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The impacts of window design on the internal luminous environment – Case study: the New Art Exchange, Nottingham

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Abstract

This paper explores the closed relationship between three factors – daylight, visual perception and window design. In the scope of this study, role of windows in providing the desirable luminous environment will be shown in distinctive functional spaces of building – the New Art Exchange, Nottingham. In addition, possible impacts from windows design and their fenestration on facades of this building will be considered in terms of visual environment and then, opportunities to improve quantity and quality of natural light level for internal spaces will be suggested. To understand explicitly the interaction between window design and visual delight is that both daylight and sunlight performance inside building is investigated in different conditions of sky by physical model testing, field measurement, computer simulations as well as a survey of occupants based on their activities at each room. Indeed, the derived brief of this project is to find harmonious counterbalance between exterior aesthetics of façade and interior visual comfort of a building by window design.
Keywords: daylight, visual environment, window design, fenestration.

1. INTRODUCTION

In early stages of design process, the architects do not usually regard to daylight strategies thoroughly. Hence, they underestimate opportunities to understand performance of these strategies in achieving a desirable internal luminous environment of a building. Despite of any daylight solutions applied, the most important point is that visual comfort should be considered to achieve two major properties: to provide a good vision for tasks, a good-looking space and to decrease discomfort this is caused by of glare and unbalance of brightness (Ruck el at., 2000). By the case study of the New Art Exchange in Nottingham, this study will investigate the interaction of windows and an attractive visual environment in terms of the unity of fenestration design and occupants' activities and visual needs according to each particular function of space in this building. Besides that, the characteristics of window like as shape, size, position and orientation will be considered with the same as a goal in achieving indoor desirable lighting conditions in working harmony with climatic patterns.

1.1 Case study

Figure 1 Location and perspectives of the New Art Exchange

The New Art Exchange is the first art centre of Black and Asian Art in UK. This building was finished in 2008 by both Russell Brown and Roger Hawkins. It is a charcoal cube which is orientated in a deviation of 5° from due north to west. It appears impressively by distinctive colour and typology among ubiquitous red clay buildings of the neighbours. Whole building with total floor area of 1360sqm provides various functional spaces into 4 stories (Figure 1).

The access to the gallery starts at glass box pushed out into the street at the ground floor to attract passengers. All stories have the similar layout. Generally, floor height is 2.7 meter excluding main gallery and performance room with double height. All spaces of the building are opened exterior environment to optimise good view and good penetration of daylight (Figure 2).

Figure 2 Plans, two sections of the New Art Exchange

The external walls - structure double skin of concrete block and black brickwork cladding are as a strong thermal envelope to minimize extreme fluctuations in the internal environment. The animation of a range of windows (0.16 to 4.84sqm) is arranged interestingly on most facades of the building, especially on south and west facades. This design is considered rationally for needs of particular activities for different functions of room. Each space is punctured by an individual pattern of windows. All windows are frameless and installed up and down, either aligned or pushed back 250mm with outer surface of façade.

1.2 Research Methodology & Limitations

In this study, the application of the different analytical tools helped understand the daylight and sunlight performance in the building. These tools showed the role of windows to each space in term of lighting control, needs of function and visual comfort.

Figure 3 Photographs of the physical model in Artificial Sky and Heliodon testing

- By sketches and photos, initial observations of daylight environment into rooms were drawn. Additionally, the onsite measurements were taken in March 2012 under both sunny and overcast sky conditions. This tool will translate efficiency of windows and skylight in providing a real luminous environment into these rooms.
- Physical models are tested in Artificial sky to predict daylight levels and distribution in different cases. Materials of models are described similarly to reality to achieve best results.
- Physical models were also tested on Heliodon to investigate the solar penetration.
- Three dimensional computer simulations are used by Ecotect and Radiance software to support exactly prediction of daylight distribution in the building. The external illuminance used is 8500 lux (overcast sky in England in December) as a worst scenario is tested.
- Collection of opinions of visitors and occupants on site supports the quantitative studies.

2.DAYLIGHTING AND SUNLIGHTING PERFORMANCE ANALYSIS

2.1 Climate

Location of Nottingham in England is central with geographic place of 53°0’N 1°2’W. Generally, the climate in Nottingham is temperate: temperature in summer (June to August) is between 14.86°C to 29.5°C, while in winter (December to February) is from -6.7°C to 3.3°C. The sky in Nottingham is typically overcast; in details, during summer months there is an average of 6 hours of daily sunshine and 17 hours of daily daylight. During winter months, there is an average of 2 hours of daily sunshine and 8 hours of daily daylight. The solar altitude in summer is quite steep - 62°, 38° in equinox but it is so low in winter about 15° (Nottingham climate guide). Thus, the approach of environmental design in this climate is to provide passive solar heating in the winter and to prevent overheating in summer. This responsibility relates to distribution of two main factors be envelope designs and window apertures.

2.2 Window performance and their impacts on the internal luminous environment

In this section, the key architectural elements of the building which control the light will be investigated. The analyses are based on function of room, needs of activities and task of occupants by key factors of window design including fenestration, size, shape, position and orientation. To this building, two daylight strategy applied are the followings:

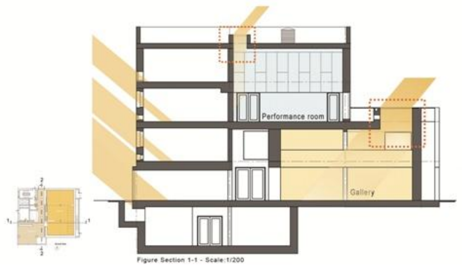

Figure 4 Lighting strategies shown in section

A. Windows: side windows to provide daylight, natural ventilation and views out.
B. Top lights are mostly arranged in the performance room and main gallery.

A. Windows

Looking at this building from outside on Gregory Boulevard, an attraction to passers is animation of numerous apertures that pierce the envelope of the building with a range of frameless windows. Density of them is concentrated primarily on west and south façades of first and second floors where rooms like as office and learning require high levels of illuminance on task from 300lux to 500lux (CIBSE, 2002). There are two types of windows - awing window and fixed window. The awning ones are pulled back into 250mm of outer surface of external walls instead of alignment like as fixed windows. The movement of windows on facades creates change of daylight distribution inside. Some of them are low and some are high, as a result, curve of daylight interior is also changed from near the windows to further towards back wall.

As window design, the fenestration plays a considerable role to permit availability of daylight. Especially, office room and performance room require a high level of illumination. Punctuation of several windows on the envelope in the high fenestration will increase amount of light and produce more even distribution of light in the room (Figure 6) (Communities, 1993).

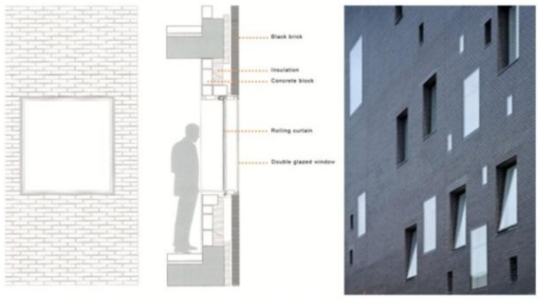

Figure 5 Animation of windows on facades and detail of installation of window

Between two rooms, the fenestration of office is much higher than performance room about 10%. The fenestration in the office is very high 27.7% of west façade and 32.1% of south façade. Consequently, room will be lit well in the morning by windows on south or east walls and in the afternoon, daylight can be admitted by windows on south or west facades. However, the higher fenestration is, the more problems of thermal control and glare can be happened. At that time, roller curtains prove their effect to control problems (Figure 6).

The high fenestration as well as up and down position of windows does not bring an expecting result for internal luminous environment. The first observations by site photos and result of onsite measurements which were taken in overcast sky condition showed uneven light distribution. Zone close to the windows is brighter than other zones of room (Figure 7). Light levels at these points are so lower than 100lux. This causes a great contrast between this area and the back of room.

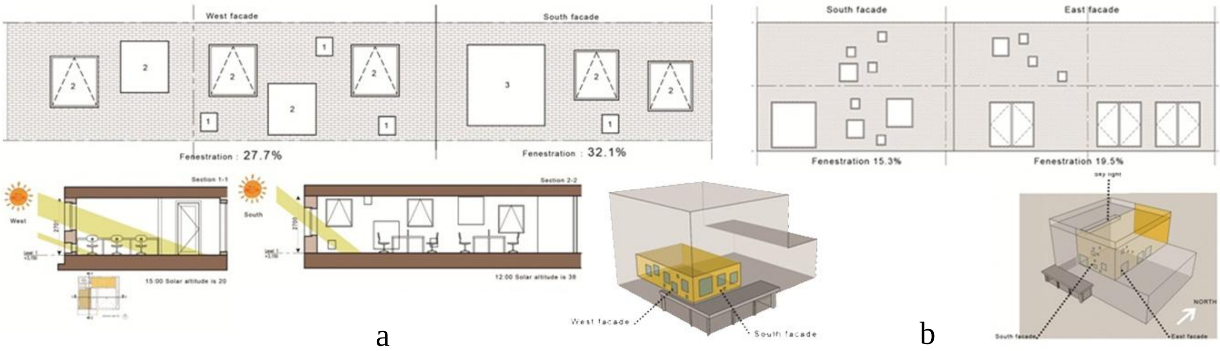

Figure 6 Fenestration, position and orientation of windows of office room (a) and performance room (b)

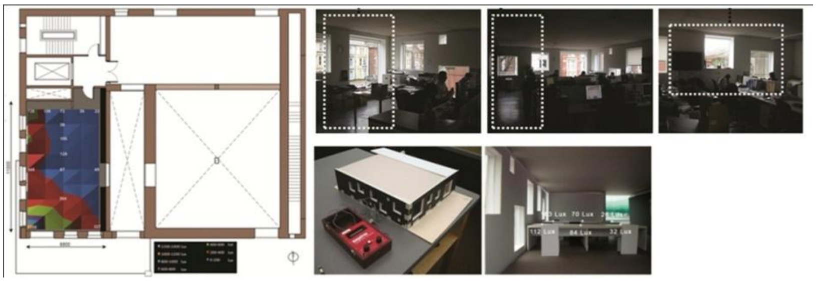

Figure 7 Existing luminous environment of office room and site measurement and physical model in Artificial sky

Based on the computer simulations, the internal daylight levels in the overcast sky are not adequate and the daylight distribution is uneven and does not satisfy visual comfort on task of occupants by medium daylight factor of 2.18% and low Uniformity ratio of 0.12. This pointed out the similarity between investigated methods and this result also brings to a doubt about efficiency of windows in terms of light control.

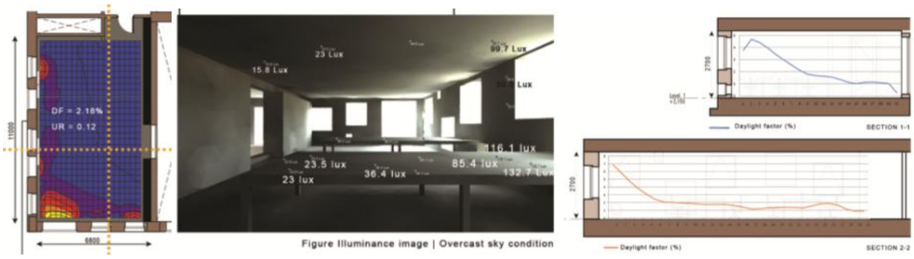

Figure 8 Daylight distribution and radiance image of office room (computer simulation)

However, by a careful observation, this problem can be explained by significant difference of reflectance between finishing materials interior. For lighting design of opened office, the reflectance of each surface should be considered to create a suitable ratio between surfaces.

It is very important to provide the best overall visual environment for the space. Particularly, reflectance of ceiling is minimum 0.6 (CIBSE, 2005). As for the existing office, reflectance of medium grey concrete ceiling, white wall and dark concrete floor is 0.4:0.85:0.14. So, a simple change of ceiling reflectance by bright surface is from 0.8 to 0.9. Interestingly, a result is very impressive because an increase of both daylight factor and the Uniformity Ratio is very desirable. The daylight factor and the Uniformity Ratio between two cases are as follows: original room (overcast sky): DF 2.18%, UR 0.12, room after changed colour of ceiling (overcast sky): DF 4.31%, UR 0.3.

The images of two cases taken in the Artificial Sky show that zone of back wall and dark ceiling of second case become brighter. The contrast between surfaces in room is adequate to create a harmony scenario of daylight.

Figure 9 Comparison of daylight distribution between existing case and case after changing reflectance of ceiling

More importantly, from two curve sections of distribution, quantity as well as quality of daylight in the room is also improved significantly. The achieved 4% DF is a better and expecting result because DF% level is approaching to an adequate level 5% for the internal office space. As for the uniformity ratio, above 0.5 indicates a relatively even lit internal environment, while 0.3 shows an acceptable light distribution.

B. Roof light

Roof lights are designed for performance room and main gallery which are large rooms and have double height of about 6 meter. Otherwise, there are the large numerous windows in performance room. They are arranged mostly on the lower part of wall of the room to ensure enough illumination on task. However, the large apertures can bring to potential problem of glare and overheating in summer. The performance room is a flexible room for various activities with diverse requirement of light level. To satisfy this, an automatic roller curtain system is applied to decrease intense sunlight or to block light out for activities like as performance and cinema (Figure 10). Normally, as for seminar or practice of dancing or lectures, the room admits a space of full daylight from side windows and top light.

Figure 10 Automatic roller curtain system applied in performance room

It can be noted that east façade with three large openings at lower part of this wall is pulled back over 7meters of external wall of gallery. It means that this is effort to optimise penetration of daylight from obstruction of next baptist church. This is suitable solution to satisfy availability of daylight for activities which require high illumination – 300 lux and even light distribution of 5% for practice of dancing, lectures and seminars (CIBSE, 2002).

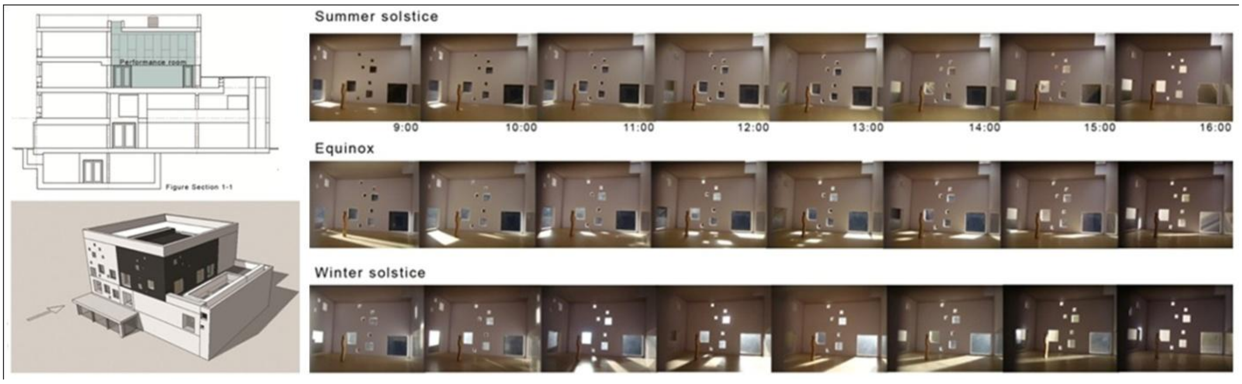

Figure 11 Position and solar ingress of the performance room

The appearance of roof light at the back wall is smooth the daylight distribution of the room by increasing the daylight levels at the back. Diffused light is provided during whole year because of special detail of glazing with a fabric layer in the middle. The thick walls of window show capacity to block the direct light outside in summer and both diffused and direct light are admitted during the winter, spring and autumn months. A comparative study has been found out to investigate solar ingress in the room and role of skylight and side windows in enhancing the luminous environment by using Heliodon and computer simulations. From Heliodon testing, it is obvious that whole space is percieved as well day-lit, lower part of the front wall and back wall is always brighter where skylight and windows of adjacent wall are introduced.

Comparison between three cases shows different scenarios of the internal lumisnous environment as well as the daylight distribution in the room when there are changes of light source following: only sky light, only side windows, both sky light and side windows (Figure 12). In overcast sky condition and curtains opened, computer simulation results show that the space is not adequate illuminated – in the existing scenario, the internal daylight levels are greater with 5.07% and the daylight distribution is more even with UR 0.66. So, in the large and high space, beside side windows, contribution of skylight in the internal luminous environment is very significant.

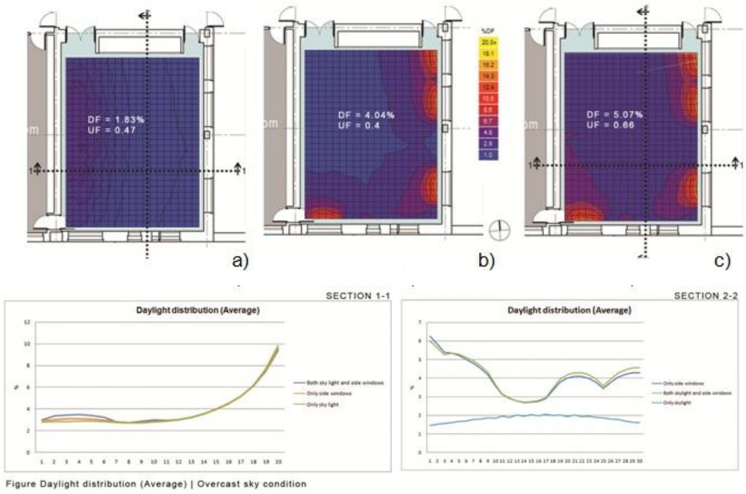

Figure 12 Daylight distribution between three cases (a: only skylight opened, b: only windows opened, c: skylight and windows opened)

3. CONCLUSION

The New Art Exchange - an interesting example demonstrates the window and shading design on the fabric have important impacts on the internal luminous environment of a building. Besides that, the explanation of connection from function of room and specific activities of occupants in each space to architectural elements on elevations was shown. Absolutely, to achieve desirable lighting conditions and visual comfort for occupants requires a careful synthetic consideration of various factors around exterior and interior environment in term of daylight performance. Finally, role and effectiveness of each daylight strategy applied are understood clearly. This is the purpose of this paper.

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