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A Study of Light Zone in Commercial Buildings: Assessing Energy Efficiency for Shading Devices

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Abstract: This paper addresses the daylighting compromises of the passive architectural feature of sunshades, owing to the subdivision of varying illumination level of light zones into the interior luminous environment. In light zones, under and over-lit zones may cause visual and thermal discomfort, in addition to consequent energy consumption. However, using daylight, dependency on artificial lighting sources can be minimized, resulting in energy efficient sustainable buildings. This paper presents a simulation study of assessing the luminous performance of most commonly used shading devices, for recent tall office buildings of Dhaka. It emphasizes in the context of the most vulnerable—south, east and west orientation for this location—during the overheated period of summer. Six selected fixed external shading devices, from a field survey, have been evaluated, based on the light zone distribution. The simulation results indicate that both the geometrical, as well as the material characteristics of shading devices, can have a noteworthy influence on the desired luminous performance. The results also clearly illustrate the necessity of selecting proper shading devices to modify the dimensional relations of the light zone and enhance energy efficiency in offices of similar tropical areas.

Keywords: Light zone, energy efficiency, shading device, commercial buildings.

INTRODUCTION

Artificial lighting at present shapes 30% of global energy consumption in office buildings (Brotas and Rusovan, 2013). Being no exception, artificial light in the offices of Dhaka is the main contributor to the visual environment, even though there is an abundance of daylight and the working hours in offices utilize much of the daylight hours. However, electric lighting energy use can be reduced by 25-50% with advanced light sources, design strategies and controls, and by 75% with the addition of daylighting (Joarder et.al., 2009, p.218). In cities like Dhaka, beset by load-shedding and electricity interruption, inmates of buildings regularly need to depend solely on daylighting, as a prime consideration for adequate visual performance (Joarder, 2009, p.6). Therefore, daylight is being encouraged in office/commercial buildings all around the world, as well as in Dhaka. The recent trend is seen to be a high rise, deep plan, open layout offices, with extensive use of curtain glass envelopes, using large apertures (Rahman and Ahmed 2008, 15). Though hardly any attention is paid to the interdependence between achieved daylight illumination level in the interior and envelope design.

Generally, daylight inclusion into large interiors creates two types of luminous areas or light zones within a space for a specific task: a daylight zone of abundant daylight and a dark or under-lit zone, requiring artificial light (Trisha and Ahmed, 2016). In the Tropics, unwanted heat may enter with direct sun light in over-lit areas, causing thermal discomfort. Too much or unguided daylight may cause visually uncomfortable glare-prone over-lit zone (Mayhoub 2012). Therefore, the improper and unconsidered addition of daylight may cause harm, rather than any targeted benefit (Joarder, Price and Mourshed 2010).

Shading provision is argued to be considered as an integral part of fenestration system design for office buildings in order to balance daylighting comfort requirements of light zone, versus the need to reduce energy consumption (Ahmed, 2014, p.139). According to the U.S. Department of Housing and Urban Development (1999), stopping the sun's heat, before it penetrates windows by external shading devices is up to seven times more effective, than using interior blinds or curtain. Another study accentuates the design significance of static solar protection for office buildings (Hans, 2006, p.16). However, the extent of shading devices hasn't yet been investigated (RAJUK 2008) for the Dhaka context.

In a recent study, luminous-thermal conflicts of tall air-conditioned office buildings of Dhaka, with fenestrations, using the most common external fixed shading devices for south orientation have been evaluated (Trisha and Ahmed, 2016). This research paper is based only on the comparative luminous performances of those shading devices for the south, east and west orientations by using 'Ecotect' (version 5.50) computer simulation program with ray trace based software 'Radiance'. The aim of the study was to identify the efficiency of shading devices with respect to lighting.

LIGHT ZONE AND ITS DISTRIBUTION

Conceptually, light-zone(s) are areas, fields or zones of light. The daylight in a space can be regarded as a composition of light-zones ((Merete 2007). In this paper, the light zone has been regarded analytically, as spatial groupings of the lighting variables (intensity, direction, distribution and color), which are significant to space. In any space, a light zone may consist of both direct sun light and diffuse light or only diffuse light. Variation in their illumination level creates over-lit, accepted and under-lit zone (Figure 1)

METHODOLOGY

Quantitative determination of average luminous variables was used, to evaluate the energy efficiency of shading devices in this research. The adopted methodology of this study is as followed (Figure 2):

Energy efficiency assessment criteria

According to the International Energy Agency (IEA, 2000, p.3-5), the luminance ratio set ideally within the visual field include the following: Central field (5): background (2): environment (1). However, whenever this ratio exceeds 10:3:1, the visual problem of glare occurs, due to over-lit zone. The minimum standard illumination level for general office is considered to be 300lux (CIBSE, 2002) (BNBC, 1993, p.8.7).Therefore, on the basis of the distribution of the illumination level (Joarder et al., 2009, p.920-927) in deep plan open office spaces, the luminous energy efficiency of shading devices can be evaluated, under the fulfillment of the four luminous/lighting criteria of Table 1.

Table 01: luminous variables for energy efficiency assessment

Area of daylight zone: acceptable illumination level	Area of over-lit zone	Area of under-lit zone	Maximum depth-accepted illumination level/daylight zone
≤900-≥300lux	≥900lux	≤300lux	≤300lux

Maximizing area of accepted daylight zone is the prime criteria for good quality for daylighting (BNBC, 1993, p.8.3). Both glare-prone over-lit and under-lit or artificial light zone, are considered under efficient, in daylit buildings, for office tasks, and should be minimized, compared to the acceptable area of daylight zone. However, the over-lit zone is given preference compared to the under-lit zone as it requires no energy consumption for artificial lighting. Moreover, it may be converted into usable area merely by changing the direction of seating in the interior layout (Jakubiec and Reinhart, 2012, p.149-170).

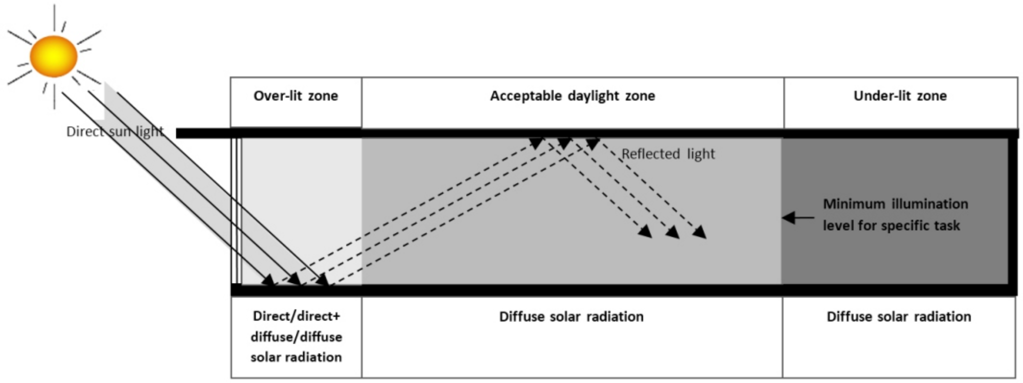


Figure 01: Distribution of light zones in section

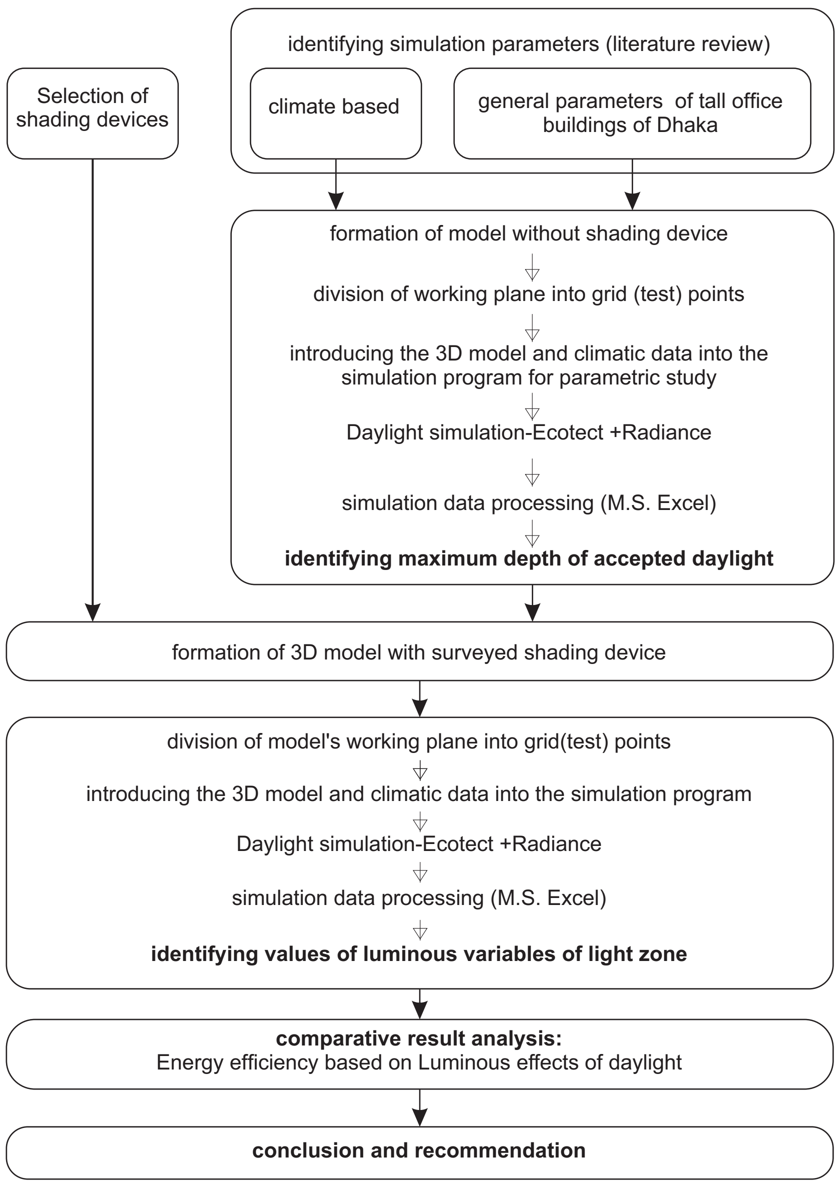
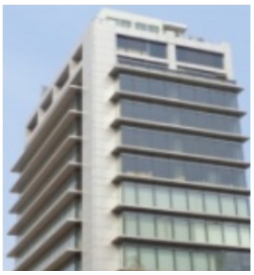
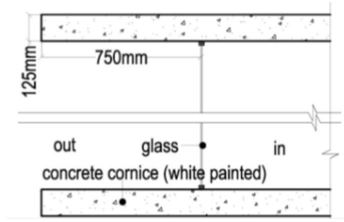
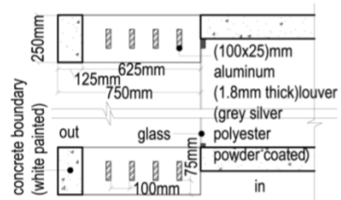
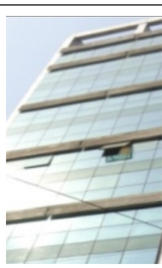
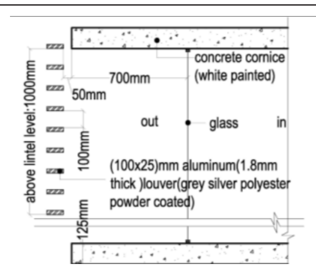
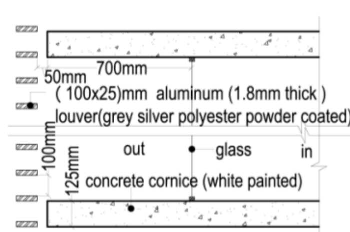


Figure 02: Flow diagram of simulation process

Field survey and selection of shading devices

For the simulation models, parameters of shading devices were derived from a field survey of tall office buildings of Dhaka. As there is no defined aspect of tallness (CTBUH, 2014, p.1-5), buildings above six stories were regarded as tall buildings, considering walk up limit and fire escape provision (RAJUK, 2008, p.33). After a pilot survey, involving 106 buildings, six were finally selected, based on the most commonly found parameters of shading devices (Figure 3).

<table>
<tr><th>Selected building</th><th>Section of the case shading</th><th>Simulation parameters of shading device</th></tr>
<tr><td></td><td>
</td><td>cornice depth:750mm,thickness:125mm
Material:
White paint on concrete
reflectance:0.55,
U value:1.8w/m^{2}k</td></tr>
<tr><td>Nuruzzaman Biswas Tower, Gulshan</td><td colspan="2">Horizontal concrete cornice (ID:H01)</td></tr>
<tr><td></td><td>
</td><td>cornice depth:750mm,
Boundary depth:625mm, thickness:250mm,
louver:100mmx25mm,
spacing:100mm,thickness:1.8mm
Material:
White paint on concrete boundary,
reflectance:0.55, U value:1.8w/m^{2}k.
grey silver polyester powder coated aluminum louvers, reflectance:0.796, U value:1.7w/m^{2}k</td></tr>
<tr><td>I-Center, Dhanmondi</td><td colspan="2">Horizontal aluminum louvers with concrete boundary (ID:H02)</td></tr>
<tr><td></td><td>
</td><td>cornice depth:700mm,thickness:125mm,
offset from overhang:50mm ,
overhang depth:1000mm,
louver:100mmx25mm,
spacing:100mm,thickness:1.8mm
Material:
White paint on concrete boundary,
reflectance:0.55, U value:1.8w/m^{2}k.
grey silver polyester powder coated aluminum louvers, reflectance:0.796, U value:1.7w/m^{2}k</td></tr>
<tr><td>The Alliance Building, Baridhara</td><td colspan="2">Horizontal aluminum louvers in overhang (ID:H03)</td></tr>
<tr><td></td><td>
</td><td>cornice depth:700mm,thickness:125mm,
offset from screen:50mm,
louver:100mmx25mm,
spacing:100mm, thickness:1.8mm ,
Material:
White paint on concrete boundary,
reflectance:0.55, U value:1.8w/m^{2}k.
grey silver polyester powder coated aluminum louvers, reflectance:0.796, U value:1.7w/m^{2}k</td></tr>
<tr><td>Uday Tower, Gulshan</td><td colspan="2">Horizontal aluminum louvers in vertical plane (ID:H04)</td></tr>
</table>

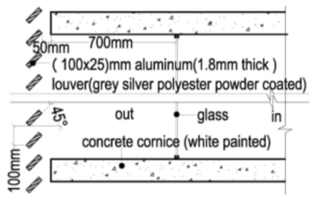
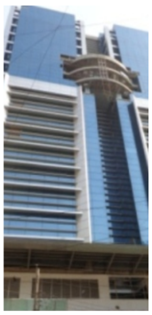
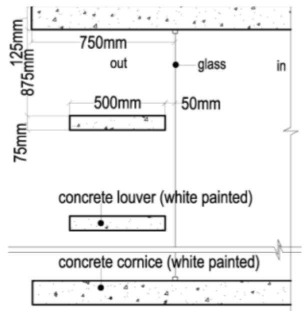
Selected building	Section of the case shading	Simulation parameters of shading device
		cornice depth:700mm,thickness:125mm, offset from screen:50mm louver:100mmx25mm,spacing:100mm, angle:45˚,thickness:1.8mm, Material: White paint on concrete boundary, reflectance:0.55, U value:1.8w/m^2k. grey silver polyester powder coated aluminum louvers, reflectance:0.796, U value:1.7w/m^2k
Mika-Cornerstone, Uttara	**Horizontal angled aluminum louvers in vertical plane (ID:H05)**	
		cornice depth:750mm,thickness:125mm louver depth:500mm, thickness:75mm offset from glass:50mm,spacing:875mm Material: White paint on concrete reflectance:0.55, U value:1.8w/m^2k
NCC-Bank, Head office, Motijheel	**Horizontal concrete louvers (ID:H06)**	

Figure 03: Case shading devices from field survey, 2016.

Simulation parameters

The office period between 9.00-17.00 hrs. of 15 April and 'sunny with sun' sky condition was chosen for simulation, characterizing extreme climatic features (U.S. dept. of Energy) of the hottest month of the year, for the study region of Dhaka. The general parameters of the tall office building of Dhaka i.e. typical column grid, clear height, working plane height for simulation models, selected from the literature review (Rahman, A. and Ahmed, K.S., 2008, p.15), are followed in Table 2. Material parameters (Table 2) were used from default material specification, considered by the chosen software.

The depth of the simulation model was derived from the maximum depth reached, of accepted illumination level of 300 lux, for a 'model without shading'. Using daylight thumb rule, i.e. daylight penetrates about 2.5 times the head height of the aperture into the room from a window (Robbins, 1986, p.64), parametric daylight

Table 02: General parameter of tall office building of Dhaka.

Model dimension		
Model Width	6000mm	typical column grid
Floor height	3000mm	typical clear height
Aperture Width	5750mm	the whole span between two columns up to full floor height
Aperture head height	2875mm	
Working plane height	760mm	ergonomics standard

Material specification	
Ceiling	white painted on 12.5mm plaster, 150mm RCC (reflectance:0.7, U value:2.05w/m^{2}k)
Wall	150mm brick work with 18.5mm plaster (reflectance:0.5, U value:2.602w/m^{2}k)
Floor	200mm thick concrete slab plus tiles finishes (reflectance:0.3, U value:2.9w/m^{2}k)
Glazing	Single glazed clear with aluminum frame for maximum visual transmittance with thermal gain. (reflectance:0.89, U-value:6w/m^{2}k)

simulation studies for South, East and West orientations were carried out by considering the severity of direct sun light. The results revealed that 300 lux reaches its maximum depth after 15.00 hours in the West orientation, and at 9.00hours in the East (Figure. 4). With aperture/window heights of 2875 mm, the maximum depth 2.5x2xaperture head height, 13750 mm, was considered the depth of the simulation model.

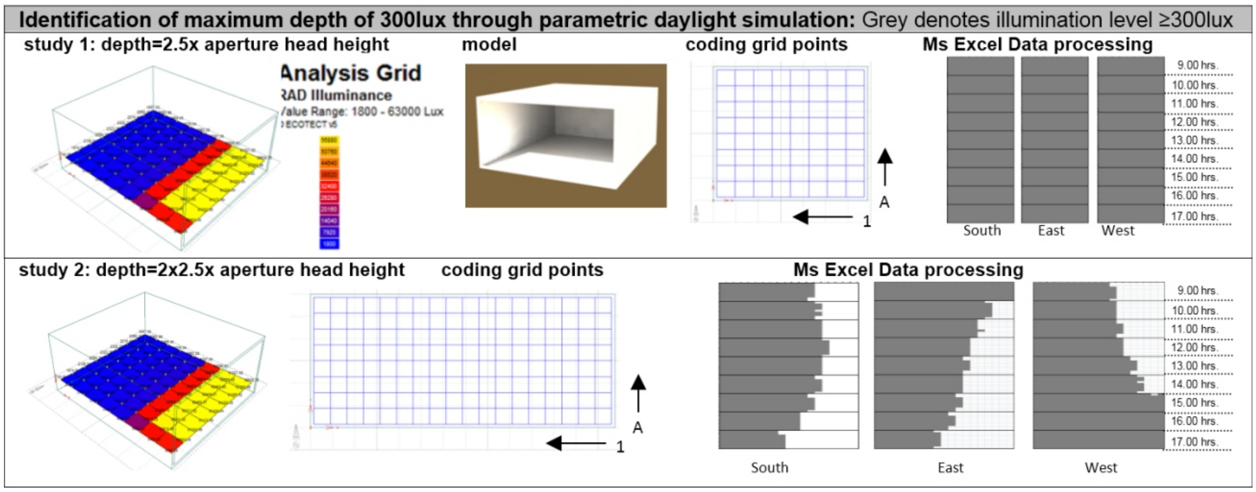
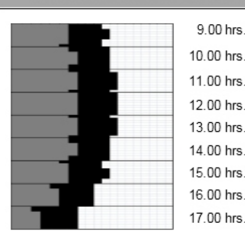
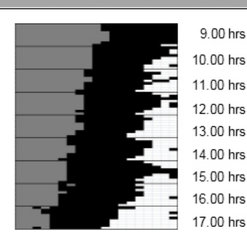
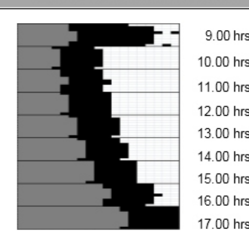
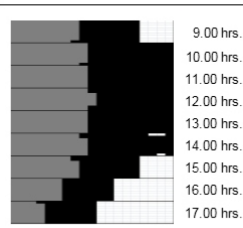
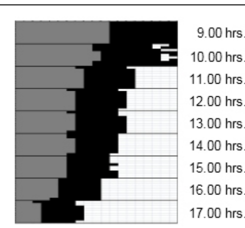
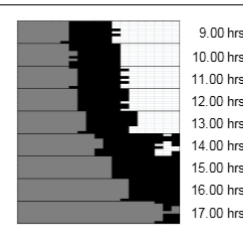


Figure 04: Depth of simulation model.

Generation of simulation model and daylight simulation results

The simulation models with selected shading devices were generated, using the shading device parameters from Figure 3, general parameters of tall office building from Table 2 and the identified depth

Simulation models	Simulation result-south	Simulation result-east	Simulation result-west
			
			

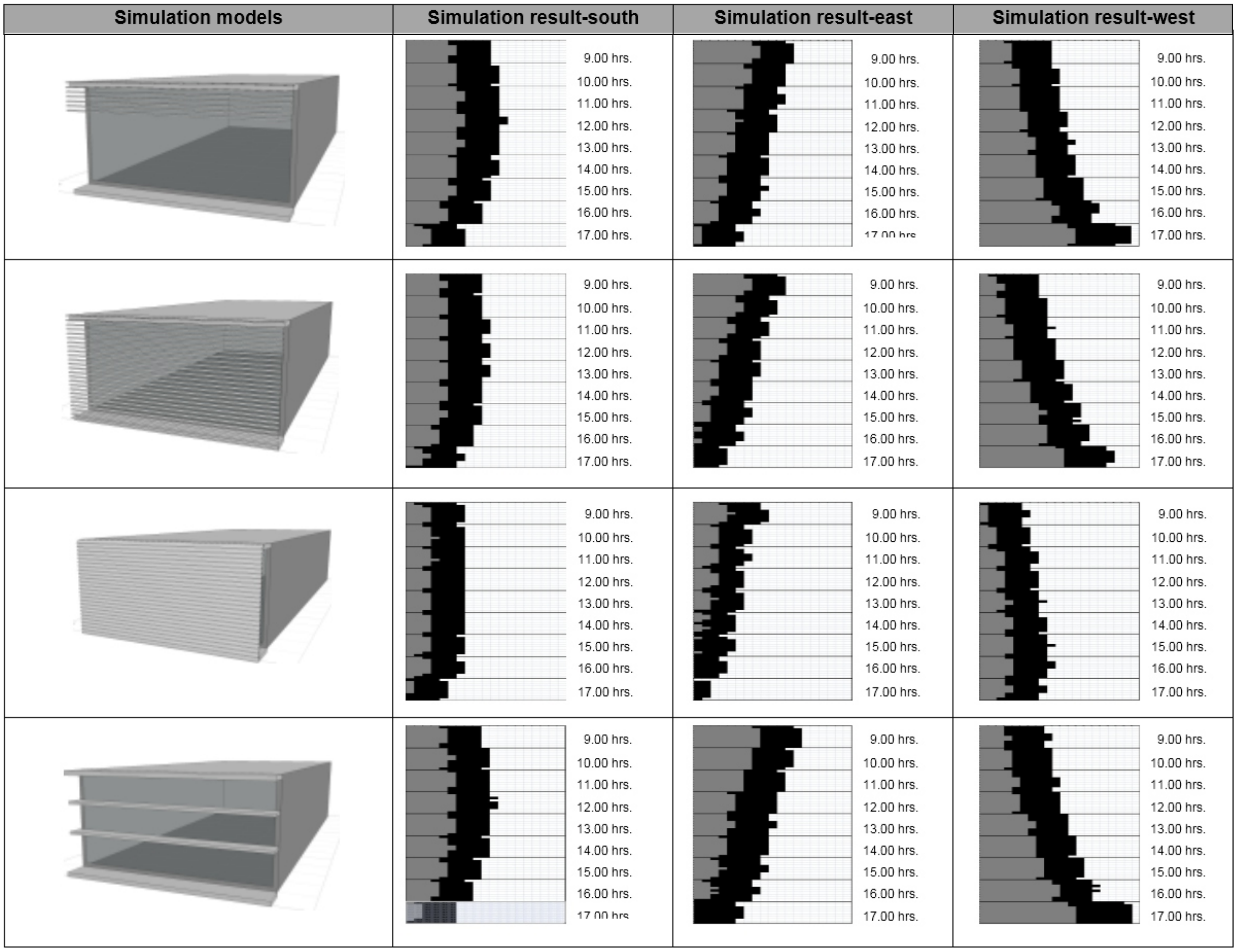


Figure 05: Daylight simulation results for south, east and west orientation.

from Figure 4. In daylight simulation results for the south, the east and west orientation of Figure 5 gray, black, and white denotes over-lit, accepted daylight and under-lit zone accordingly. The simulation process was carried out considering all other variables constant, except shading devices, using the grid points code similar to that of the parametric study 2 in Figure 4.

RESULT ANALYSIS AND DISCUSSION

The comparative evaluation of the simulation results of the shading devices for the south, east and west orientation are as followed:

South Orientation

The average of daylight simulation results of south oriented shading devices (Figure.6) shows that, in general, a total of over and under-lit zones, constitute greater area, than accepted daylight zone, for all the tested models. Values of the Maximum depth of acceptable daylight zone as well as overlit zone, for the south orientation, generally characterize the direct relationship with the accepted daylight zone. Although, the relation between underlit and accepted daylight zone, is inverse. These three variables for H06, only yields opposite relationship, with the accepted daylight zone, when compared to that of the values of H04. For all the tested models, the values are also not directly or inversely proportional, to that of the accepted daylight zone.

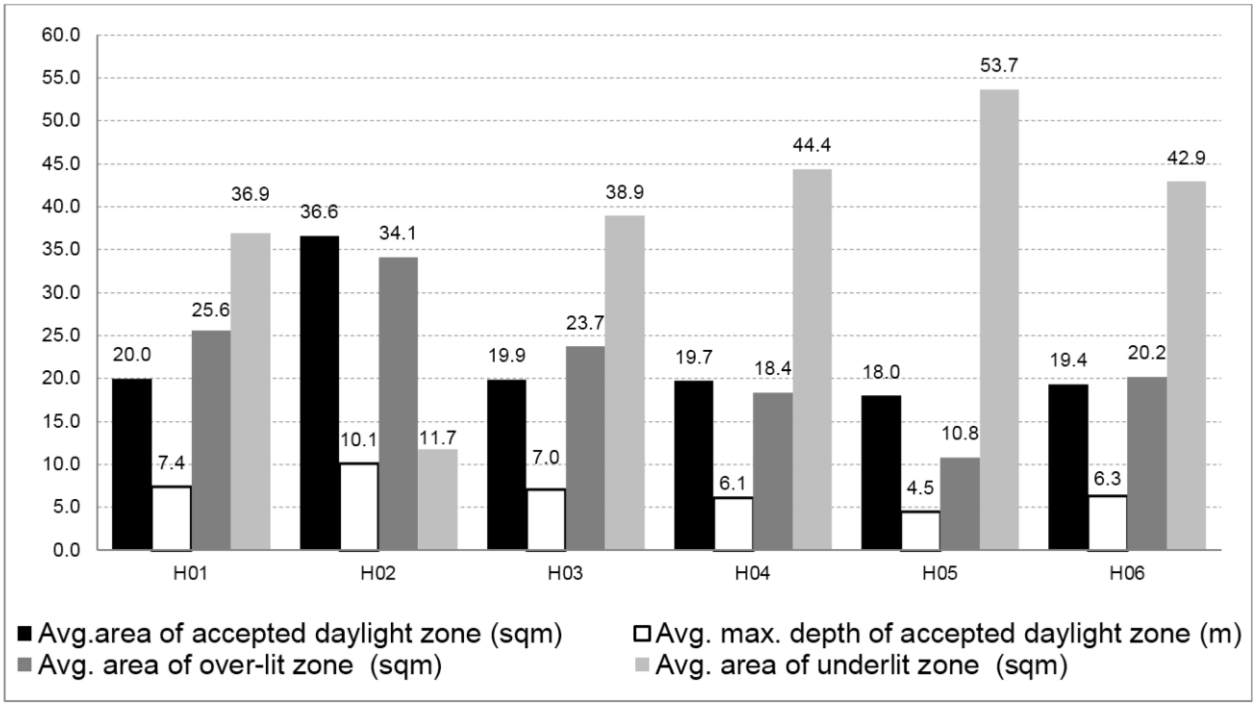


Figure 06: Comparison of different light zones from average of daylight simulation results in the south.

Among the shading devices tested, only H02 yields smaller under-lit or artificial light zone compared to its over-lit glare area. The over-lit area for H02 as well as for H04 and H05 are smaller than that of their accepted daylight zone. However, the area of the under-lit zone, for H04 and H05 is much greater, compared to the rest of the tested shading devices. H05 also presents the worst case scenario, characterizing the least values under other considered criteria. On the other hand, H02 yields a much smaller under-lit zone. It is even smaller than its accepted daylight zone. Moreover, the area of accepted daylight zone, over-lit zone and maximum depth of accepted daylight zone, for H02 has the highest value. H01 shows the second highest value, for these three criteria, though the values are markedly smaller than that of H02. H01 also occupies the second lowest area of the under-lit zone, though it is much greater compared to H02. Over-lit area for H01 is also greater than its accepted daylight zone. With the lesser performance, H03 and H06 yield similar comparative results among their variables, as do H04 and H05. H04 and H06 yields very close results. H04 fulfills the prime criteria of greater accepted daylight zone. However, its performance is not as good as H06, considering the other three criteria. Considering the above discussion on light zones distribution, the identified selection order of the south oriented shading devices for energy efficiency is specified in Table 3.

Table 03: Shading device selection order in the south.

Selection order	1	2	3	4	5	6
Shading device	H02	H01	H03	H06	H04	H05

East Orientation

The average of daylight simulation results of east oriented shading devices (Figure 7) shows that all the tested models constitute a greater area of the total over and under-lit zones than accepted daylight zone. With the accepted daylight zone, values of rest of the three considered variables, characterize relationships, as mostly found in the southern orientation. Only values of H03 yields opposite relationship between overlit and accepted daylight zone, when compared to that of H06.

Among the shading devices tested, only H01 and H02 yield smaller under-lit or artificial light zone, compared to than that of their respective over-lit glare area and accepted daylight zone. However, the area of the under-lit zone for H02 is very close to its accepted daylight zone. Only H02 occupies a greater area of the over-lit zone than accepted daylight area, among all tested devices in the eastern orientation. Its area of the over-lit zone is smaller but very close to that of the highest value for H01. Under-lit zone for H01 is much higher than that of H02. Under the rest of the criteria, the performance of H02 is also not as good as H01. On the other hand, H01 yields the least area of the under-lit zone, among all tested shading devices. Moreover, it occupies the highest value, for the area of accepted daylight zone and its maximum depth. With lesser performance accordingly, H06, H03, H04 and H05 yield similar comparative results, among their variables. Only H03 depicts the almost equivalent area of over-lit and accepted daylight zone, among these shading devices. H05 presents the worst case scenario, characterizing the highest area of the under-lit zone and the least values under rest of the criteria.

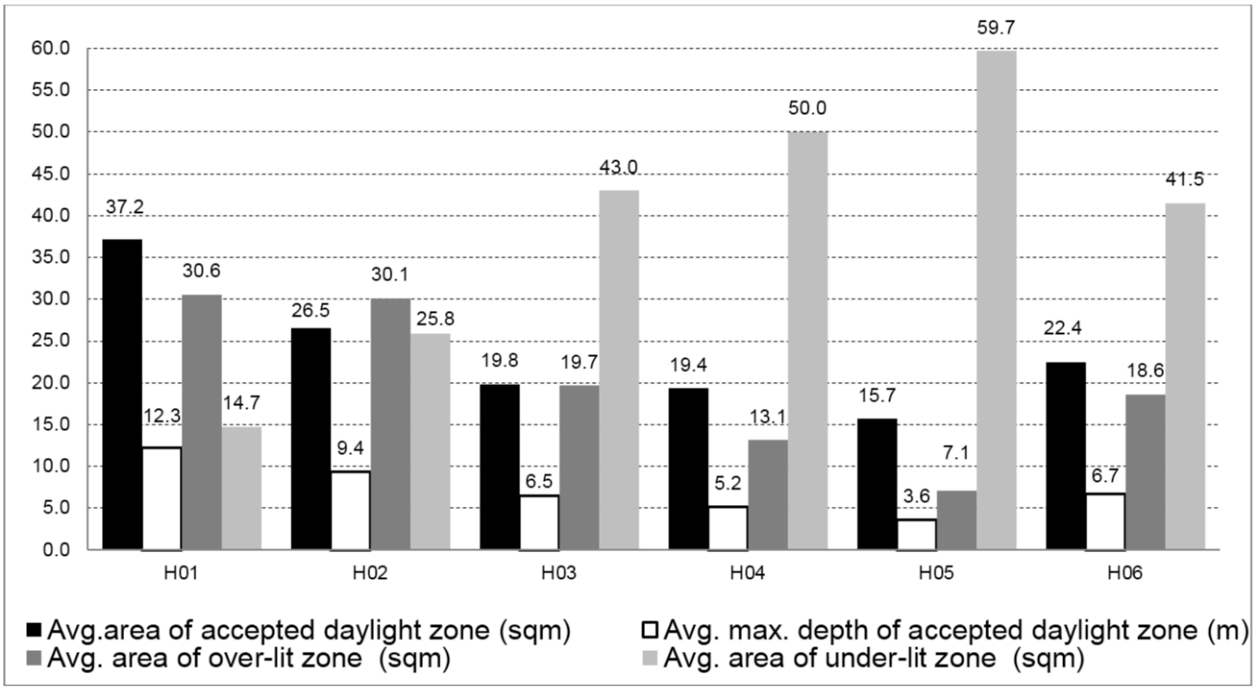


Figure 07: Comparison of different light zones from average of daylight simulation results in the east .

Considering the above discussion on light zones distribution, the identified selection order of the east oriented shading devices for energy efficiency is specified in Table 4.

Table 04: Shading device selection order in the east.

Selection order	1	2	3	4	5	6
Shading device	H01	H02	H06	H03	H04	H05

West Orientation

The average of daylight simulation results of west oriented shading devices (Figure 8) shows that similar to the results of south and east orientations, all the tested models constitute a greater area of the total over and under-lit zones, than accepted daylight zone. With the accepted daylight zone, values of rest of the three considered variables, characterize similar relationship, to that of the results mostly found in the last two considered orientation. Opposite relationship with very close values is found when compared between H03 and H06.

Among the shading devices tested, H01 and H02 yield similar comparative results among their variables, as do H03, H04 and H06. Only H01 and H02 yield smaller under-lit or artificial light zone, compared to their respective over-lit, as well as accepted daylight zone. H01 depicts smaller over-lit glare-prone area than that of the highest value of H02. But for H01, the area of accepted daylight zone is almost equivalent to its under-lit zone. The performance of H01 is also not as good as H02, under rest of the criteria. On the other hand, H02 presents the highest area of accepted daylight zone and its maximum depth, among all shading devices. It also has the least area of the under-lit zone. With the lesser performance, H03 and H06 yield almost equal area of accepted daylight zone. Over-lit area of H03 is greater, compared to that of H06. However, H03 characterizes the greater maximum depth of accepted daylight zone, with the less under-lit area. H04 shows, lower performance than H06, under all the criteria. H05 presents the worst case scenario in the west. It characterizes the highest area of the under-lit zone and the least values under rest of the criteria. The only noticeable preferred result about H05 is, its least over-lit area, among all tested models in the western orientation. Even it comprises the much lower over-lit area than its accepted daylight zone.

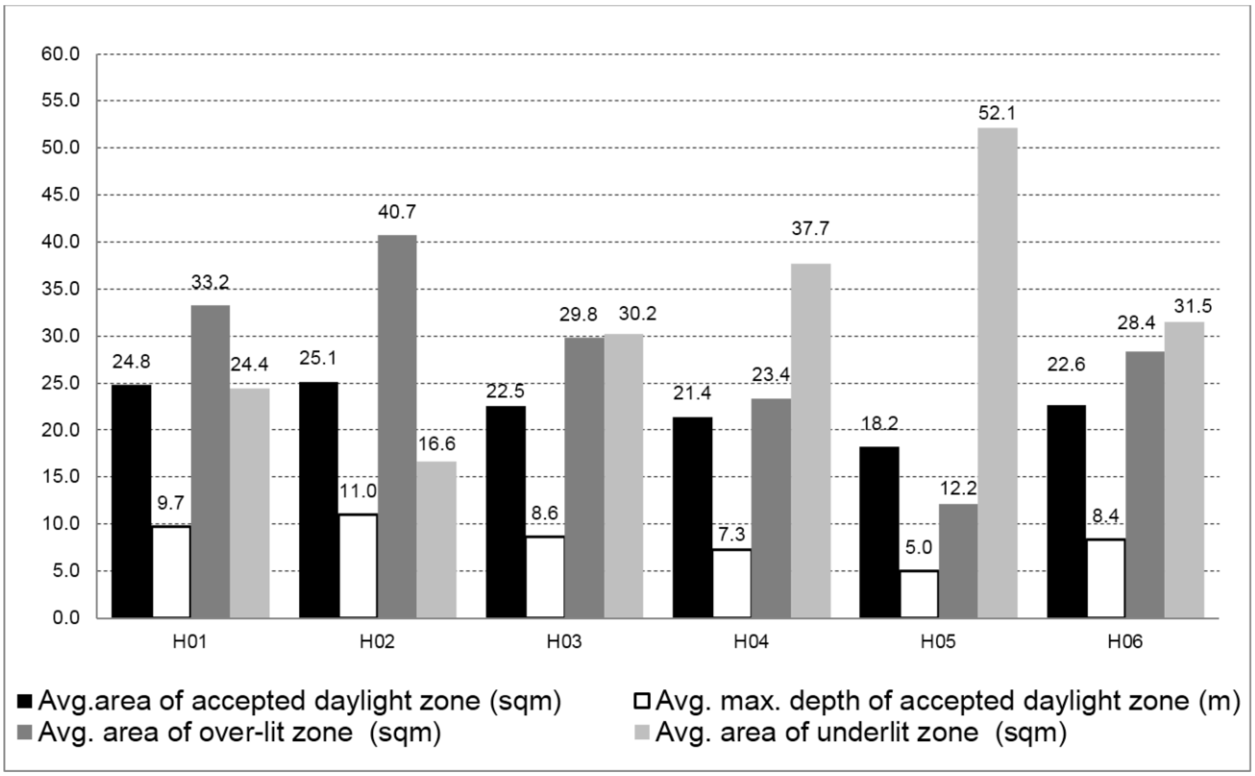


Figure 08: Comparison of different light zones from average of daylight simulation results in the west.

Considering the above discussion on light zones distribution, the identified selection order of the east oriented shading devices for energy efficiency is specified in Table 5.

Table 05: Shading device selection order in the west.

Selection order	1	2	3	4	5	6
Shading device	H02	H01	H03	H06	H04	H05

CONCLUSIONS AND RECOMMENDATIONS

In this paper, luminous performance evaluation of shading devices (Figure 3), reveals that their proper selection, in controlling the distribution of light zone, can advance energy efficiency, in commercial office buildings of tropical cities significantly. Moreover, proper physical characteristics of shading devices can be significant in minimizing artificial light zone as well as, maximizing glare-free acceptable daylight zone. The summary of the findings, from results, discussion and analysis of Table 3,4 and 5, are given below:

- Under-lit or artificial light zone of the unusable area needs to be reduced, through the reduction of depth in space. For south orientation, it should be limited from 1.57 to 3.51 times of the aperture head height. That is 2.40 times of the aperture head height on average. For east orientation, the depth limit should be between 1.25 to 4.27 times of the aperture head height, which is about 2.55 times, on average. The recommended limit for west orientation is between 1.74 to 3.83 or approximately 2.90 times of the aperture head height. (space depth limit for the considered three orientations are calculated from Figure 5, counting the grid distance from Figure 4)

- Over-lit zone should be converted into usable daylight area, particularly in the western orientation. It must be taken into account that, glare reduction should not adversely minimize accepted daylight area and its maximum depth, increasing under-lit zone.

- Aluminum louvered arrangements in concrete cornice are more suitable than solid ones, for south and west orientation. Its geometric and material combination is good for east orientation, as well. Controlling markedly high over-lit zone may further increase its efficiency.

- The arrangement of horizontal aluminum louvers in a horizontal plane should be preferred, to that in the vertical plane.

- Horizontal concrete louvers containing a multiple numbers of cornices are not as energy efficient as a single concrete cornice. But increased number of cornice helps to minimize over-lit glare-prone area.

- Aluminum louvered screens <1800angle is less beneficial than those of 1800, though, both are preferable for daylighting in shallow plan open spaces. Moreover, aluminum louvered screens <1800angle is the most suitable shading device, to eliminate glare-prone over-lit area.

- The addition of 1800 horizontal aluminum louvers, with bare concrete cornice, in vertical planes, helps to control over-lit zone. But, for luminous energy efficiency, the bare concrete cornice is more preferable, to those louvered ones.

- Increasing number of horizontal aluminum louvers covering vertical plane helps to decrease over-lit zone. However, its adverse effect on daylight zone of accepted illumination level and under-lit zone needs to be taken into account, to increase energy efficiency.

This research assesses the luminous energy efficiency of the fixed external commonly used shading devices of tall office buildings of Dhaka, facing South, East and West orientations only. It also gives guidelines to increase their efficiency. Thermal effects of daylight for these shading devices also needs to be explored, with parametric design, to ensure their optimized energy consumption and comfort in total, all the year round.

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Dhaka", submitted to the Department of Architecture, Bangladesh University of Engineering and Technology (BUET), on 20 December 2016.

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