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North-South vs East-West: The Impact of Orientation in Daylighting Design for Educational Buildings in Bangladesh

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Abstract Day lighting is one of the important environmental factors that affect the health, emotions and academic performance of the students as well as the energy consumption of the educational buildings. These days it is obvious that designer must consider both the quantity and quality of the day lighting system of the building. In educational building windows are considered as the main fenestrations to provide proper daylight and natural ventilation. Daylight coming through the window depends on some internal variables (fenestration's size, shape, position on the wall, materials, colours, reflectance, transparency and space geometry). Besides these internal variables designer should consider some external environmental variables climate, sky condition, orientation of the building and orientation of window wall. In efficient daylight design these internal variables varies according to the external variables especially according to the orientation of the fenestration or window wall. During clear and partly cloudy conditions, each of the four cardinal orientations offers a light source that contrasts in both character and illuminance levels. But unfortunately daylighting haven't been designed well at most of the educational buildings in our country. Some prototype window having same size, shape, materials, shedding and control are used in same position in walls at any orientation. So, either glare or duskiness phenomenon is often happens in classrooms and dependency on artificial lighting is increased. This study examines the impact of lighting distribution of the same prototype windows in different wall orientation. This study also shows how different window's shapes, sizes, geometries and positions in different orientation respond to lighting distribution. This paper deals with light coming into the rooms through the window, where window is considered the only system to provide, control, and distribute light flux. ECOTECT and Radiance software are used to simulate the proposed window conditions. This study explores a new daylighting design method and process for educational building. This study can be used to build sustainable education buildings that are highly efficient with low running cost.

Keywords Orientation, Daylighting, Window Design, Sky Illumines, Simulation

1. Introduction

Previous researches on the use of daylight and sunlight in classrooms has shown that some Parameters are closely related to issues like human performance and energy consumption of buildings [1]. Educational institute designers must consider human characteristics and stimulate higher performance by managing natural day lighting accurately. Establishing day lighting objectives will improve classroom conditions and can help improve student's learning by providing better lighting, air quality as well as reduced energy consumption [2].

According to [3] designer should provide following standards for lighting in classrooms:

- Day lighting should be designed to exclude penetration of direct sun.
- Contrast between light and dark areas should be minimized. An 'average to minimum' brightness ratio of less than 4:1 is recommended, along with a 'maximum to minimum' ratio less than 8:1.
- Daylight levels should provide 500 lux at work plain. Science and art rooms should need greater illumination.
- For lighting measurement work plain is considered .76m (30 inches) above the floor for general classrooms.

Although previous researches had focused on the quantity of day lighting in educational spaces, recent works prove that quality of lighting is at least as important as quantity [4]. During clear and partly cloudy conditions, there are profound differences between north, south, east and west light sources in terms of quality, quantity, colour and directionality. Good day lighting design will intercept

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and diffuse the sun, which is excessively bright and hot to be used effectively for day lighting.

The present work examines the impact of orientation of window wall of classrooms on the daylight distribution and illuminance ratios. The aim of this research is twofold:

- To examine the existing lighting condition for windows in all wall orientation.
- Compare the performance of existing window and a window without shading by using an experimental computer modelling system for effective day lighting in a class room.

This paper deals with light coming into the rooms through the window, where window is considered as the only system to provide, control, and distribute light flux. However surrounding building, different microclimate, outside obstruction, density of materials also influence the quality of day light, but this study only associated with Window configuration and orientation. It is expected that this research would be helpful to be used as a basis for further investigation of the consequences associated with proper window configuration and day lighting.

2. Material and Methods

The paper consists of two major parts. The first part is assorted with selection and analysis of study building to determine the external design parameters. Second part presents the effect of orientation on two types of window configuration in the case model, through both static and dynamic daylight simulation through a comparative analysis.

2.1. Selection of Site and Design Vibrant

For the purpose of this simulation study, an educational building was searched that have no exterior obstruction at a distance that may affect the daylight in any direction. According to the above criteria the five storeys DR. M.A. Wazed Building (3rd academic building) of Hajee Mohammad Danesh Science and Technology University was selected for examination and simulation study **(Figure 1)**.

The second floor of the building was chosen for the simulation study, as it is one of the typical floors. During the physical survey it was identified that the impact of orientation was fully ignored by using a same recessed window in exterior wall in all four side. Daylight simulation is done for a typical class room having window in one side and daylight coming from the corridor through door is ignored. At first, Two alternative models of the same space is created having the same window area and size but one with existing section and one with no shading **(Figure 2)**. Analysis is done with these two models in each direction (north, south, east, and west).

Two simulation softwares RADIANCE and DAYSIM are used in this research. For 3d modelling interface ECOTECT software is used as RADIANCE does not have any built-in graphical interface to generate physical model **(Figure 3)**. A primary analysis of DF is also done with ECOTECT. For critical decision-making these models are exported to Radiance Synthetic Imaging software to generate realistic predictions of lighting levels. Finally a performance metrics is done with DAYSIM 2.1.P4 simulation program to get a complete annual picture. As weather data of Dinajpur is not available, whether file of Dhaka is used for all simulation. Climatic conditions of Dhaka and Dinajpur are apparently same. Other parameters were the same as those found during physical survey. The findings of the computer simulation are evaluated based on the static and dynamic performance metrics showed in **Table 1** and **Table 2**.

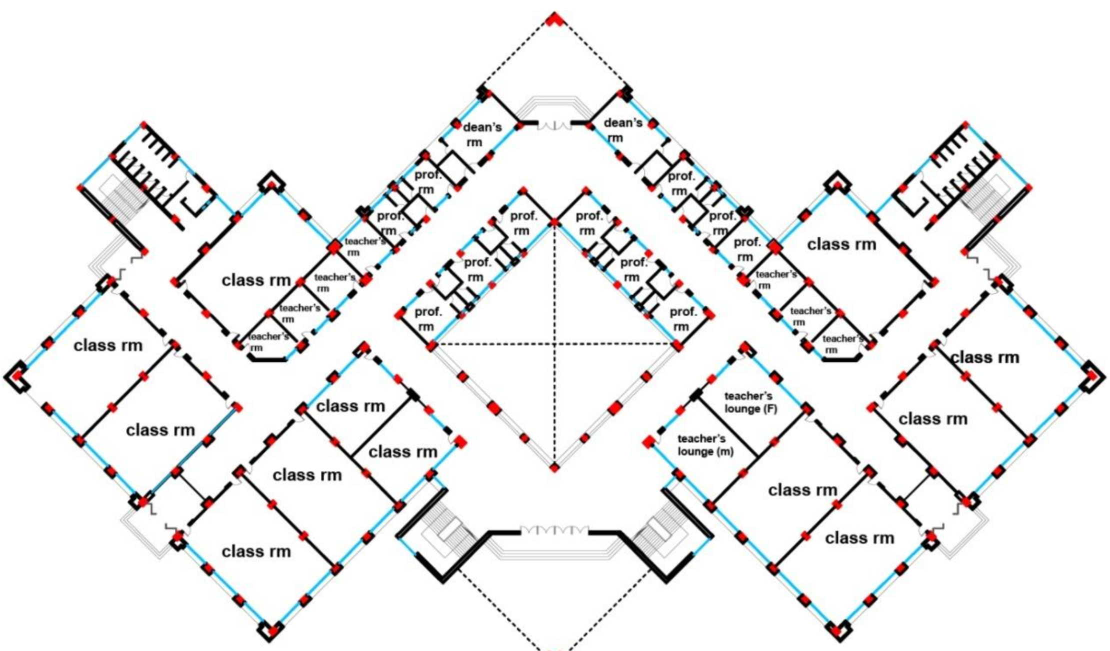

Figure 1. Typical floor plan of the study building

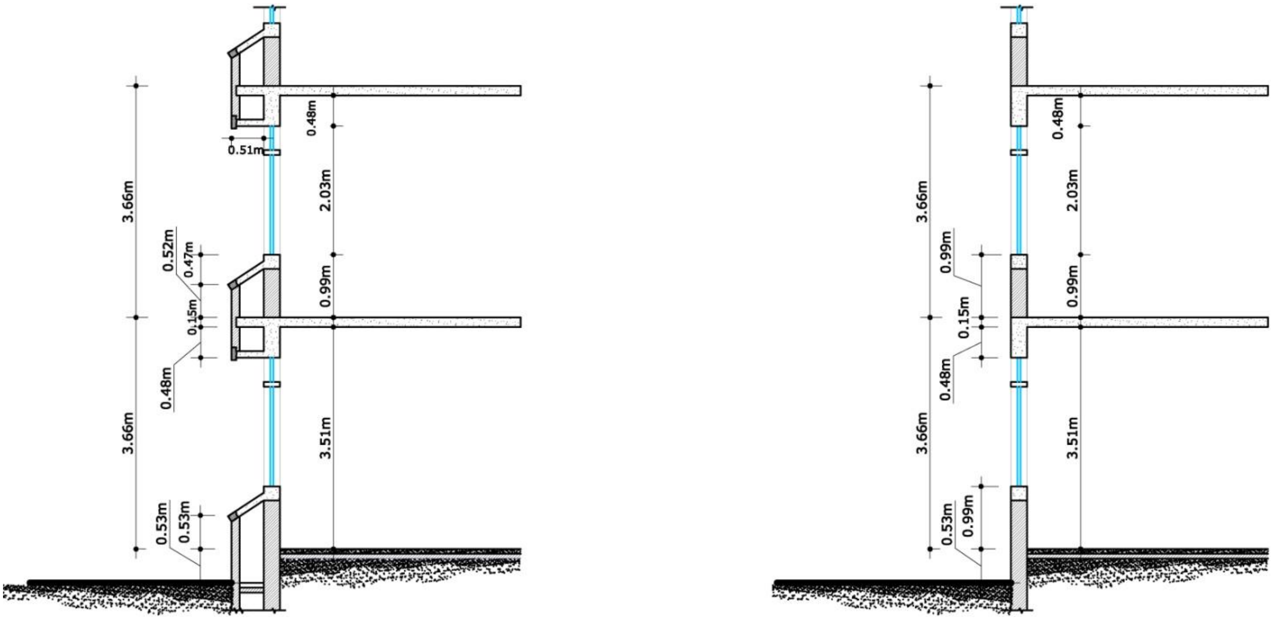

Figure 2. Section shows two types of window with and without shading

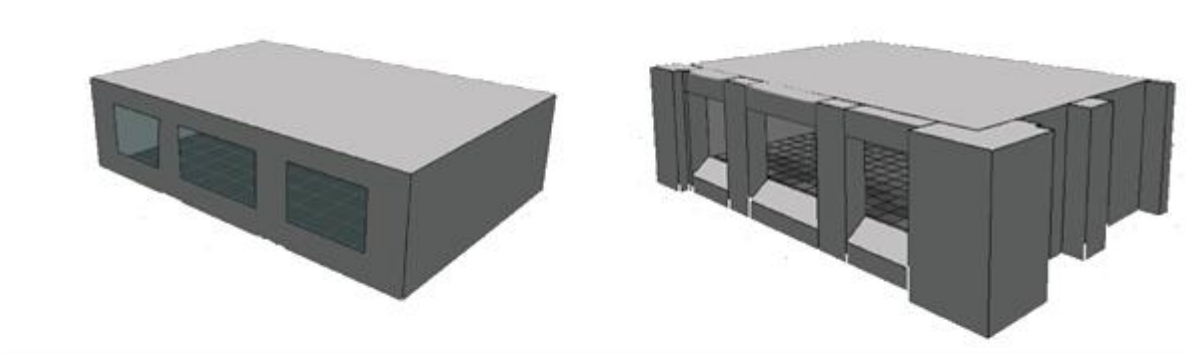

Figure 3. ECOTECT models used for simulations

2.2. Simulation Parameters

The quantitative and qualitative assessments for the daylight simulation were based on the following parameters:

Location	Dinajpur, Bangladesh.
Longitude	88.63 E
Latitude	25.63 N
Local Terrain	Sub-Urban
Calculation Settings	Full Daylight Analysis
Precision	Medium
Window (dirt on glass)	Average
Sky Illumination Model	CIE Overcast
Design illumination	500 lux
Design Sky Illuminance	11,000 Lux
Time	12.30 pm
Date	1, April (April is the hottest month, displaying the highest average temperature, during which the sky varies between conditions that are both clear as well as overcast, as found in the climatic study).

A typical class room from the second floor of the building was chosen for the simulation study. To analyse the effect of orientation widows are used in only one side.

Total floor area	4510 sq. m
Typical class room size	135 sq. m
Clear height	3.5m (no false ceilings)
Work Plane height	0.76 m above floor level
Lintel height	3m
Sill height	1m

The following parameters of existing internal finish materials (as found in the field survey) were used in the model for simulations.

Roof	White painted plaster (reflectance: 0.7)
Internal wall	White painted brickwork (reflectance: 0.7)
Floor	White ceramic tiles finishes (reflectance: 0.6)
Glazing	Single pane of glass with aluminium frame (Reflectance: 0.92, U value: $6W/m^2K$)

For the purpose of the simulation, the entire class room is divided into grids with reference to column-structural grid **(Figure 4)**. Then 187 are selected for generation of daylight levels at 0.76m above floor level, representing the work plane height for class room. Each intersection point of the grid is coded according to the number-letter system shown in **Figure 4** and the location of two core work plane sensors are then fixed at “a” (9D), and “b” (9H). Point ‘a’ is close to the window where point ‘b’ is close to the back wall.

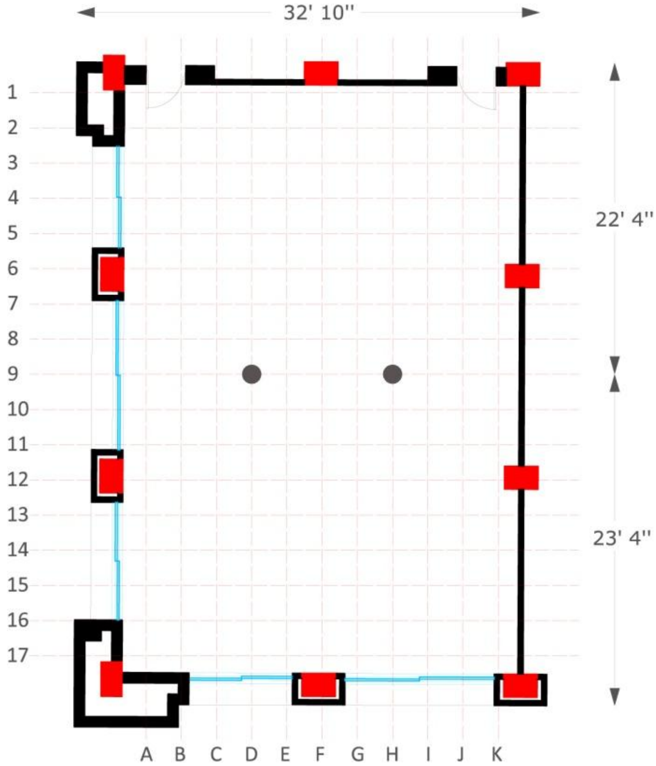

Figure 4. Plan showing the grid with node and two core work plane sensor

3. Result and Discussion

3.1. Static Simulation with ECOTECT

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.

3.2. Result of Dynamic Simulation with RADIANCE

Under dynamic simulation in RADIANCE 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 [5].

3.3. Convert the Simulation Results into Performance Measure

The impacts of orientation on two different configurations (window with and without shading) on different day lighting performance metrics are shown in **Table 3**. According to the static metric DF, window without shading is superior to the window with shading in any orientation. But comparison of the results of dynamic annual performances (DA, DA_{con}, DA_{max} and UDI) between two window configurations shows that window with a shading have better performance in north and south direction. So window with shading performs better when other types of sky conditions, (e.g., clear sky and intermediate sky) apparent in different periods of the year.

According to the DA metrics window without shading is superior in any direction. But, the other dynamic metric DA_{con} shows window with shading performs well in north south direction as 71% and 81% of all sensors have DA_{con} above 60%. DA_{max} above 5% shows that window with shading is superior in any direction. But this matrix also show that window with shading work better in north-south direction as for north and south 0% and 14% all sensors have DA_{max} above 5% while for east and west it is 20% and 16%.

The UDI metrics shows that window with shading is superior than window without shading as 61% (n), 69% (s), 61% (e), 33% (w) of all sensors have UDI (100-2000). But in west direction 59% of all sensors of window with shading and 81% of all sensors of window without shading have UDI greater than 2000. UDI above 2000 will cause excessive light and glare that these two types of window will fail to meet in west direction.

3.4. Compare Performance Measure for Different Configurations

Two types of windows can be easily rated by metric analysis. **Table 4** shows the rating of the two type of window for north, south, east and west direction. When a metric led to different rating for the two core work plane sensors, the mean result and the minimum to maximums range were compared.

Ranking was done considering the studied metrics, e.g. DF, DA, DA_{con}, DA_{max}, and UDI range values and mean value of core sensor points for each blind configuration. For 1st and 2nd place rating points were considered as 1 point and 0 point respectively [49]. After summing all the rating points achieved by the studied window configurations, window with shading is found as superior with 3 points than o window without shading for north and south side **(Table 5)**. But for east and west side window without shading is better with 3 points.

Table 1. Metrics conducted to assess static daylighting performance [6], [7], [8]

Daylight factor (DF)	<2%	Gloomy appearance with rare daylight. Electric lighting needed during daylight Hours.
	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.

Table 2. Metrics conducted to assess dynamic daylighting performance

	Criteria	Description
Daylight autonomy (DA)	——	The percentage of the occupied period (Hours) of the year that the minimum daylight requirement is exceeded through the year [9], [10], [11].
Continuous daylight Autonomy	>80%	Excellent daylight designs
	60-80%	Good daylight designs
	40-60%	Adequate daylight designs [9], [12].
Daylight autonomy Max (DA_{max})	>5%	Not acceptable. A high probability that this will lead to a situation with a direct sunlight patch and hence glare.
	<5%	Acceptable [12].
Useful daylight illuminance (UDI)	<100 lux	Gloomy room with insufficient daylight.
	100-2000 lux	The room is with useful daylight levels for the occupants
	>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 [13], [14].

Table 3. Simulation results for two type of window on four different directions

Variant	North				South				East				West			
Work Place	Without shading		With shading		Without shading		With shading		Without shading		With shading		Without shading		With shading	
DF	14.7	1.7	8.8	1.2	6.5	1	3.4	.8	7.7	1.1	4.3	0.9	18.8	1.6	10.2	1.4
DF of 2% or higher	38% of all illuminance sensors		25% of all illuminance sensors		40% of all illuminance sensors		25% of all illuminance sensors		41% of all illuminance sensors		31% of all illuminance sensors		43% of all illuminance sensors		32% of all illuminance sensors	
DA	97	52	94	16	95	39	89	19	96	46	92	30	98	60	96	46
DA_{con}	98	82	97	68	98	77	95	64	98	80	97	70	99	84	98	79
$DA_{con} > 60\%$	62% of all illuminance sensors		71% of all illuminance sensors		72% of all illuminance sensors		87% of all illuminance sensors		84% of all illuminance sensors		71% of all illuminance sensors		76% of all illuminance sensors		68% of all illuminance sensors	
DA_{max}	9	0	0	0	16	0	1	0	17	0	11	0	42	0	22	0
Max DA > 5%	5% of all illuminance sensors		0% of all illuminance sensors		22% of all illuminance sensors		14% of all illuminance sensors		28% of all illuminance sensors		20% of all illuminance sensors		26% of all illuminance sensors		16% of all illuminance sensors	
UDI<100	14%		6 %		12%		7%		8%		7%		11%		8%	
UDI 100–2000	17%		61%		31%		69%		30%		61%		8%		33%	
UDI>2000	69%		34 %		57%		24%		62%		33%		81%		59%	

Table 4. Rating point distribution for different dynamic metrics of two type window variants based on Table 3

Variant	North		South		East		West	
Work Place	Without shading	With shading	Without shading	With shading	Without shading	With shading	Without shading	With shading
DF	1st	2nd	1st	2nd	1st	2nd	1st	2nd
DA	1st	2nd	1st	2nd	1st	2nd	1st	2nd
DAcon	2nd	1st	2nd	1st	1st	2nd	1st	2nd
DAmax	2nd	1st	2nd	1st	2nd	1st	2nd	1st
UDI	2nd	1st	2nd	1st	2nd	1st	2nd	1st

Table 5. Ranking of window variants based on Table 4

Orientation	Window without shading	Window with shading
North	2 point	3 point
South	2 point	3 point
East	3 point	2 point
West	3 point	2 point

3.5. Discussions

In this computer base analysis two window having same size, position, material and glazing are used with different shading system. Performance of each window type in north, south, east and west is simulated. This simulation result shows orientation of window has great impact on day lighting performance (DA_{con} and UDI) for each type of window. This analysis shows that window with shading works well for north and south. But for east and west window without shading is best. From this study it is evident that windows in north and south direction act similarly for different matric analysis and also true for east and west direction. Study also shows Especial attention should be given for west orientation as these two window fail to address glare and excessive light problem in west. The Shading (horizontal) used in this study is helpful for north and south while analysis of other different type of shading may find appropriate shading for east and west as well.

4. Conclusions

Day lighting is recognized as a key architectural strategy in achieving high performance educational building as it insure psychological and biological benefits of natural light as well as save electricity for lighting and cooling. With a Computer based simulation analysis this study examines the impact of orientation on opening designing for an educational building. Two types of windows are analysed with static and dynamic simulation and results are compared. From this study it is found that window with shading is better for north and south wall. In east and west wall window without shading is better than existing window with shading. The result may vary from current one if Windows having different configuration, size, position, glazing and shading are used. But it is expected that the research will be helpful guiding tool for production of day-lit educational buildings and can contribute to select efficient opening to generate a sustainable built environment.

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