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Daylighting inside Glass Box: Responsiveness of Interior Design to External Facade

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Abstract

The purpose of this paper is to emphasise the importance of responsiveness in the interior design, to the concept, and principle, of exterior architecture. This has been highlighted through the disagreement between curtain glass walls and traditional drop ceilings, as a simple case that is common in many modern office buildings in Dhaka, and in other cities in the World. Using daylight simulation programs, this paper examines the impact of drop ceilings on indoor daylight illuminance on work plane height, at a typical office space contained in a glass box building. Daylight simulation was performed in this study, by creating the virtual environment based on the information of an existing urban office building located in Dhaka, Bangladesh, a tropical location, with predominantly overcast skies. The 3D models were first generated in the ECOTECT, to study the distribution and uniformity of daylight within the interior space using the 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 show that daylight entering from different sides of the glass box building, is affected vastly near the periphery of the floors, by the design of drop ceilings, thus influencing the overall illuminance and luminance distribution to the interior. The eradication of drop ceiling near window by careful design, e.g. ‘L’ shaped, corbelled, sloped, concaved and convex edged drop ceilings, allows more daylight into the space, increased sky view, thereby, reducing the negative impact of drop ceilings on blocking daylight into reaching deeper parts of the interior.

Key words: *daylighting, building simulation, office space, glass box, drop ceiling, responsive design*

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Introduction

It is a good architectural practice to keep the interior and exterior designs of a building consistent with each other. In reality many existing buildings have failed to show responsiveness of the interior design to the concept and principle of their exterior architectural facades. Figure 1 shows some snap shots of some commercial buildings, located at different places of Dhaka city. Figure 2 shows some pictures of the interior of the buildings. From the Figures, it is difficult to match the interiors of the buildings with their respective exteriors or vice versa, as there is little or no co-ordination between interior and exterior design of the buildings. The main reasons for this inconsistency is that, in most of the cases, different people designed the interiors at different times, after the finishing of the construction of the exterior; and when designing the interior, the major emphasis was given on artificial lighting, where drop ceiling is a common feature for most of these office buildings. A previous survey by Joarder (2009) on office buildings located at Dhaka, revealed that, among 50 surveyed cases, 74% of the offices (37 offices) use drop ceilings, thereby reducing the clear height of the working space, and creating restrictions to the window head height.

The depth of a daylit zone largely depends on window head height, along with other architectural design variables, such as, the glazed area, wall area, the nature of the glazing, and colour and height of ceilings. Typically, the depth of a daylit zone is limited to two times the window head height, in order to provide a 5% daylight factor (DF) close to the window, with a 2% DF at the rear of the space, that creates an overall sense of the space being daylit (Phillips, 2004). Greater height of window from floor provides deeper daylight penetration into the space. Therefore, a modern glass box building, which can be considered as a structure inside one full window, or a building with elevations composed of only windows, has high potential for deep daylight penetration, given its maximised window head height. In case of curtain walls, i.e. full windows, the glass area near the ceiling permits deeper daylight penetratation, but the use of drop ceilings (to accommodate concealed lighting and HVAC systems), effectively blocks the upper portions of the glass surface near the structural ceiling, limiting daylight penetration, only through the glass area below the drop ceilings. Thus, the daylight potential of the curtain-walled spaces above the drop ceiling, is compromised. Although there are a lot of glass surfaces on the outside of the building (Figure 1) - the effective parts of the glass are not equal in the interior (Figure 2). This approach of interior design, is not sensible to the factual principle of a glass box building, that potentially advocates maximum utilisation of daylight.

The paper presents the importance of the responsiveness of the interior design to the concept and principle used in the exterior or facade, by challenging the design conflict between curtain glass wall and traditional drop ceiling: a simple case that is common in many modern office buildings in Dhaka (Figure 1 and 2) and other cities in the world. The paper consists of two major parts. The first part describes the research concept and methodology.

The second part presents the results of the simulation analysis with recommended modification of drop ceillings, to increase responsiveness and design consistency in glass box architecture. It is expected that, the examples of daylight simulation presented in this paper, will help designers to comprehend the significance and benefits, of integration and agreement of interior and exterior design in architecture, quantitatively, in terms of daylighting, and for overall visual comfort.

Figure 1. *Snap Shots of some Commercial Buildings located at Different Places of Dhaka*

Figure 2. *Snap Shots of Interiors of some of the Commercial Buildings shown in Figure 1*

Methodology

Selection of Building and Site

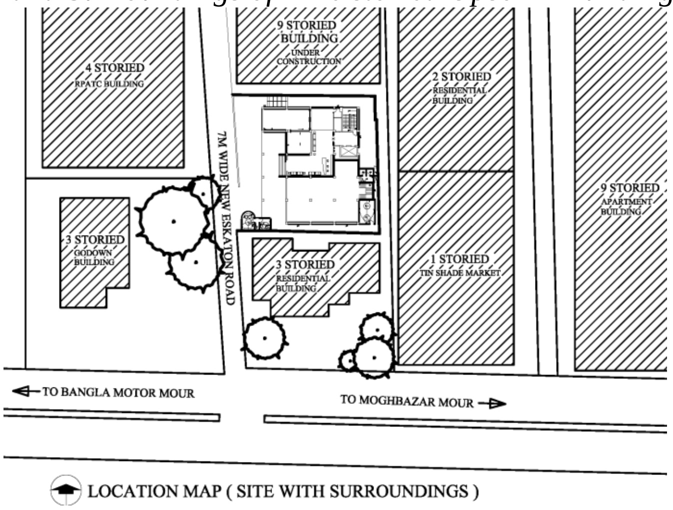
In order to test the extent of curtain walls and drop ceilings interfering with interior daylight penetration into offices located in Dhaka, it was necessary to identify a building where measurements could be taken, and the space could be used for simulation. The criteria for site and building selection, to determine the case office space, were based on the following factors.

a) The site was to be located within the urban boundary, having characteristics typical of the general urban fabric of Dhaka city (Figure 3).
b) The case office building would represent the trend of typical office design in Dhaka with curtain wall and traditional drop ceiling.
c) The building would be built in accordance with the Building Construction Regulations recommended by the City Authorities.
d) Internal layout of the case office space would be such that, there should be provision for ample daylight inclusion and distribution.
e) The scale and volume of the building would be representative within the conurbation.

Figure 3. *Location of Nine Story Opsonin Building in Urban setting*

After a survey of 50 office buildings in the city (Joarder, 2009), based on the above criteria, the nine-storey Opsonin Building (corporate office of Opsonin Pharma Limited) was selected for the study (Joarder et al., 2009a; 2009b). The 2nd floor of the building was chosen as the case 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 nine-storey building, 2.5m from the northern edge was under-construction during the survey; 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 4).

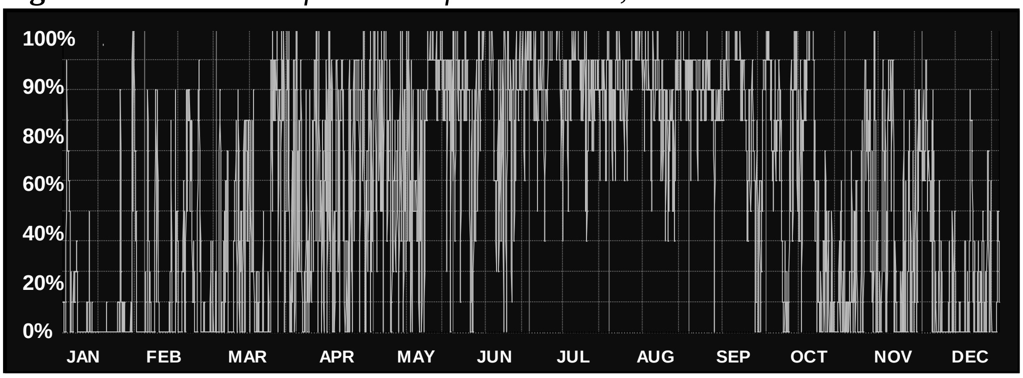
Figure 4. *Site and Surroundings of Nine storied Opsonin Building*



Sky Condition

The climate of Dhaka is tropical and has 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 can be both clear (with sun) as well as 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 remains mostly clear. Figure 5 shows sky condition of Dhaka, with respect to cloud cover, for test reference years (TRY).

Figure 5. *Cloud Cover for Test Reference Years, Dhaka*



(Source: U.S. Department of Energy, 2008)

In composite climates, such as that in 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 sky conditions are quite contrasting to each other (Ahmed, 1987), for example, windows with fixed horizontal overhead shading is suitable for overcast sky condition, while, vertical and movable devices are recommended for clear skies. 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, 1980).

The calculations of the simulation study of this paper follow the DF 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 (Joarder et al. 2009a).

Simulation Study

The amount of daylight penetration, and its quality inside office interiors, under the impact of drop ceilings, can be assessed by simulation study. Parametric simulation allows study of the exclusive effect of small modifications of different design elements (i.e. drop ceilings) on daylighting, keeping other elements constant, e.g. floor area, window to floor ratio and internal finish materials. This effect is difficult to achieve in real world studies, due to the simultaneous influence of the combined impacts of different environmental and artificial aspects (e.g. maintenance). The observation of simulated behaviour, related to the design of drop ceilings, allows the identification of shape(s), the introduction of which in design, contributes towards increased daylight penetration. Another significant advantage of a simulation study is, that it becomes possible to analyse the lighting situation for any period of the year, simply by assigning the relevant simulation parameters (e.g. location, date, time and sky condition). In the present study, two simulation programs were used, to investigate and analyse, the impact of drop ceilings, on indoor daylight illuminance, at work plane height. The first program is a comprehensive building analysis software, ECOTECT v5.20, which is a highly visual, architectural analysis tool (Crawley et al, 2005), with lighting, thermal, energy, shading and acoustic performance analysis functions (Osaji et al, 2009). The second one is a more focused and accurate daylighting simulation tool, Desktop RADIANCE 1.02 (Baker, N. et al., 2002; Ward, 1994).

Simulation Parameters

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

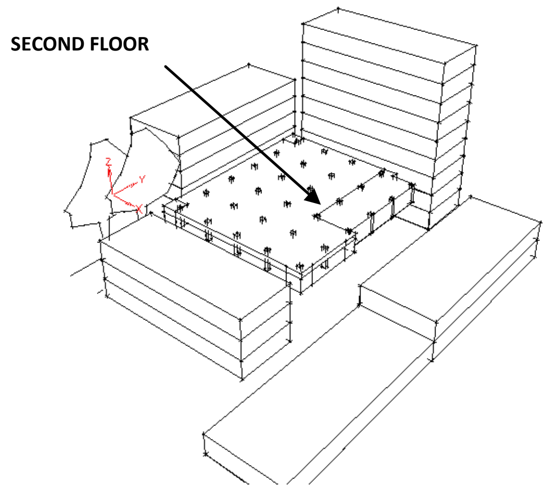
Location : Dhaka, Bangladesh (90.4^0 E; 23.8^0 N).

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).

Case Space

The second floor of the building was chosen, as the case space for the simulation study (Figure 6). All indoor and outdoor conditions were kept constant, as found in a physical survey (Joarder, 2007). The models were created, assuming un-shaded, peripheral glazing wall. The interior space was 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 difference of the impacts of the different ceiling conditions being assessed. The other parameters of the model of the case space, which were incorporated from values found in the physical survey, are as follows.

Figure 6. *View of Model used for the Simulation*



2nd floor dimension	: 25m x 28.5m
Total floor area	: 692 sqm
Usable office space	: 577 sqm
Service area	: 115 sqm
Floor to ceiling (structural) height	: 3m
Floor to ceiling (drop) height	: 2.10m
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.

Drop ceiling : 10mm suspended white plaster board ceiling (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: $6W/m^2K$).

The upper and lower floors of the case space were shown hidden during simulation, as it was found during trial simulation study, that these floors had negligible contribution to simulation output, while their inclusion merely prolonged the simulation processing time (Joarder et al. 2009a; 2009b) (Figure 6).

Performance Evaluation Process

For the purpose of the simulation, the entire office case space was divided into grids, with reference to column-structural grid (Figure 7). Then 83 intersecting points in the open office space were selected to generate daylight levels, at 0.75m above floor level, representing the work plane height for offices in Dhaka (Joarder, 2009). The simulated illumination values, generated by ECOTECT, for the 83 grid points were then plotted into Tables, with the codes coinciding with intersection of letters (rows) and numbers (columns) (Tables 1, 2 and 3). These values were then compared for the different situations. Two additional axes XX' and YY' (Figure 7), were created across the plan, to assess the fluctuation of daylight levels, from the window towards the opposite wall of the space (Figures 7 and 8).

Table 1. *Daylight distribution on nodes with the presence of drop ceiling*

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
1	NA	***409***	***358***	***412***	***334***	***396***	206	NA	NA
2	*1058*	103	64	74	63	55	32	NA	NA
3	*1137*	66	41	26	22	24	14	NA	NA
4	*1083*	100	40	21	12	10	9	NA	NA
5	*1188*	66	32	13	13	7	9	NA	NA
6	*1156*	105	33	25	14	6	8	NA	NA
7	*1172*	68	29	23	14	20	8	NA	NA
8	*1156*	133	40	26	20	39	54	124	***882***
9	*1130*	77	38	32	26	43	16	183	0
10	*1068*	126	71	72	70	95	108	234	*1352*
11	NA	*1125*	*1063*	*1110*	***899***	*1143*	***649***	*1157*	0
Contour range: 0-1400 lux			**Grid points: 83**				**Average value: 296 lux**		

Table 2. *Daylight distribution on nodes with the absence of drop ceiling*

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
1	NA	***707***	***664***	***766***	***533***	***682***	***360***	NA	NA
2	*2199*	***409***	219	164	139	142	76	NA	NA
3	*2283*	284	143	91	73	62	40	NA	NA

4	*2524*	***472***	102	58	35	39	32	NA	NA
5	*2356*	***369***	122	39	37	35	15	NA	NA
6	*2410*	***421***	117	85	40	17	18	NA	NA
7	*2386*	***319***	147	75	42	53	27	NA	NA
8	*2383*	***485***	158	101	80	141	153	***328***	*1569*
9	*2427*	***358***	217	179	118	180	107	***502***	0
10	*2135*	***720***	***407***	***415***	***378***	***454***	***525***	***748***	*2554*
11	NA	*2034*	*1948*	*2216*	*1695*	*2204*	*1374*	*2185*	0
Contour range: 0-2600 lux			**Grid points: 83**				**Average value: 650 Lux**		

Table 3. *Daylight distribution on nodes with slope ended drop ceiling*

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
1	NA	***707***	***653***	***751***	***526***	***678***	***356***	NA	NA
2	*2190*	***371***	125	111	91	82	47	NA	NA
3	*2272*	262	76	37	37	36	17	NA	NA
4	*2520*	***455***	61	29	16	12	12	NA	NA
5	*2348*	***360***	55	15	17	10	11	NA	NA
6	*2401*	***408***	60	27	17	6	8	NA	NA
7	*2370*	286	63	31	15	22	8	NA	NA
8	*2373*	***825***	61	35	35	46	55	178	*1547*
9	*2380*	***307***	81	44	36	52	22	***300***	0
10	*2092*	***536***	203	198	164	210	251	***383***	*2475*
11	NA	*2027*	*1913*	*2192*	*1691*	*2187*	*1372*	*2114*	0
Contour range: 0-2500 lux			**Grid points: 83**				**Average value: 591 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.*

Figure 7. *Plan showing the column/structural grid with node references*

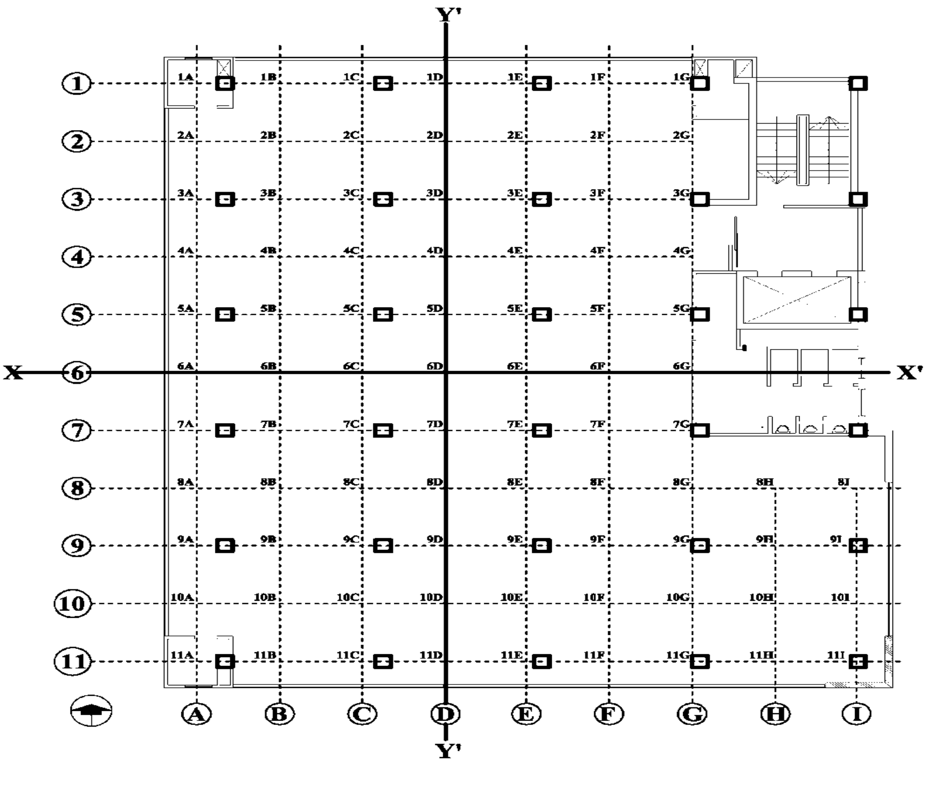
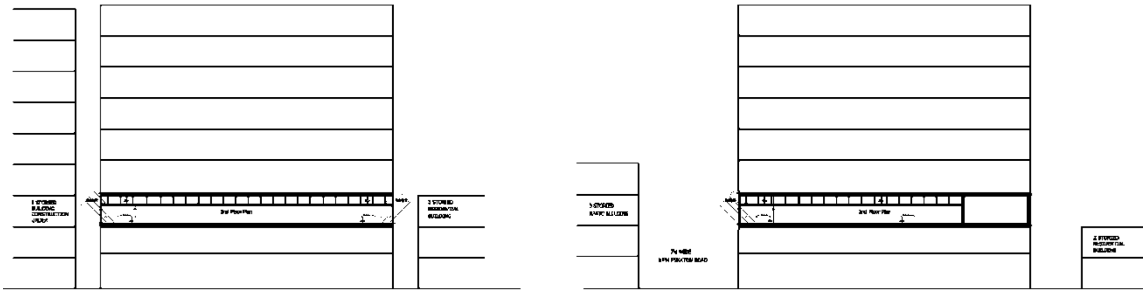


Figure 8. *Conceptual building section thru XX' & YY'*



The ECOTECT program first simulated the amount of daylight incident on each grid point on the work-plane of 3D models of the case space. 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 depict the daylight contour map on work plane height (Figure 9).

Figure 9. *Drop ceiling in the surveyed office interior*

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

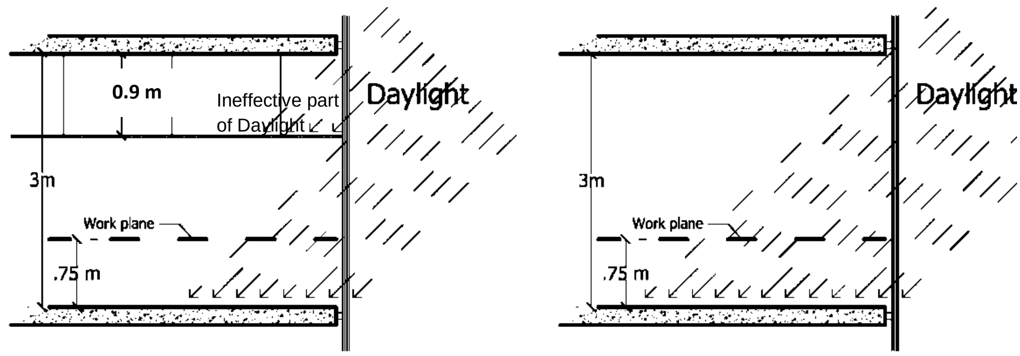
a) Indoor average daylight level on the work-plane height.
b) Number of intersecting points within acceptable illumination levels (300-900 lux). According to the Bangladesh National Building Code (BNBC, 1993), the recommended illumination level for office work is 300 lux. As the ratio between background of visual task and environment should not exceed the 3:1 (Goulding, 1992), values higher than 900 lux on workplane are likely to generate visual discomfort. In this study, the interior acceptable illumination range at workplane, has been considered to lie within 300-900 lux.

c) Fluctuation of daylight levels from the window towards deeper parts of the space. Excessive fluctuation is likely to produce glare and lack of uniformity.
d) Comparison of rendered images of the case space, generated by RADIANCE for luminance levels on specific surface.

Results

This section presents the results of daylight simulation, conducted with the presence and absence of drop ceiling on the case space (Figure 10). An alternative model of the same space, was created, by removing the drop ceiling (Figure 10b). The clear heights of the two models are, 2.10m and 3.00m from floor level, respectively.

Figure 10. *Sections show daylight penetration with presence and absence of drop ceiling*

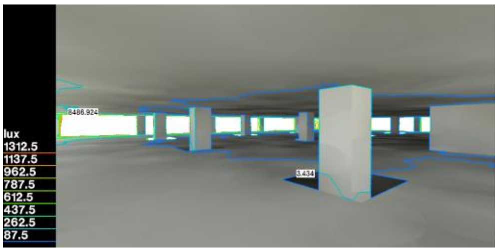


a) Presence of false ceiling. **b) Absence of false ceiling.**

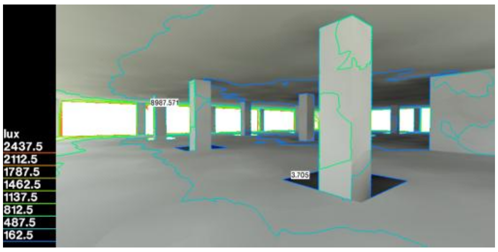
In Table 1 the values of daylight level, on the 83 grid points, show an average of 296 lux with the presence of a drop ceiling at 2.10m above floor level. Figure 11a, the output of RADIANCE, shows the daylight contour distribution at work plane height, for this condition.

Table 2 shows the values of daylight level, on the same 83 grid points, in the absence of drop ceiling. The average in this case, is considerably higher, at 650 lux. In Figure 11b, the output of RADIANCE shows the daylight contour distribution at work plane height, for this condition.

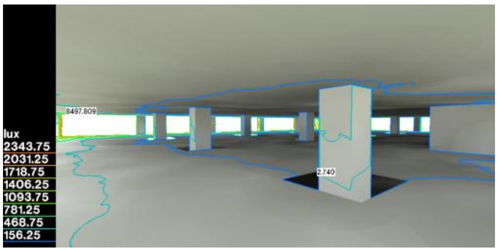
Figure 11. *Daylight contour distributions for the different ceiling conditions*



(a) Presence of a false ceiling.



(b) Absence of false ceiling.



(c) Modified false ceiling.

Comparison

Comparing the above two conditions, it is found that the average daylight level reduces by 54.46%, with the introduction of a drop ceiling at 2.10m height. Although with a drop ceiling, the average value of incident daylight on work plane height is 296 lux, only 23 points among the 83, have values higher than 300 lux, which is the recommended level mentioned in BNBC (1993), for office work. If the inner parts of the office interior, can achieve recommended illumination values by supplementary light, then 15 of the peripheral points among 23, will create glare, as they exceed three times the recommended value (Littlefare, 1996). Therefore, only 8 points are within the range of accepted daylight illumination level (300-900 lux). On the other hand, removing the drop ceiling, the number of points that receive more than 300 lux increases to 40 points, among which 22 are within the acceptable range (300-900 lux). Another comparison of illumination along the XX' and YY' axes (Figure 12 and 13), where the points that received illumination under the highest limits (900 lux) are shown, revealed that higher levels of daylight have been achieved near windows, when there is no drop ceiling. The three-dimensional qualitative comparison, along with daylight contour distribution on work plane height, generated from RADIANCE output, also shows (Figure 11) qualitative improvement in overall daylight level, in the absence of drop ceilings.

Figure 12. *Drop of light along XX' axis for different ceiling conditions within acceptable range*

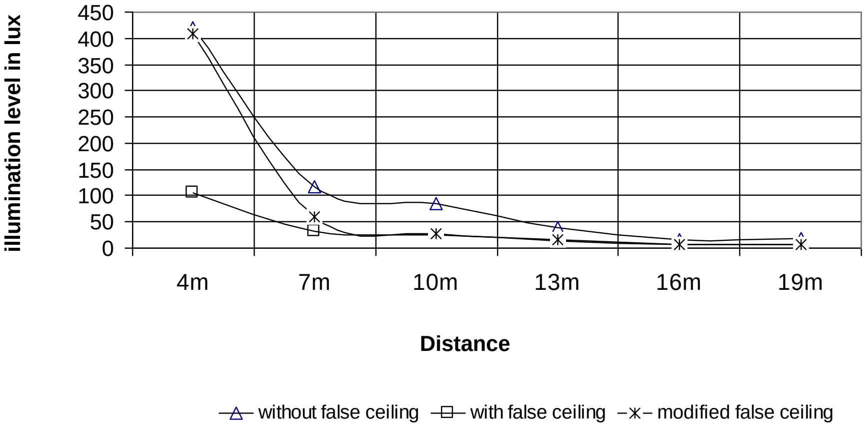
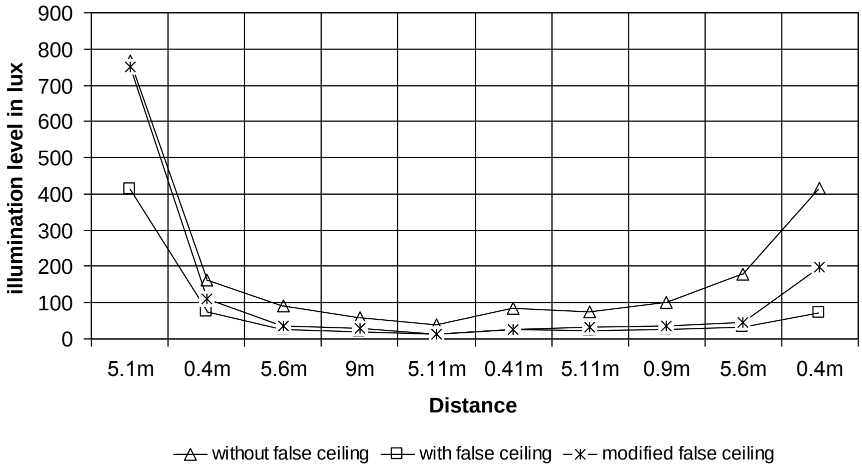


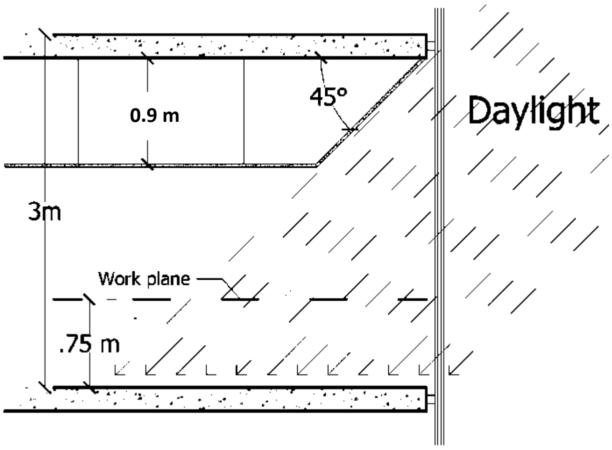
Figure 13. *Drop of light along YY' axis for different ceiling conditions within acceptable range*



Criteria based on above findings

It is evident from Figures 12 and 13, that illumination level near the windows varies widely, when drop ceilings are introduced. However, the need for drop ceilings in offices cannot be discounted. Drop ceilings serve to hide wiring and ducts, and also considerably reduce the volume of space to be artificially conditioned for use. A simple modification by introducing a 45^o sloped ceiling near the window is suggested in this paper (Figure 14), that keeps the drop ceiling, but allows the glass window its full height exposure. Evaluation of the modified ceiling, by simulating the daylight levels at the same 83 points, displays an average value of 591 lux (Table 3). The average illumination value, with the modified ceiling, is almost double (99.66% increase), compared to the existing condition, with typical drop ceiling. Furthermore, the number of points with illumination levels higher than 300 lux, increased by 45.8% (a total of 33 points), among which 15 fall within the acceptable range (300-900 lux). The sharpness in drop of daylight, from window to interior, is also compared for the two situations (Figures 12 and 13).

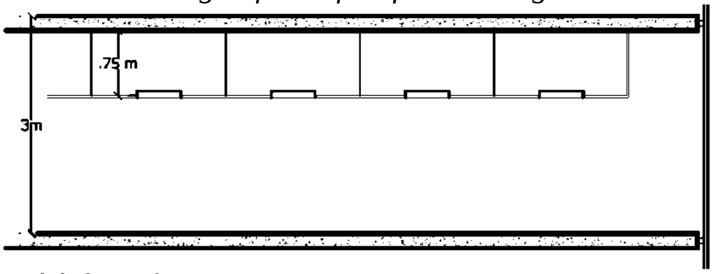
Figure 14. *Section shows daylight penetration with slope ended drop ceiling*



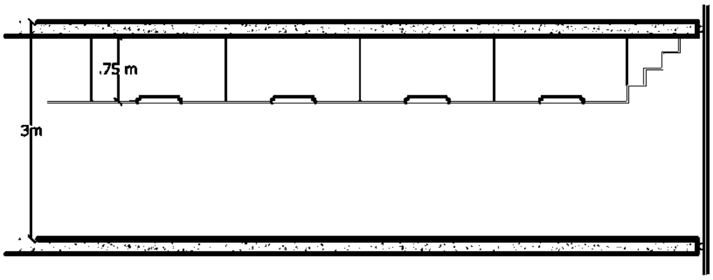
It is evident from these graphs, that the case without drop ceiling, closely matches the modified drop ceiling's performance near the window, though towards the rear, it matches the graph of the case with drop ceiling. Finally, the three-dimensional qualitative RADIANCE image, with daylight contour distribution on work plane height, also shows qualitative improvement in overall daylight level for modified ceiling (Figure 11c), compared to the existing drop ceilings.

Following the same concept, some other design alternatives have been shown in Figure 15: L-shaped, corbelled, sloped, concaved and convex ended drop ceilings. The simulation results of these were also found to be very similar to that quoted above. These modifications also integrate the facade design of curtain walled buildings, with their interior spaces and artificial lighting fixtures, which then live up to the expectation of large windows. Consistency in architecture is, thus, an additional benefit of these drop ceilings, modified sensitively.

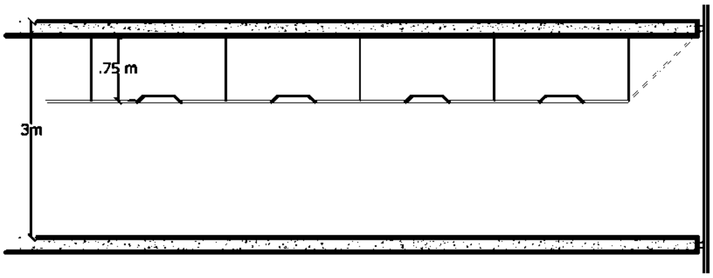
Figure 15. *Alternative design of modified false ceiling based on sloped concept*



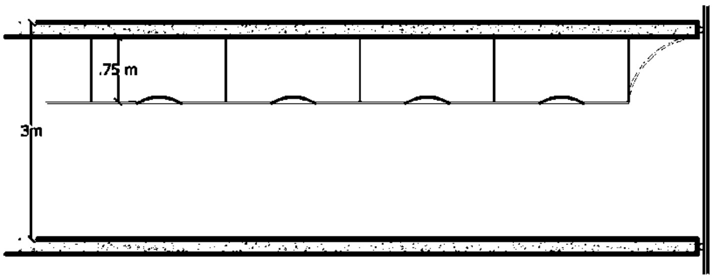
a.'L' shaped.



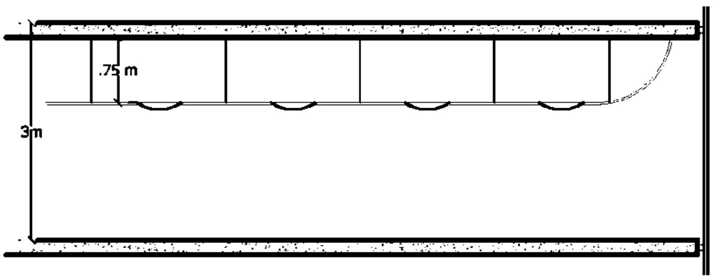
b. Corbel ended.



c. Slope ended.



d. Concave ended.



e. Convex ended.

Validation

To validate the simulation results, measurements of daylight levels were taken by a light meter (TES 1332 Digital Lux Meter), on the case space, to compare illumination values generated by the ECOTECT program, with the actual measured 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 found to be 5% (15 lux on average) approximately (Joarder, 2007).

Conclusion

It was found in this simulation study, that the impact of the drop ceiling, with reduced floor to floor opening, is more pronounced near the window, than on spaces further from the window. Greater height of window provides better daylight penetration. However, it is still sometimes essential to provide drop ceiling, to hide the electrical conduits and air-conditioning ducts. Yet, it is possible to restrict ducts near the edge of a room, where the windows are located. The eradication of drop ceiling near window, by careful design, can increase sky view, as well as welcome more daylight.

This paper presents the importance of responsiveness of the interior design, to the concept and principle of exterior architecture, by highlighting the disagreement between curtain glass wall and traditional drop ceiling, as a simple case that is common in many modern office buildings in Dhaka, and in other cities of the World. The responsibility of architects, for creating building form and facades sensitive to interior design, and vice versa, is vital. It is expected that the quantitative findings of this paper, will help architects and interior designers, to conceptualise the benefits of the integration and agreement of interior and exterior design in architecture, in terms of daylighting and for improved visual environments.

References

Ahmed, K.S. (1995). 'Approaches to Bioclimatic Urban Design for the Tropics with Special Reference to Dhaka, Bangladesh.' Ph.D. diss., Architectural Association School of Architecture, London, U.K.

Ahmed, Z.N. (1987). 'The effects of Climate on the design and Location of windows for Buildings in Bangladesh.' M.Phil. diss., Sheffield City Polytechnic.

Baker, N. and Steemers, K. (2002). *Daylight Design of Buildings*. London: James and James.

BNBC. (1993). *Bangladesh National Building Codes*. Dhaka: Housing and Building Research Institute and Bangladesh Standards and Testing Institute.

Crawley, D.B., Hand, J.W., Kummert, M. and Griffith, B.T. (2005). 'Contrasting the Capabilities of Building Energy Performance Simulation Programs.' Joint Report

Version 1.0. International Building Performance Simulation Association, August 15 – 18, Montreal.

Evans, M. (1980). *Housing Climate and Comfort*. London: The Architectural Press.

Goulding, J.R., Lewis, J. O., Steemers, T. C. eds. (1992). Energy Conscious Design: A Primer for Architects. London: Batsford for the European Commission.

CIE. (2004). Spatial distribution of daylight - International Commission on Illumination standard general sky, second edition.

Joarder, M.A.R, (2009). 'A Survey on Daylighting Potentiality in the offices of Dhaka Bangladesh.' *Global Built Environment Review (GBER)* 7 (1): 5-22.

Joarder, M.A.R, Ahmed, Z.N., Price, A.D.F. and Mourshed M.M., (2009a). 'A Simulation Assessment of the Height of Light Shelves to Enhance Daylighting Quality in Tropical Office Buildings under Overcast Sky Conditions in Dhaka, Bangladesh.' 11th IBPSA Conference, 27- 30 July, Glasgow, UK: 1706 -13.

Joarder, M.A.R, Ahmed, Z.N., Price, A.D.F., and Mourshed M.M., (2009b). 'Daylight Simulation for Sustainable Urban Office Building Design in Dhaka, Bangladesh: Decision-making for Internal Blind Configurations.' 2nd SUE-MoT Conference, 22-24 April, Loughborough, UK: 218-41.

Joarder, M.A.R. (2007). 'A Study of Daylight Inclusion in Luminous Environment of Offices in Dhaka City.' M.Arch. diss., Department of Architecture, Bangladesh University of Engineering and Technology, Dhaka.

Koenigsberger, O.H., Iingersoll, T.G., Mayhew, A. and Szokolay, S.V. (1997). *Manual of Tropical Housing and Building, Climatic Design*. Chennai: Orient Longman.

Littlefare, P.J. (1996). *Designing With Innovative Daylighting*. Building Research Establishment report. Herts: Construction research Communications.

Osaji, E.E. and Price, A.D.F. (2009). 'The Role of Parametric Modelling and Environmental Simulation in Stimulating Innovation in Healthcare Building Design and Performance.' HaCIRIC 2nd International Conference, April: 135-44.

Phillips, D. (2004). *Daylighting: Natural Light in Architecture*. Burlington: Architectural Press.

U.S. Department of Energy. (2008). *Weather Data: EnergyPlus*, Last Updated: 27 Nov 2008. Available at http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/2_asia_wmo_region_2/BGD_Dhaka_SWERA.stat [15 April 2009].

Ward, G.J. (1994). 'The RADIANCE Lighting Simulation and Rendering System, Computer Graphics.' 94 SIGGRAPH conference, July: 459-72.

Khan, M.N.Z.I. (2005). 'Rethinking Learning Spaces: in warm-humid climatic context with special reference to Dhaka, Bangladesh.' M.A. diss. Architectural Association Graduate School, London.