A NEW DAYLIGHTING STRATEGY FOR A MIDDLE SCHOOL IN NORTH CAROLINA

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ABSTRACT

This paper investigates the findings of daylighting studies being conducted at the Northern Guilford Middle School in Greensboro, North Carolina. Over the past fifteen years, a number of daylit schools have been built in North Carolina. Many of these schools incorporate roof monitors and dormer clerestories to introduce natural light into the classroom. A new daylighting strategy has been developed and incorporated into the design of the Northern Guilford Middle School. For the first time, the architects have incorporated an entirely new approach to daylighting design. This design utilizes a unique curved, translucent interior light shelf, working in combination with a highly reflective ceiling in the classroom spaces. While preventing glare, this strategy diffuses daylight in a very uniform manner and assists in reflecting daylight deeper into the classroom spaces. The daylighting glazing area is reduced by 40% compared to that used in past daylighting applications. Whole building energy analysis results indicate a 50% lighting energy reduction, a 10% cooling energy reduction, and a 11% total building energy reduction through daylighting (about 60% of the total square footage of the building is daylit), as compared to a code compliant base case without daylighting.

1. INTRODUCTION

The Northern Guilford Middle School has been designed as a 3-D textbook so the students, teachers and the community can learn about sustainable design strategies and how they reduce the impact that human activity has on our environment. The Northern Guilford Middle School has 140,000 square feet and includes classrooms for 950 students plus dining, gymnasium, auditorium, science, art, music, technology, media center and administration facilities. The school also features rainwater harvesting, extensive bio-swales and three constructed wetlands, wastewater treatment, and subsurface irrigation systems. The school has been oriented on an east-west axis to maximize the southern solar potential for daylighting, passive solar, solar domestic hot water, and photovoltaic applications. East and west glazing is minimized to reduce heat gains. Figures 1 & 2 show the exterior and interior of the classroom wings with their unique daylighting design.

Fig. 1: Exterior view of classrooms

Fig. 2: Interior view of classroom with daylighting

2. DAYLIGHTING DESIGN CONCEPTS

All classrooms are daylit with south-facing clerestories. Figure 3 shows the overall plan of the school with the 3 classroom wings on the west. All wings are single-storied, with a sawtooth-shaped section. Figure 4 shows a typical classroom wing section. The daylighting strategy for the south side classrooms is a combination of an exterior and interior light shelf with an overhang sized to block summer time solar radiation while allowing winter sun, consistent with good passive solar design. A white ceiling reflects the daylight deep into the spaces. The roof of the corridor is highly reflective, and acts as a huge light shelf for the north side classrooms. Indirect fluorescent lighting is installed throughout the school building. The lighting is dimmable and controlled by occupancy and daylight sensors that work in conjunction with the daylight to minimize artificial light usage.

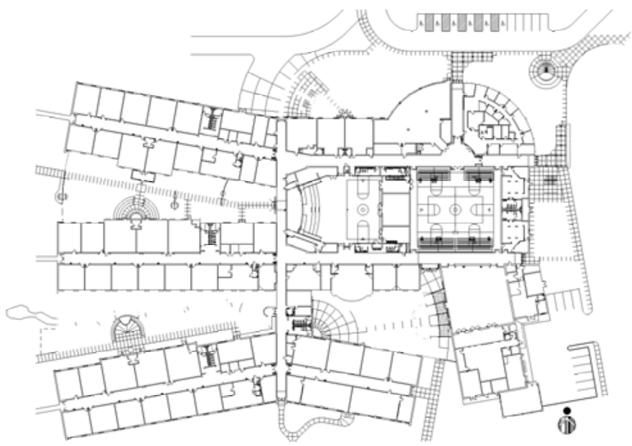

Fig. 3: Overall plan of the school

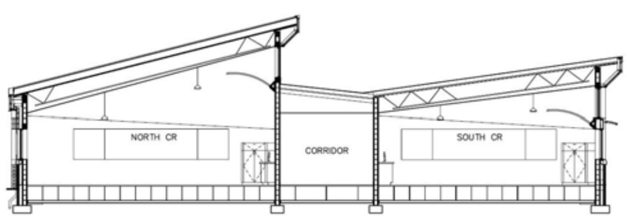

Fig. 4: Typical classroom wing section

Another innovative daylighting strategy used in the classrooms is a unique interior dropped soffit that slopes up towards the rear of the space. This architectural element is situated to intentionally shade the projection screen area and the TV monitors mounted on the wall without blocking views. This eliminates the need for manual/automatic window shading devices. Figure 5 shows a schematic section illustrating this idea.

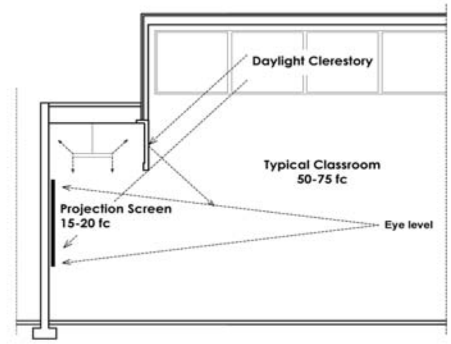

Fig. 5: Interior dropped soffit shades projection screen

2.1 Interior Light Shelf

The main element of the daylighting design is the interior light shelf (see Figure 6). The design is unlike any other light shelf design seen in conventional practice. This was a custom product specially manufactured for this school project. The frame is constructed out of 2.5" square hollow aluminum tubes with a white, powder-coated finish. White, translucent acrylic panels with a 20-25% visible light transmittance are attached to the aluminum frame. The entire lightshelf is pre-assembled before installation. A special design feature is the ability to entirely lower the light shelf through a hinged support next to the wall to facilitate cleaning the top portion of the panels. The light shelf is shaped so as to diffuse direct light, while at the same time reflecting it onto the highly reflective ceiling tiles and to the back of the classrooms.

Fig. 6: Interior light shelf in the classroom

3. DESCRIPTION OF PROTOTYPE SPACES

Original daylight testing was done in two south side classrooms. Table 1 gives the exact room dimensions and other details relevant to daylighting. Further testing is being conducted in both, the south and north side classrooms. A typical classroom plan is shown in Figure 7. The dashed line running from the front to the rear on the left side of the classroom represents an angled soffit that drops down as it approaches the window as seen in Figure 2. This serves to shade the television corner and wall containing the projection screen. The television sits on the left front corner cabinet in the furnished classroom. The soffit is about 5'-6" from the wall. The regular wall view windows seen in the plan and photographs are not considered as reliable daylighting sources, and hence were covered with opaque boards during the daylight testing.

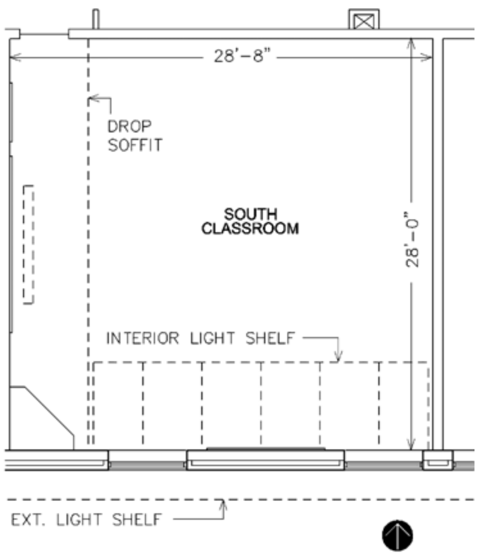

Fig. 7: Plan of a typical south side classroom

TABLE 1: DETAILS OF DAYLIT SPACES

Classrooms	South	North
Size (width x depth)	28'-8" x 28'-0"	24'-8" x 32'-0"
Typical Area	803 sq.ft.	789 sq.ft.
Daylighting	Clerestory	Clerestory
Glazing	Clear Insulated	Clear Insulated
V.L.T. (%)	80	80
Glass to floor ratio (%)	11.6	10.8
Exterior element	Light shelf	White Roof
Interior Reflectances		
Walls (%)	60	60
Floors (%)	35	35
Ceilings (%)	80	80
Overhang depth	2'-0"	2'-0"
View windows	2 No. South	2 No. North
Exterior Shading	Light shelf	None
Interior Shading	Blinds	None

4. RESEARCH METHODOLOGY

The objective of this research was to understand the performance of the new daylighting design in terms of daylighting quality and quantity in the classroom spaces. Particular attention was paid to the fact that adequate lighting plays a very important part in the design of learning environments. The results would go through an intense evaluation to determine future daylighting designs.

4.1 Equipment Selection

The first step in the research process was to select light level measuring and recording equipment. After an extensive search into what is available, conversations with people who have used light measuring equipment in the past, and budgetary consideration, it was decided to purchase light sensors and data loggers from LI-COR Biosciences.

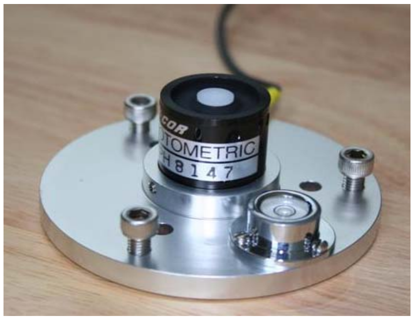

Fig. 8: LI-COR photometric sensor

The LI-COR equipment was used for the indoor measurements. A HOBO weather station from Onset Computer Corporation was purchased for outdoor solar insolation measurements. The LI-210 Photometric sensor is constructed with a filtered silicon photodiode contained in a fully cosine-corrected sensor head. This sensor has a spectral response that falls within ±5% of the CIE Standard Observer Curve. This curve is a measure of the spectral responsivity of the average human eye (LI-COR). Figure 8 shows a LI-COR photometric sensor. Ten LI-210 sensors were purchased, with the original intent of using nine sensors inside the classroom and one sensor outside to gather the outdoor level of illuminance. The sensors measure the illuminance in klux, which can be easily converted to the English units of footcandles.
Two LI-1400 Data Loggers were purchased to record the readings from the photometric sensors. Each data logger has five channels that can be used with the photometric sensors. A simple software program allows the user to set up logging routines and intervals, indicate which sensor is plugged into a specific channel, and download recorded data. Figure 8 shows one of the loggers with sensor cables attached to it.

Fig. 9: LI-1400 Data Logger

In order to be able to compare the indoor light levels as recorded on different days, a measure of the outdoor solar insolation is required. Onset Computer Corporations' HOBO Micro Station was chosen for it's simplicity, portability, and price. The Micro Station is a four-channel weatherproof data logger that records data from a variety of possible sensors. The Silicon Pyranometer Smart Sensor and the Photosynthetic Light (PAR) Smart Sensor were purchased to provide solar insolation data. A simple weather station stand was constructed to mount the sensors and data logger. This allowed all the outdoor sensors to be on one portable stand that could be placed anywhere on the roof of the subject facilities. The Pyranometer and PAR sensors are mounted on the bracket arms, while the data logger is in the small box on the post. Figure 10 shows the weather station as installed on the roof. It should be noted that none of the light sensing equipment used does very well at detecting radiation reflected from a horizontal surface below the level of the sensor.

Fig. 10: Weather Station on the roof

4.2 <u>Data logger setup</u>

Data was collected at five-minute intervals. Five minutes is frequent enough to see gradual changes in light levels, and also a long enough increment that the data is not affected by stray clouds that may pass over for just a few seconds or a minute. The Pyranometer and PAR sensors for this study were set up with a sampling interval of 30 seconds and a logging interval of five minutes. This means the sensor samples a data point every 30 seconds, and then every five minutes those 10 data points are averaged and recorded to memory. Thus each data point recorded is really an average of the solar radiation over the last five minutes. The LI-COR sensors were set up with both the sampling and logging intervals being five minutes.

4.3 <u>Daylight sensor setup</u>

A typical layout of a classroom can be seen in Figures 2 and 6. It consisted of a dry-erase board on one wall, windows on one wall, computer desks up against a wall, a few cabinets in the back/side of the room, and student desks in the center of the room.

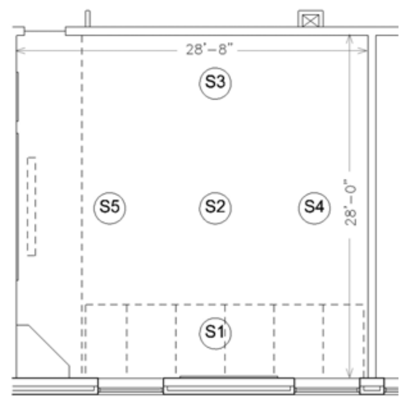

Fig. 11: Sensor layout in a typical classroom

Five equidistant sensors were setup in the space, being mounted on small wooden tables about 25 inches high. The sensor arrangement is shown in Figure 11. The sensor cables were then attached to the data loggers, and each sensor was leveled using three leveling screws provided in the sensor bracket. For most part, the classroom layout was left undisturbed.

5. <u>DAYLIGHT PERFORMANCE RESULTS</u>

This is the first time that the new interior light shelf design has been implemented. Though full-scale mock-ups of the light shelf had been constructed before actual installation, it was thought a good idea to experiment with 2 different positions for the light shelf, first the existing, and second at a lower angle. Daylight measurements were taken at the same time in 2 similar, adjoining classrooms so as to collect consistent data. Figures 12 and 13 show the existing and lowered position for the light shelf.
The difference can be seen in relation to the sprinkler head on the right. The results indicated a slight increase in

interior daylighting levels due to the lowered position, but not significant. Hence, later analyses were conducted with the existing higher light shelf position.

Fig. 12: Existing light shelf position

Fig. 13: Lowered light shelf position

5.1 October 21st, 2006 Analysis

The daylight levels are being measured in a continuous manner throughout the whole year in order to fully analyze, evaluate, and understand the performance of the daylighting strategy. The initial daylighting tests were conducted over the weekend of October 21 – 22, 2006. Light sensors were set up in accordance with Figure 11. Since the school was still under construction, testing had to be coordinated with the construction superintendent to ensure that the test area could be closed off and left undisturbed over an entire weekend. Future tests will be conducted in rooms on both sides of the hallway, in order to measure the effect of the roof reflectance. Saturday, October 21st was a clear, sunny day, while Sunday the 22nd was rainy and overcast for much of the day. The analysis graphs shown are for October 21st. The output from the data loggers has been plotted in 2 directions: from west to east, and from front to the back of the classroom. Figure 14 shows the daylight distribution in the central portion of the classroom, from west (sensor S2) to east (sensor S4). Figure 15 shows the daylight distribution across the length of the classroom, from the front (sensor S1) to the back (sensor S3).
Figure 14 indicates that the daylight distribution along the width of the classroom is fairly uniform, with an average deviation of only 20 footcandles.

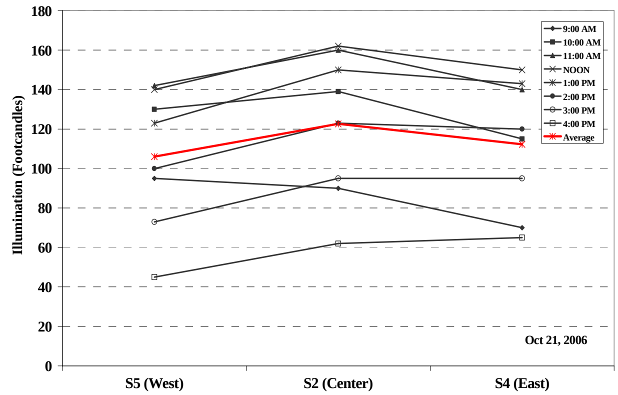

Fig. 14: Daylight distribution along the width of classroom

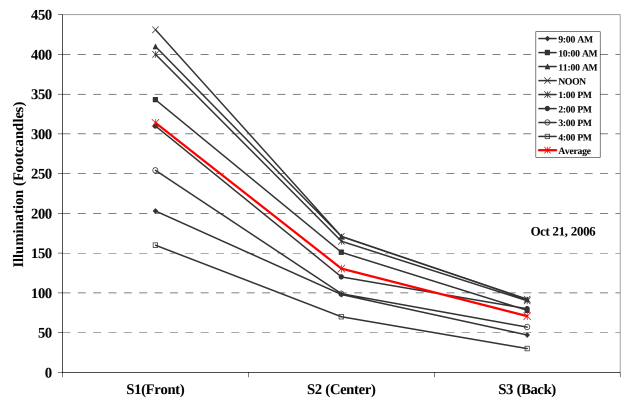

Fig. 15: Daylight distribution along the length of classroom

The maximum daylight level along the width is 162 fc at 12 PM at the center of the room, while the minimum daylight level is 45 fc at 4 PM on the west side of the room. Except at this lowest level point, daylighting at all other times of the day between 9 AM and 4 PM is more than 50 fc.
Figure 15 indicates that the daylight distribution along the length of the room (from front to back) is not uniform, but follows a downward curve, with higher daylight levels in the front, and lower daylight levels in the back. The maximum daylight level along the length is 431 fc at 12 PM to the front of the room, while the minimum daylight level is 30 fc at 4 PM near the back of the room. Except at one other time of the day (9 AM) at the back of the room, daylighting at all other times of the day between 9 AM and 4 PM is more than 50 fc.

5.2 March 15th, 2007 Analysis

The next daylighting tests are being conducted from the beginning of this year. The construction of the school is complete, and the 6th grade students have started their

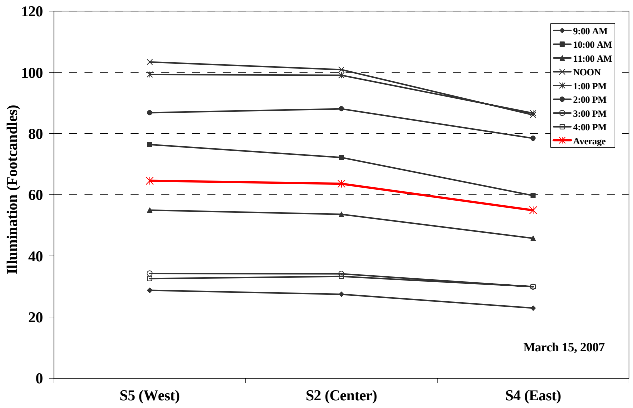

Fig. 16: Daylight distribution along the width of classroom

classes. However, the 7th and 8th grade classrooms wings will still be vacant for the next few months. This presented the opportunity to fix the daylight sensing equipment in 2 rooms without having to go through the process of installing and removing it depending on the school schedule. The output from the data loggers has been plotted in a similar manner to the October 21 data. Figure 16 shows the daylight distribution in the central portion of the classroom, from west (sensor S2) to east (sensor S4). Figure 17 shows the daylight distribution along the length of the classroom, from the front (sensor S1) to the back (sensor S3).

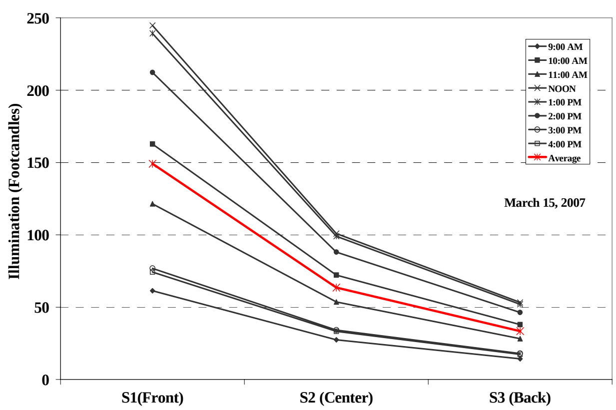

Fig. 17: Daylight distribution along the length of classroom

Figure 16 indicates that the daylight distribution along the width of the classroom is fairly uniform, with an average deviation of about 20 footcandles. Figure 17 indicates that the daylight distribution along the length of the room (from front to back) is not uniform, but follows a downward curve, with higher daylight levels in the front, and lower daylight levels in the back. These trends are similar to the October analysis.

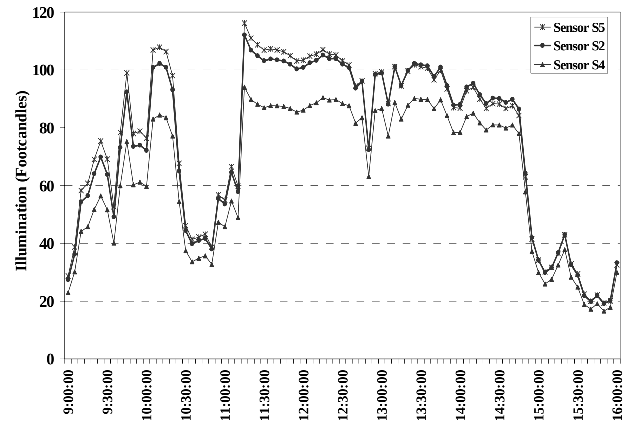

Fig. 18: Hourly daylight distribution at the middle row

The maximum daylight level along the width is 104 fc at 12 PM at the center of the room, while the minimum daylight level is 23 fc at 9 AM on the east side of the room. The daylighting was more than 50 fc from 10 AM to 2 PM, and was between 25 to 40 fc during early morning and late afternoon times.
The maximum daylight level along the length is 245 fc at 12 PM at the front of the room, while the minimum daylight level is 15 fc at 9 AM near the back of the room. The daylight levels at the back were less than 50 fc for most part of the day.

5.3 <u>Solar Radiation and Illuminance</u>

The hourly illuminance data was plotted for the sensor points S2, S5, and S4, to understand the trends observed for different times of the day. Figure 18 shows the hourly data values from 9 AM to 4 PM for March 15th, 2007.

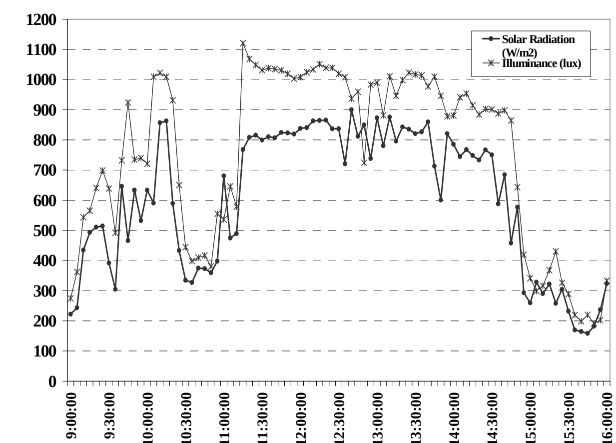

Fig. 19: Solar radiation and interior illuminance

Illuminance data at all 3 sensor locations followed the same trend, with a drop in values between 10:15 AM and 11:15 AM. This was attributed to weather change or the presence of cloud cover for that portion of the day. The illuminance was found to be lower than 50 fc for less than 30 minutes. The solar radiation data collected from the roof was plotted against the illuminance data to ascertain the reason for the lower values. Figure 19 shows this comparison for sensor location S2.

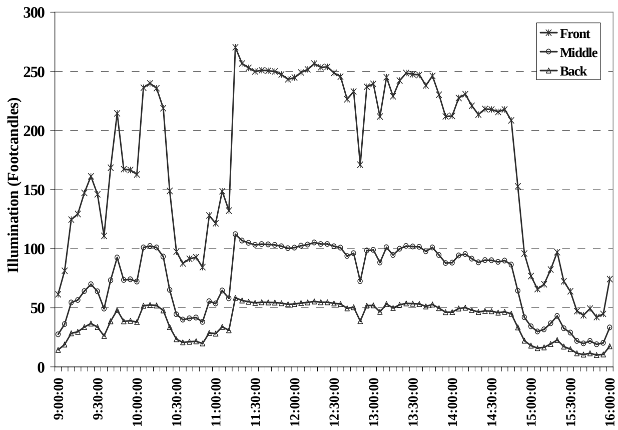

Fig. 20: Hourly daylight distribution for all 3 rows

Figure 20 provides a different perspective on the difference in light levels between the front and the rear of the classroom as it plots the hourly levels on each row over the entire day.

6. FUTURE WORK

The data shown in Figures 15 and 17 have led to indicate that though the daylighting levels are better the recommended values for most part of the day, the front portion of the classrooms receives a lot more light than is required. This can be a potential glare issue, and thus needs to be worked upon.

The first steps in this direction are already underway. In order to understand this issue, a 1'-0" high opaque insulation board element was added to the lower part of the clerestory windows. The objective was to reduce light reaching the front of the classroom, while still maintaining enough daylight levels in the remaining portion of the classroom. This idea, if properly explored, would lead to lower glazing areas and installed costs than is currently used, while not affecting the daylight distribution in the classrooms. Figure 21 and 22 show exterior views of the classrooms, with and without the additional board. Daylight testing was conducted simultaneously in these 2 adjoining classrooms. The output was then plotted in a similar manner as before, and is presented in Figure 23 and Figure 24.

Fig. 21: Existing window configuration

Fig. 22: Modified window configuration with opaque board

A comparison of the new data with the existing data indicates that this change is a step in the right direction. Figure 23 shows the daylight distribution along the length of the room, which confirms that the levels near the front are less than before, while the average daylight distribution is still maintained around 50 fc. Figure 24 indicates that the daylight levels along the width follow the same trend as before, also averaging around 50 fc.

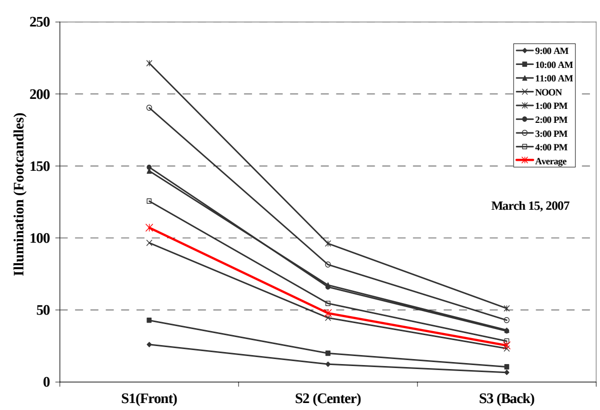

Fig. 23: Daylight distribution 1 with the modified window

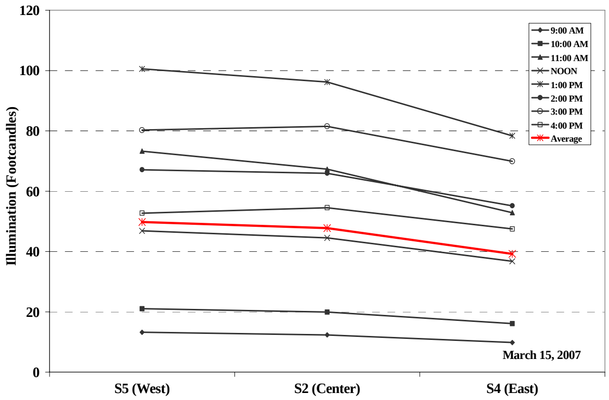

Fig. 24: Daylight distribution 2 with the modified window

7. CONCLUSIONS & RECOMMENDATIONS

1. The new daylighting strategy incorporated in the Northern Guilford Middle School provides a more uniform quality of daylight when compared to earlier designs (see Figures 14 and 16). This improved performance is particularly true in the east-west direction, where the variation is limited to 20 footcandles. On good solar days, light levels are above 50 footcandles everywhere in the classroom between 9:00 am and 3:00 pm (see Figure 14). Performance during overcast periods is also quite good (as seen between 10:30 and 11:00 am in Figure 20).
2. Another important development is the effectiveness of the dropped soffit that provides sufficient shade along one side of the classroom to permit easy viewing of the TV monitor and overhead transparencies without the need for operational shades or blinds (see Figure 5). This has long been a serious problem for teachers working in a daylit classroom. The soffit system is a positive step toward addressing this issue.
3. The subject research indicates that additional work needs to be done in achieving greater balance in daylighting between the front and rear of the classroom. Work in this area is already underway and preliminary results look promising. Some of the research areas in process include adjustments to the solar glazing area, modifications in the transmissivity of the interior light shelf, and the effect of roof reflectance on the daylight and passive solar gains for the north side classrooms (see Figure 4).
4. Additional research is also needed in gathering performance data on daylighting system performance over an entire school year. The Northern Guilford Middle School situation provides an excellent opportunity for conducting these experimental studies over a range of seasons. When one considers the population growth in North Carolina and the new schools that will be needed to educate our children, the incorporation of good daylighting practices can have a significant impact on the energy efficiency and learning environment of these new schools.

8. REFERENCES

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