

A SIMULATION ASSESSMENT OF THE HEIGHT OF LIGHT SHELVES TO ENHANCE DAYLIGHTING QUALITY IN TROPICAL OFFICE BUILDINGS UNDER OVERCAST SKY CONDITIONS IN DHAKA, BANGLADESH

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ABSTRACT

The objective of this paper is to highlight the effectiveness of light shelves in tropical office buildings to enhance interior daylighting quality. Daylight simulation was performed for custom light shelves for a typical office floor of Dhaka City in Bangladesh, to determine the best possible location under overcast sky conditions. Six alternative models of a 3m high study space were created with varying heights of light shelves. The 3D models were first generated in the Ecotect to study the distribution and uniformity of daylight in the interior space with split-flux method. These models were then exported to a physically-based backward raytracer, Radiance Synthetic Imaging software to generate realistic lighting levels for validating and crosschecking the Ecotect results. The results showed that for achieving light levels closest to specified standards, light shelves at a height of 2m above floor level perform better among the seven alternatives studied including the alternative where no light shelves are present. Finally, the decisions were verified with DAYSIM simulation program to ensure the compliance of the decisions with dynamic annual climate-based daylight performance metrics.

KEYWORDS

Daylight Simulation, Light Shelves, Overcast Sky, Tropical Region.

INTRODUCTION

Light shelves are typically placed just above eye level to reflect daylight into the interior ceiling and to use the ceiling as a light-reflector for deeper parts of the room. However, it is believed by many that light shelves and overhangs are not efficient in terms of light penetration under overcast sky conditions and reduce the amount of daylight reaching the interior space (Eagan et al., 2002; Littlefair, 1996; Christoffersen, 1995; Aizlewood, 1993). Standing on a neutral position, daylight simulation was performed in this study for custom light shelves for a typical office floor of Dhaka City, Bangladesh, a tropical location, with predominantly overcast skies, to determine the validity of this opinion. The findings of the computer simulation have been evaluated based on average daylight level on the work-plane height, number of points within standard illumination levels,

rate of fluctuation of the daylight levels from the window towards deeper spaces, comparison of rendered images of the study space for luminance levels on specific surfaces and lastly varied with different annual performance metrics. Comparing all the findings, the best possible location of light shelves under the given conditions has been suggested.

LIGHT SHELVES AND SHADING

Architectural shading solutions are typically part of the exterior facade. Light shelves, overhangs, fins, shade screens, venetian blinds, vertical blinds, miniature louvers, and roller shades are commonly used shading systems. One drawback of using shading devices is the risk of reduced daylight level, as all shading devices reduce the view of sky, which is a potential source of daylight. This can increase the use of artificial lighting for interior task.

One of the effective forms of shading devices is the light shelf. Light shelves are horizontal projections placed below a window lintel to reflect sunlight further into the interior. Typically placed just above eye level, the light shelf reflects daylight onto the deeper part of the room using the interior ceiling as a reflector instead of a typical shaded interior ceiling (A.G.S., 2000). At the same time, the light shelf shades the lower portion of any window, reducing the amount of light near the window, which normally has much higher illumination than the deeper parts of spaces and projects the light towards the back. The result is a balanced luminous environment, with less contrast and glare.

A light shelf divides a window into a view area below and a clerestory area above. Literature survey shows that light shelves and overhangs are not effective for redistributing light under overcast sky conditions and may reduce the amount of daylight reaching the interior space (Eagan et al., 2002). Both full-scale and scale model measurements have shown that windows with internal light shelves produce an overall reduced daylight factor on the work plane throughout the interior space compared to a non-shaded window of equal size (Littlefair, 1996; Christoffersen, 1995; Aizlewood, 1993). To reach a clearer idea about this impact, daylight simulation was performed in this study for custom light shelves with different height levels.

SKY CONDITIONS OF DHAKA CITY

The climate of Dhaka is tropical and has mainly three distinct seasons – the hot dry (March-May), the hot humid (June-November) and the cool dry season (December-February) (Ahmed, 1995). The sky can be clear or overcast in different parts of the various seasons. During summer (Hot Dry) the sky remains both clear (sunny with sun) and overcast. However, during the warm-humid (March-November) period, which includes the monsoons, the sky remains considerably overcast most of the time. It is only during the winter (December-February) that the sky mostly remains clear. Figure 1 shows sky condition of Dhaka city with respect to cloud cover for Test Reference Years (TRY).

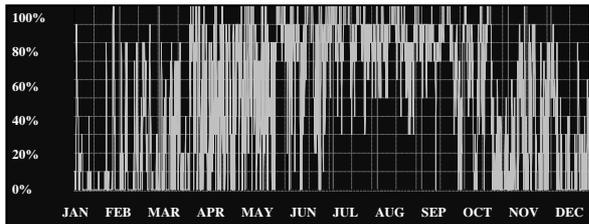


Figure 1: Cloud cover for Test Reference Years, Dhaka. (Source: U.S. Department of Energy, 2008)

In composite climates like Dhaka, where both overcast as well as clear conditions are observed during the course of each year, designers face difficulties to choose the condition, based on which they should take the design decisions. The ways and means of tackling the two conditions are quite contrasting to each other (Ahmed, 1987). Windows with fixed horizontal overhead is suitable for overcast sky condition, on the other hand vertical and movable devices are recommended for clear sky. In such cases, it is the overcast sky with steep luminance gradation towards zenith and azimuthal uniformity (CIE, 2004) that presents the more critical situation and hence, design for daylight should satisfy good lighting criteria under overcast conditions (Evans, 1987).

METHODOLOGY

Selection of Site and Building for simulation

The climatic characteristics of Dhaka City differ from other cities of the country due to its location and rapid physical development in last few decades. Physical and environmental characteristics are further modified in different locations within the city. This is due to the density of built environment, building types, building heights and orientations, surface quality of the area – whether hard or soft depending on vegetal cover and presence of water bodies and ponds - materials used for construction, and other related factors.

The criteria for site and building selection to determine the typical example office space was based on the following factors:

- The site should be within the urban boundary and should have characteristics typical of the general urban fabric of Dhaka city (Figure 2);
- The example office building should represent the trend of typical office design in Dhaka;
- The building should be built in accordance with the Building Construction Regulations of the City Authority;
- Internal layout of the example office space should be such that, there should be provision for daylight inclusion and distribution; and
- The scale and volume of the building should be representative within the conurbation.



Figure 2: Location of nine storied Opsonin Building in urban setting

After a survey of 50 office buildings in the city, based on the above criteria, the nine-storey Opsonin Building (corporate office of Opsonin Pharma Limited) was selected for the study (Joarder, 2007). The 2nd floor of the building was chosen as the example space for simulation. This floor is one of the typical floors of the building, the plan of which is repeated on the rest of its six upper floors, and it has different exterior conditions on four different sides. The building has a 7m wide road on the west, some single-storey semi-permanent establishments and a two storey building opposite the lift core on the east, another under-construction nine-storey building 2.5m from the northern edge and a three-storey building 2.5m from the south edge. There is a four-storey building and some greenery just opposite the road in front of the office building (Figure 3).

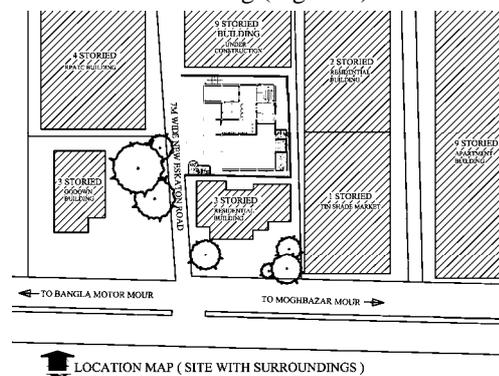


Figure 3: Site and surroundings of nine storied Opsonin Building

Simulation Study

The amount of daylight penetration and its quality in office interiors due to the changes in the height of light shelves can be assessed by simulation study. In reality, due to the simultaneous influence of many different factors, it is difficult to isolate the exclusive effect of one single aspect, or the changes due to it. Daylight simulation allows the study of the effect of changes in any one aspect, keeping other aspects constant. The observation of simulated behaviour related to changing parameters allows the identification of elements, the reduction or introduction of which in design, contributes to increased daylight penetration into the interior. Another significant advantage of simulation study is that it is possible to analyze the lighting situation for any period of the year simply by assigning simulation parameters (like location, date, time, sky condition etc). In this paper, three PC version simulation programs were used to investigate and analyse the impact of the different heights of light shelves on daylight level at work plane height, aiming to find out the better light shelf height. The first program is a comprehensive building analysis software Ecotect v5.20 which is a highly visual, architectural and analysis tool (Crawley et al, 2005) with lighting, thermal, energy, shading and acoustic performance analysis functions (Osaji et al, 2009). The second a more focused and accurate daylighting simulation tool, Desktop Radiance 1.02 (Baker, N. et al., 2002; Ward, 1994). The last one is DAYSIM 2.1.P4 simulation program based on the concept of dynamic annual daylight performance metrics (Reinhart et al., 2006).

Simulation Parameters

The quantitative and qualitative assessments for the design strategies were based on the following parameters:

Location	: Dhaka, Bangladesh.(90.4° E, 23.8° N)
Time	: 15 April, 12.30 pm (Time of physical daylight measurements by a light meter to compare with simulation outputs)
Calculation Settings	: Full Daylight Analysis
Precision	: High
Local Terrain	: Urban
Window (dirt on glass)	: Average
Sky Illumination Model	: CIE Overcast
Design sky Illuminance	: 16,500 Lux (Khan, 2005)

Study space

The second floor of the building was chosen for the simulation study (Figure 4). All indoor and outdoor conditions were kept constant as found in a physical survey (Joarder, 2007). The models were created assuming unshaded peripheral glazing wall, as shading obstructs a major part of daylight penetration. The interior space was also modelled as

vacant, devoid of any partitions or furniture, to avoid the effects of such surfaces, which both block and reflect daylight, and may hide the actual impacts of light shelves. The other parameters of the model of the example space, which were incorporated from values found in a physical survey, are as follows.

2nd floor dimensions	: 25m x 28.5m
Total floor area	: 692 sqm
Usable office space	: 577 sqm
Service area	: 115 sqm
Clear height of office space	: 3m
Window to floor ratio	: 0.36
Work Plane height	: 0.75m

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

Ceiling/ Roof of 2nd floor : White painted plaster (reflectance: 0.7).

Internal wall : White painted brickwork (reflectance: 0.7).

Floor : Reddish ceramic tiles finishes (reflectance: 0.6).

Glazing : Single pane of glass with aluminium frame (reflectance: 0.92, U value: 6W/m²K).

The upper and lower floors of the study space were hidden during simulation, as it was found during trial simulation study that these floors had no contribution to simulation output but prolong the simulation processing time unnecessarily (Figure 4).

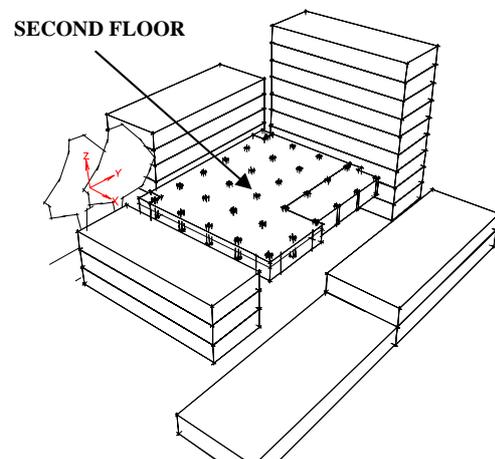


Figure 4: View of model used for the simulation.

Performance Evaluation Process

For the purpose of the simulation, the entire office space was divided into grids with reference to column-structural grid (Figure 5). Then 83 points in the open office space were selected for generation of daylight levels at 0.75m above floor level, representing the work plane height for offices in Dhaka (Joarder, 2007). Each intersection point of the grid was coded according to the number-letter system shown in Figure 5, which is then transferred to Tables later (see Figure 13 & Table 2).

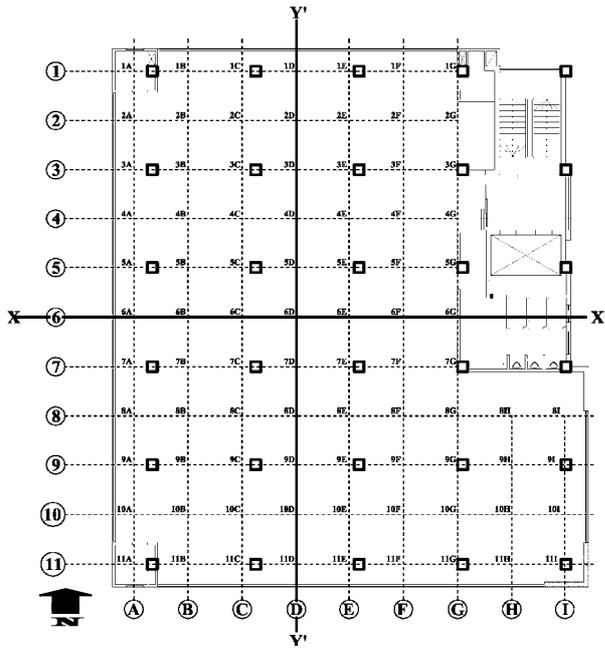


Figure 5: Plan showing the column/structural grid with node references

Daylight simulation was done by Ecotect for these grid points to find predicted daylight levels first (Figure 13). The simulated illumination values were then plotted into Tables with the codes coinciding with intersection of letters (rows) and numbers (columns) (Table 2). These values were then compared for different situations. Two additional axes XX' & YY' (Figure 5) were created across the plan to show the fluctuation of the daylight levels from the window towards the opposite face of the space (Figures 5 & 6). The calculations consider the Daylight Factor Concept, which is considered valid (the ratio remains constant) only under overcast sky conditions, i.e. when there is no direct sunlight (Koenigsberger et al., 1997). This is the assumed characteristic of Dhaka's skies during much of the year.

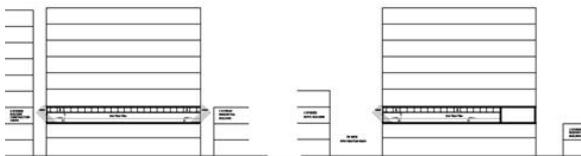


Figure 6: Conceptual building section thru XX' & YY'

The 3D models were first generated for computer simulation in the Ecotect program to calculate the amount of daylight incident on each grid point on the work-plane. The models were then exported to Radiance Synthetic Imaging software to generate realistic predictions of lighting levels. For Desktop Radiance an additional imaginary horizontal plane 0.75m above floor level was created to show daylight contour map on work plane height (Figure 12). Finally a performance metrics was done with DAYSIM to get a complete annual picture.

The findings of the computer simulation were evaluated based on the following criteria:

- Average daylight level on the work-plane height.
- Number of points within acceptable illumination levels.
- Fluctuation of daylight levels from the window towards deeper parts of the space.
- Comparison of rendered images of the example space generated by Radiance for luminance levels on specific surface.
- Different performance metrics with DAYSIM to verify the compliance of the decisions with annual performance.

Simulation of Light shelves

Daylight simulation was done for custom light shelves (metal deck, reflectance: 0.88, U value: 7.14 W/m²K) provided in Ecotect software of varying heights for the space under study. According to the Dhaka Metropolitan Building Construction Rule 2006, a maximum overhang of 0.5m is allowed over mandatory open spaces (clause no. 50.6G). Six alternative models of the same space were created for varying heights of light shelves by limiting the projection of the light shelves to a maximum of 0.5m on the exterior, and extending it to the same depth in opposite direction to the interior above eye levels. The varying heights investigated for the fixed light shelves were 1.50m, 1.75m, 2.00m, 2.25m, 2.50m and 2.75m above floor level (Figure 7).

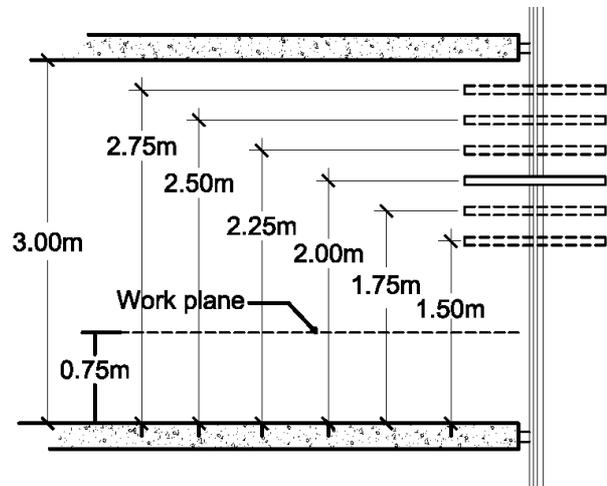


Figure 7: Section showing varying light shelf heights investigated in this study

COMPARISON

Table 1 summarizes the simulation results for daylight illumination level on the 83 visible nodes of the grid with no light shelves and light shelves at heights of 1.50m, 1.75m, 2.00m, 2.25m, 2.50m and 2.75m above floor level. Figure 12 is an output of Radiance Synthetic Imaging software, shows the daylight contour distribution of the same spaces at work plane level for the different heights of light shelves mentioned.

Table 1: Daylight distribution on node points with no light shelves and light shelves at different heights

Light shelves height (m)	Analysing nodes	Minimum illumination value (lux)	Maximum illumination value (lux)	Average illumination value (lux)	No. of points with values higher than 300 lux	No. of points with values within 300-900 lux
None	83	0	2600	650	40	22
1.50	83	0	1700	466	39	22
1.75	83	0	1400	370	39	26
2.00	83	0	1300	315	37	35
2.25	83	0	1500	367	34	22
2.50	83	0	1700	422	31	15
2.75	83	0	2000	478	30	13

Table 1 shows an average of 650 lux daylight level for the case of without any light shelf where contour range varies from 0 to 2600 lux. Even though the average illumination is greater without light shelves, the distribution is worst because there are greater differences between the max and min values. Comparing the alternative six heights of light shelves, it is found that the average daylight level above work plane is reduced with the introduction of light shelves at all heights compared to the condition without any light shelf (650 Lux). However, among six alternative heights the maximum average daylight condition on work plane height is observed for a light shelf at a height of 2.75m above floor level (478Lux) and the minimum average daylight condition on work plane height is observed for a light shelf at a height of 2.00m above floor level (315 Lux, see Figure 8).

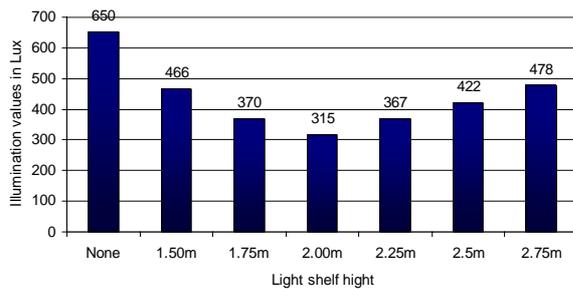


Figure 8: Average illuminance levels vs. light shelf heights

For the case of without any light shelf 40 points among 83 have values higher than 300 lux, which is the recommended level mentioned in Bangladesh National Building Code (BNBC, 1993) for general office work. If the deeper parts of the office interior are supplied with the recommended illumination level by supplementary light, the points that have values higher than 900 lux will create glare, as these levels exceed three times the recommended values (Littlefare, 1996; Goulding et al., 1992). Therefore, 18 peripheral points among the 40 points will create

glare, leaving only 22 points within the range of acceptable daylight illumination level (300-900 Lux). Figure 9 shows Comparison among different light shelf heights for illumination values more than 300 lux with acceptable illumination range (300-900 lux).

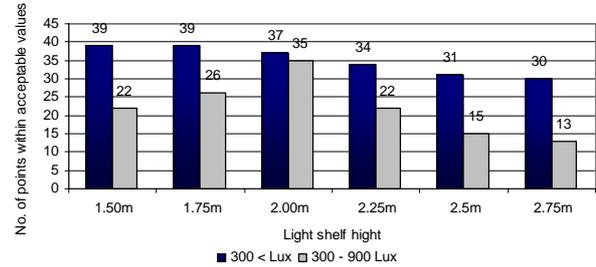


Figure 9: Number of points with an illuminance level value above 300 lux and within the acceptable range (300-900 lux) against different light shelf heights

Another comparison shows the drop of light along XX' and YY' axis within the highest limits (900 lux) in Figure 10 & 11 among three significant height of light shelf (at 1.5m, 2m & 2.5m height), which demonstrates that drops in illumination level become sharper with increasing heights of light shelves.

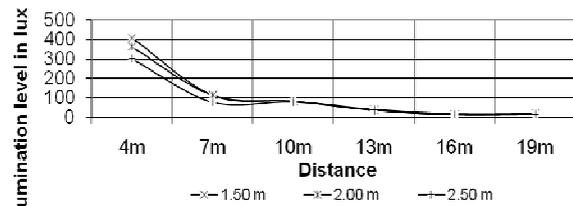


Figure 10: Drop of light along XX' axis with light shelves of three alternative heights within acceptable range (300-900 lux)

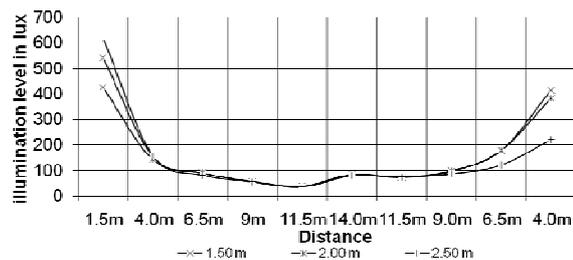
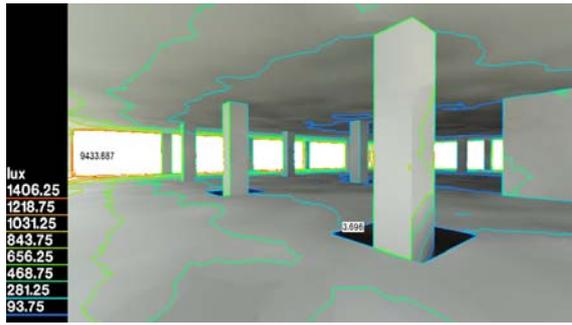
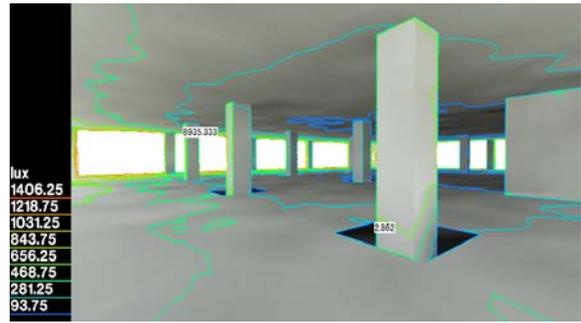


Figure 11: Drop of light along YY' axis with light shelves of three alternative heights within acceptable range (300-900 lux)

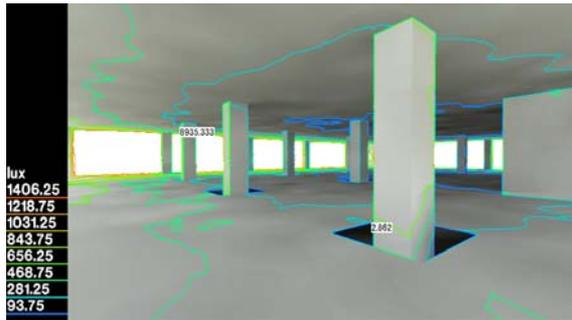
In the deeper areas, the effect of light shelf height on illumination level at work plane was not as significant due to overcast sky condition. However, the three-dimensional qualitative comparison along with daylight contour distribution on work plane height generated from Radiance output shows (Figure 12) brightest interior ceiling for a light shelf at a height of 2.00m above floor level and darkest interior ceiling for a light shelf at a height of 2.50m.



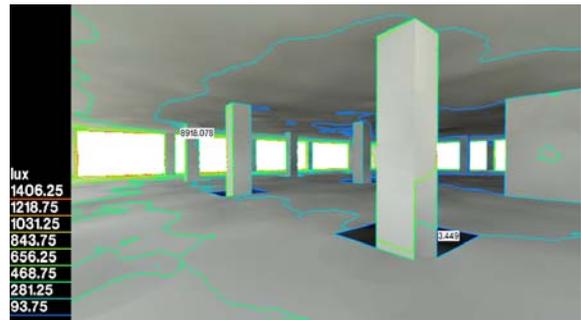
(a) Light shelves 1.50 m above floor level



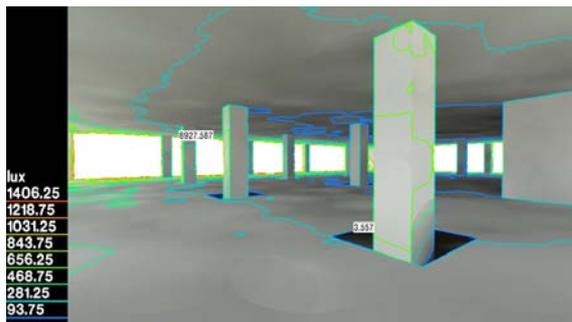
(b) Light shelves 1.75 m above floor level



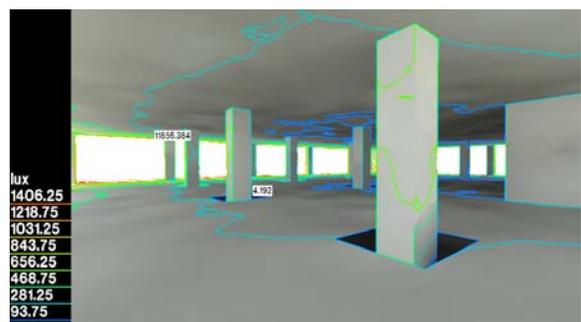
(c) Light shelves 2.00 m above floor level



(d) Light shelves 2.25 m above floor level



(e) Light shelves 2.50 m above floor level



(f) Light shelves 2.75 m above floor level

Figure 12: Daylight contour distributions with light shelves of six alternative heights above floor level.

DECISION BASED ON SIMULATION STUDY

The comparisons in Figures 10 & 11 show that illumination level near the windows varies widely due to the introduction of light shelves. Figure 8 shows that with light shelf at 2m height a maximum of points (35 points) fall within acceptable illumination range (300-900 Lux) with minimum average illumination value (315 lux from Figure 8) which meets the requirement of BNBC (1993) for office work (300 Lux). Therefore, to keep the desired light levels closest to standard, light shelves at a height of 2m above floor level perform better among all alternative heights studied for a space with 3m ceiling height with illuminated ceiling (Figure 12c). Daylight distribution on node points with light shelves 2m above floor level is shown in Figure 13 & Table 2.

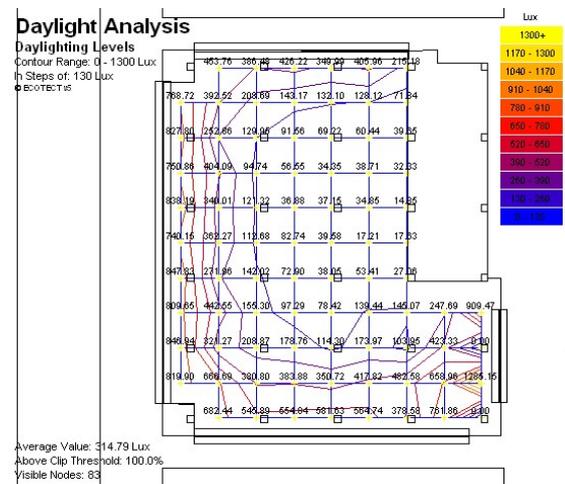


Figure 13: Daylight distribution on node points with light shelves 2.00 m above floor level.

Table 2: Daylight distribution on node points with light shelves 2.00 m above floor level.

	A	B	C	D	E	F	G	H	I
1	-	<i>454</i>	<i>386</i>	<i>426</i>	<i>350</i>	<i>406</i>	215	-	-
2	<i>769</i>	<i>392</i>	209	143	132	128	72	-	-
3	<i>828</i>	253	130	91	69	60	40	-	-
4	<i>751</i>	<i>404</i>	95	56	34	39	32	-	-
5	<i>838</i>	<i>340</i>	121	37	37	35	15	-	-
6	<i>740</i>	<i>362</i>	113	83	40	17	18	-	-
7	<i>848</i>	272	142	73	38	53	27	-	-
8	<i>810</i>	<i>442</i>	155	97	78	139	145	248	909
9	<i>847</i>	<i>321</i>	209	179	114	174	104	<i>423</i>	0
10	<i>820</i>	<i>667</i>	<i>381</i>	<i>384</i>	<i>351</i>	<i>418</i>	<i>482</i>	<i>659</i>	<i>1285</i>
11	-	<i>682</i>	<i>546</i>	<i>555</i>	<i>582</i>	<i>565</i>	<i>379</i>	<i>762</i>	0
Contour Range: 0-1300 Lux, Visible Nodes: 83, Average Value: 315 Lux									

*Italic points have values higher than 300 lux, Italic Bold points have values within acceptable range (300-900 lux), points on XX' and YY' axes are shaded.

VALIDATION

To validate the simulation results, measurements of daylight levels were taken by a light meter (TES 1332 Digital Lux Meter) on the study space, to compare illumination values generated by the Ecotect program with the actual daylight levels on April 15, 2007 at 12.30 pm (date and time used in simulation) when the sky was overcast. The deviation between actual and simulated point illumination was 5 % (15 lux on average) approximately (Joarder, 2007).

Although overcast sky presents the more critical condition, it is also important to get a complete picture about the performance of the studied light shelves in other types of sky conditions (clear sky, intermediate sky etc.) apparent in different period of the year (Joarder et al., 2009). So, finally a simulation was run with DAYSIM to calculate daylight levels under all possible sky conditions that may occur at building site in a year. Table 3 summarizes the non- default Radiance simulation parameters.

Table 3: Utilized Simulation Parameters in DAYSIM.

Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient resolution	Specular threshold	Direct sampling
5	1000	20	.01	300	0.15	0.2

For different heights of light shelves, daylight factor (DF), conventional daylight autonomy (DA), continuous daylight autonomy (DAcon), and useful daylight index (UDI) were calculated. For all performance metrics, the same annual illuminance profiles were used based on DAYSIM calculations. The simulation time step was one hour. Results for different performance metrics are shown in Table 4.

Comparing the annual performance metrics for seven conditions, it is found that the DA, DAcon above 80% and UDI are same for all cases. However, point illumination that has a DF of 2% or higher above work plane is minimum for light shelf at 2m height (80%) compared to all other conditions, but still satisfy the requirement of LEED-NC 2.1 (to qualify

for the LEED-NC 2.1 daylighting credit 8.1 a minimum Daylight Factor of 2% is needed in 75% of all space occupied for critical visual tasks). DAmax above 5% is reduced with the increase of the height of the light shelves. If the values of 5th column (average illumination value) and 6th column (no. of points with values higher than 300 lux) of Table 1 is compared with the values of 2nd column (DF \geq 2 %) and 5th column (DAmax > 5%) of Table 4, it is found that the values are similar in characteristics with respect to the changing height of light shelves. Therefore, the objective comparison confirming that the assumption based on which the simulation was done for critical evaluation (time, sky condition, design sky illuminance, etc) can be considered as representative of the whole year for the particular studied situation.

Table 4: DAYSIM simulation results for no light shelves and light shelves at six alternative heights

Variant	DF \geq 2 %	DA %	DAcon \geq 80%	DAmax \geq 5%	UDI \geq 100	UDI \geq 100
None	87	0 - 100	98	73	100	0
1.50	86	0 - 100	98	73	100	0
1.75	84	0 - 100	98	72	100	0
2.00	80	0 - 100	98	71	100	0
2.25	83	0 - 100	98	69	100	0
2.50	83	0 - 100	98	67	100	0
2.75	83	0 - 100	98	67	100	0

CONCLUSION

This simulation study was performed to find out the effectiveness of light shelf in tropical location, with predominantly overcast skies. The findings agree with past studies that in a tropical location, such as Bangladesh, the introduction of lightshelf at any height produces an overall reduction of illumination on the work plane throughout the interior space. At the same time, the findings also demonstrate that light shelves at a height of 2m above floor level within 3m high ceilings perform better to enhance daylighting quality in the interior space compared to the alternative locations (Figures 12c & 13, Table 2),

including the alternative where no light shelves are present. Although the average illumination is higher without light shelves (Table 1), the distribution is better with light shelves at 2m height. Lastly, it can be concluded that light shelf can be an effective element to enhance the quality of daylight in tropical buildings, if designed and located properly. The interior space was considered vacant for this simulation study, however different arrangements of partitions or furniture can affect the output. Only the height of the light shelf was investigated although size, shape, surface angle, and surface properties of light shelves also have significant influence on their ability to enhance daylighting quality in a space.

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