Effects of Different Fenestration Configurations on Daylighting Performance in Unilateral Window under Clear and Overcast Sky Conditions

편측창에서 창개구부의 형상이 천공상태별 채광성능에 미치는 영향

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Abstract

Daylighting provides the opportunity for both energy savings and improved visual comfort. An accurate estimation of the amount of daylight entering a building is the key step for daylight designing. This research aims to assess comparative daylighting performance of four different configurations of fenestration in case of unilateral windows and their variation under clear and overcast sky conditions. The selected window openings in this study were single punched, double punched, multiple punched and clerestory, and the area was same for each type of window. The experiment was designed for an office space using 1/10 scale model. Daylighting performance was evaluated by measuring the illuminance on work-plane height using Agilent data logger and photometric sensor Li-Cor. Thecomputer program ECOTECT was also used to simulate the pattern of interior illuminance distribution. Clerestory window showed the best performance in term of both illuminance level and distribution in the experiment. Multiple punched window provided more uniform illuminance distribution than single punched window. Lowest daylighting performance in the experiment was shown by double punched window.

Keywords : Daylighting performance, Configuration of windows, Scale model, ECOTECT, Clear sky, overcast sky
키워드 : 자연채광성능, 창의 배치, 스케일 모델, 에코텍, 청천공, 담천공

1. INTRODUCTION

Daylighting is the practice of placing windows, or other openings, and reflective surfaces so that, during the day, natural light provides effective internal illumination [1] and it has long been considered as an important element in modern architecture. Now daylighting is widely recognized as an important energy-conservation design strategy in an office building which requires careful architectural design and effective window management in order that its benefits are realized to the maximum [2].

Energy from 10% to 40% can be saved by applying a daylighting scheme depending on the building envelope and climate zones [3]. Apart from energy consumption, indoor daylighting is also related to human well being and performance. Sufficient daylight reduces stress and increase productivity.

Windows are the most common way to admit daylight into a space. Daylight admitted through windows is ideal for illuminating horizontal surfaces and work planes [4]. Spaces can be daylit with windows unilaterally, bilaterally, and multilaterally with varying effects. Unilaterally lit rooms receive light entering through windows in one wall only. Bilaterally lit spaces are illuminated by light entering through windows in opposing walls and multilaterally lit areas receive light entering through fenestration in at least two non-opposing walls [4].

Unilateral sidelighting is the standard daylighting case, its implementation requires care. It aims to distribute daylight into the depth of a space, to provide enough light to perform a task in the room while avoiding glare and allowing a view to the outside [5].

It is necessary to know which arrangement of windows give the best performance and should be incorporated during designing a building. The likely performance of daylighting by different configurations of fenestration in the unilateral windows (single punched, double punched, multiple punched and clerestory) in an office space in the clear sky condition and also comparing it with the performance in the diffuse daylight of overcast sky condition are the subjects of this research.

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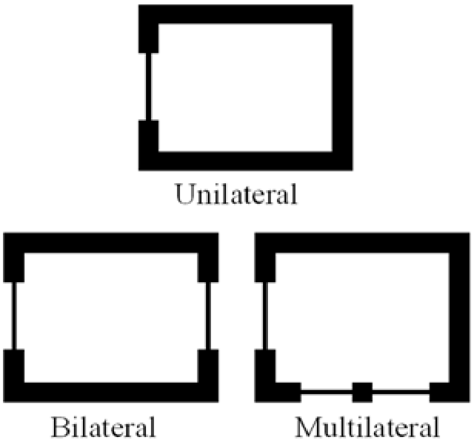


Figure 1. Different types of sidelighting

Figure 2 shows the photographs of clear and overcast skies. The overcast sky is defined as a sky in which at least 90% of the total sky is visually obscured by clouds and obviously, this sky cannot be combined with sun in a meaningful way [6]. This is the sky condition applied in daylight factor calculations. On the other hand, clear sky has less than 30% cloud cover, or none. This sky is most likely to be combined with sun [7]. In this study, the interior daylight illuminance data were measured in the scale models and day light distributions were simulated using ECOTECT computer simulation software to assess the daylighting performance of different configuration of windows.

(a) Clear sky b) Overcast sky

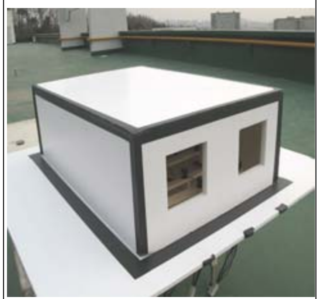
Figure 2. Clear sky and overcast sky

2. EXPERIMENTAL METHODOLOGY

2.1 Configuration of the Scale Models

The experiment was carried out using four scale models (scale 1:10) of an office space. The interior dimensions of the room was 6 x 9 x 2.7 m (width x depth x height, full scale) which were installed on the rooftop of the Engineering Building, Kyung Hee University(KHU), South Korea (latitude 37.30 N, longitude 127.01 E). Relatively light colored materials were used to finish the interior of the room. The colours of the floor, wall and ceiling were light brown, light cream and white respectively.

Table 1. Configurations of the windows

Window Type	Photographs of the model	Measurements of the Windows
Single punched		* Area: = [(1.4×w)×opening no.] =1.4m × 3.048m x1 = 4.2672 sq. m. * Height from the floor: 0.8 m
Double punched		* Area: = (1.4m×1.524m)×2 = 4.2672 sq. m * Height from the floor:0.8 m
Multiple punched		* Area: = (1.4m×0.762m)×4 = 4.2672 sq. m * Height from the floor:0.8 m
Clerestory		* Area: = 0.762m × 5.6m = 4.2672 sq. m * Height from the floor:1.5 m

Four different patterns of windows were selected for the study which were single punched, double punched, multiple punched and clerestory. Each model contained a single type of window on its side wall (unilateral). The area of the openings for each type of window was same (4.2672 sq. m.). The models were placed on the proper horizontal level facing the windows in south orientation. In the model, the window opening was not covered by any glazing. The features of the windows are listed in table 1.

2.2 Monitoring Method

The LI-210SA photometric sensors were used to monitor an outdoor daylight illuminance and the indoor illuminance on work plane height of 80 cm [8]. The sensitivity of the photometric sensor was typically 20mA/100 klx and the maximum deviation of linearity was 1% up to 100 klx. Total 21 sensors were installed inside the model in a grid arrangement (3 columns and 7 rows) (Figure3). The illuminances in the module were monitored every 1 second by using a HP34970A data logger.

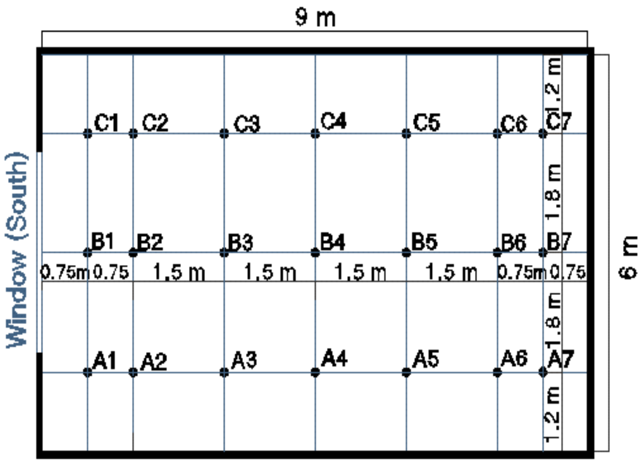


Figure 3. Position of the photo sensors

The measurements were carried out on Friday, 27 March for clear sky condition and on another Friday, 03 April in overcast sky condition. The monitoring time was from 9:00 to 18:00.

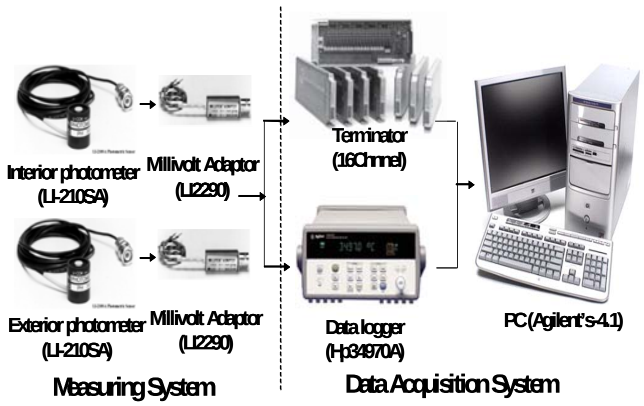


Figure 4. Monitoring system

2.3 Data Acquisition

As a primary index to represent the data from the experiment, traditionally, daylighting is often determined in terms of the light factor (LF). By definition, the LF is the percentage of the outdoor light that is available indoors. This evaluation method was developed in England, where the solid overcast sky condition is predominant for much of the year. The Light factor is mathematically defined as-

$$LF = \frac{\text{Indoor illuminance from daylight at a given point}}{\text{Unobstructed exterior horizontal illuminance}} \times 100(\%)$$

Figure 5. Set up of the experimen

According to the guide published by the British Council for offices, an average LF for daylight of 2% to 5% is recommended for an office workplace [9]. As pointed out in literature [10], an average LF for daylight of 5% or more will ensure that an interior looks bright and that electric lighting is not required as much. An average LF of less than 2% generally makes a room look dull, leading to frequent use of artificial lighting.

2.4 ECOTECT model and Simulation

The program ECOTECT was used to simulate the pattern of indoor illuminance distribution. The ECOTECT tool offers a range of lighting analysis options. Its main focus is on natural lighting analysis. However, it can also analyse rudimentary artificial lighting design. A wide range of display options are provided for the analysis grid. These range from 3D mesh plots to fully colored contour maps. It features a designer-friendly 3D modeling interface fully integrated with acoustic, thermal, lighting, solar and cost analysis functions. Same configuration of the office space (colour, window and room area) that had been used for scale model was also used in ECOTECT. The following main parameters were used in the program:

Location: KHU, Korea (37.3 N & 127.01 E)
Day = 27 March, 12:00 (GMT +9)
Orientation: South
Local Terrain: Urban
Lighting analysis: Natural light level (Daylight level)
Sky condition: Clear sky and Overcast sky

Ray tracing precise: High
Calculate over: Analysis grid
Work Plane Height = 80cm

3. ANALYSIS OF DAYLIGHTING PERFORMANCE OF SCALE MODEL EXPERIMENT

3.1 Outdoor daylight illuminance of clear sky and overcast sky condition

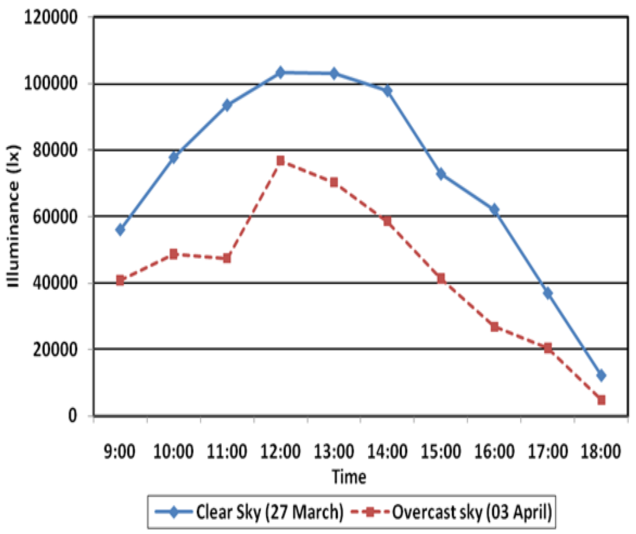


Figure 6. External Illuminances of clear and overcast sky conditions at different times of the day

Figure 6 shows the comparative outdoor illuminance between two days of clear sky and overcast sky condition at different times of study. In case of clear sky condition, the highest illuminance was around 100000 lux at 12:00 pm and the lowest illuminance was around 10000 lux at 6:00 pm. In case of overcast sky condition, the highest and lowest illuminance were also found at 12:00 and 6:00 pm which were around 80000 and 5000 lux respectively.

3.2 Average interior daylight factor at different times of the day

Figure 7 and 8 present the average interior light factors at different times of the day under clear and overcast sky condition respectively.

The interior LF by different windows were significantly variable at different times in clear sky condition particularly from 9:00 am to 1:00 pm. On the other hand the variability was lower and comparatively homogeneous in overcast sky condition. After 2:00 pm the range of the variation of daylight factors by different windows was almost similar in both sky conditions.

Clerestory windows showed the best performance at 10:00 am in both clear and overcast sky conditions but the highest LF values were different at that time and these

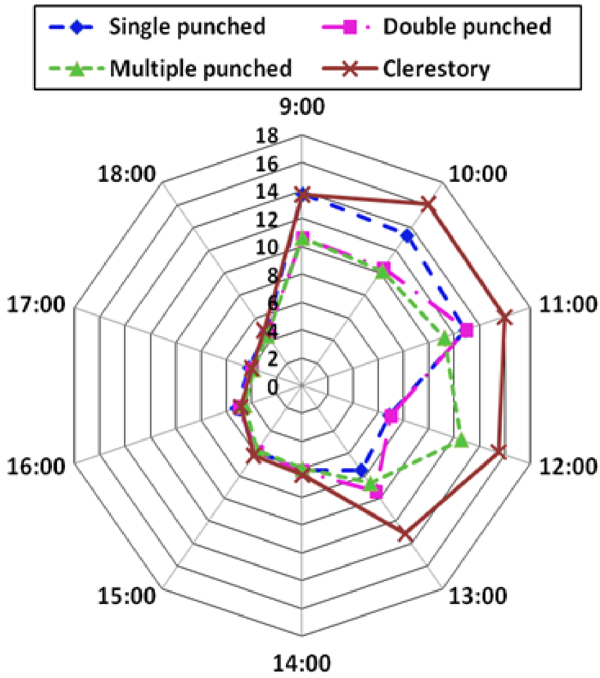


Figure 7. Average interior LF at different times in clear sky condition

were around 16% in clear sky and 10% in overcast sky condition.

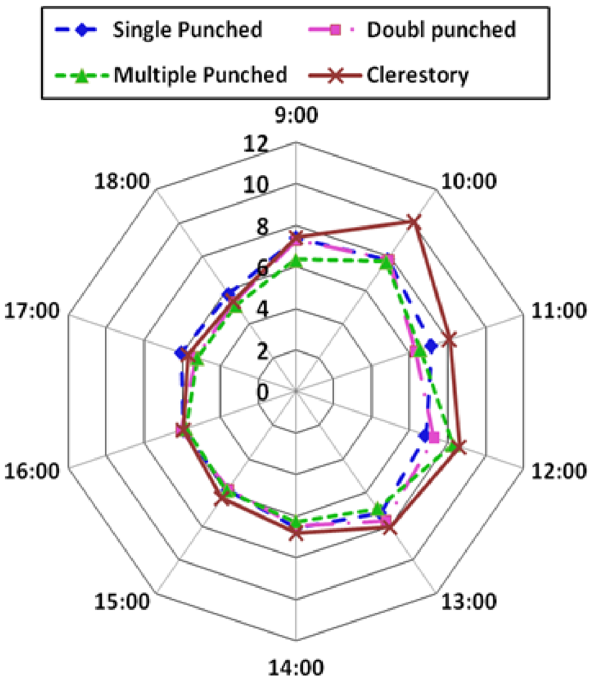


Figure 8. Average interior LF at different times in overcast sky condition.

In case of multiple punched window, the highest LF was found at 12:00 pm in both sky conditions. The LF was around 12% in clear sky condition and 8% in overcast sky condition at that time. After 2:00 pm multiple punched windows showed the lowest daylight performance among all windows. Although the multiple punched window gave lower light factors than single and double punched windows at several times of the day it gave less fluctuation in providing daylighting those windows all over the day.

Double punched window showed the highest LF at 11:00 am in clear sky condition which was around 13%. Under overcast sky, the highest LF was obtained at 10:00 am by this window and it was around 8%. On the other hand the lowest LF was found at 5:00 pm. in both sky condition which was around 4% in clear sky and 5% in overcast sky respectively.

Single punched window gave the highest light factor at 9:00 am in clear sky condition which was around 14% and about 8% in overcast sky condition. The lowest LF was found at 5:00 pm in clear sky condition (around 4%) and at 6:00 pm in overcast sky condition (around 6%).

3.3 Daylight distribution at different sides (sensor lines) of the room

Depending on the position of the line of photo sensors, the working level can be roughly divided into 3 areas on the basis of light entrance direction, Sensor line A represents the right side of the room. Line B and line C represent middle portion and left side respectively. Figure 9, 10 and 11 are showing the interior daylight factor on line

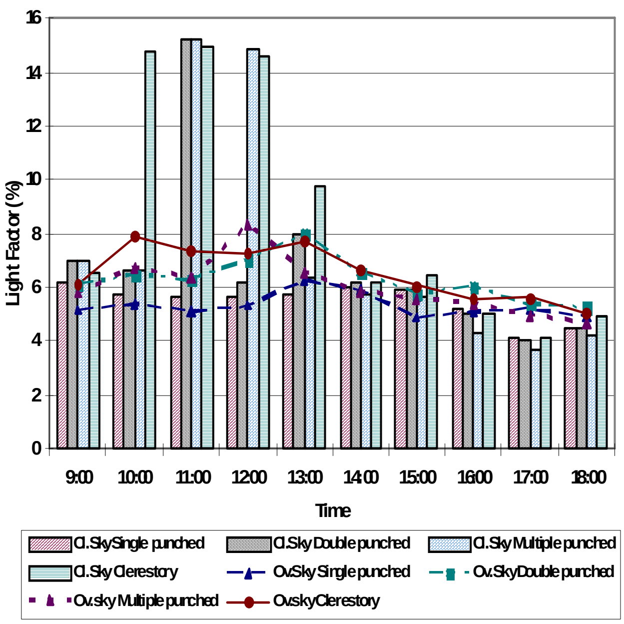


Figure 9. Average LF on the sensor line A (right side of the room)

A, B and C respectively. In general it can be said that the interior LF by different windows were relatively higher up to 1:00 pm. Later on the daylight level sharply decreased and showed almost invariable.

In case of line A, in clear sky condition, the highest LF was given by double punched window at 11:00 am which was around 15%. The highest LF in overcast condition was shown by multiple punched windows at 12:00 pm which was about 8%.Single punched windows overall showed the lowest performance in overcast sky condition.

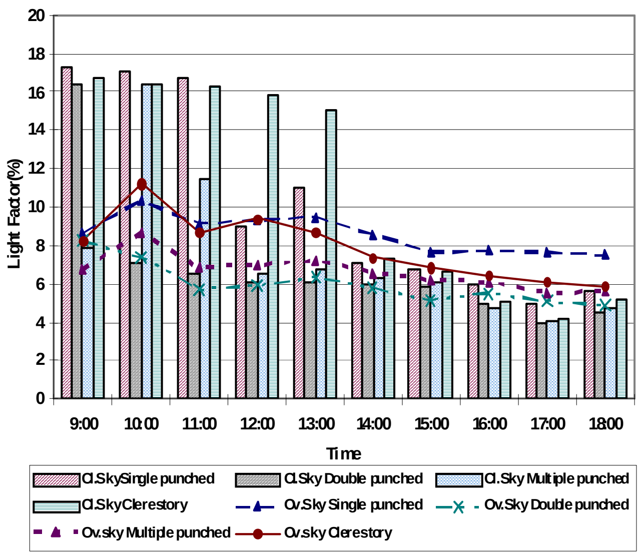


Figure 10. Average LF on the sensor line B (middle of the room)

In case of line B, in clear sky condition, single punched windows gave the highest LF (about 17%) at 9:00 am. In case of overcast sky condition, the highest LF was given by multiple punched windows at 10:00 am which was around 11%. Double punched window showed overall the lowest performance among all windows.

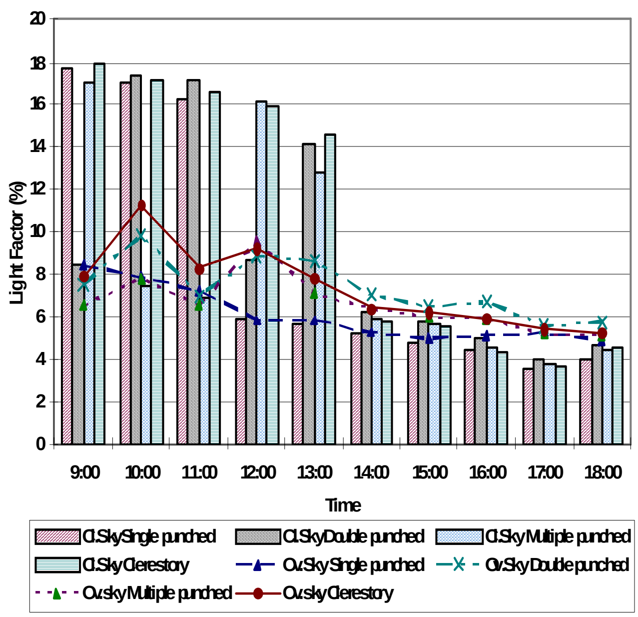


Figure 11. Average LF on the sensor line C (left side of the room)

In case of line C, single punched window showed over all the lowest performance along the day in overcast sky condition. The highest LF was shown by clerestory window in both clear and overcast sky condition at 9:00 and 10:00 am respectively.

One common finding from all the three lines is that, the clerestory window provided relatively higher uniform day light along the day.

3.4 Average interior Daylight factors at different distance from windows

Figure 12 and 13 present the LF level from nearest position of windows to depth of the room.

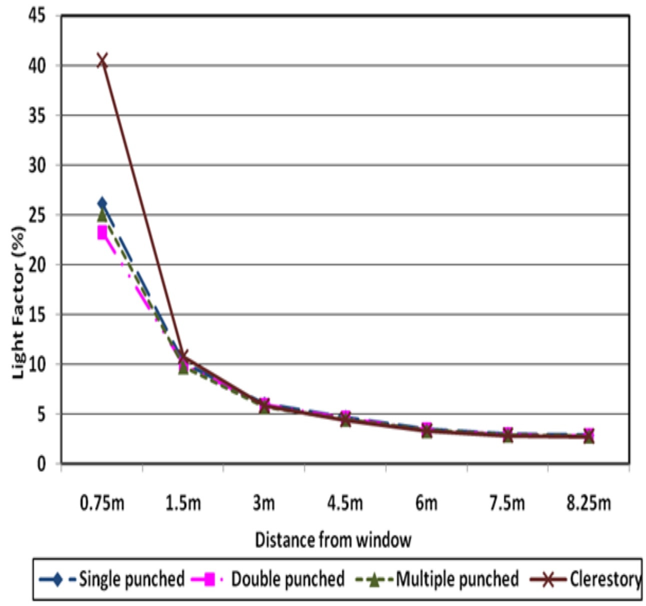


Figure 12. Average LF at different distance from windows in clear sky condition

Upto 3m of distance from window LF by different windows were relatively higher and varied from around 40% to 5% in clear sky and 20% to 6% in overcast sky conditions. After 3m distance up to the rear of the room the LF were relatively low and almost same for all windows in both sky conditions which varied from about 5% to 3%.In case of clear sky condition, clerestory provided the highest light up to 3m where as in overcast sky condition, it was up to 4.5m. On the other hand, if we see exact data, the highest illuminance level from 3 to 6 m under clear sky condition and from 4.5 to 6m distance under overcast sky condition were obtained by single punched window. After 6m distance double punched and multiple punched windows gave the highest illuminance level under clear and overcast sky respectively. However from 3m up to end of the room, the illuminance variation was insignificant among all windows.

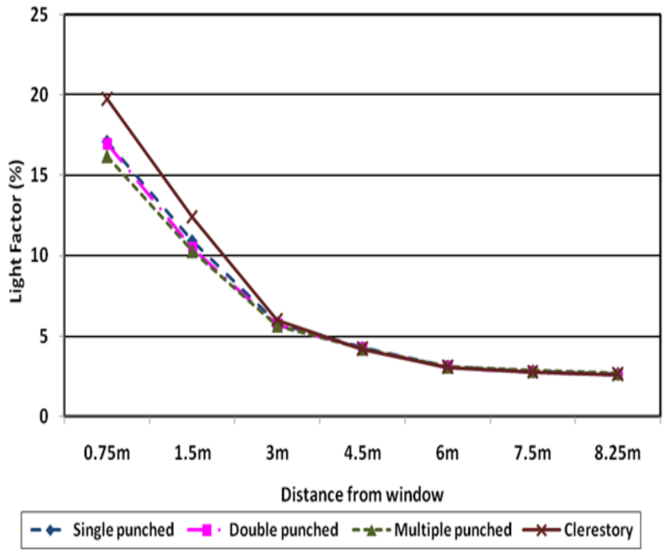


Figure 13. Average LF at different distance from windows in Overcast sky condition

3.5 Average daylong Light Factor by different windows under clear and overcast sky Condition

Figure 14 is indicating that clerestory showed the best performance followed by multiple, single and double punched windows respectively in both sky conditions.

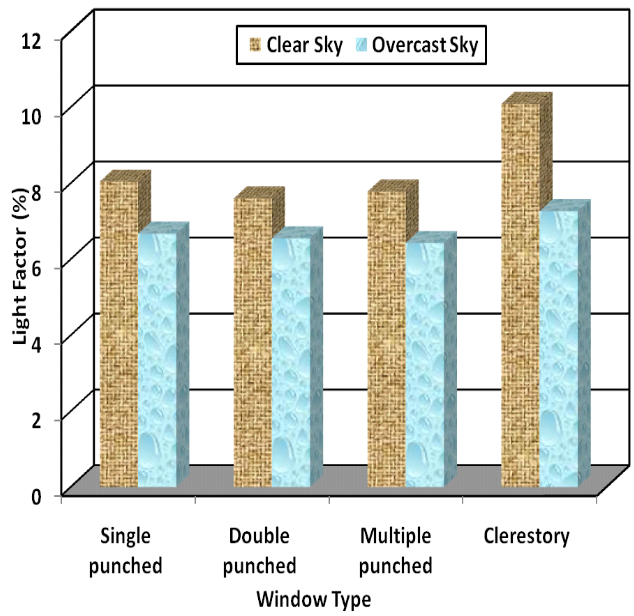


Figure 14. Comparison of average indoor LF by different windows in clear and overcast sky conditions

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Under clear sky condition the highest LF which was supplied by clerestory was around 10.5% and the lowest LF was shown by double punched window which was about 7.8 %. In case of overcast sky condition, clerestory afford the highest light factor which was about 7.5% and the lowest was shown by double punched window which was

5.9%. The multiple and single punched windows showed almost similar performance among which single punched showed slightly higher LF in both sky conditions.

4. SIMULATED RESULTS OF DAYLIGHT DISTRIBUTION FROM ECOTECT

4.1 Under Clear Sky Condition

Figures 15, 16, 17 and 18 show the simulated illuminance distribution pattern by ECOTECT inside the room by 4 different arrangements of tested windows at 12 p.m. under clear sky condition

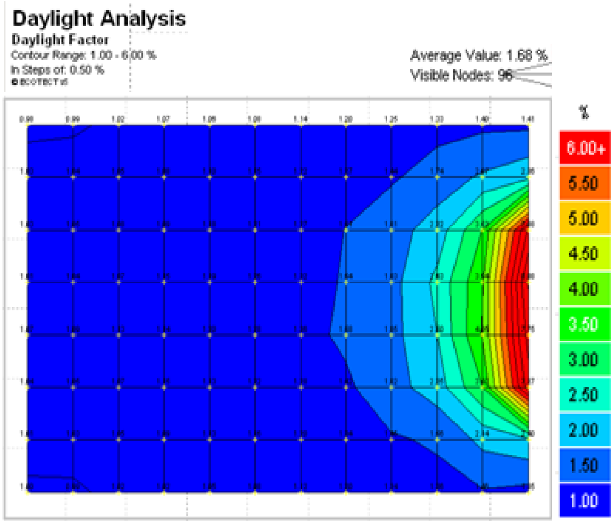

Figure 15. The contours of the interior illuminance with single punched window

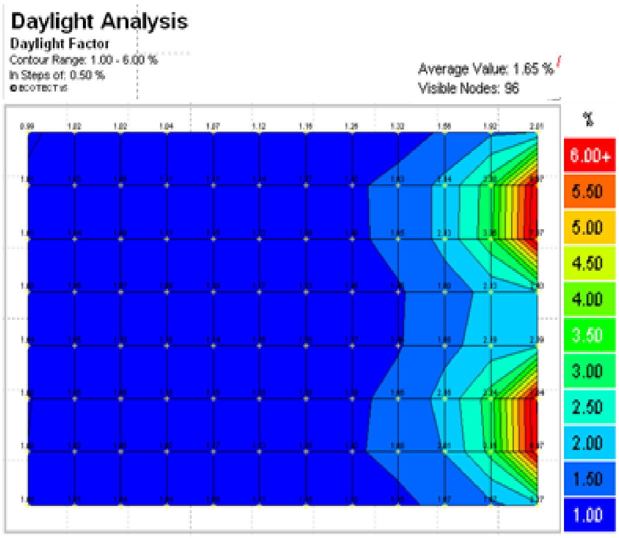

Figure 16. The contours of the interior illuminance with double punched window

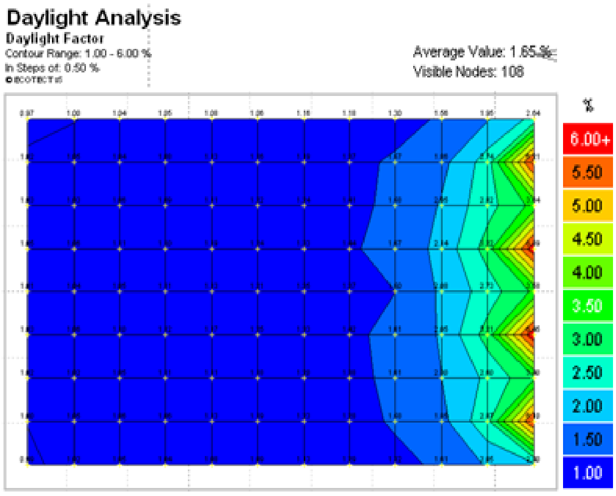

Figure 17. The contours of the interior illuminance with Multiple punched window

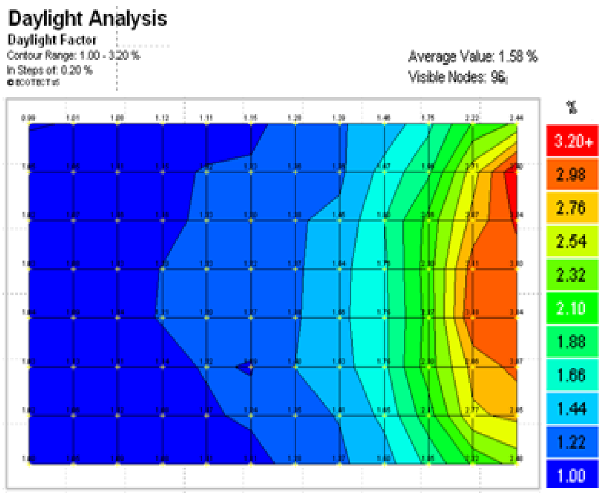

Figure 18. The contours of the interior illuminance with Clerestory window

The clerestory window gave the most uniform illuminance distribution inside the room under clear sky condition. It also provided daylight to the highest depth of the room followed by single punched window. Double punched windows created darker area between openings which can be considered as a disadvantage of this window. Double punched window showed the lowest performance of daylight penetration to the deeper part of the room. Multiple punched window provided more uniform daylight distribution than single punched window.

4.2 Under Overcast Sky Condition

Figures 19, 20, 21 and 22 show the illuminance distribution inside the room by 4 different arrangements of windows at 12 p.m. under overcast sky condition.

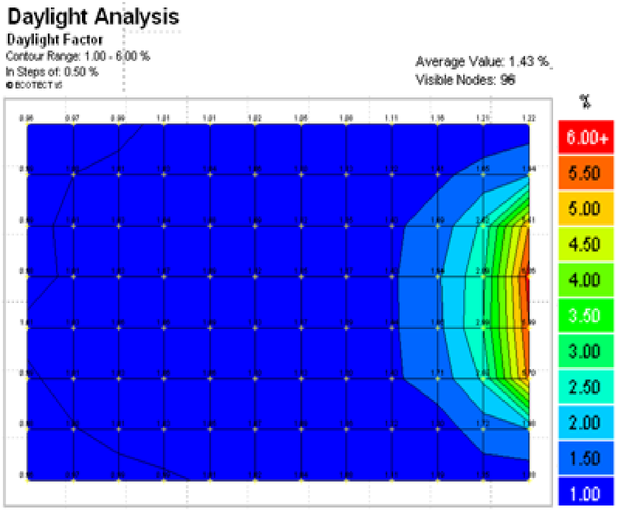

Figure 19. The contours of the interior illuminance with single punched window

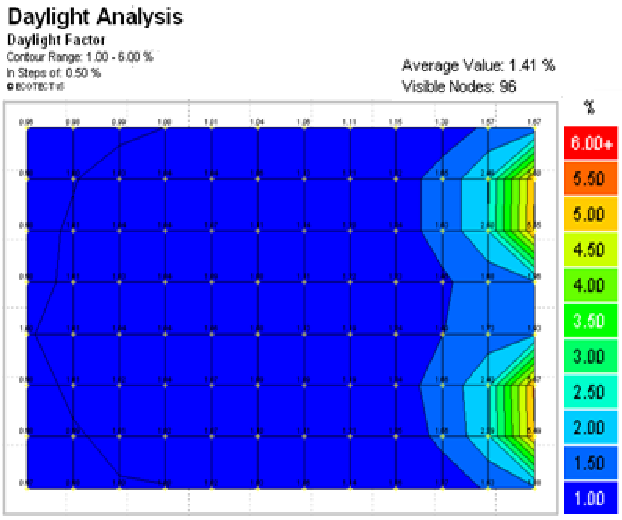

Figure 20. The contours of the interior illuminance with double punched window

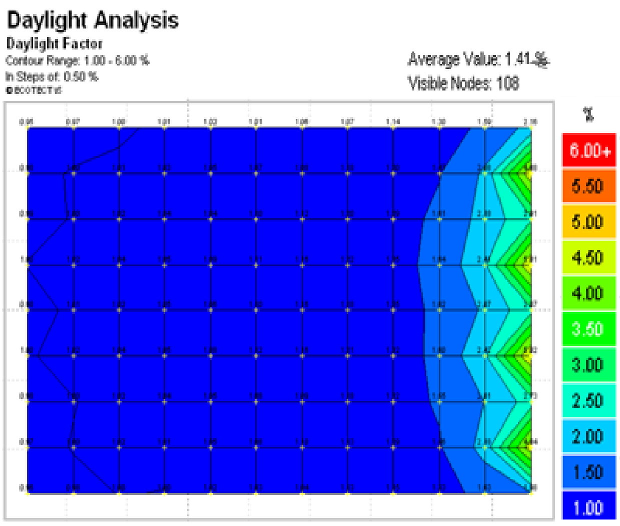

Figure 21. The contours of the interior illuminance with multiple punched window

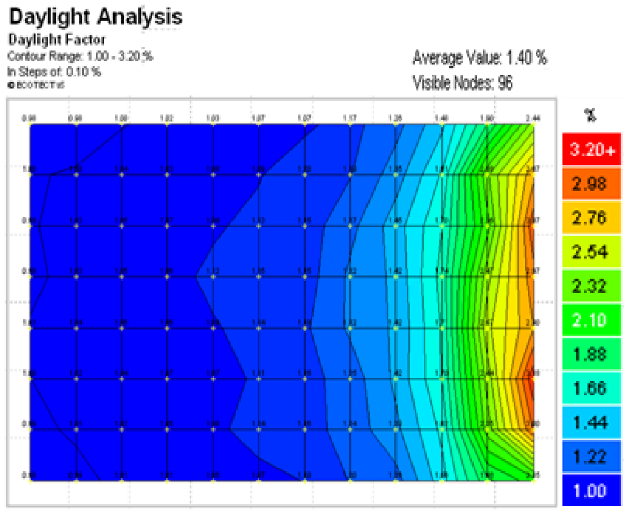

Figure 22. The contours of the interior illuminance with clerestory window

From the above simulated figures of daylight distribution under overcast sky condition, it was found that overcast sky provides less illumination to the deeper area of the room than clear sky. However the pattern of daylight distribution is the same as clear sky condition.

5. CONCLUSION

This experiment was an attempt to investigate the comparative daylighting performance of four different arrangements of identical window area. The study was carried out under the inverse brightness relationship of a clear versus an overcast sky condition to observe the variation in their performance. The findings from the experiment can be summarized as below:

1. Clear sky tends to provide more illumination per window area than overcast sky since the window faces a region of sky of higher illuminance. However the interior illuminance characteristics and the nature of daylighting performance by different windows in both sky conditions were almost same.

2. Brighter and uniform light across an entire room is more desirable particularly for the region where overcast sky is predominant. In the study, clerestory window showed the best performance both in term of illuminance level and uniformity of distribution among all windows. So, we can say, of the same area, the wider window at high level provides the higher daylight illumination and uniformity, therefore, window should be placed as high in the wall as possible to allow more light penetration into the room and it is more desired under overcast sky condition.

3. Among rest other three types of windows (single,

double andmultiple punched), although single punched window provided highestaverage daylong illuminance, multiple punched window showed comparatively less fluctuation and homogeneous (uniform) daylight inside the room at different times of the day.

4. In the experiment double punched window showed the lowest daylighting performance regarding both illuminance level and uniformity of distribution among all windows. It created darker area between the openings which can be considered as a disadvantage of this window.

The findings of the study will hopefully provide a preliminary ideato the building professionals for daylight designing of a building by predicting the indoor daylight quality

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