine if daylighting is even possible for the WCA classrooms.
7. Determine how much energy is saved by using the daylighting features, from a financial standpoint.
8. Determine the cost, schedule, and installation time of adding the new sensors.
9. Make a recommendation on whether adding daylighting features to each classroom is a worthwhile investment for the WCA.

11.5 Tools/Resources

1. Research daylighting through articles and information on the internet
2. Washington Christian Academy Construction Documents
3. AGi32 Lighting/Electrical Computer Software
4. AutoCAD 2008 for 3D modeling purposes
5. Penn State Architectural Engineering Faculty
6. 5th year AE lighting students

11.6 Expectations

I expect that the current room configuration is not suitable for incorporating daylighting features. However, I think that after a simple redesign the room will be more equipped for daylighting. I expect that this investment will be beneficial for the owner because it will reduce energy consumption greatly, and that it will be a worthwhile investment for the success of the students and staff.

11.7 Research on Daylighting

Daylighting can be defined as the practice of using windows, skylights, or clerestories to allow penetration of natural light so that there are effective illumination levels in a given space. Energy savings from daylighting is achieved from the reduced use of electrical lighting. Electrical lighting savings occur because daylighting photosensors automatically turn off or dim electrical lights when a certain level of daylight has entered the room and an adequate amount of illuminance is reached. The U.S. Department of Energy had this to say about daylighting.

In addition to energy savings, daylighting generally improves occupant satisfaction and comfort. Recent studies are implying improvements in productivity and health in daylighted schools and offices. Windows also provide visual relief, a contact with nature, time orientation, the possibility of ventilation, and emergency egress. High daylight potential is found particularly in those spaces that are predominately daytime occupied.

-*Daylighting* found at

<http://www.eere.energy.gov/buildings/info/design/integratedbuilding/passivedaylighting.html>



Studies have found that students with daylighting practices used in their classrooms “perform 20 to 25% better on reading and math tests than students without access to daylight and can progress up to 20% faster than their counterparts in rooms with smaller window areas¹⁹”. These statistics and information from the U.S. Department of Energy make it clear why using daylighting techniques would benefit the students and teachers occupying the WCA Flagship Building classrooms.

Increasing the quality of education is important to the WCA owner. So the above arguments would most likely be enough to convince them that daylighting is a positive improvement to the classrooms. In addition, however, the owner will reap the energy cost savings each month by a reduced electrical load. Daylighting saves energy when the lights are dimmed or shut off, but only when they are dimmed or shut off. Therefore, daylighting controls are needed to spur the lights to dim or shut off.

11.8 Daylighting and Occupancy Sensor Controls

Without turning or dimming the electrical lights, the net energy consumption of the building would increase due to the increased amount of light and heat entering the room. Therefore, daylighting must have controls that trigger lights to shut off. Based on advice from the U.S. Department of Energy, there are two main control systems that should be coupled with daylighting practices; occupancy sensors and light level sensors.

Occupancy Sensors

Occupancy sensors detect when a space is occupied by using infrared technology. Heat or movements from persons in the room signal the lights to stay on. A preset amount of time can be set for the sensor, and once no motion has been detected for that preset amount of time the lights will be automatically shut off. Initially, this seems like a good idea for schools. One large proponent of this system is The Pennsylvania State University. Most of the classrooms on campus employ occupancy sensors, which is a good thing considering how many classrooms there are and the potential to rack up electrical costs due to left on lights.

The reason these are so effective on a college campus is that many times classrooms sit empty and previous occupants may have left the lights on thinking another class is about to enter. After speaking with Dr. Rick Mistrick, a member of the Penn State AE faculty, I have come to agree that this technology is not best suited for a K-12 school environment. Typically, a teacher has his or her own classroom and they would know if someone is coming directly in the room after them. In most cases they are the only teacher using that room. Simply put, when the teacher is in the room they can switch on the lights and when they leave turn them off. This would have the same final result of using the occupancy sensors, but without the cost of installing and maintaining them. A simple laminated sign above the switches reminding teachers to turn off their lights would be as beneficial and much more economical for the WCA than using occupancy sensors.

¹⁹ *Classroom Lighting Know How* found at http://www.designlights.org/downloads/classroom_guide.pdf



Light Level Sensors

Light level sensors will trigger certain lamps to turn off or dim when a preset illuminance level is met within a classroom. Light level sensors have a photoelectric “eye” that measures the illumination²⁰. The sensors will also have preset delay timers which prevent the lights from turning off or dimming when there is momentary cloud cover. Fluorescent lamps, like the ones used in the WCA classrooms, are the most common lamps used for daylighting. In the classrooms of the WCA Flagship Building, it would be best to use daylight sensors that switch lights off rather than dim for two reasons; cost savings and educational benefits.

Switching lights off is more financially economical than dimming. If the lamps were to be dimmed, specialized dimming ballasts would have to be used. These cost more than the typical on/off switching ballasts that are already scheduled to be installed in the classrooms. This presents another benefit of switching rather than dimming; the school is already designed for switching so a redesign would not be necessary.

Perhaps the most interesting benefit of using on/off switching daylight photosensors is the educational opportunity it provides for the students. This will appeal to the WCA owner just as much as the cost savings. Children are often taught to turn lights off when leaving a room, but how often are they taught when not to turn on lights in a room? By switching the lights off when there is an adequate amount of daylight in the classroom, it teaches students to be daylight conscious and realize when there is enough natural light to perform a task. When the photosensors reach the pivotal shut off point, the teacher can use the switching lamps as an educational lesson on the value of daylight and energy savings. In a generation that needs to focus on sustainability, using switching and not dimming ballasts with daylighting techniques is a great way to create an interactive learning environment.

²⁰ Daylighting found at <http://www.eere.energy.gov/buildings/info/design/integratedbuilding/passivedaylighting.html>



11.9 Daylighting Technical Analyses and Calculations

In order to model a typical classroom and perform daylighting analyses two programs were used. AutoCAD 2008 was used to create a basic three dimensional model of a typical WCA classroom. The model was then imported to AGi32, which is a lighting design software. AGi32 has modeling and calculation capabilities; however it was only used for calculations in this analysis. Specifically, the goal of the calculations was to evaluate the illuminance levels from the electrical lights as well as from the natural light and ensure that the proper levels were being met. Additionally, the daylighting factor for the daylight zone should be over 2% in over 75% of the room area in order to obtain a LEED point. Since this project is not aiming for LEED certification, the illuminance levels and daylighting factor will not be required to meet the 2% in 75% of the room requirement, but will be used for reference.

Daylight factor (DF) is a ratio of the daylight illuminance in a zone in a give space due to the light received directly or indirectly from the sky²¹. Wattstopper.com is a valuable resource in defining daylighting terms. Below are terms frequently used in daylighting techniques which will be referred to in each individual analysis.

On/Off Setpoint Levels: The user defined daylight levels that must be reached before the lights are turned on or off.

Deadband: Control margin above the fixed on setpoint or below the fixed off setpoint in which minute variations in light levels will not trigger an on and off response from the electric lights.

On/Off Time Delay: Time-based interval that must elapse after the setpoint has been reached before the controlled lighting will turn on or off. Deadband settings and time delays are used to prevent over switching when there is simply cloud cover or momentary sunlight.

Target Level: User defined daylight level that must be reached before the lights are shut off or turned on.

Daylighting allows the owner or designer to customize many of the settings for the WCA classrooms.

²¹ Definition obtained from wattstopper.com
(<http://www.nxtbook.com/nxtbooks/wattstopper/psg0708/index.php?startpage=262>)



Two classrooms between two of the symbolic peaks were used for modeling purposes. The reason for this is because the protruding sections of the building would shield light from the classrooms. Therefore, these peaks had to be modeled so their shadowing effects could be accounted for. The red box in Figure 11.1 highlights an example of the two classrooms between the peaks. This example is repetitive throughout the rest of the building, both North and South elevations. Figure 11.2 is the basic three dimensional model constructed of the two classrooms situated between the protruding building sections.



Figure 11.1 WCA Flagship Building Elevation

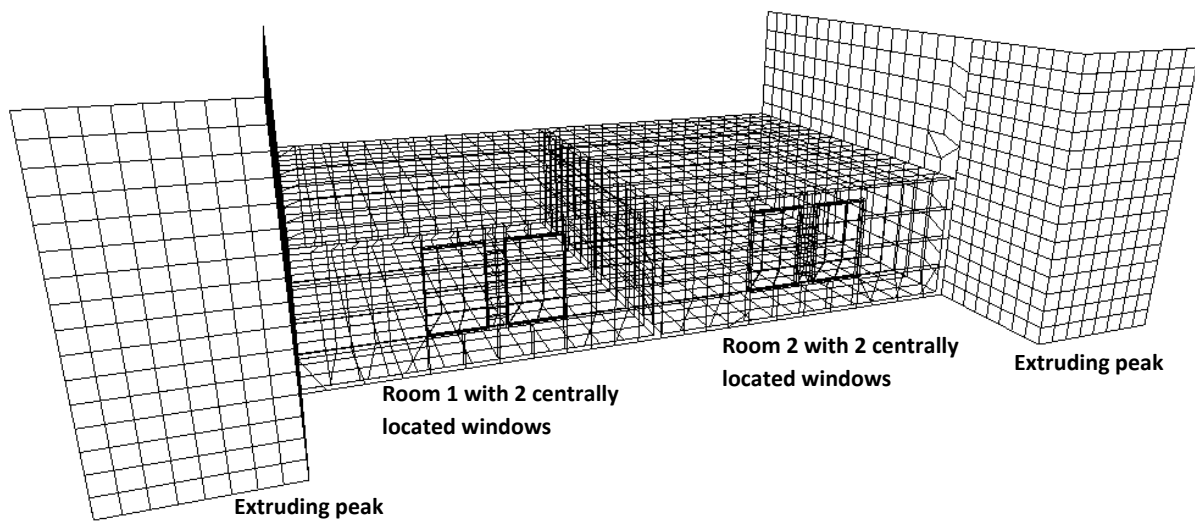


Figure 11.2 3D model of two WCA classrooms situated between peaks as currently designed

Below is a detailed list of the luminaires, lamps, and glass found in each room according to the WCA construction documents.

- 2x4 recessed fluorescent light fixtures
- (4) T-8 lamps per fixture
- 4L Ballast



- 1" insulated glass: ¼" clear glass, ½" air space, ¼" clear glass with low-e coating
- Mounting height: 9'-6" above floor

In order to run a model in AGi32 for daylighting calculations, a user must choose a luminaire and make some assumptions about light loss factors and transmittance levels. Listed below are the assumptions made for the AGi32 model.

- Fixtures²²:
 - XP/XA 2'x4' Lens Recessed Fluorescent XP/XA432, 4 Lamp, T8 from Lightolier
 - XP/XA 2'x4' Lens Recessed Fluorescent XP/XA332, 3 Lamp, T8 from Lightolier
- Transmittance:
 - Ceiling: 0.8
 - Walls: 0.5
 - Carpet: 0.2
 - Window: 0.7
- Desk height (work plane) is 2'-6"
- Light Loss Factor (LLF) is 0.70 for conservative measure
- Goal illuminance is 50 foot candles for a classroom +/- 10%
- Sky type is overcast which negates any reason to calculate different months (natural light will always be the same when the sky is overcast. This creates a conservative model.)

²² Cut sheets for the Lightolier fixture can be found in **Appendix E** and also at www.lightolier.com



A. Daylighting Analysis 1: Current Room Design

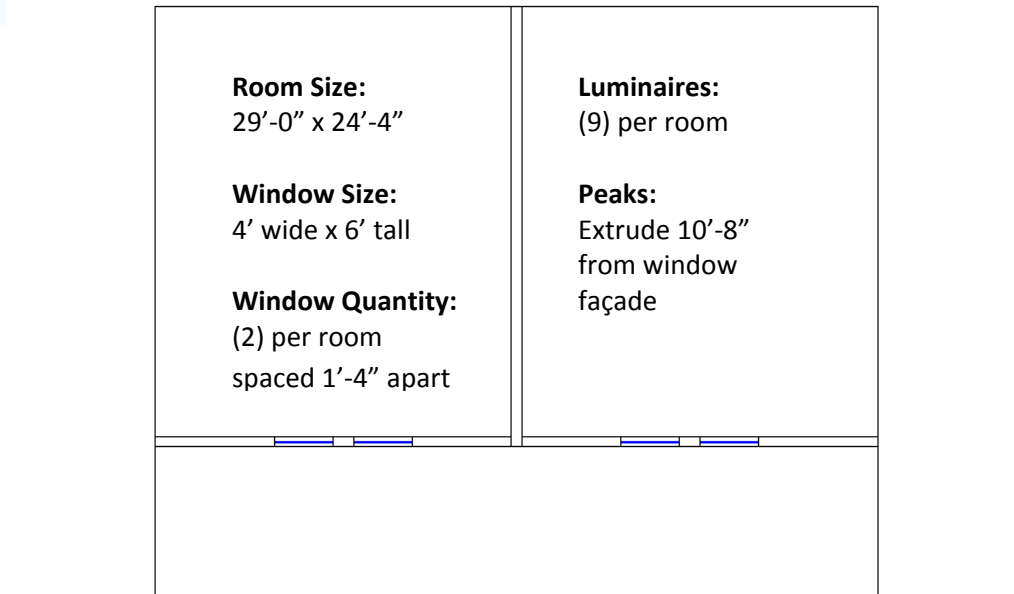


Figure 11.3 Plan view of classrooms with room details

Figure 11.3 is a plan of the two classrooms that were analyzed. Each room has two windows spaced the nominal length of one CMU block for easy installation. Upon running calculations for illuminance and daylight factor in AGI32, the following results were produced.

Out of 6 different trials, the results were:

Table 11.1 AGI32 illuminance result summary with current classroom design.

Category	Trial	Description	No. Lamps	Lum. Orientation	Illuminance (E)		
					Average (fc)	Max (fc)	Min (fc)
I	A	All Lights On (No Daylight)	4	typical	85.6	109.0	57.3
	B	All Lights Off (All Daylight)	4	typical	10.0	52.0	1.0
	C	Both Lights & Daylight	4	typical	95.9	123.0	69.0
	D	2 Rows Lights On, 1 Row Off	4	typical	67.9	95.0	23.0
II	A	All Lights On (No Daylight)	4	rotated 90°	87.2	103.0	66.0
	B	2 Rows Lights On, 1 Row Off	4	rotated 90°	68.9	93.0	23.0



Result Discussion:

- The green and blue rows in Table 11.1 correspond to trials that had the same amount of electric light and outdoor light; the only difference was the luminaires were rotated 90 degrees. The reason that trials II-A & II-B were attempted was to see if more light was gained near the window area by turning the luminaires so more surface area would be facing the windows. As the results prove, turning the luminaires 90 degrees has a negligible effect on the illuminance levels of the classroom. See figures 11.4 and 11.5 below. Please note that dotted luminaires mean they are turned OFF.

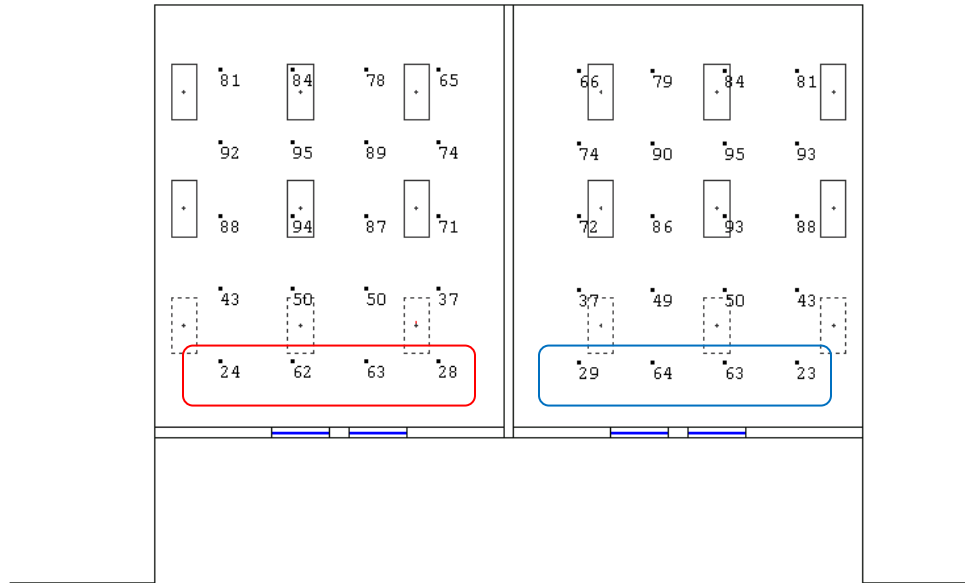


Figure 11.4 Illuminance levels with luminaires in typical layout (trial I-D, 2 rows on, 1 row off)

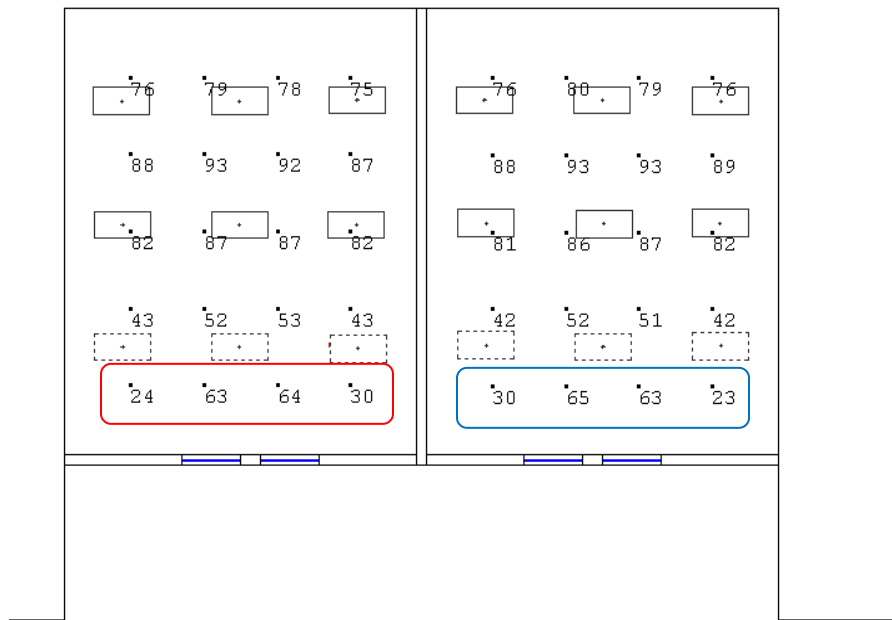


Figure 11.5 Illuminance levels with luminaires rotated 90° (trial II-B, 2 rows on, 1 row off)



- Illuminance from the daylight with the current classroom design is not substantial. Looking at trials I-B & I-C, the average illuminance in all areas of the room was only increased by 10 footcandles due to daylight. The average illuminance in trial I-D signifies that there actually is enough daylight to light the space even when one row of lights is turned off. The important factor in this analysis is not the average though. The deciding factors will be ensuring the illuminance levels near the windows and corners are sufficient and looking at the daylight factor. Figure 11.6 is a rendered image of one classroom looking from the outside-in with two rows of electric lights on and one row off. Figure 11.7 shows the illuminance level in all areas of the room when the luminaire row nearest to the window is turned off.

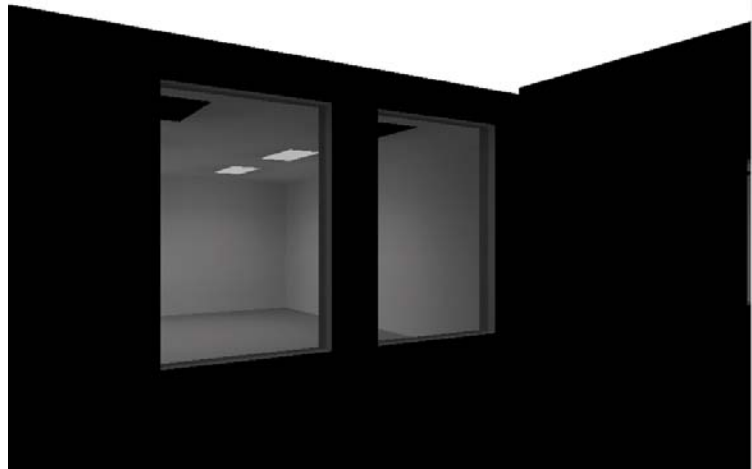


Figure 11.6 Rendered image of classroom with 2 rows on, 1 row

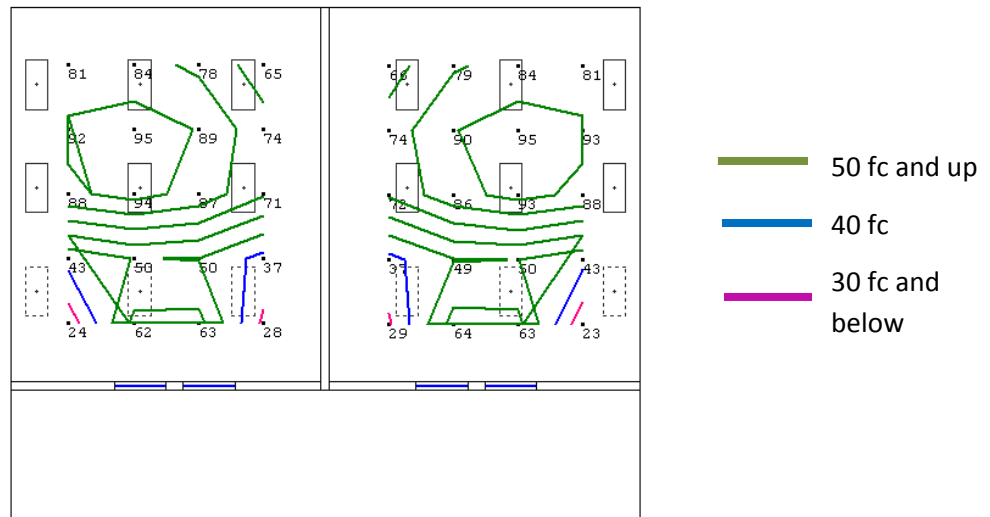


Figure 11.7 Illuminance levels with typical room layout, 2 windows (trial I D, 2 rows on, 1 row off)

Figure 11.7 clearly shows that there is a peak amount of illuminance anywhere the luminaires are turned on (2 rows) and directly in front of the windows. The areas of the room which do not meet the required 50 fc illumination are in the corners of the room, which would have the least amount of light from the windows because the windows are centrally located on the wall. This lighting layout is unacceptable anywhere the blue and pink lines are shown. In some spots the illuminance is as low as 23 footcandles which is too low for a classroom.



Below is the daylight factor in the room. A good goal to reach is 2% DF in over 75% of the room, although it is not required for this particular project.

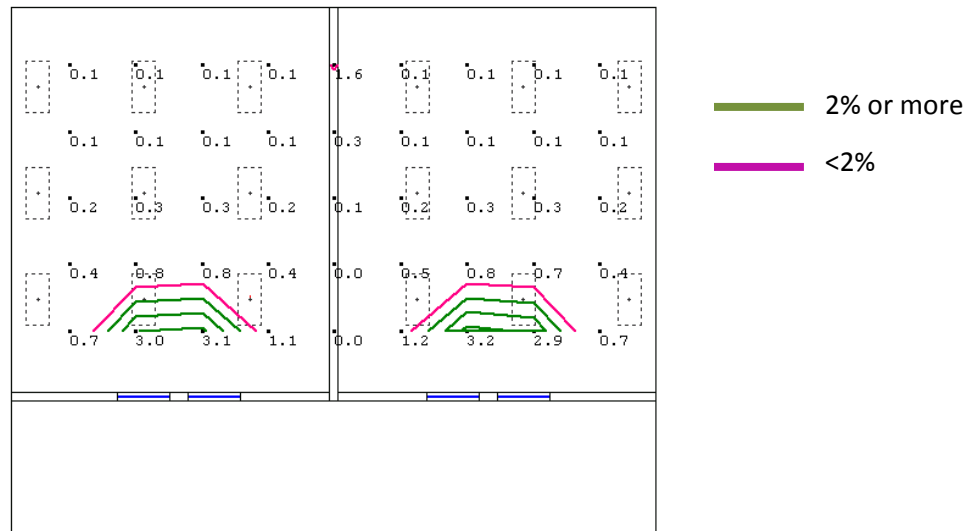


Figure 11.8 Daylight Factor (DF) for typical classroom with 2 windows

Table 11.2 AGi32 daylight factor results for a typical classroom with 2 windows.

Categories	No. Windows	Daylight Factor (DF)			
		Average	Max	Min	% area over 2% DF
I & II	2	0.7	8.3	0.0	10.6

When coupling the results from Table 11.1 and Table 11.2, my conclusion is that the current room layout is not adequate for daylighting practices. While the 4 lamp luminaires provide more than enough light when all 3 rows are turned on, as soon as 1 row is turned off the corners of the room do not sustain enough illuminance for a productive working plane in the classrooms. Furthermore, the daylight factor is below where it should be. There is simply not enough natural light entering the room.



B. Daylighting Analysis 2: New Room Design

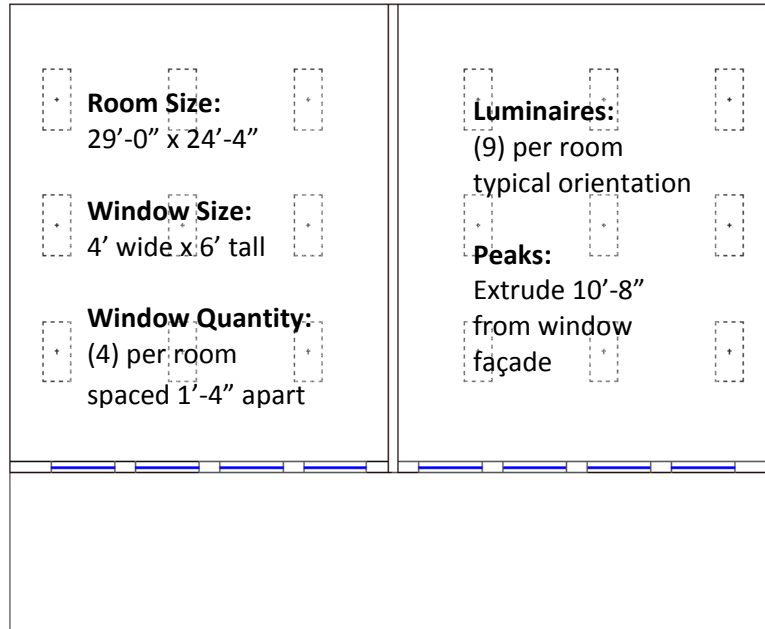


Figure 11.9 Plan view of new designed classrooms with room details

The new room design kept everything constant except the number of windows in each room, which was increased from 2 to 4. By adding more windows, the low illuminance levels in the corners of each room should be eliminated. Also, this design allows more daylight to enter the room and therefore increase the daylight factor. The overall architectural appearance of the building should not change drastically. The focal point of the building is the peaked towers and they do not change at all. The windows will still be separated by a CMU block length and brick façade, which will keep the windows distinct rather than a ribbon window or clerestory. The brick façade will still speak of tradition and integrity.

Upon running calculations for illuminance and daylight factor in AGI32, the following results were produced.

Table 11.3 AGI32 illuminance results summary with new designed classroom.

Category	Trial	Description	No. Lamps	Lum. Orientation	Illuminance (E)		
					Avg (fc)	Max (fc)	Min (fc)
III	A	All Lights Off (All Daylight)	4	typical	39.3	126.0	12.2
	B	2 Rows Lights On, 1 Row Off	4	typical	92.0	134.0	54.7



Result Discussion:

- Trials III-A & III-B suggest that the added windows greatly increase the illuminance levels of the classroom.
- When comparing I-B with III-A (2 windows vs. 4 windows), there is an increase in daylight from an average of 10 fc to 39 fc. This is almost four times the amount of illuminance, which is a surprising result because the window area was doubled and yet the illuminance was quadrupled.

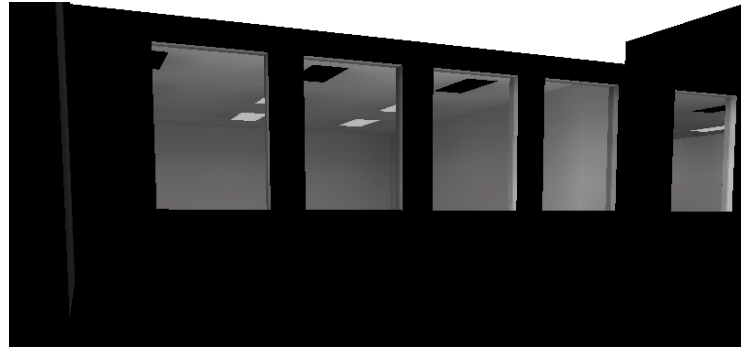


Figure 11.10 Rendered image of classroom with 2 rows on, 1 row off

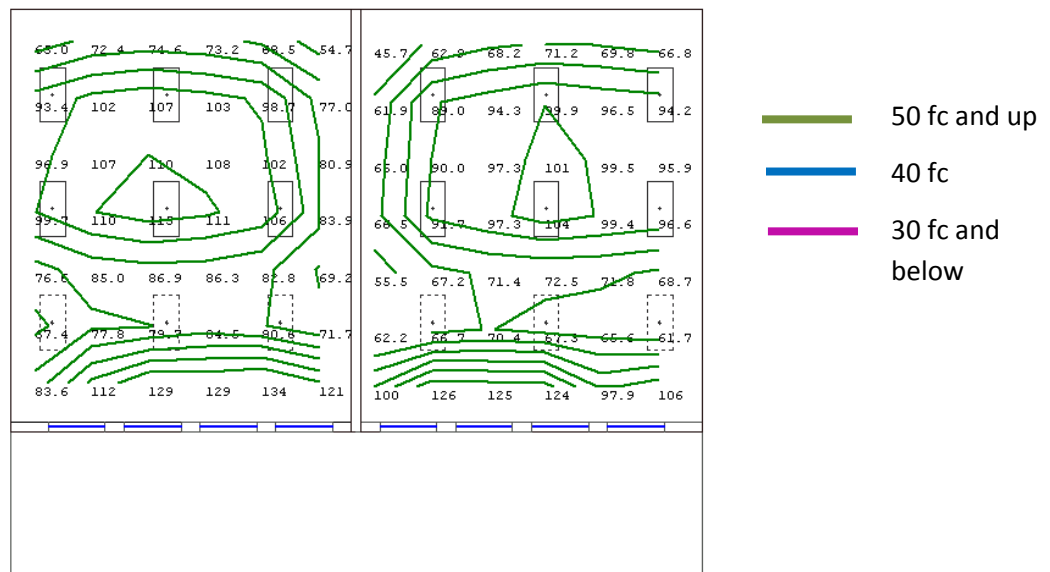


Figure 11.11 Illuminance levels with new room layout, 4 windows (trial III-B, 2 rows on, 1 row off)

With the new room design (4 windows), all areas of the room pass the 50 fc and up requirement when the row of electrical lights nearest the window are turned off. In fact, the average for the entire room is 92 fc. Even the corners of the room which were by far the lowest in Figure 11.7 have increased dramatically. The lower right corner of the right room jumped from 23 fc to 106 fc.



Below is the daylight factor in the room. A good goal to reach is 2% DF in over 75% of the room, although it is not required for this particular project.

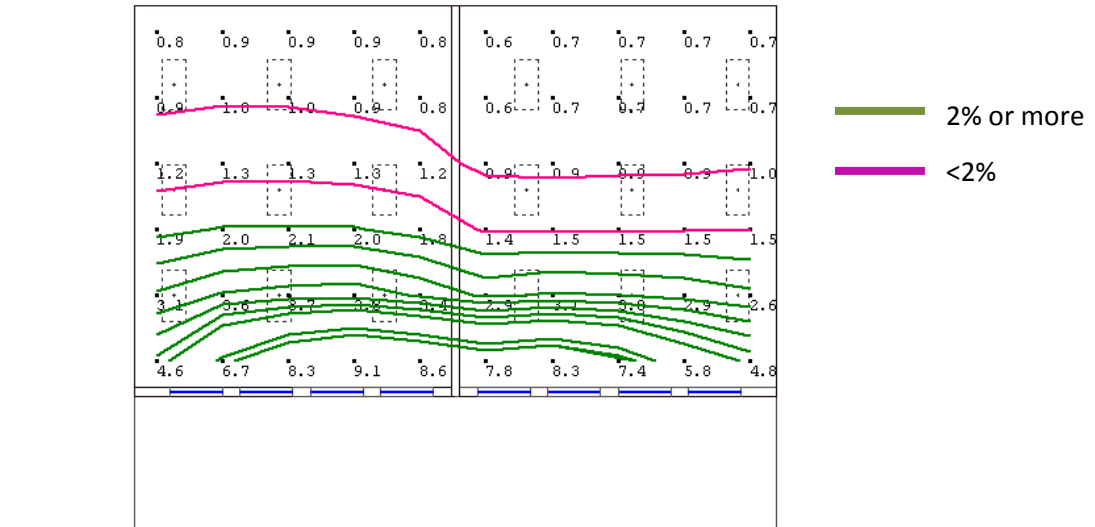


Figure 11.12 Daylight Factor (DF) for new designed classroom with 4 windows

Table 11.4 AGi32 daylight factor results for a new designed classroom with 4 windows.

Categories	No. Windows	Daylight Factor (DF)			
		Average	Max	Min	% area over 2% DF
III & IV	4	2.6	6.2	0.9	49.7

While this classroom layout has a much higher daylight factor average, it still is not over 75% of the area. Therefore, it would not obtain a LEED credit for natural lighting. In my opinion, however, this room is still a perfect candidate for daylighting. Figure 11.11 proves that there is more than an adequate amount of light in the classroom when 1 row of electric lights is shut off and replaced with natural lighting. In fact, I feel that there is too much lighting and energy is being wasted. This has inspired me to look at using the new designed classroom with 4 windows and using 3 lamps per luminaire rather than 4. The daylight factor would not change because the daylight factor only depends on the window sizes.



C. Daylighting Analysis 3: New Room Design and Lamp Change

This analysis is very similar to *B. Daylighting Analysis 2: New Room Design*. Therefore, the room plan is the same and so are the windows. The only thing that changes is the luminaires have 3 lamps rather than 4. Table 11.5 lists the illuminance results from this trial. Since the illuminance levels in category III were far above the 50 fc requirement, I decided to investigate whether using daylighting and 3 lamps would provide sufficient illuminance to the classroom. Table 11.5 shows that the average illuminance is still plenty high at 79.9 fc.

Table 11.5 AGi32 illuminance results summary with new designed classroom with 3 lamps.

Category	Trial	Description	No. Lamps	Lum. Orientation	Illuminance (E)		
					Avg (fc)	Max (fc)	Min (fc)
IV	A	All Lights On (No Daylight)	3	typical	59.8	82.6	28.3
	B	Both Lights & Daylight	3	typical	99.0	163.0	46.5
	C	2 Rows Lights On, 1 Row Off	3	typical	79.9	133.0	44.8

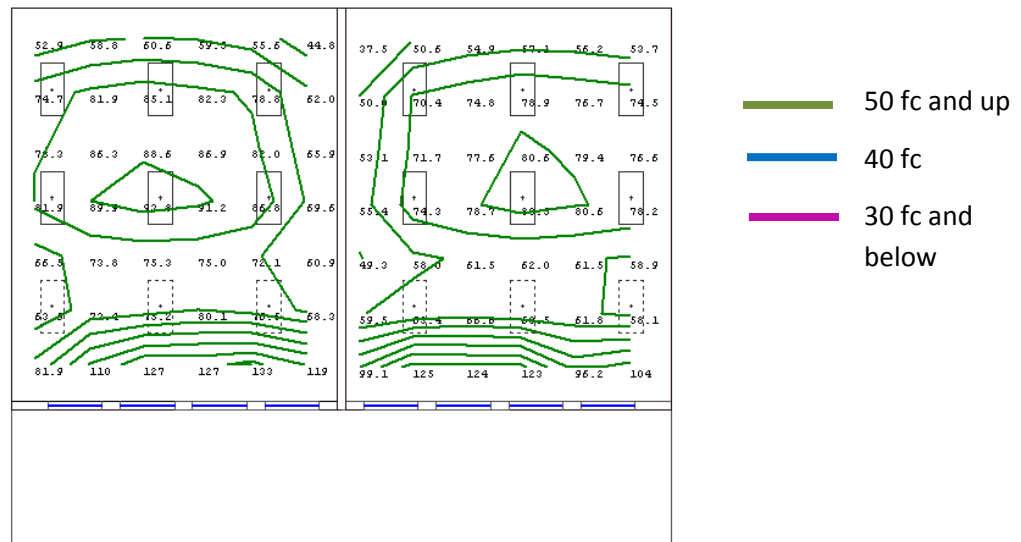


Figure 11.13 Illuminance levels with new room layout, 4 windows, 3 lamps (trial IV-C, 2 rows on, 1 row off)

Figure 11.13 graphically demonstrates that all areas of the room meet the minimum 50 fc requirement for classrooms. As seen in Table 11.5, with one row of lights turned off the minimum illuminance in the room is 44.8 fc, which is right on the +/- 10% illuminance allowance. Additionally, it should be reminded that a 70% light loss factor was used. So if the lights are functioning at a higher rate than 70%, there will be even more light in the classrooms. Please note that the daylight factor for this room layout is in Table 11.4. Changing the number of lamps would not affect the daylight factor in the room; only changing the amount of windows has an effect on the daylight.



11.10 Daylighting Technical Analyses Comparison

Analyses 1, 2, and 3 determined that daylighting is possible in the WCA classrooms, but not with the current room design. With two windows per room, there is simply not enough daylight entering the room to use daylighting techniques. Below is a summary of the results from all three analyses.

Table 11.6 Attempted daylighting hypotheses result summary.

Hypothesis Attempted	Daylighting Capabilities	
	Improve	Not Improve
Rotate Luminaires 90°		✓
Increase to 4 windows/room	✓	
Decrease to 3 lamps/luminaire	✓	

Table 11.7 Analyses summary for use of daylighting techniques.

Analysis	Feature Descriptions	Daylighting Techniques	
		Acceptable	Not Acceptable
1. Current Room Design <i>Trials I & II</i>	2 windows		✓
	4 lamps		
2. New Room Design <i>Trial III</i>	4 windows	✓	
	4 lamps		
3. New Room Design & Lamp Change <i>Trial IV</i>	4 windows	✓	
	3 lamps		

The best option for the WCA classrooms is Analysis 3. With the increase to four windows per classroom, the illuminance level on the desks is plenty high to reach the required 50 fc. Additionally, the reduction of lamps from four down to three saves 25% of cost on lamps for all of the classrooms, and therefore at least a 25% electrical savings. With three lamps the ballasts will be smaller and cheaper. Furthermore, using three lamps gives teachers more flexibility in switching options. There are two switches in every room, which will allow teachers to achieve three different light levels; all on, two lamps on, or one lamp on. This will help with technology presentations in the classrooms.



11.11 Choosing a Daylighting Sensor

The cut sheet for Daylighting Sensor LS-101 can be viewed in **Appendix E**.

Using Wattstopper.com for product information and installation guidelines of daylighting sensors has lead to using the Light Saver LS-101 Daylighting Controller²³. Outlined in this section is the decision process in choosing a daylighting sensor.

Wattstopper.com Product Selection Guide 2007-2008.

1) Standalone or system controls?

I chose a standalone system because it controls a single group of lights. In the WCA classrooms, it needs to control the row of lights nearest the window in one, single group. Also, it is simple to install, low in cost, and suitable for relatively small rooms.

2) Single or multiple control zones?

A single control zone was chosen because this is most commonly used with standalone systems and only one zone is being controlled per sensor.

3) Open or closed loop technology?

I decided to go with closed loop technology, although a more qualified lighting designer may choose differently. I chose closed loop because it allows for on/off switching and it measures daylight and electric light levels in the room. In case the lights are functioning below 70% (the light loss factor in which the trials were tested), I felt it was important that the sensor account for the entire light in the room, not just the natural daylight. Also, the closed loop allows for manual override in case the teachers wanted the extra lights on for a specific reason.

4) Placement?

The best place to put a daylighting sensor is on the ceiling. It needs to be near the window and pointed toward an area representative of the work space. Please refer to Figure 11.14 for an example sensor location within a room.

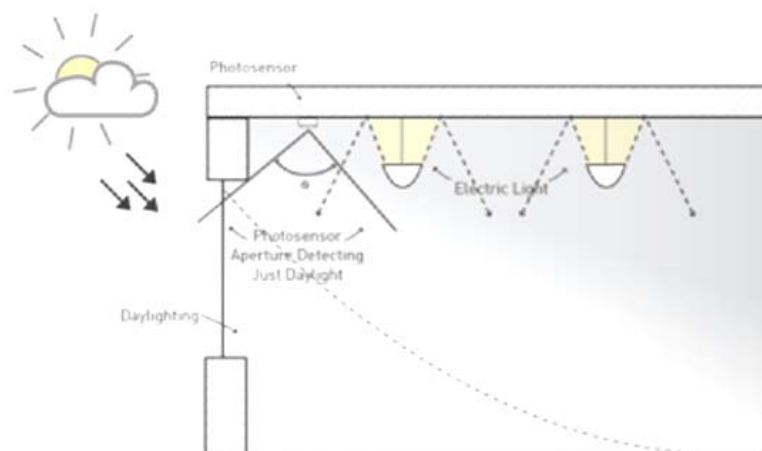


Figure 11.14 Daylighting room graphic from Wattstopper.com

²³ Wattstopper.com Product Selection Guide 2007-2008 found at <http://www.nxtbook.com/nxtbooks/wattstopper/psg0708/index.php?startpage=262>



	On/Off Switching	Dimming
Single Zone	LS-101 (either)	LS-301 (closed loop)
Multi Zone	LCO-203 system (open loop)	LCD-203 system (open loop)

Figure 11.15 Daylighting sensor selection chart

Figure 11.15 suggests using a LS-101. The LS-101 is a Light Saver Daylighting Controller that can sense 1-1400 footcandles. The product overview says,

The LS-101 Daylighting Controller is a single zone, ON/OFF device which can be installed in an open or closed loop application to turns lights off automatically when sufficient natural daylight is present. It consists of an advanced digital multiband photosensor that measures light similar to the way the human eye perceives it, an on-board microcontroller, and an LCD display. This photosensor is positioned behind a 100P cone that cuts off unwanted light, preventing false triggering.

-LS-101 Product Overview, more available in **Appendix E**

Below is a diagram featured on Wattstopper.com which shows the elements of a LS-101 controller.



Figure 11.16 LS-101 features diagram from Wattstopper.com



11.12 Cost and Schedule Considerations

Cost

There is no doubt that using daylighting techniques saves energy and therefore reduces the electrical costs for the owner. The question is by how much. Unfortunately, I do not have the resources to examine a dollar figure. It can be assumed that since the lamps are being reduced from 4 lamps to 3 lamps, there is an automatic 25% cost savings. This alone is significant. By shutting off the row of lights nearest the window, there would be a 33% reduction in electrical cost per classroom. It is difficult to estimate how often these lights could be turned off, which makes cost analysis even tougher. However, the test trials of the space were conducted when the sky type was overcast. This conservative estimate gives hope that a large amount of days will be overcast or better, and therefore the daylighting techniques will be able to function. Coupling the lamp reduction with the possibility of turning off one row of lights during most of the day results in substantial savings to the owner and the environment.

The cost of adding the daylighting photosensors to the classrooms would be offset by electrical savings within the first year. Since I chose to switch the lights on and off rather than dim, the ballasts do not have to be changed. Therefore, the only additional cost to the owner is the actual sensors. A sensor could cost approximately \$100 to \$200 dollars. Taking the average and multiplying by the 24 classrooms yields a cost of \$3600. The automatic 25% savings from the lamps should account for this addition. Beyond the first year would be only more savings.

Increased mechanical load to cool the building due to the extra windows is not expected. The window area was doubled, but still only makes up 40% of the exterior wall. The wall is insulated and the windows have a low emissivity glazing which helps heat loss and gain. Additionally, these windows are only being added to the 24 classrooms. None of the windows on the peaks will change, and these peak windows will receive the most direct sunlight and therefore heat gain. Many classrooms with daylighting have ribbon windows or clerestories; and these WCA classrooms are still well below that amount of windows.

Schedule

The photosensors would not cause any delay or extra time in the schedule. They are not a long lead item and are readily available through manufacturers with proper order preparation. However, adding daylighting techniques would not reduce the schedule, either. The most dramatic schedule change would occur in the design phase. To incorporate daylighting into the WCA classrooms, it should have been considered in the initial design phase of the school. Even as far back as schematic because the number of windows needs to be high enough to allow in a substantial amount of light. The architect and lighting designer need to work together in the initial project stages to create a system that works both aesthetically and electrically. Then, the owner would have to approve such an addition. Although with the long term energy cost savings and proven benefits for the occupants, it is difficult to find a reason not to employ daylighting techniques when possible.



11.13 Conclusion & Recommendation

Based on the current WCA classroom design, it would not be advisable to use daylighting techniques. In addition, it would be a waste of money to install occupancy sensors. Rather, I recommend educating teachers about the benefits of turning out the lights and possibly placing laminated or permanent signs above the switches that remind teachers to shut the lights off when leaving the room.

As far as daylighting is considered, there is nothing that can be done now for the WCA classrooms considering construction is so far along. Had this been two years ago, I would recommend that the architect, lighting designer, and owner collaborate to incorporate the necessary amount of windows to achieve daylighting into the initial building design.

The trials conducted with AGi32 concluded that rotating the luminaires 90 degrees had no effect on the lighting in classroom. Positively, though, it also concluded that with four windows per classroom the lamps per luminaire could drop from four to three and daylighting techniques could be used.

Overall, I recommend designing four windows per classroom which provides ample natural light for daylighting and visual comfort for students. It would create a more environmentally friendly and cohesive space for students. Also, I recommend using three lamps per luminaire which reduces energy and gives teachers more switching options during presentations or different activities. I think the LS-101 daylight photosensor should be used in every classroom which would control the row of lights nearest the windows.



Figure 11.17 Classroom with natural light entering
<http://www.cstrainingcenter.com/images/classroom6.jpg>

This sensor would switch the row on and off rather than dim which provides yet another educational benefit to the space and allows teachers to make an example of how turning the lights off is energy efficient and can be done when there is enough light in the room to still perform all necessary tasks.

While the cost of the daylighting system is slightly more expensive than the current system, the benefits of energy cost savings and a better educational environment for students far outweigh the additional money spent. The schedule is not impacted so the WCA would still be able to finish on time and open for the 2008-2009 school year.