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Light Zone: An Assessment Tool of Spatial Depth and Aperture Height Relationship for Tall Office Buildings of Dhaka

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ABSTRACT

Light zone is a key concept in assessing the luminous environment of the building. It is the subdivision of spaces inside the building that have varying illumination level. Zones vary with orientation and with aperture to environmental conditions at different times. Therefore, a basic climate responsive planning at the conceptual stage is to make the effective light zone as large as possible to reduce energy consumption. This paper presents a simulation study of evaluating performance of aperture height for tall office buildings in the context of Dhaka. Three selected aperture heights were evaluated based on depth of light zones on working plane. Simulation results showed that the design of building envelope with opening height need to be explored for desired performance. The results also indicated that height of aperture has significant effect on efficient lighting level performance. Modification of the parameters may make the aperture height effective in different orientations at the desired periods.

Keywords: Light zone, spatial depth, aperture height, tall office buildings, the simulation study, Dhaka

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INTRODUCTION

With With the rapid growth of urbanization and industrialization, development of science and technology has shifted from low to high-rise buildings due to the pressure of population in much of the world and Dhaka is no exception. Dhaka is the fast growing capital city of Bangladesh. In 2011 it had an estimated population of about 20 million (STP report 2011) and every year the city is adding more than 400,000 people to its population. With such a growth scenario, Dhaka has become the center of commerce and economy in Bangladesh. Due to increase in demands for working spaces, high-rise office buildings have evolved with the new concept of healthy open office from globalized world leaving backward conventional compartment system. To satisfy the new addition of single floor office the modern office buildings are being planned with large floor area. As a result with dark zone dependency on artificial lighting is increasing energy consumption. To solve the obstacle of the new era the recent construction of tall office buildings in urban areas of Dhaka is being characterized by extensive use of glass as envelope on large apertures. They have been designed without any respect to the interdependence between outdoor and indoor climate (Ahmed, 2003). The common practice now is to provide curtain glass envelope which is aesthetically pleasing as well as invites natural light and view for the occupants.

Fenestration and building envelope design has been found to be the most significant factor affecting energy use in high-rise buildings in the tropics (Muhammad, et. al., 2005).Vast vertical glass surfaces of recent tall buildings helps in natural light inclusion to enhances the visual quality adding drama, excitement and dynamism in the architecture and aesthetics of spaces. Among the advantages of daylight are physiological as well as psychological benefits for users (Robbins, C.L., 1986). Not only does it allow one to save on electricity consumption for lighting, but some studies show that provided glare can be controlled, people perform better when exposed to daylight (Boyce, P., et. al., 2003). In the tropics, with the direct sun light may enter unwanted heat. Too much or unguided direct daylight may cause glare (Bell, J., Burt, W., 1995). All these negative effects have energy implications, i.e. electricity consumption may be required to minimize these adverse effects. Therefore an informed balance must be struck between energy saved from artificial lighting use by daylight inclusion and that spent to get rid of excess heat by air-conditioning (Ahmed, Z.N., 2006).

The question of daylight inclusion in current tall office buildings is extremely important for economic, environmental sustainability and energy issues. Being day use buildings, a significant portion of the use of these spaces coincides with times of substantial outdoor lighting. Natural light inclusion in glass buildings in the tropics would be more effective if effective daylight can be enhanced excluding direct sun light penetration. Aperture height may play a great role in this respect. However, at present in Dhaka there is only little consciousness regarding the vast glass facades, aperture height and performance in spatial depth.

A dynamic computer simulation program named 'Ecotect' (version 2011) with 'Radiance'(version 2.0b) has been used for this simulation study to examine the existing aperture height-spatial depth ratio in different orientation at different times of the day in terms of their performance in increasing effective light zones.

AIMS AND OBJECTIVES

The study is an attempt (Fig.1) to investigate the performance of commonly applied opening heights for glass facades of tall office buildings of Dhaka as a method of light zoning with the following objectives:

- To evaluate the existing opening heights, as direct and diffuse light control tools.
- To develop an understanding, regarding issues relevant to opening height-spatial depth relationship.

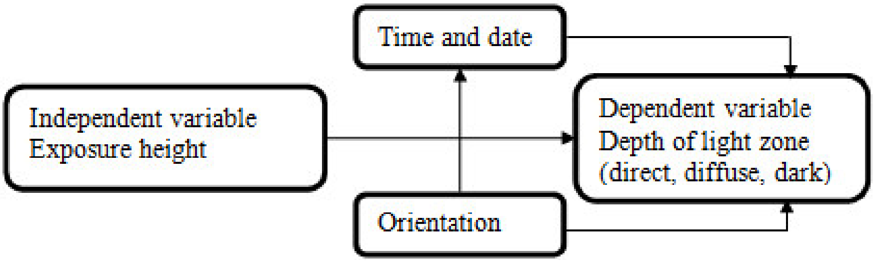

Fig. 01: The conceptual framework of the objective with other fixed variables

TALL BUILDING: DEFINITION AND CRITERIA

The experts differ in defining the physical parameters of tall buildings. According to the Council for Tall Buildings and Urban Habitat (CTBUH), a tall building is not strictly defined by the number of stories or its height. The important criterion is whether or not the design, use or operation of the building is influenced by some aspects of tallness.

David Fisher defines the tall buildings as 'We build tall buildings of necessity; how we build them is a reflection of society. Tall buildings do not have to be beautiful, they simply must be functional; so it is the degree of our concern for their beauty that serves as a measure of our humanity' (Attia, 1990).

According to Ken Yeang (Yeang, 1997), a tall building can be characterized by

a) A small foot-print in comparison to its total built-up space
b) Tall facades due to its height
c) Small roof-area in comparison to external-wall area
d) Specialized engineering systems, different from the low rise building type simply because of its height.

Taranath defines tall building from structural aspects, design and construction point of view. According to him (Taranath, 1998), it is simpler to consider a building tall when its structural analyses and design are in some way affected by the lateral loads.

However, there is no fixed parameter of height to denote tall and high-rise building. In view of the considerations stated below, buildings above six storeys may be considered tall in the present context of Dhaka city.

a) Walk up limit I provision for lift:
   - According to Building construction rules (2006), buildings of seven storied and above in height shall have provision for lift.
   - According to Bangladesh National Building Codes (1993), lifts shall be provided in buildings more than six storied or 20m in height.
b) Fire escape provision:
   - According to Fire Service and Civil Defense rules, buildings of seven storied and above in height shall have provision for Fire escape/ alternative staircase.

LIGHT ZONE

The term 'light-zone(s)' is a translation of the Danish word lysrum, which most immediately can be translated as 'light space(s)', or more aptly as 'light-zone(s)'(Madsen,2007).A common nomenclature is the tropic is to use three main natural light zones, the direct, diffuse and dark zone. A direct zone is direct sun ray lit and makes use of solar gain for heating. Direct sun light helps to illuminate the nearest surroundings as non direct light and becomes diffuse with the distance from aperture. In addition to this sky light, internally and externally reflected light of day light act as prime component of diffuse light zone. After a certain distance from aperture illumination level falls below accepted level for specific works can be called dark zone. Diffuse light zone uses less man-made energy than direct and dark zone as it maintains effective illumination level with minimum thermal gain.

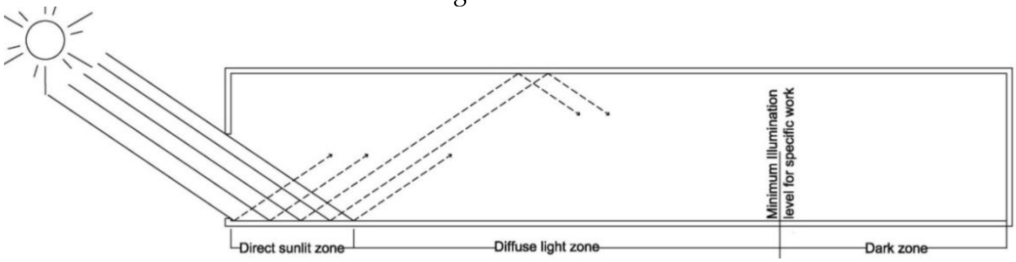

Fig. 02: typical zoning of natural light in space

Direct sun light penetration depends on the following factors (McMullan, 1992):

- The geographical latitude of the site, which determines the height of the Sun in the sky.
- The orientation of the building on the site
- The season of the year, this also affects the height of the Sun in the sky.
- The local cloud conditions, which can block solar radiation.
- The angles between the Sun and the opening with time because maximum heat gain from direct sun light occurs when surfaces are at right angles to the rays from the Sun.
- The nature of the window glass and whether it absorbs or reflects any radiation.

In spite of these, day light penetration may depend upon the following factors:

- Window size
- Space color
- Space geometry
- External obstruction
- External shading device
- Internal curtain, blinds, furniture
- walls, floor, ceiling material

Performance Evaluation Process

The performance of opening height and its impact on light zone creation can precisely be evaluated by simulation study. In reality, due to the simultaneous influence of many different conditions, it is not easy to isolate the exclusive effect of one single aspect or the changes of it. Simulation allows it in one aspect, keeping other factors constant .it is possible to analyze the performance of opening for any period of the year simply by modifying simulation parameters. Evaluation process comprises the following steps:

- Selection of opening height
- Setting criteria for performance evaluation
- Preparing climate database
- Setting simulation parameter
- Simulation program verification with physical case study.
- Developing simulation model
- Analyzing results of simulation

SELECTION OF OPENING HEIGHT

Before making selection of opening, tall glass facade office buildings of Dhaka in different commercial areas like Motijheel, Dilkhusha, Karwan Bazaar, Panthapath, Sher-E-Bangla Nagar, Banani and Mohakhali were identified. After that buildings were categorized on the basis of the opening heights. Three opening heights were selected (Table I) to evaluate performance in terms of light zone in respect of illumination level.

Sl.no.	Identification no.	Location	Opening height
1	H01	BCC Bhaban,Agargaon	2134mm
2	H02	Royal Tower,4 Panthapath	3048mm
3	H03	BDBL Bhaban,12,Karwan Bazar	3658mm

Table I: selected case study with aperture height

CRITERIA FOR PERFORMANCE EVALUATION

An Australian publication (Piax, 1962) has already given a simplified version of lumen method for the prediction of day lighting. From a basic graph they read the illumination level for points at various distances from window (expressed as multiples of the window head height above the working plane), for continuous strip window. However, they did not consider direct sun light for analysis. They did not identify direct and diffuse light zone with time. In order to evaluate the performance of aperture height in creating light zones in various spatial depths at different orientations and periods of the day, graphs are analyzed in this paper on the basis of the following developed simple equations:

Spatial depth vs. time for considered aperture height:

- Spatial depth=∑ depth of (direct sun light and diffuse light zone)
- Depth of direct sun light zone = depth of the zone illuminated by direct sun light from aperture location on working plane
- Depth of diffuse light zone = depth of (zone providing required illumination level of 500lux on working plane from aperture location - direct sun light), According to Chartered Institute of Building Services Engineers (CIBSE,2002) minimum illumination level for general office=500lux
- aperture height=window head from floor level

Average depth of direct sun light zone vs. aperture height:

- Average depth of direct sun light zone

$$= \frac{\sum \text{depth of direct sun lit zone at hourly interval for the critical period of the day}}{\sum \text{duration at critical period}}$$

Average depth of Diffuse light zone vs. aperture height:

- Average depth of Diffuse light zone

$$= \frac{\sum \text{depth of Diffuse light zone at hourly interval for the critical period of the day}}{\sum \text{duration at critical period}}$$

As dark zone continues from 500lux to infinity, depth of the dark zone is not analyzed in this paper.

SIMULATION PARAMETERS

To investigate the results of the simulations, a specific day has been selected (from the weather database for the year 2012, Dhaka, Tejgaon (Mil) Bangladesh) on the basis of some specific attributes to observe the results. The test day is March 21 (Day: 80). Outdoor air temperature range of this day is 24.5°C -35.4°C and sky condition is clear. From 0900-1700 hours the cloud cover is 1.1 out of 8.0 (13.8% coverage). This is a day with considerable high outdoor air temperature but not the extreme one and bears a common character regarding the climatic features especially of the hot season. The average temperature of this day (29°C) is very close to the average temperature of the season (28.02^{0}C). It has been observed that the sky condition in the given climate is clear for 67 percent of the whole pre-monsoon period and the 'clear sky' condition prevail for the chosen day. This 'clear sky' condition of the chosen day is also important to investigate the impacts as clear sky condition enhances the direct sun light to reach the openings.

The height on top of the aperture works as overhang which can be called a fixed shading device. For a fixed shading device, the shading period is symmetrical about June 21. This is because the position of the sun cycles, relative to earth, through the sky on a seasonal basis. Thus, the sun will pass through the same path twice every year, the first time when going from winter to summer and the second time when traveling back to winter. Thus, any shading device will always shade between two dates. In the northern hemisphere, an optimized shading device for March will actually shade from the 21st of March, right through June until the 21st of September (Lechner, 2001). Thus, the whole over illumination period (hot-dry and warm-humid) is taken into account for simulation.

For simulation, to investigate the performance of the opening height, the period is considered when the space is used during office hours. In general, the office time is from 0900 to 1700.This period is taken as critical to examine depth of light zones for four orientations- north, south, east and west.

LIMITATIONS

There are many variables i.e. glare, thermal radiation, obstruction of both interior and exterior space which may give different results in defining effective light zone. In this paper the investigation is done on the basis of illumination level, depth of the zones of direct sun and diffuse light.

CLIMATE DATABASE

The weather file 'Dhaka_Bangladesh.wea' has been prepared for the research purpose by using the Weather Tool, associated software of Ecotect. Hourly weather data 'BGD_Dhaka.419230_SWERE.epw was collected from US Department of Energy. Hourly weather variables for Dhaka/Tejgaon_(MIL) are given(Table II) for the year 2012.

Parameters	Details
Latitude	23.8°' North
Longitude	90.4° East
Time Zone (hours ahead of GMT)	GMT +06.00

Table II: site parameters of Dhaka for weather file

Using the hourly weather variables, the simulation program 'Ecotect' with 'Radiance' is capable to analyze hourly illumination level at any point on the working plane of the selected site.

SIMULATION PROGRAM AND VERIFICATION

'Ecotect' cannot analyze change of hourly illumination level with time. Model from 'Ecotect' is exported to 'Radiance' as luminance image for grid analysis using 'current date and time' and 'sunny with sun sky' .Then it is again imported to 'Ecotect' after final render of the interior view.

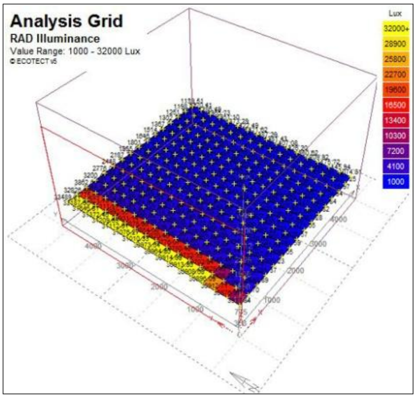

Fig. 03: Rad illuminance in'Ecotect'

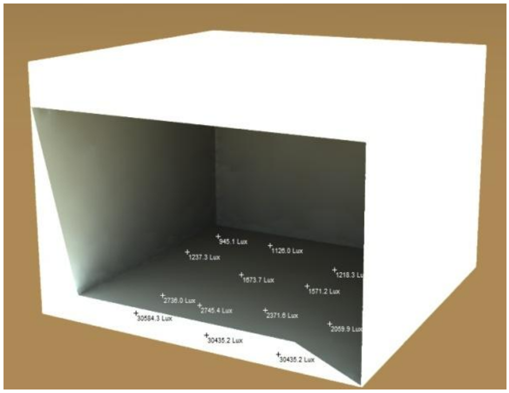

Fig. 04: 'Radiance' render output

For verification of the simulation programs a room (appendix)has been taken as case study and readings of illumination level at a distance from aperture are taken using Digital Lux Meter (Mastech Lux meter LX1330B, Ranges: 0-200/2,000/20,000/200,000 Lux)at various times of the day. These data are compared with the simulation data under same condition (Table III). The difference between Lux meter and simulation reading is so negligible that no correction factor has been used for the simulation readings in this paper.

Time(Hrs)	Distance from aperture(mm)	Lux meter reading (lux)	Simulation reading(lux)	**Building Parameters:**
09:00 21 March	305	1758.1	1764.3	Office room dimension: 5105mm x 5242mm Floor height : 3658mm Window orientation : West Width : 5242mm, height:3658mm Overhang: No overhang Wall: brick plaster Concrete ceiling Concrete slab on ground working plane: 760mm height from the ground
	1524	1385.9	1397.2	
	3048	1102.2	1110.1	
13:00 21 March	305	31611.3	30875.1	
	1524	2430.4	2577.3	
	3048	1698.1	1761.4	
17:00 21 March	305	14121.5	14118.1	
	1524	14440.8	14446.9	
	3048	14890.4	14500.3	

Table III: comparison of the simulation reading and Lux meter reading

Simulation Model

Following models (Fig. 7.2-9.2) have been developed for simulation that represents the selected aperture height with overhang. However, for the variation of material in selected buildings void for opening, floor and ceiling of concrete and brick plastered wall are assumed for the ease of simulation and comparison. The room size for simulation model is 18288mm x 6096mm which is considered to be located at an intermediate floor (Fig.05) of a high-rise building. The room breadth 6096mm is taken from the typical high-rise column grid and length 18288mm is taken analyzing sun path diagram for west façade at 5p.m. as the sun comes to the lowest point near horizon for this orientation during the selected critical period. Opening width 6096mm has been considered as the window covers the whole span between two columns (Fig.06).For the ease of calculation, a working plane at 760mm height from floor has been considered. In terms of depth of light zone, direct and diffuse light zone analysis, the simulations are done for the three typical aperture heights 2134mm, 3048mm and 3658mm found in survey.

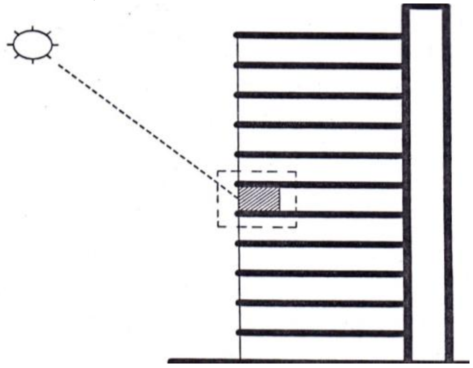

Fig.05: Section of typical high rise building (Source: Rahman.A and Ahmed.K.S, 2008)

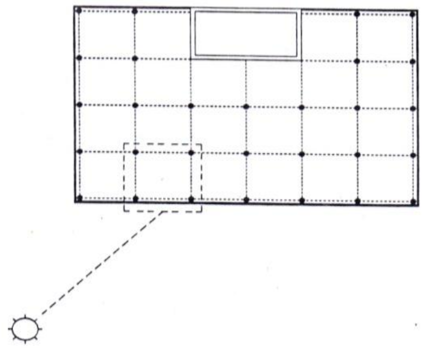

Fig.06: Typical floor plan of high rise building (Source: Rahman.A and Ahmed.K.S, 2008)

SIMULATION RESULTS

To evaluate the performance on the basis of set criteria discussed earlier, a comparative analysis among the selected apertures are summarized in the following section.

Performance of aperture height with change of time: North

Table IV shows the depth of light zones on working plane by three selected aperture heights for north orientation. All apertures are capable of maintaining maximum depth of diffuse light zone excluding direct sun light all day long during the critical period. The depth of the diffuse light zone decrease as time passes before and after 1200 hrs (Fig.10.1). Simulation results show that among the three apertures, H03 can bring diffuse light up to the maximum depth of 9.45m from the aperture. Similarly, H02 and H01 can lit maximum 8.87m and 7.35m.

Aperture Height	H01			H02			H03		
Time	Total	Direct	Diffuse	Total	Direct	Diffuse	Total	Direct	Diffuse
900	6.10	0.00	6.10	7.92	0.00	7.92	8.99	0.00	8.99
1000	6.71	0.00	6.71	8.47	0.00	8.47	9.14	0.00	9.14
1100	7.25	0.00	7.25	8.78	0.00	8.78	9.39	0.00	9.39
1200	7.35	0.00	7.35	8.87	0.00	8.87	9.45	0.00	9.45
1300	7.16	0.00	7.16	8.84	0.00	8.84	9.45	0.00	9.45
1400	6.77	0.00	6.77	8.53	0.00	8.53	9.14	0.00	9.14
1500	6.34	0.00	6.34	8.08	0.00	8.08	8.93	0.00	8.93
1600	5.64	0.00	5.64	7.47	0.00	7.47	8.32	0.00	8.32
1700	5.03	0.00	5.03	6.55	0.00	6.55	7.92	0.00	7.92
Avg.	6.48	0.00	6.48	8.17	0.00	8.17	8.97	0.00	8.97

Table IV: Variation of light zonal depth (m) with time (hrs) for the north, 21 March

Performance of aperture height with change of time: South

Table V shows in south orientation, direct sun light zone remains constant from 900 to 1500 hrs and after that begins to fall. The depth of the diffuse light zone decrease as time passes before and after 1200 hrs (Fig.10.2). However, depth of diffuse light zone decreases slowly after 1200hrs than before. H03 can bring direct sun light up to 0.91m and at 1200hrs diffuse light up to the maximum depth of 12.07m.H02 and H01 can light maximum 11.43m and 9.81m after direct sun light zone with diffuse light.

Aperture Height	H01			H02			H03		
Time	**Total**	**Direct**	**Diffuse**	**Total**	**Direct**	**Diffuse**	**Total**	**Direct**	**Diffuse**
900	7.92	0.30	7.62	10.42	0.61	9.81	11.28	0.91	10.36
1000	9.45	0.30	9.14	11.28	0.61	10.67	12.19	0.91	11.28
1100	10.06	0.30	9.75	11.89	0.61	11.28	12.80	0.91	11.89
1200	10.12	0.30	9.81	12.04	0.61	11.43	12.98	0.91	12.07
1300	10.06	0.30	9.75	11.92	0.61	11.31	12.83	0.91	11.92
1400	9.60	0.30	9.30	11.43	0.61	10.82	12.34	0.91	11.43
1500	8.87	0.30	8.56	10.67	0.61	10.06	11.77	0.91	10.85
1600	7.62	0.27	7.35	9.45	0.46	8.99	10.21	0.91	9.30
1700	5.79	0.21	5.58	7.62	0.30	7.32	8.53	0.91	7.62
Avg.	8.83	0.29	8.54	10.75	0.56	10.19	11.66	0.91	10.75

Table V: Variation of light zonal depth (m) with time (hrs) for the south, 21 March

Performance of aperture height with change of time: East

Table VI shows in east orientation, direct sun lit zone depth gradually decreases from 900 to 1200 hrs and after that there is no existence of direct sun light zone. The depth of the diffuse light zone decrease all along the critical period as time passes (Fig.10.3) and it is faster before 1200 hrs. H03 can bring direct sun light at maximum depth of 3.05m from aperture location at 900hrs and diffuse light up to maximum depth of 13.26m.H02 can light maximum 12.19m and H01 can light maximum 10.82m with diffuse light.H03 helps to bring maximum direct and diffuse light in comparison to other two apertures at the same time.

Aperture Height	H01			H02			H03		
Time	**Total**	**Direct**	**Diffuse**	**Total**	**Direct**	**Diffuse**	**Total**	**Direct**	**Diffuse**
900	12.04	1.22	10.82	14.63	2.44	12.19	16.31	3.05	13.26
1000	10.70	0.64	10.06	12.80	1.83	10.97	13.87	1.52	12.34
1100	9.14	0.30	8.84	10.97	0.46	10.52	11.89	0.91	10.97
1200	7.47	0.03	7.44	9.17	0.06	9.11	9.75	0.12	9.63
1300	7.07	0.00	7.07	8.84	0.00	8.84	9.45	0.00	9.45
1400	6.77	0.00	6.77	8.53	0.00	8.53	9.14	0.00	9.14
1500	6.13	0.00	6.13	7.99	0.00	7.99	8.99	0.00	8.99
1600	5.49	0.00	5.49	7.38	0.00	7.38	8.20	0.00	8.20
1700	4.60	0.00	4.60	6.64	0.00	6.64	7.59	0.00	7.59
Avg.	7.71	0.24	7.47	9.66	0.53	9.13	10.58	0.62	9.95

Table VI: Variation of light zonal depth (m) with time (hrs) for the east, 21 March

Performance of aperture height with change of time: West

Table VII shows in west orientation, there is no existence of direct sun light zone till 1200hrs. After 1200hrs direct sun as well as diffuse light zone depth gradually increases as time passes (Fig.10.4). H03 can bring direct sun light at maximum depth of 10.67m from aperture location at 1700hrs and after 1300 hrs diffuse light zone exceeds the full spatial depth of the model.H02 and H01 can light maximum 8.23m and 4.88m with direct light at 1700hrs.H01 helps to bring maximum diffuse light with minimum depth of direct sun lit zone in comparison to other two apertures at the same time.

Aperture Height	H01			H02			H03		
Time	Total	Direct	Diffuse	Total	Direct	Diffuse	Total	Direct	Diffuse
900	6.13	0.00	6.13	7.96	0.00	7.96	8.56	0.00	8.56
1000	6.71	0.00	6.71	8.53	0.00	8.53	8.87	0.00	8.87
1100	7.16	0.00	7.16	8.84	0.00	8.84	9.39	0.00	9.39
1200	7.35	0.00	7.35	9.14	0.00	9.14	9.75	0.00	9.75
1300	8.87	0.06	8.81	10.67	0.30	10.36	11.73	0.61	11.13
1400	10.52	0.61	9.91	12.50	1.22	11.28	13.47	1.52	11.95
1500	12.19	1.22	10.97	14.33	2.13	12.19	15.85	3.35	12.50
1600	13.41	2.13	11.28	17.37	3.66	13.72	18.59	4.88	13.72
1700	14.94	4.88	10.06	19.81	8.23	11.58	22.86	10.67	12.19
Avg.	9.70	0.99	8.71	12.13	1.73	10.40	13.23	2.34	10.89

Table VII: Variation of light zonal depth (m) with time (hrs) for the west, 21 March

Average Performance of aperture height

Table VIII presents the average depth of light zones during the critical period for different aperture heights and orientations. For north orientation, H03 brings diffuse light up to maximum 8.97m average depth from aperture location that is higher in comparison to others. In south H03 creates maximum depth of both direct and diffuse light, 0.91m of direct sun lit zone and 10.75m of diffuse light zone. In the east maximum average depth of direct and diffuse light zone for H03 is 0.62m and 9.95m. In the west, H03 creates direct and diffuse light zonal average depth up to 2.34m and 10.89m. West opening brings maximum direct sun light .Then south and east comes in comparison. North is devoid of direct sun light.

Orientation	East			West		
Aperture Height(m)	Total	Direct	Diffuse	Total	Direct	Diffuse
2.13	7.71	0.24	7.47	9.70	0.99	8.71
3.05	9.66	0.53	9.13	12.13	1.73	10.40
3.66	10.58	0.62	9.95	13.23	2.34	10.89
orientation	**South**			**North**		
aperture height(m)	**Total**	**Direct**	**Diffuse**	**Total**	**Direct**	**Diffuse**
2.13	8.83	0.29	8.54	6.48	0.00	6.48
3.05	10.75	0.56	10.19	8.17	0.00	8.17
3.66	11.66	0.91	10.75	8.97	0.00	8.97

Table VIII: Average depth (m) of light zones, 21 March

DISCUSSION AND CONCLUSION

The investigation was carried out to evaluate the performance of commonly used aperture heights in increasing efficient light zone. Analysis of the simulation results indicated a clear understanding of the light zones with time for different aperture heights and orientation (Fig.10.1-10.4) and their contribution to defining useful spatial depth (Fig.11.1-11.4).

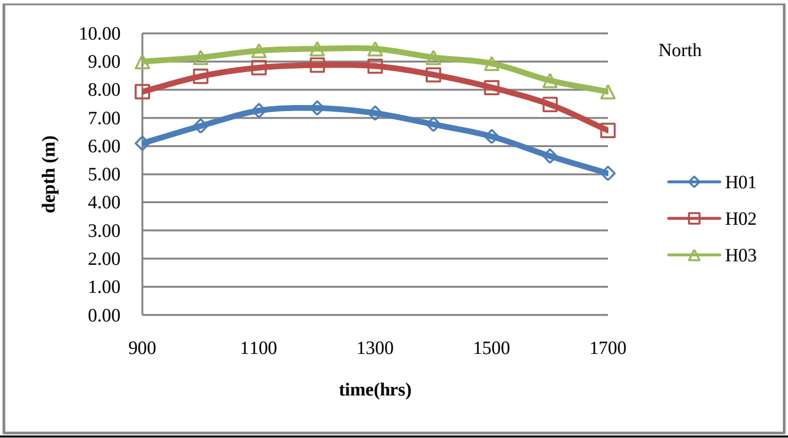

Fig. 10.1

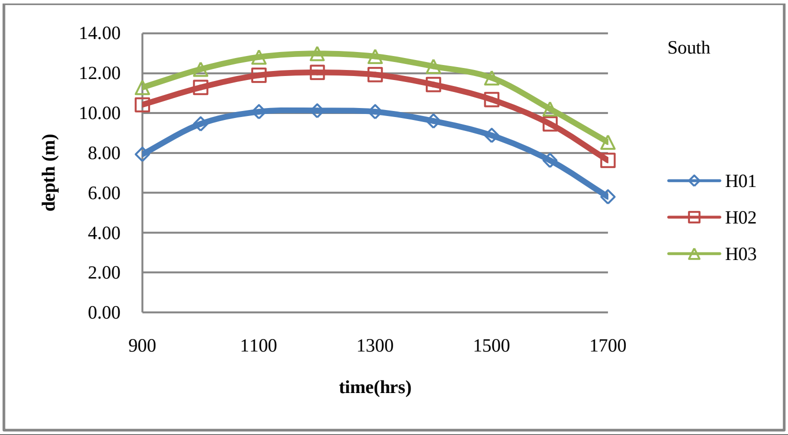

Fig. 10.2

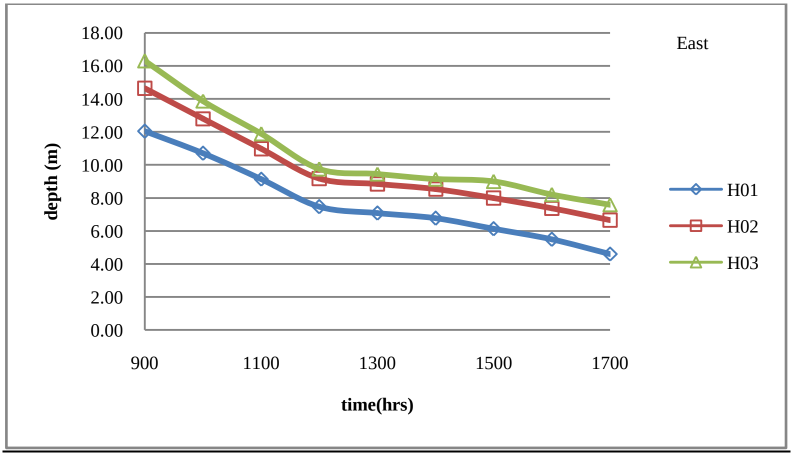

Fig. 10.3

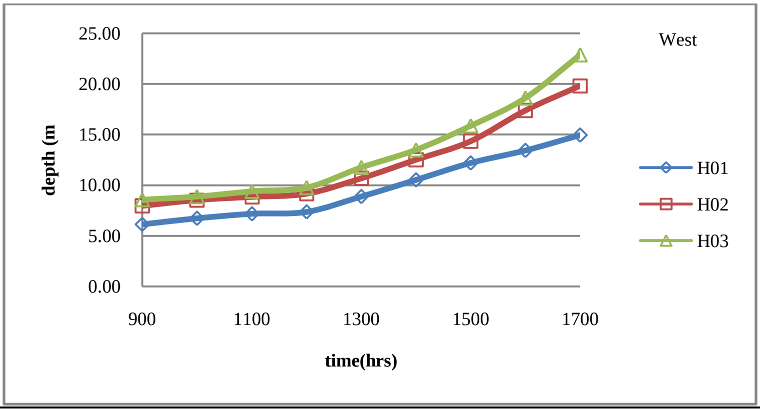

Fig. 10.4

Fig. 10: Variation of light zonal depth (m) with time (hrs), 21 March; (10.1) North, (10.2) South, (10.3) East, (10.4) West

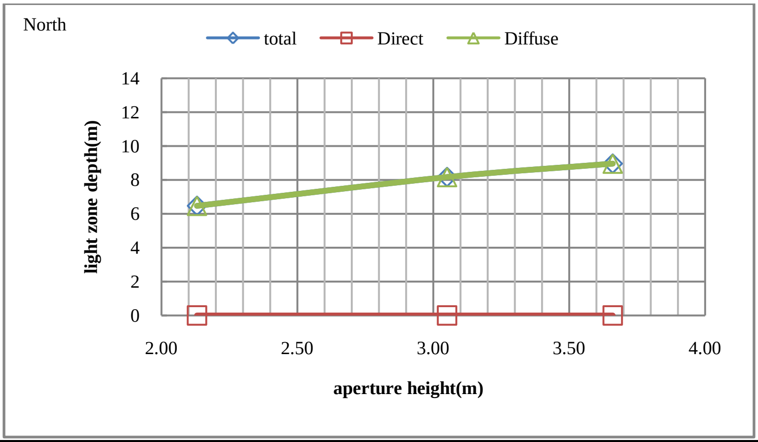

Fig. 11.1

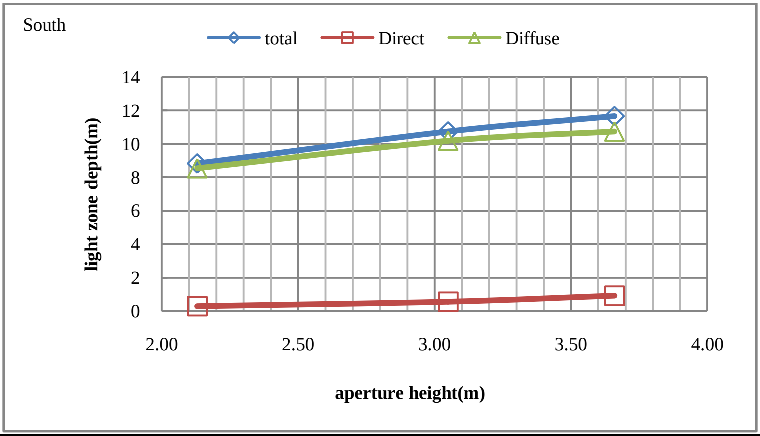

Fig. 11.2

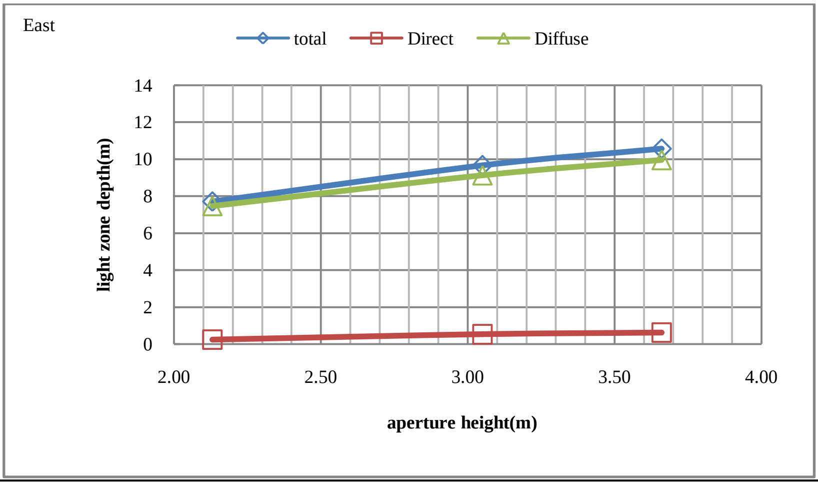

Fig. 11.3

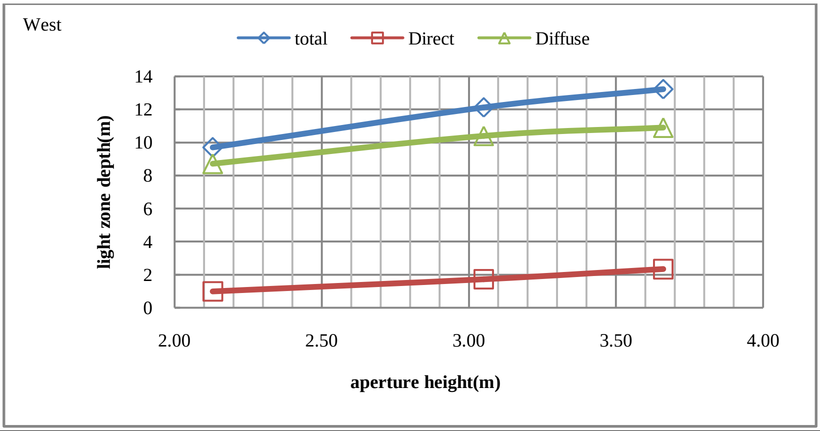

Fig. 11.4

Fig. 11: Average depth (m) of light zones,21st March; (11.1)North, (11.2)South, (11.3)East, (11.4)West

Result of the simulation indicates that for north H03 is able to create more effective light zone with the maximum depth compared to other two apertures. Diffuse light zone depth increases almost proportionately with the higher aperture height (Fig.11.1). H03 creates diffuse light zone approximately 2.5 times of the aperture height both for average and peak light period. For north higher aperture height performed better in bringing effective diffuse light as maximum spatial depth can be achieved without any direct solar gain. Full height aperture can be the most beneficial for north orientation.

In the south orientation depth of light zones with time shows almost similar nature as in the north (Fig.10.2). However, in south presence of direct sun light can be found. Diffuse and direct, depth of both light zone increases almost proportionately with the higher aperture height (Fig.11.2). H03 creates both direct and diffuse light zone with maximum depth compared to other two apertures. H03 creates direct sun lit zone approximately 0.25

times and diffuse light zone (after direct light zone) approximately 3.5 times of the aperture height for peak light period. Average direct light zone shows the same character as in peak light hour and diffuse light zone is almost 3 times of the aperture height. Full height aperture is the most beneficial for south orientation in respect of depth of lit area. Therefore, it may cause glare, thermal discomfort and light pollution for the penetration of direct sun light .In the south effective light zone can be created by taking measures to cut off direct light and converting it to diffuse during the critical period.

In the east, diffuse and direct, depth of both light zones increases almost proportionately with the higher aperture height and shows almost similar nature (Fig.11.3) as in the south. H03 creates both direct and diffuse light zone with maximum depth. H03 creates direct sun light zone approximately 0.84 times and diffuse light zone approximately 3.7 times of the aperture height for peak light period. Depth of average direct light zone is 0.17 times and diffuse light zone is almost 2.8 times of the aperture height. After 1200hrs large opening height brings huge amount of diffuse light without direct sun light. Measures should be taken for protection from direct sun before 1200hrs.For the rest of the time large opening height performs better, if the indoor-outdoor contrast level remains at moderate level.

In the west average depth of light zone vs. opening height shows almost similar nature (Fig.11.4) as in the south and east. However increase of depth is comparatively high with opening height than other orientations. H03 creates both direct and diffuse light zone with the maximum depth. H03 creates direct sun light zone approximately 3 times of the aperture height for peak light period and diffuse light zone exceeds the model depth. H01 creates direct sun light zone approximately 1.3 times and diffuse light zone 2.8 times of the aperture height for peak light period. Depth of average direct light zone is 0.65 times and diffuse light zone is almost 3.0 times of the aperture height. In respect of average performance large opening height performs better on the basis of direct and diffuse light zone ratio. However at most of the hours of the critical period large opening height penetrates direct sun light covering large spatial depth and increasing severe uncomfortable space. Therefore, for west orientation small opening height performs better than large ones with time.

To get average performance of the aperture height, analyzing the nature of the graphs of Fig. 11.1-11.4, using trend option(logarithm) of Microsoft excel (2007) the following equations can be derived from which depth(y) of effective light zone can be calculated for aperture height(x).

- **North:** Total, $y = 4.612\ln(x) + 3.002$; Direct, $y = 0$; Diffuse, $y = 4.612\ln(x) + 3.002$
- **South:** Total, $y = 5.238\ln(x) + 4.879$; Direct, $y = 1.094\ln(x) - 0.568$; Diffuse, $y = 1.468\ln(x) + 5.496$
- **East:** Total, $y = 5.312\ln(x) + 3.705$; Direct, $y = 0.714\ln(x) - 0.288$; Diffuse, $y = 4.597\ln(x) + 3.994$
- **West:** Total, $y = 6.565\ln(x) + 4.750$; Direct, $y = 2.429\ln(x) - 0.881$; Diffuse, $y = 4.135\ln(x) + 5.632$

Building materials, furniture, operable blinds and louvers, solar sensitive lamination on glass with the change of time, placing of the aperture, buffer zone creation and many other design and technology based options can then help to rectify the further problems. Otherwise over protection from direct sunlight without awareness can drop the illumination level of the interior of the glass facades .As these equations give the average performance the designer can design more precisely focusing on the change of depth of light zones with time. According to the simulation, before and after 1200hrs direct sun light as well as depth of light zones changes. Before 1200hrs west and after 1200hrs east needs no measures to predict direct sun light. However, south needs measures and north needs no control all day long of the critical period when light pollution, glare, contrast, obstacles can be controlled in the tropical environment.

After investigating the performance of commonly used aperture heights, it could be stated that more exploration of aperture height is important for optimum performance. The results of the simulation study indicate that aperture height has a significant effect on creating effective light zones. Identification of aperture height in the earliest most conceptual stages may make the luminous environment of the interior of the tall glass façade office buildings more effective in different orientations at the critical periods expanding effective light zones.

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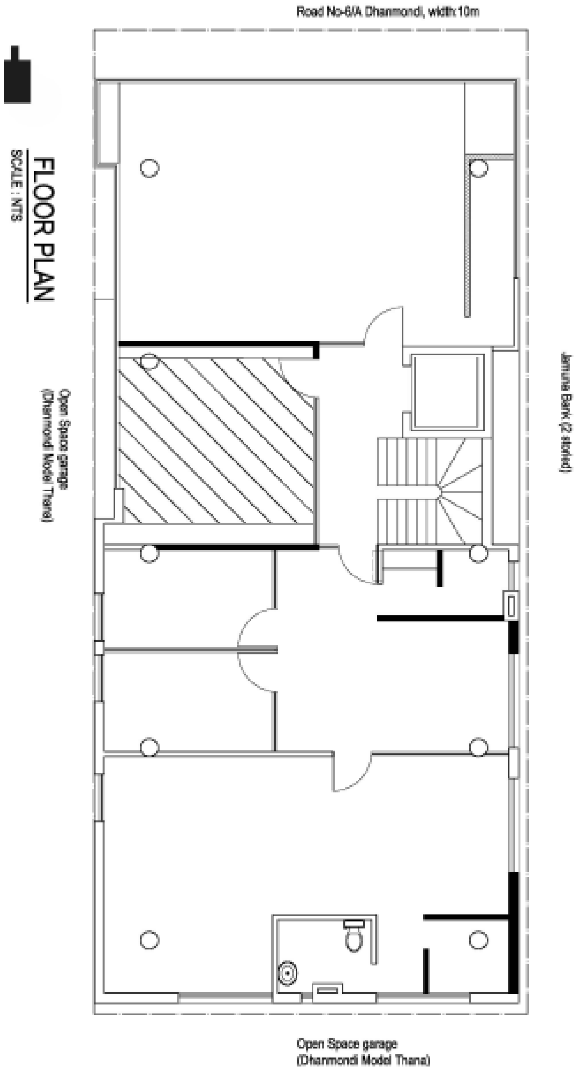
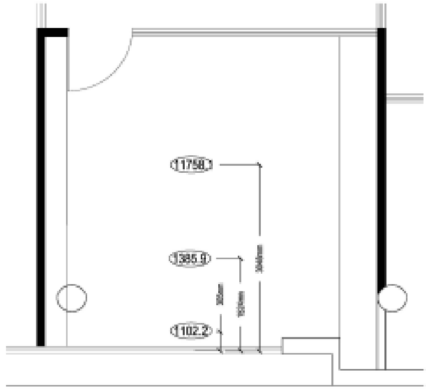
Appendix

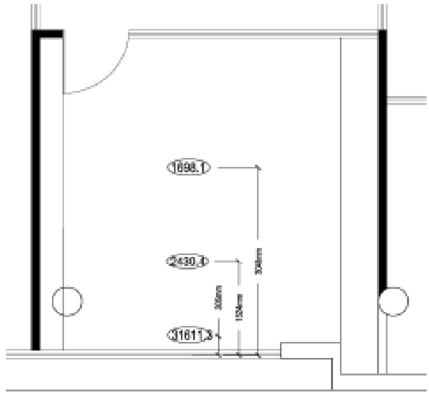
Note: Values in the ellipse are measured by Lux meter at distance from the Aperture.



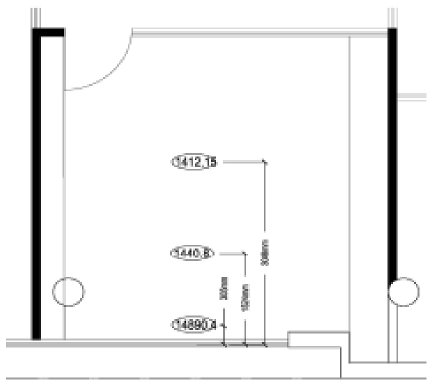
Selected for survey



Lux meter reading at 900hrs



Lux meter reading at 1300hrs



Lux meter reading at 1800hrs

- Off Pantai Dalam, Kuala Lampur, **Malaysia**
- Road # 4, Shyamoli, Dhaka-1207, **Bangladesh**
- 3900 Woodhue Place, Alexandria, VA 22309, **USA**

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