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Influence Of External Shading Devices On Daylight Availability In South-Facing Classrooms In The Tropics

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Abstract
Adequate daylighting is a vital element of effective learning environments, profoundly affecting students' visual comfort, cognitive performance, and psychological well-being. Insufficient access to natural light not only hampers academic productivity but can also negatively impact the physical and mental health of occupants. In tropical climates such as Chittagong, Bangladesh, the design of educational buildings must strike a careful balance between daylight access and thermal comfort. While external shading devices play a crucial role in minimizing solar heat gain and glare, they can also obstruct daylight entry, potentially diminishing indoor lighting quality. This study explores how different configurations of external shading devices influence daylight performance in south-facing classrooms, using a typical classroom at the Chittagong University of Engineering and Technology (CUET) as a case study.
A mixed-method approach was adopted, integrating on-site illuminance measurements with daylight simulation tools to evaluate the effectiveness of the existing shading strategies. Alternative shading configurations were subsequently proposed and analyzed to assess their impact on indoor daylight distribution. The findings indicate that carefully optimized shading geometries can enhance daylight penetration while maintaining acceptable thermal comfort levels, thus improving overall indoor environmental quality. This research provides evidence-based design recommendations for the integration of passive shading solutions in classroom architecture, aiming to assist architects and designers in creating sustainable, energy-efficient educational environments that support both visual comfort and occupant well-being in tropical regions.

Keywords: *Day-lighting; Shading configuration; Energy efficiency; Illuminance levels; Parametric modeling.*

INTRODUCTION

The study of daylighting in classrooms has long been a topic of significant interest due to its critical role in educational settings. Daylight not only influences a person’s ability to perform visual tasks but is also psychologically preferred over artificial lighting (Jackson, 2006). Recent research has confirmed that daylight enhances academic performance and contributes positively to the health and well-being of occupants.
In modern urban contexts, buildings consume a substantial amount of energy for heating, cooling, and lighting, contributing to energy crises and global warming. Notably, artificial lighting alone can account for up to 50% of a building’s total energy consumption (Jackson, 2006). Poor daylighting design often necessitates increased use of artificial lighting, creating visually uncomfortable environments (Hossain & Ahmed, 2013). As a response, researchers advocate for sustainable design approaches that promote energy efficiency and reduce reliance on non-renewable resources.
Daylight, as a natural and abundant light source, holds immense potential for reducing energy consumption when effectively integrated into architectural design. Tropical regions like Bangladesh benefit from plentiful daylight throughout the year (Ahmed & Joarder, 2007), and with appropriate design strategies, a significant portion of lighting energy demand can be offset (Jackson, 2006). However, improper daylighting strategies can result in excessive energy use rather than savings. The likelihood of occupants using artificial lighting is influenced by the uniformity of daylight distribution within a space (Hunt, 1980). Even spaces with lower absolute light levels may appear brighter if daylight is distributed uniformly (Aizlewood, 1993), as the perception of brightness is often dictated by the contrast between the darkest and brightest areas (Hunt, 1980).
In tropical climates, large openings can enhance daylight penetration but often come with the drawback of increased solar heat gain, adversely affecting indoor thermal comfort during hot seasons. Since a significant share of air-conditioning energy is used to cool perimeter zones, the inclusion of shading devices is essential. These

devices help block direct solar radiation, thereby reducing cooling loads—but may also limit the availability of natural light indoors.

Considering Bangladesh's climatic conditions, the north and south orientations are typically more favorable for classroom placement. The north side remains free from direct solar radiation throughout the day, whereas the east, west, and south receive solar exposure during the morning, evening, and all day, respectively. Therefore, architects must carefully balance daylight access and thermal comfort when designing educational spaces.

This study focuses on a south-facing classroom at the Chittagong University of Engineering and Technology (CUET), where all academic buildings share a similar shading configuration on all four façades (north, south, east, and west). The research investigates how modifying the existing shading configuration can improve daylight performance and energy efficiency in the selected south-facing classroom.

Aim and Objectives

In tropical countries, where overheating poses a significant challenge, architects often prioritize the use of shading devices to protect building interiors from adverse weather conditions such as rain, glare, and excessive solar heat gain. However, when the goal is to introduce glare-free daylight into interior spaces, it becomes essential not only to consider the positioning of openings but also to evaluate the reflective properties of the shading elements. Effective shading devices should therefore fulfill a dual function: offering protection from environmental elements while ensuring adequate luminance levels indoors to support a comfortable and healthy environment.

This research has two primary objectives: (i) to assess the daylight performance of the existing external shading device, and (ii) to compare various shading configurations in terms of daylight effectiveness in order to identify the most suitable option for a south-facing classroom through experimental model studies.

Scope and Limitations

Designers frequently face the challenge of balancing the exclusion of unwanted solar heat gain with the admission of sufficient daylight to ensure both visual comfort and energy efficiency. This study examines the role of external shading devices in improving daylight performance within a classroom context. While the research provides meaningful insights, certain limitations must be acknowledged.

First, for the purpose of validating simulation results, illuminance levels from both on-site measurements and simulation outputs were compared based on a single day and selected time intervals under clear sky conditions. Second, some influential parameters—such as surface reflectance, fenestration type, window-to-wall ratio, thermal radiation characteristics, interior and exterior obstructions, and material color—were considered in a limited manner.

Despite these constraints, the study offers a foundational understanding of how different shading configurations influence daylight distribution. It is expected that the findings will inform future research and support the development of integrated design strategies that enhance both daylight responsiveness and thermal comfort in educational buildings.

RESEARCH METHODOLOGY

This study follows the research methodology and simulation protocols proposed by Joarder, A. R. (2015), offering a structured framework for evaluating daylight performance in educational buildings. The research is conducted in two main phases.

The first phase establishes the theoretical foundation by reviewing fundamental concepts of daylighting and identifying key performance metrics relevant to classroom environments—such as daylight autonomy (DA), useful daylight illuminance (UDI), and glare index. These indicators serve as essential benchmarks for evaluating visual comfort and energy efficiency in learning spaces.

The second phase involves a comparative analysis of three distinct window configurations observed in the case study model, which focuses on a library building at the Chittagong University of Engineering and Technology (CUET). Both static and dynamic daylight simulations were employed to assess the performance of each configuration in terms of daylight distribution, uniformity, and consistency throughout the academic day and across different seasonal conditions.

By integrating static and climate-based simulations, this dual-method approach offers a comprehensive understanding of the spatial and temporal behavior of natural lighting. The findings aim to inform evidence-based design strategies that enhance indoor environmental quality in educational settings, contributing to more effective and sustainable architectural solutions.

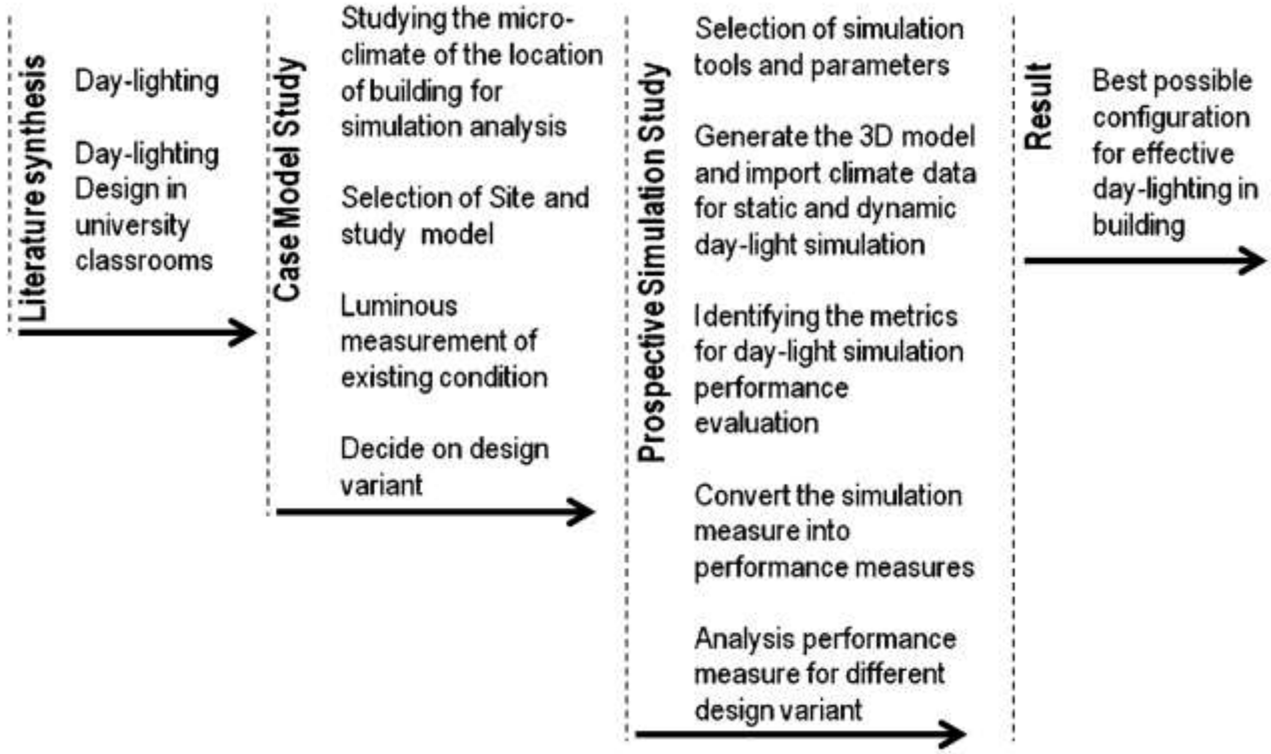


Figure 1. Research flow diagram

LITERATURE REVIEW

An effective daylighting design not only reduces energy consumption and maintenance costs but also significantly enhances the aesthetics and psychological quality of learning environments. In classrooms, well-integrated daylighting has been shown to improve student performance, mood, health, engagement, and overall productivity (Boyce, Hunter, & Howlett, 2003; Tawil, 2011). It also contributes to creating healthier indoor environments. As such, the integration of daylight should be considered from the earliest stages of architectural design. One of the most critical aspects of successful daylighting design is understanding its impact on human behavior and well-being. Among all sustainable design strategies, daylighting arguably has the most direct and positive influence on classroom environments. The primary lighting requirements for classrooms include: Providing sufficient illumination for visual tasks such as reading and writing. This involves designing openings that avoid uncontrolled direct sunlight, thereby preventing overheating while maintaining appropriate light levels for visual comfort.

Minimizing sharp contrasts in light within the space. This requires careful glare control, achieved through thoughtful window placement and the use of effective sun-shading devices. Importantly, effective daylighting does not simply mean adding numerous windows. Excessive or poorly controlled direct sunlight can result in glare, leading occupants to draw blinds and rely on artificial lighting—completely undermining the goals of a daylighting strategy.

Additionally, daylight availability varies greatly depending on geographic latitude and the Earth's orbit around the sun, resulting in both spatial and temporal fluctuations in interior illuminance. For instance, daylight levels typically decrease as the distance from a window increases. Within a given room, daylight distribution also

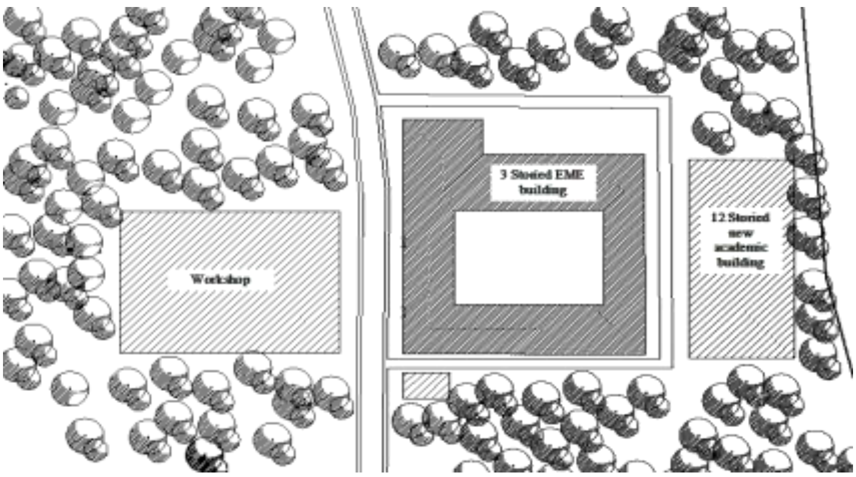
changes significantly over the course of a day (as the sun moves from east to west) and across seasons (due to variations in solar altitude). Sky conditions further affect daylight quality—on cloudy days, the light tends to be more diffuse, while on clear days, it is more directional. Overcast skies offer consistent, though lower-intensity, illumination throughout the day (Dean, 2005).
Because students spend a significant portion of their time in classrooms, daylighting strategies must outperform artificial lighting in terms of comfort and quality. They should also aim to maintain relatively consistent light levels. Without such consistency, occupants are likely to switch on electric lights upon entering the space, defeating the purpose of passive daylighting. To guide appropriate lighting design, the Bangladesh National Building Code (BNBC) provides recommended illumination levels for various building types based on activity patterns. The recommended values for classroom environments are presented in Table 1.

Table 1: Recommended values of illumination required for classroom according to BNBC

Library Area or Activity	*Illuminance*
General	150 lux
When use for examination	300 lux
Platforms	300 lux
Class and lecture rooms desk	300 lux
White/blackboards	250 lux

Source: BNBC

CASE MODEL STUDY
The geographical location of the building for simulation analysis is Chittagong. The weather of Chittagong is characterized by tropical monsoon climate. The dry and cool season is from November to March; pre-monsoon season is from April to May which is very hot. The sunny and the monsoon season is from June to October, which is warm, cloudy and wet. During the hot-humid period, which includes the monsoon, the sky remains considerably overcast at the most of the time. During the dry and cool season in winter the sky remains mostly clear. Under static simulation, the overcast sky presents more critical situation, and hence when faced with both sky types, design for daylight should satisfy good lighting criteria under overcast sky conditions (Evans, 1980). Under dynamic simulation, sky and solar division schemes distinguish between contributions from various luminous sources, such as :145 diffuse sky segments, 145 indirect solar positions, 2305 direct solar positions, one diffuse ground segment and more than 4380 (365X12 hours per day) hours daytime illuminance (Bourgeois et al. 2008). The building chosen for the research purpose is a south-facing classroom in the Electrical and Mechanical Engineering (EME) (Fig. 2) building of CUET. It is located in sub –urban terrain, in the Pahartali union under Raozan sub-district, by the north side of the Chittagong-Kaptai road about 25 kilometers from the center of Chittagong City. Both static and dynamic simulation considers the actual surrounding condition of the building.



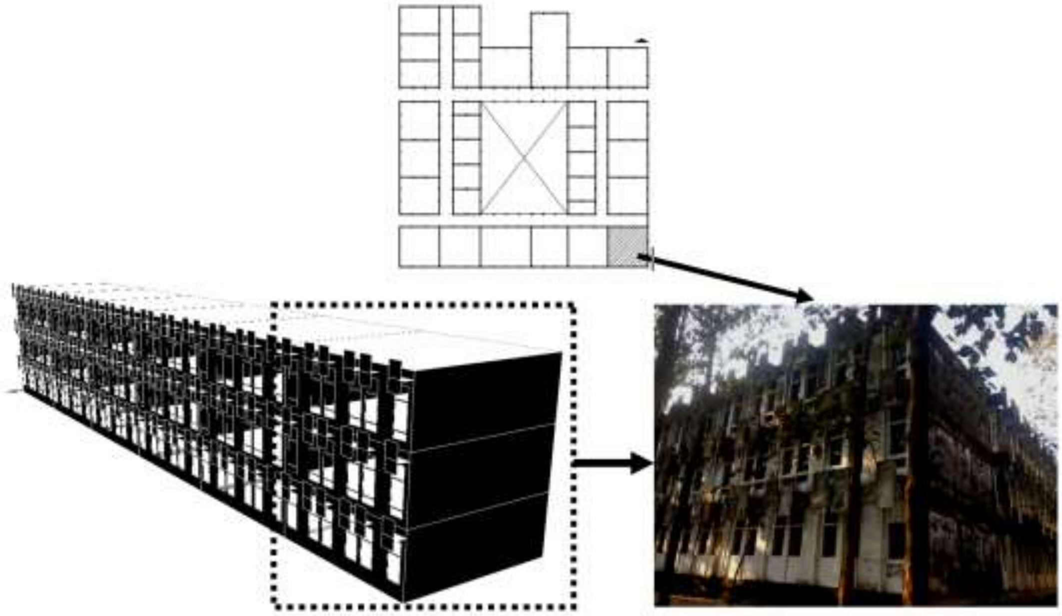


Figure 2. Site and surroundings of three storied EME building in CUET, Chittagong

During survey period luminous measurements of existing condition (Fig. 3), are taken with the help of Extech EN300 5-in-1 Environmental Meter at different points on the working plane (0.76m from the floor level) for data verification that means that if the deviation between field survey and simulation result is very low then the simulation results can be considered for the research. Daylight simulation for this study was done to find out an effective shading configuration for classroom to increase useful daylight within the space in the context of Chittagong. The dimension of the existing shading configuration is shown in fig: 02. In the study the basic H-shape shading configuration followed by CUET is not changed but the dimension of its vertical and horizontal parts and relative position of it is altered.

Name/No	8 am			4pm		
	Beside exterior window	Middle of the room	Beside interior Window	Beside exterior window	Middle of the room	Beside interior Window
1	118	34	23	484	45	52
2	124	31	19	550	42	23
3	137	33	18	371	47	29
4	139	42	22	200	55	11
5	162	64	55	210	52	18

Luminous measurement of existing classroom at 8am and 4pm

Daylight in classroom at 8am

Daylight in classroom at 4pm

Figure 3. Luminous measurements of existing condition

The depth of the overhang of the shading devices depends on the opening height and it is independent of the window width. The performance of the horizontal shading device increases with the increase of the depth of the overhang. The important factor is the ratio between the depth of the overhang and the height of the opening.

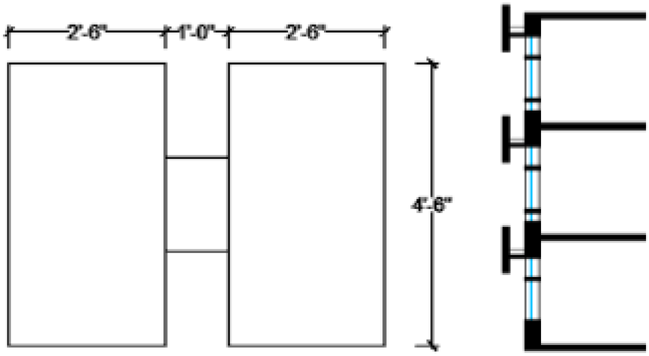


Figure 4. Diagram showing the dimension of existing shading device

For optimum shading, the ratio between depth of overhang and height of the opening is (Rungta and Singh, 2011),

D = 7/16 x H (1)

Where, D = depth of overhang, H = height of opening.

The ratio between the side offset from opening edge of overhang and height of the opening is,

W = H/2 (2)

Where, W = Side offset from opening edge, H = height of opening.

Optimum shading can also be determined by the ratio between Depth of overhang and opening height,

D = H / tan∅ (3)

Where, vertical shadow angle = tan∅

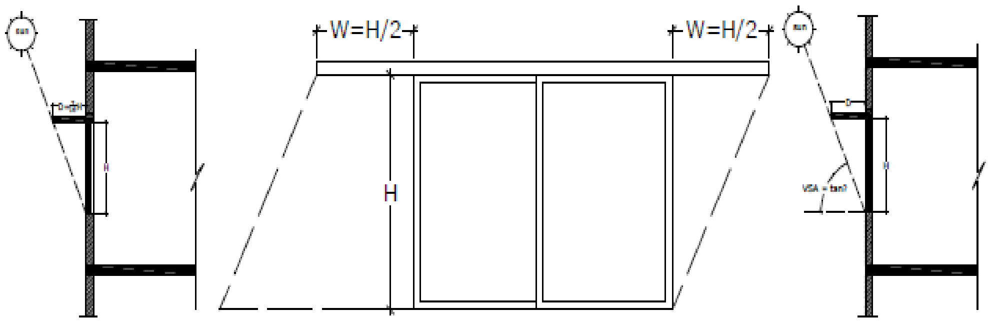


Figure 5. Schematic diagram showing the parameter of horizontal shading device

Calculation of Depth of Shading for Existing Condition

At first, the requirement of horizontal overhang for an opening height of 4ft has been Checked: D = 7/16 x 7.5'= 3.28'

Considered Cases:

As the existing overhang is 1.5'; so, theoretically it is not adequate for optimum shading performance during the warmest part of the day. So in the study a 2.5 ft and 3.5ft (> 3.28ft) depth of shading without awning are taken as design variants. In the existing condition awning is at a height of 7'0" from the floor level. It can be extended up to 5ft from the floor without hampering outside view as 5ft is considered as the standard eye-level when a person stands. Based on the fact, 3 specific heights of the awning 5ft, 6ft and 7ft from the floor level respectively are considered for the study. Finally 6 different situations are determined for the study: 2.5ft and 3.5 ft overhang depth without awning and with having awning heights of 5ft, 6ft and 7ft from the floor level respectively. For convenience they are demarked as Ba, Bb, Bc, Ca, Cb, Cc (Fig. 6) where Ba, Bb, Bc are .76m horizontal component with 1.37m vertical awning at 1.52m, 1.83m and 2.13m height from respective floor level respectively

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and Ca, Cb, Cc are 1.06m horizontal component with 1.37m vertical awning at 1.52m, 1.83m and 2.13m height from respective floor level respectively. Static and dynamic simulations are done considering three types of window configuration on southern façade individually.

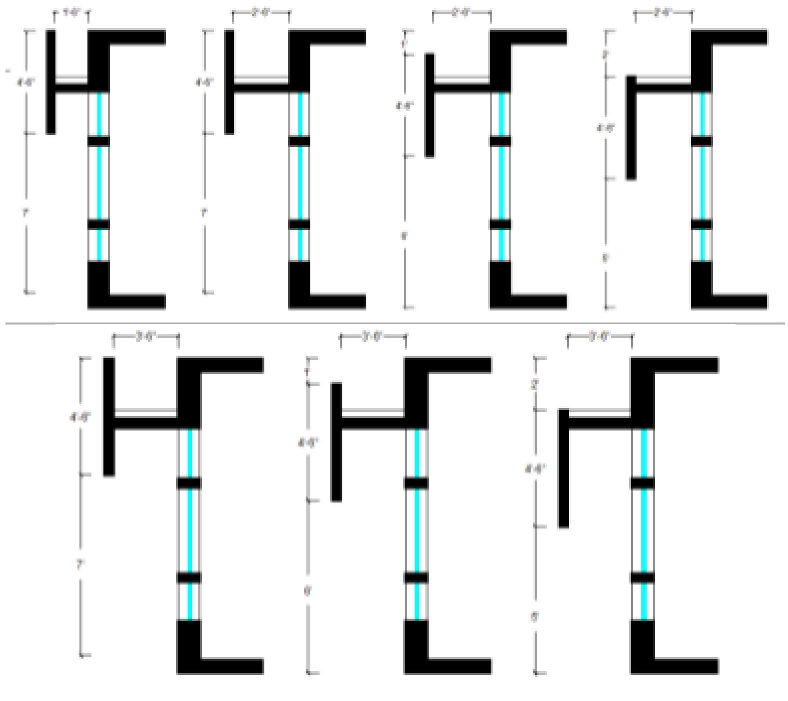

Figure 6. a. Existing option 1 (Ba), 2(Bb) and 3(Bc) respectively b. Option 4(Ca), 5(Cb) and 6(Cc) respectively

PARAMETRIC STUDY

Two simulation software RADIANCE and DAYSIM are used in this research. RADIANCE is currently a mature ray tracing software package that enables accurate and physically valid lighting and day-lighting simulation. Static and dynamic simulation metrics can be readily compared in RADIANCE with the same set of geometry, material, weather input files and simulation parameters (D.H.W, et al, 2004). However, it is not possible to generate three dimensional physical model in RADIANCE. So, AUTOCAD, ECOTECT etc software are used for three dimensional model generation.

In this research, a dynamic climate-based daylight simulation software is used called DAYSIM. DAYSIM is a validated RADIANCE based day-lighting analysis software that models the annual amount of daylight in and around buildings. Simulation outputs range from climate-based daylighting metrics such as daylight autonomy and useful daylight illuminance to annual glare and electric lighting energy use. Over the past decade a new family of daylighting metrics to describe and evaluate daylight in spaces have been developed. These metrics summarize the daylight availability over the year and throughout a space. Two prominent daylighting metrics which are calculated by DAYSIM are Daylight Autonomy and Useful Daylight Illuminance.

The third floor of the EME building is chosen for the simulation study as it is one of the typical floors. Table 2 shows the parameters of the model.

Table 2: Parameters of the model

Name	***Specification/ Dimension***
Typical room dim.	30ft x 30ft (approx.)
Typical floor area	900 sq.ft.
Opening orientation	south-facing with green at south
Opening dim.	5’ x 2.5’

Window frame	Wooden
Window swing	Single pane of glass with wooden frame (transmittance: 0.8)
Existing depth of Shading	1ft, H shape, with vertical awning
Floor height	11ft
Ceiling	White emulsion paint on concrete (reflectance: 0.6)
Internal wall	Brick with plaster either side (reflectance: 0.5)
Floor	Ceramic tiles (reflectance: 0.3)
Secondary opening	2ft high window 6ft 9inch above the floor level
Working plane	2ft 6inch above the floor

For simulation purpose, the total space is divided into grids. Then 30 points are selected for generation and calculation of lighting levels at 2.5ft above floor level, representing the work plane height for reading zone in classroom. Location of three core work plane sensors are fluxed at grid intersection points C1, C2, C3, C4, C5 and C6 shown in Figure 7.

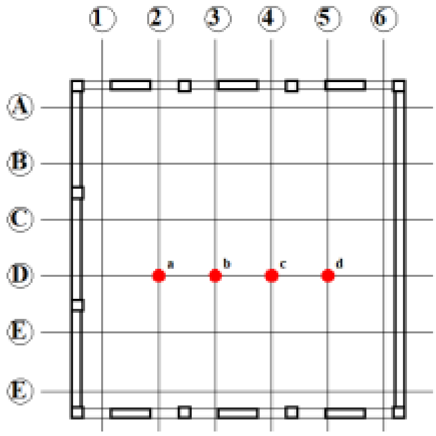

Figure 7. Showing node references and three core work plane sensors

The assessments for the static and dynamic simulation were based on the following parameters:

Location	: Chittagong, Bangladesh (longitude: 91.8123°, Latitude: 22.3475°)
Ground reflectance	: 0.2
Time	: 9.00 AM-5.00 PM
Window (dirt on glass)	: Average
Design Illumination	: 300 lux
Static sky simulation model	: CIE Overcast
Static design sky illuminance	: 11,000 lux
Dynamic sky model	: Perez sky model
Duration for dynamic simulation	: Whole year

Performance Metrics for Day-lighting Simulation:
The findings of the computer simulation are evaluated based on the following static and dynamic performance metrics done with DAYSIM to get a complete annual picture.

Daylight Factor (DF)
Daylight factor (DF) is the most widely conducted metric for daylight performance in buildings (DiLaura, 2011).A daylight factor is the ratio of internal light level at one point in a building to the unshaded external light level under the Standard CIE overcast sky (Trezenga and Loe, 1998; Pollock, 2009; Cantin and Dubois, 2011). Daylight factor is static simulation (i.e. at one time step) and used in architecture and building design for assessing the internal daylight availability as perceived on the working plane or surface based on the occupants' work activities. DF is calculated on the three core work plane sensors. A minimum of DF of 2% is needed in 75% of all occupied spaces for critical visual task to qualify for the LEED-NC 2.1 daylighting credit 8.1).

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Daylight Autonomy (DA)

Daylight autonomy (DA) is the simplest and most widely conducted annual metric. It is generally defined as the percentage of the occupied period (hours) of the year that the minimum daylight requirement is exceeded through the year. Such metric as DA could be employed to evaluate performance at individual points and address the spatial daylight distribution (Reinhart, 2006; DiLaura, 2011). The main advantage of daylight autonomy over the daylight factor is that it takes facade orientation and user occupancy profiles into account and considers all possible sky conditions throughout the year (Reinhart, 2002).

Continuous Daylight Autonomy (DAcon)

In addition to daylight autonomy, a modified metric "continuous daylight autonomy" (DAcon) proposed by Rogers attributes partial credit to time steps when daylight illuminance lies below the minimum illuminance level (Rogers2006). For example, in the case where 500 lux is required and 300 lux of daylight is received at a given time step, partial credit of 300 lux/500 lux=0.6 is attributed for that time step. Thus, the metric acknowledges that even a partial contribution of daylight to illuminate a space is still beneficial.

Maximum Daylight Autonomy (DAmax)

To simultaneously consider the potential appearance of glare, Rogers (2006) also proposed a second indicator called daylight autonomy maximum (DAmax). DAmax compiles the percentage of times during a year when the illuminance at a sensor is at least 10 times the recommended illuminance. For instance, for a library with a design illuminance of 300 lux DAmax corresponds to 5000 lux (Reinhart, 2006). In such a situation, there is a high chance that this will correspond to a situation with a direct sunlight patch at the sensor and hence glare (Dubois and Flodberg, 2013).

Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) is another modified version of Daylight Autonomy (Nabil and Mardaljevic, 2005a; Nabil and Mardaljevic, 2005b). This metric complies the number of operating hours based upon three illuminance ranges, namely 0-100 lux, 100-2000 lux, and greater than 2000 lux. Useful daylight is considered to occur when the daylight illuminance fall into the range of 100 lux and 2000 lux (UDI100-2000) (DiLaura, 2011). Thus, it provides full credit only to values between 100 lux and 2,000 lux suggesting that horizontal illumination values outside of this range are not useful.

Table 3. Metrics to assess daylighting performance in building in tropics

Metric	*Criteria*		*Description*	*Reference*
Static	Daylight factor (DF)	<2%	Gloomy appearance with rare daylight. Electric lighting needed during daylight hours.	(Trezenga and Loe, 1998; Pollock et al., 2009; Cantin and Dubois, 2011)
		2%-5%	Predominant daylight appearance. Some supplementary electric lighting required.	
		>5%	Daytime electric lighting rarely needed. Thermal/glare issues may occur along with the high levels of daylight.	
Dynamic	Daylight autonomy (DA)	–––	The percentage of the occupied period (Hours) of the year that the minimum daylight requirement is exceeded through the year.	(Reinhart, 2002; Reinhart et al., 2006; Di-Laura, 2011)
	Continuous daylight Autonomy DAcon)	>80%	Excellent daylight designs	(Reinhart, 2002; Rogers, 2006)
		60-80%	Good daylight designs	
		40-60%	Adequate daylight designs	
	Daylight autonomy Max (DAmax)	>5%	Not acceptable. A high probability that this will lead to a situation with a direct sunlight patch and hence glare.	(Rogers, 2006)
		<5%	Acceptable	
		<100 lux	Gloomy room with insufficient daylight.	(Nabil and Mardaljevic, 2005a;
		100-	The room is with useful daylight levels for the	

	Useful daylight illuminance (UDI)	2000 lux	occupants	Nabil and Mardaljevic, 2005b)
		>2000 lux	The room is too bright and exceeds the upper threshold of the useful range. Higher levels glare or discomfort maybe delivered together with overheating issues.	

The effect of six types of shading configurations on different daylighting performance metrics are shown in Table 4. According to static simulation, it is clear that from DF analysis that under overcast sky situation, performance of type Bb, Bc, Ca, Cb and Cc are same though a very little difference exist among them and if we arrange the four according to their performance sequence will be somewhat Cc, Bc, Ca and Cb, then comes the type Bb and A and lastly type Ba.

According to the DA metric again Cc is superior to all other types mentioned above. Then comes type A, Bc, Ca, Cb, Bb and Ba respectively. But as per DAcon metric Bc is superior then all other types and the rest come in a sequence of Cc, A, Ca, Bb, Cb and Ba respectively. Results of DAcon of all illuminance sensors reveals that the A and Ca type light the space more evenly than other types variant with 83% of all illuminance sensors having continuous daylight autonomies over 60%, compared to 76%, 74%, 69%, 64% and 62% of the space for Cc, Bc, Bb, Cb and Ba type respectively. But when DAmax is considered, 17% of all illuminance sensors lies for window type Bb and Bc, so when other sensors are considered for DAmax over 5%, there lies a probability of glare for over lighting and for other types 14% of all illuminance sensors lies for window type Ba and 12% of all illuminance sensors lies for window type A, Ca, Cb and Cc. But the UDI metrics show that setting up of all types Ba, can successfully amplify the useful daylight at point "a" compared to the other types of shading and the rest comes in a sequence of Ca, Cb, Bc, Bb, Cc and lastly A.

Comparison of Performance Metrics for Shading Configurations

Table 5 represents the rating of seven (existing one and six altered configurations) types shading configurations according to the different dynamic metrics where mean results and minimum- maximum ranges are compared for different values of four core work plane sensors.

Table 4. Simulation Result for Three Different Shading Configuration

Variant	Type A Existing				Type B												Type C											
					Type Ba				Type Bb				Type Bc				Type Ca				Type Cb				Type Cc			
Work place	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
DF	3.6	1.5	1.1	1.6	1.9	1.1	.9	4.1	2.9	1.5	1.1	1.4	2.9	1.6	1.2	3.7	2.6	1.3	1.1	4.5	2.8	1.3	1	3.5	3.2	1.3	1.5	4.2
DF 2% OR HIGHER	36% of all illuminance sensors				45% of all illuminance sensors				48% of all illuminance sensors				48% of all illuminance sensors				48% of all illuminance sensors				48% of all illuminance sensors				48% of all illuminance sensors			
DA	91	66	50	63	77	52	37	88	89	68	44	53	89	73	50	86	89	61	47	90	87	60	44	84	91	59	66	89
DA_{CON}	96	87	81	85	92	80	73	95	95	88	78	81	95	90	81	94	95	85	79	96	95	85	77	94	96	84	88	95
DA_{CON}>60%	83% of all illuminance sensors				62% of all illuminance sensors				69% of all illuminance sensors				74% of all illuminance sensors				83% of all illuminance sensors				64% of all illuminance sensors				76% of all illuminance sensors			
DA_{MAX}	1	0	0	0	3	0	0	0	4	0	0	0	4	0	0	0	3	0	0	0	4	0	0	0	4	0	0	0
Maximum DA >5%	12% of all illuminance sensors				14% of all illuminance sensors				17% of all illuminance sensors				17% of all illuminance sensors				12% of all illuminance sensors				12% of all illuminance sensors				12% of all illuminance sensors			
$UDI_{<100}$	1	4	5	4	3	5	6	2	2	3	5	4	2	3	5	2	2	4	5	2	2	4	5	2	2	4	3	2
$UDI_{100-2000}$	71	94	95	95	85	94	94	98	76	94	95	96	77	93	95	98	79	94	95	93	77	94	95	98	74	95	96	95
$UDI_{>2000}$	27	2	0	1	12	1	0	1	22	2	0	0	21	4	0	1	19	2	0	3	21	2	0	0	24	1	0	3

Table 5. Point distribution for different metrics of three types shading configuration

Metric	*1st place*	*2nd place*	*3rd place*	*4th place*	*5th place*	*6th place*	*7th place*
Rating points	6 point	5 point	4 point	3 point	2 point	1 point	0 point
DF	Cc	Bc	Ca	Cb	Bb	A	Ba
DA	Cc	A	Bc	Ca	Cb	Bb	Ba
DACON	Bc	Cc	A	Ca	Bb	Cb	Ba
DAMAX	Bb, Bc, Cb, Cc	Ba, Ca	A				
UDI	Ba	Ca	Cb	Bc	Bb	Cc	A

Table 6. Simulation Result for Three Different Shading Configuration

Metric	*1st place*	*2nd place*	*3rd place*	*4th place*	*5th place*	*6th place*	*7th place*
Total Ranking Points	24 points	24 points	20 points	16 points	14 points	13 points	11 points
Type	Type Cc	Type Bc	Type Ca	Type Cb	Type A	Type Bb	Type Ba

From first to seventh place rating points were considered as 6 point – 0 point respectively. Ranking was made allowing for different daylighting metrics – DF, DA, DAcon, DAmax, UDI range values and mean value of core sensor points for individual shading configurations on south façade. When two types achieve equivalent point, their degree of order from first to fourth positions is also considered for ranking.

RESULTS AND DISCUSSIONS

After demarcation of the rating points, both Bc and Cc are found superior with 24 points than other configurations, but considering their degree of order of achieving first to fourth place for different metrics, Bc in south facade is considered least suitable for the building. With points of 20, 16, 14, 13 and 11, Ca, Cb, A, Bb and Ba scored the 3rd, 4th, 5th, 6th and 7th position respectively. Comparing all the metrics, it is found that Cc (horizontal component 1.06m with a vertical 1.37m component at a level of 2.13m from respective floor level) is the most useful configuration for south facade for effective day-lighting in the classroom of CUET.

From ranking of shading configurations, it is evident that shading with horizontal component 1.06m with a vertical 1.37m component at a level of 2.13m from respective floor level is well-matched for the south façade of the building out of seven options including the existing one. But considering the figure values of core work plane sensors for UDI values for this type shading, it is evident that it may create glare on some points because of excessive lighting. Further investigation by altering the both vertical and horizontal components, say instead of solid component considering perforated elements, louver or tilting the components etc. for both horizontal and vertical part, it is possible to improve the day-lighting situation by avoiding resulting glare.

The study comprehensively examined the impact of various external shading configurations on the daylighting performance of a typical south-facing classroom at the Chittagong University of Engineering and Technology (CUET). Both static (Daylight Factor) and dynamic metrics—including Daylight Autonomy (DA), Continuous Daylight Autonomy (DAcon), Maximum Daylight Autonomy (DAmax), and Useful Daylight Illuminance (UDI)—were employed to evaluate six design alternatives against the existing shading device configuration.

1. **Static Simulation Findings (Daylight Factor - DF)**

Under CIE overcast sky conditions, the DF metric revealed that configurations **Cc, Bc, Ca, and Cb** outperformed the others. The **Cc configuration** (1.06m horizontal component with 1.37m vertical awning placed at 2.13m height) showed the highest daylight factor values at the core sensor points. This suggests improved potential for daylight penetration even in cloudy conditions, which are common in the monsoon-heavy tropical climate of Chittagong.

2. **Dynamic Simulation Findings**

Daylight Autonomy (DA): Configuration **Cc** again led in performance, with a higher percentage of hours achieving the target illuminance (300 lux), followed closely by configurations **A** and **Bc**. This indicates that **Cc** enables classrooms to remain within the preferred daylight range for longer periods throughout the year.
Continuous Daylight Autonomy (DAcon): The **Bc configuration** slightly surpassed **Cc**, showing better performance when considering partial credit for sub-optimal daylight levels. However, **Cc** and **A** still provided robust outcomes, showing that these configurations are more consistent in maintaining illuminance levels above the threshold across the entire workday.
Maximum Daylight Autonomy (DAmax): High DAmax values indicate potential glare risks due to excessive daylight. Configurations **Bb and Bc** showed DAmax values exceeding the acceptable threshold (>5%) in more than 17% of the grid points, indicating possible discomfort due to glare. **Cc**, while performing well overall, had

12% of points exceeding the threshold, signaling a moderate risk of over-illumination.
Useful Daylight Illuminance (UDI100–2000): Interestingly, while **Cc** excelled in other metrics, it ranked lower in UDI performance. **Ba**, one of the simpler configurations, performed better in achieving illuminance within the preferred 100–2000 lux range at certain nodes, indicating a better balance in some zones but less overall effectiveness.
3. **Overall Performance and Ranking**
A composite ranking based on cumulative scores across all five metrics placed **Cc and Bc** at the top (24 points each). However, **Cc** was deemed more favorable due to its consistent performance across multiple metrics and a lower risk of glare compared to **Bc**.

Configuration	Total Points	Rank
Cc	24	1st
Bc	24	2nd
Ca	20	3rd
Cb	16	4th
A	14	5th
Bb	13	6th
Ba	11	7th

The **Cc configuration**, which features an extended horizontal and vertical awning arrangement, was found to strike an optimal balance between daylight sufficiency and visual comfort, making it the most effective solution for the studied context.

4. **Design Implications and Further Considerations**
While **Cc** performed well, there were concerns about glare at specific grid points. This points to the necessity of further refinement, potentially through: Introducing perforated or louvered vertical elements to allow diffused light while minimizing glare. Tilting horizontal shading elements to reflect light deeper into the room. Using light-colored, high-reflectance surface materials to balance daylight distribution. Thus, this study emphasizes that the optimal shading strategy should not only enhance illuminance levels but also minimize glare, ensuring a visually comfortable and energy-efficient learning environment.

CONCLUSIONS
This research highlights the critical role of external shading design in maximizing daylight utility while minimizing visual discomfort in south-facing classrooms in tropical climates. Through a detailed parametric study using both static and dynamic simulation methods, the investigation offers key insights into how subtle modifications in shading geometry can profoundly affect indoor daylight performance.
The following key conclusions can be drawn:
Optimized shading geometry—specifically the Cc configuration (1.06m horizontal depth with 1.37m vertical component placed at 2.13m)—provides the best balance of daylight availability and visual comfort, outperforming both the existing and alternative designs.
Dynamic metrics like DA and DAcon provide a more comprehensive understanding of daylight behavior over time than static metrics alone, making them indispensable for climate-responsive classroom design.
Glare potential, though not always dominant in simulations, should not be overlooked. Even configurations that maximize daylight (such as Cc and Bc) may need fine-tuning to reduce DAmax values, ensuring a comfortable learning environment.
The research confirms the feasibility of daylight-responsive design in educational institutions in Bangladesh using passive shading devices, which can significantly reduce reliance on artificial lighting and contribute to broader goals of energy efficiency and sustainability.
The methodology and findings of this study provide a replicable framework for similar climatic contexts across South Asia and other tropical zones, offering guidance to architects, planners, and policymakers involved in educational building design.

In moving forward, future studies should explore advanced shading materials, automated daylight-responsive controls, and occupant behavior modeling to further refine passive daylighting strategies. Additionally, integrating thermal comfort simulations would help develop holistic design solutions that consider both light and heat, especially in the context of climate-resilient architecture for the Global South.

REFERENCES

1. Ahmed, Z. N. and Joarder, A.R., An Observation on Daylight Inclusion in the Lighting of Offices in Dhaka, Protibesh, Journal of the Dept. of Architecture, BUET, Dhaka, Volume II No.1, p.51. 2007.
2. Bourgeois, D., Reinhart, C.F., Ward, G. (2008) Standard Daylight Co efficient Model for Dynamic Daylighting Simulations. Building Research and Information. Vol 36(1), pg 68-82
3. Cantin, F., & Dubois, M. (2011). “Daylighting metrics based on illuminance, distribution, glare and directivity”.Lighting Research and Technology 43:p. 291-307.
4. Dean, E., Daylighting Design in Libraries. Libris Design Project. Retrieved from http://www.librisdesign.org/docs/DaylightDesignLibs.pdf, 2005.
5. DiLaura,D.L. The Lighting Handbook: Reference and Application. New York, NY: Illuminating Engineering Society of North America, 2011.
6. Dubois, M-C., & Flodberg, K. “Daylight utilisation in perimeter office rooms at high latitudes: Investigation by computer simulations”. Lighting Research and Technology, 45 (1): p. 52-75, 2013.
7. Evans,M., Housing Climate and Comfort, The Architectural Press, London, 1980.
8. Hossain, M. and Ahmed, K. S., Illumination Conditions and Visual Comfort in Production Spaces of Ready-Made Garments Factories in Dhaka. IACSIT (International Journal of Engineering and Technology), 5(5), 2013.
9. Joarder, A.R., Climate Based Daylight Modelling and Dynamic Daylight Performance Metrics for Sustainable Building Design in Bangladesh, 2015.
10. N. Tawil, N. A. G. A. Seyedehzahra Mirrahimi, A. ANI, and N. Utaberta, Developing Conducive Sustainable Outdoor Learning (CSOL): The Impact Of Natural Environment On Student's Ability. WSEAS conference, 2011.
11. Nabil A. & Mardaljevic, J., “Useful Daylight Illuminance: A New Paradigm to Acess Daylight in Buildings”. Lighting Research & Technology, 37(1):p. 41-59, 2005a.
12. Nabil, A., & Mardaljevic, J., “Useful Daylight Illuminance: A replacement for daylight factors”. Energy and Buildings, 38(7):p. 905-913, 2005b.
13. Jackson, Q., Day-lighting in Schools: A New Zealand Perspective, M.S. School of Architecture, Victoria University of Wellington. pp. 8-10. 2006.
14. P. Boyce, C. Hunter, and O. Howlett, The benefits of daylight through windows, Troy, New York: Rensselaer Polytechnic Institute, 2003.
15. D. R. Hunt, Predicting artificial lighting use-a method based upon observed patterns of behaviour, Light. Res. Technol. P. 7-14, 12(1), 1980.
16. M.E. Aiziewood, Innovative datlighting system: an experimental evaluation, Light. Res. Technol. P. 141-152, 25(1), 1993.
17. Pollock, M., Roderick, Y., McEwan, D., & Wheatley, C., “Building simultion as An assisting tool in designing an energy efficient building: A case study”. White Paper.Glasgow: Integrated Environmental Solutions Limited, 2009.
18. Reinhart, C.F., “Effects of interior design on the daylight availability in open plan offices”. Report NRCC- 45374. Ottawa: National Research Council of Canada, Institute for Research in Construction, 2002.
19. Rogers, Z., Daylight metric development using daylight autonomy calculations in the sensor placement optimization tool. Boulder, CO: Architectural Energy Corporation, 2006.
20. Trezenga, P., and Loe, D., The Design of Lighting. London: E & FN Spon, 1998.