Daylight Simulation Analysis for the Effectiveness of Light Shelves in Adapted Architectural Design Studios of Dhaka, Bangladesh

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ABSTRACT

In Dhaka, a common design practice for non-residential buildings is to install a full façade fixed glass on roadside elevation, majorly for aesthetic purpose, whatever the orientation, with indefensible argument for maximum daylight utilization into the building. But in practice, only a few meters from glass façade is comfortable for lighting tasks and further depth is incapable for completing tasks like writing, reading, drafting, and model making. The objective of this paper is to highlight the effectiveness of light shelves as enhancing device for architectural design studios to ensure overall interior day lighting quality for drafting and model making works. Using daylight simulation programs, this paper examines the impact of light shelves on indoor daylight illuminance on work plane height (2’-6’), at an adapted design studio classroom space enclosed by three side glass surfaces. 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 6’-0” above floor level with 40” width perform better among the alternatives studied including the alternative where no light shelves were existed. Finally, the decisions were verified with DAYSIM simulation program to ensure the compliance of the decisions with dynamic annual climate-based daylight performance metrics. It is expected that the outcome of this research will help architects and designers to decide the shape and size of the light shelves to improve the daylight performance in adapted rentable spaces in future.

Key Words: Non-residential buildings, Dhaka city, adapted architectural design studios, fixed glass façades, light shelves, daylight simulation, and improved daylight performance

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INTRODUCTION

The modelling of daylight in buildings is a challenging problem of increasing importance (Andersen et al. 2008). Careful management of daylighting in a building is crucial in minimizing the environmental impact of a structure (U.S Department of Energy, 2006). It also has the potential to produce positive effects on health (Veitch, 2005; Webb, 2006), well-being and, possibly, productivity (Cuttle, 2002; Kim, et al., 2005). In addition to these benefits, it remains a predominant factor in how a space is revealed and perceived by its users (Lam, 1986; Guzowski, 2000). Therefore, a key challenge that designers face is to efficiently combine the many performance parameters involved in daylighting with aesthetic considerations. But in Dhaka, a common design practice for non-residential buildings is to install a full façade fixed glass on roadside elevation, majorly for aesthetic purpose (Figure 1), whatever the orientation, with indefensible argument for maximum daylight utilization into the building. Under tropical climate (i.e. Dhaka) it is not the good practice for East and West sides, even the South side needs incorporation of proper shadings to the facade. As a result in most cases for the East and West and partially South orienting interior spaces being shielded by blinds or put furniture to get rid of glare and hot temperature. Additionally, only a few meters from glass façade is comfortable for lighting tasks and further depth is incapable for completing tasks like writing, reading, drafting, model making in case of north oriented interior spaces.

On this contrary, daylight simulation has performed in this study for custom light shelves for an architectural Design Studio of Dhaka City, Bangladesh. The classroom (design studio) has fixed glass façade on the north side which is considering as the typical rentable commercial spaces of the Dhaka city. 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. Comparing all the findings, the best possible location of light shelves for drafting and model making works has been suggested.

The finding of this paper will be an important reference for this kind of adaptive building in tropical location, with predominantly overcast skies. This paper will also help architects
and interior designers to think incorporating light shelves as design element in a creative manner for getting better interior lighting condition.

**Methodology**

The aim of this research is to study the effectiveness of different heighted light shelves configuration at architectural design classroom to attain maximum utilization of daylight.

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. Finally, the decisions were verified with DAYSIM simulation program to ensure the compliance of the decisions with dynamic annual climate-based daylight performance metrics. The objectives and working sequences of the study are showing respectively in Table 1 and in Figure 2.

Table 1: Objectives of the study

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Description</th>
<th>Method/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective 1</td>
<td>To understand the importance of daylight on student’s visual and work efficiency</td>
<td>Literature review, Case study</td>
</tr>
<tr>
<td>Objective 2</td>
<td>To justify the requirements of efficient daylight for drafting tasks</td>
<td>Literature review, Case study</td>
</tr>
<tr>
<td>Objective 3</td>
<td>To find out an effective light shelve height and angle to increase UDI in classroom in the context of Dhaka.</td>
<td>Simulation analysis, Literature review</td>
</tr>
</tbody>
</table>

Figure 2: Methodology diagram of the study
**Literature Synthesis**

Daylight simulation can be used to predict the actual daylight levels in critical periods of the year and also can be used as a design tool, during the decision making process of the different design elements in any building. Daylight simulation as a design tool could be extremely useful in urban areas, where changes occur frequently due to the densification of the built environment, increasing building proximity, in which case buildings and other structures act as barriers or reflectors, either casting shadows or reflecting daylight into a space (Joarder et al. 2009). This study is only concern with designing with daylight for architectural design studio. Obviously, students cannot study unless lighting is adequate, and there have been many studies reporting optimal lighting levels (Mayron, Ott, Nations & Mayron, 1974). For architecture students, the studio is a place far more than just a normal classroom activity. Lighting plays an important role to these students as high-quality lighting can improve students’ moods, behaviour, concentration, and their learning, in general (Ani et al. 2012). The Centre for Building Performance and Diagnostics (CBPD) has identified twelve international case studies that indicate that improved lighting design increases individual productivity between 0.7% - 23% while reducing annual energy leads by 27-88% (Loftness et al., 2006).

The following four essential features are determined by Bangladesh National Building Code (BNBC 2012) for an efficient lighting system: a) Visual comfort through adequate illumination of the working surface; b) Prevention of glare; c) Avoidance of shadows; and d) Ease of maintenance. The code suggests that a 300 Lux is important for classroom lighting performance and 450 Lux is necessary for paper tracing jobs (Table 2). Figure 03 is showing a comparison of minimum Illuminance around the world where a 500 lux is for drafting and a 300 lux for computer works is suggested by India. Additionally, India recommends 0.3-0.7 and 0.1-0.3 surface reflectance for floor and ceiling respectively.

Table 2: Recommended Illuminance for different activities (BNBC 2012)

<table>
<thead>
<tr>
<th>Building type</th>
<th>Area of activity</th>
<th>Illuminance (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational building</td>
<td>Desk</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Black board</td>
<td>250</td>
</tr>
<tr>
<td>Commercial building</td>
<td>General drawing office</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Boards and Tracing</td>
<td>450</td>
</tr>
</tbody>
</table>

In composite climates, such as that in Dhaka, where both overcast (Figure 3) 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 sky conditions are quite contrasting to each other (Ahmed, 1987). In such cases, it is the overcast sky with steep luminance gradation towards zenith and azimuthal uniformity (International Commission on Illumination, 2004) that presents the more critical situation, and hence, design for daylight should satisfy good lighting criteria under overcast conditions (Evans, 1980).
Figure 3: Cloud Cover for Test Reference Years, Dhaka (Source: U.S. Department of Energy, 2008)

Table 3: Comparison on specifications for visual performances in neighbouring countries (adapted from Lighting and Energy Standards and Codes; www.lightinglab.fi)

<table>
<thead>
<tr>
<th>Country</th>
<th>Minimum illuminance on work plane (lx)</th>
<th>Minimum illuminance for Drawing (lx)</th>
<th>For Computer screen (lx)</th>
<th>Surface reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh*</td>
<td>300</td>
<td>450</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>300</td>
<td>500</td>
<td>300</td>
<td>Ceiling: 0.3-0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Floor : 0.1-0.3</td>
</tr>
<tr>
<td>Russia</td>
<td>300</td>
<td>500</td>
<td>200-400</td>
<td>Ceiling: 0.7-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Walls : 0.4-0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Floor : 0.25-0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Furniture: 0.25-0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Working Places: 0.25-0.4</td>
</tr>
<tr>
<td>China</td>
<td>300-500</td>
<td>-</td>
<td>-</td>
<td>Ceiling: 0.6-0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Walls : 0.3-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Floor : 0.1-0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Working Places: 0.2-0.6</td>
</tr>
<tr>
<td>Japan</td>
<td>500</td>
<td>750</td>
<td>500-1000</td>
<td>Ceiling: 0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Walls : 0.3-0.7</td>
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<td></td>
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<td></td>
<td>Floor : 0.1-0.3</td>
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<td></td>
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<td></td>
<td>Furniture: 0.25-0.5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Desk: 0.3-0.5</td>
</tr>
<tr>
<td>Malaysia</td>
<td>200</td>
<td>750</td>
<td>500</td>
<td>Ceiling: 0.6-0.9</td>
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<td></td>
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<td>Walls : 0.3-0.8</td>
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<td>Floor : 0.1-0.5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Working Places: 0.2-0.6</td>
</tr>
<tr>
<td>International Standard ISO 8995-1 - CIE S 008/E</td>
<td>-</td>
<td>Reading Area: 500</td>
<td>Computer Rooms: 500</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Art Room: 750</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Conference Room: 500</td>
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</tbody>
</table>

* Collected from Bangladesh National Building Code 2012
**CASE STUDY**

**Selection criteria of example case space**

The criteria for site and building selection to determine the typical exampled commercial space has 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
- The example building should represent the trend of typical commercial space design in Dhaka
- The building should be built in accordance with the Building Construction Regulations of the City Authority
- Internal layout of the example 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

**The selected building and its surrounding**

The building located on road no 6, Dhanmondi, Dhaka which is only 56 feet away from the Mirpur road. It is a six storied built form with four side open spaces around it. The 40 feet wide road is on north, a two story building on south which is 25 feet away from the built form, on east a 13 storied under construction vacant land and some coconut trees standing on west side vacant land (Figure 3).

![Figure 5: Site and surrounding of six storied Department of Architecture building of Stamford University Bangladesh](image)

**The study space (Studio 303)**

The ‘Studio 303’ has chosen for simulation study which is located on the second floor of the building (Figure 4). The room has 72’-0”x7”-6” single pane glass surfaced on three facades. The floor is covered with tint brown ceramic tiles and white shiny false ceiling from 7’-6” high from the floor surface (Figure 7). The southern wall is white painted where a 64 ft. Brown board nailed on the surface. The rest of the room is occupied with 27 drafting tables (white) with wooden tools for sitting (Figure 5).
Figure 6: Longitudinal section of the building with surrounding

Figure 7: Site photos, floor Plan, blow up plan and the typical sections of the case space
**SIMULATION STUDIES**

The amount of daylight infiltration and its eminence in interior spaces due to the changes in the height of light shelves can be assessed by simulation study. But Joarder et al. argues that 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 analyse the lighting situation for any period of the year simply by assigning simulation parameters (like location, date, time, sky condition etc). In this particular research, simulation process has attempted by three PC version simulation programs in following manner. Firstly, the existing situation had simulated by Ecotect 6.0 to cross check with physical survey values (Figure 8). Both the figures are showing that the Illumination values decreasing from north side fixed glass to south side solid wall. Point 1, 2 and 3 have achieved the recommended Illumination but rest six points fail to reach on recommendation. Moreover, point 7 and 8 is in poor condition for activities like drafting and model making. To achieve the desired Illuminance further simulation has to attain with innovative design approaches like using light-shelf, sky-window, reflecting duct etc.

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

Location: Dhaka, Bangladesh (90.40 E, 23.80 N)

Time: 3 October, 11:00 to 16:00 (Time of physical daylight measurements by CEM DT-8820 environment meter to compare with simulation outputs)

Calculation Settings: Full Daylight Analysis

Precision: High

Local Terrain: Urban

Window (dirt on glass): Average

Sky Illumination Model: International Commission on Illumination (CIE) Overcast

Design sky Illuminance: 16,500 Lux (Khan, 2005)

Figure 8: Survey values and simulation values of existing case space
The interior space had 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 (Joarder, 2009). The other parameters of the model of the example space, which were incorporated from values found in a physical survey, are as follows.

Dimension of Studio 303: 23'-0"x36'-2"
Clear height: 9'-6" (false ceiling at 8'-6" level)
Work plane height: 2'-6"

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

Ceiling: White Gypsum 24"x24" panels (reflectance: 0.8).
Internal wall: White painted brickwork (reflectance: 0.7).
Floor: Brownish ceramic tiles finishes (reflectance: 0.6).
Glazing: Single pane of glass with aluminium frame (reflectance: 0.92, U value: 6W/m²K).

For the purpose of the simulation, the entire room had divided into grids (Figure 9). Then 77 points in the classroom were selected for generation of daylight levels at 2'-6" above floor level, representing the work plane height for drafting in architectural studio. Each intersection point of the grid was coded according to the number-letter system shown in Figure 9.

Figure 9: Plan showing node references

Daylight simulation had 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). Two alternative models of the same space were created for varying heights of light shelves (6'-0" and 7'-0")
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.

RESULTS AND DISCUSSIONS

The simulation shows that only installing the light shelf over the eye level will increase the overall Illuminance level of the case space. Moreover, light shelf of 7'-0" high from floor level penetrates less Illuminance than that of 6'-0" high (Figure 10). But point 1-3 remains in a position of excessive Illumination and point 7 and 8 are needed more light for drafting tasks. Further design strategies can be attained for better daylighting performance in the case space. Some of the innovative installations have shown in the figure 11 where reflecting roof and ceiling been introduced with light shelf for north light. If these sections should be simulated then a comparing situation would be possible to attain a fixed solution for the improved daylight penetration of the case space.

Figure 10: Simulation results from ECOTECT V6.0
CONCLUSION

This simulation study was performed to find out the effectiveness of light shelf in tropical location, with predominantly overcast skies. 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. 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. The incorporation of reflecting ceilings and false ceilings and their proper angle will open a new domain on the decision of sustainable architectural design for this kind of non-residential buildings in future.

REFERENCES


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