Lighting Design in Workplaces: A Case Study of a Modern Library Building in Sheffield, UK

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ABSTRACT: Using natural light has always been a desirable building feature and a hallmark of a good design. With a considerable design, daylight creates an ambience of well being and visual comfort. Daylighting design has recently taken up a role among the whole design process, beyond the aesthetic and psychological aspects, with the sustainability and the energy efficiency. The alternative to daylighting is to use artificial lighting in workplaces in buildings; however there is a significant amount of energy use when compared with the consumption levels in residential buildings. The paper focuses on a recently completed modern library building in Sheffield, UK and examines its open plan offices in connection with lighting design in workplaces. Effective use of daylight in such a modern library design is both an art and a science. The aim of this study is to present the principle concepts of lighting design used for the workplaces and a case study to demonstrate if a modern library building is fulfilling some of the lighting design guidelines, and to discuss the findings of the preliminary lighting analysis.

1 GENERAL INTRODUCTION

This section of the paper is aiming to provide general information about lighting design in Architecture with a particular focus on daylighting, energy efficiency, people and workplaces.

1.1 *Lighting Design in Architecture*

Using natural light has always been a desirable building feature and a hallmark of a good design. With a considerable design, daylight creates an ambience of well being and visual comfort. Daylighting design has recently taken up a role among the whole design process, beyond the aesthetic and psychological aspects, with the sustainability and the energy efficiency. The alternative to daylighting is the use artificial lighting in workplaces in buildings however there is a significant amount of energy use when compared with the consumption levels in residential buildings.

The workplaces built-in various buildings such as open plan and traditional offices, industrial and educational buildings including library buildings. Today, in modern libraries, the main purpose is no longer limited with reading, but also incorporated widely with IT based workplaces, which makes the main function very similar to most office buildings. In such cases, lighting design therefore should be considered more like in offices rather than in traditional libraries.

Daylighting in buildings do not necessarily lead to energy efficiency. Even well daylit buildings may have high energy usage if artificial lighting is constantly on due to improper controls in place. Lighting should be switched on only when required and to the level require and therefore, the integration of daylighting and artificial lighting requires considerable planning including the appropriate choice of light source, easy controls and a strategy for energy efficiency.

1.2 *People, Lighting and Workplaces*

Whether in industrial or office settings, proper lighting makes all work tasks much easier. People receive about 85% of their information through their sense of sight. Appropriate lighting, without glare or shadows, can reduce eye fatigue and headaches. It also reduces the chance of accidents and injuries from 'momentary blindness' while the eyes adjust to brighter or darker surroundings. Millions of people spend a significantly large part of their lives working or studying, and lighting is provided at their workplaces to ensure that they can see to do their work quickly, accurately and easily. Therefore, people's satisfaction is an important factor when it comes for lighting design in workplaces.

The studies completed by Weston in 1945 have served to demonstrate the general form of the relationship between lighting conditions, task characteristics and visual performance. Accordingly, luminance level and task can form a link to each other so as to determine the work condition. People rarely change the task when working, like the size and contrast of the print. In another words, luminance level is a key point for working efficiency. Improving illuminance levels can enhance working efficient, but this is easy to get its 'saturation' (Weston, 1945).

With regards to daylight requirements, the luminance level is not enough for working situation, light quality is more important for human being. Lighting quality can be the brightness contrast, potential for glare, and colour rendered. Ignoring quality always reduce visual performance so as to reduce the productivity. Normally, natural light is considered with the best quality. The fact that daylight is desired can be shown by quite a few evidences. From research, comes the fact that almost any study which asks office workers about which light source they would like to illuminate their work area reveals a strong preference for daylight; or occupied worked near windows have higher production compare with the ones sitting further of the window (Cuttle, 1983).

Given that daylight appears to be strongly desired by most people, it is reasonable to ask what happens when people are asked to work without daylight, while it is available outside. Observation of almost any multi-story office building will reveal that people are willing to give up daylight when it causes visual and thermal discomfort. Measurements of the use of window blinds in multi-story office buildings have shown two trends. The first is that window blinds are increasing to be shut down when the sunlight through the windows cause solar glare or extra. Another trends is that many of these blinds are kept down even after the sun has disappeared on the window; and this, in some areas, the blinds are left in the down position for ages, this probably because the eyes' adoption and occupies lack of responsibility. These appearances suggest that the desire for daylight, or at least direct sunlight, is limited when it causes discomfort (Heerwagen and Orians 1986).

People also tend to increase the amount of electric lighting as the increase amount of daylighting in the office. The cause of this behaviour might be the desire to balance the luminance of the window and working area; or the surfaces brightness near the window and deep in the room. It also implies that the whole light distribution in the room is more important than the purity of daylight (Begemann, 1994). Accordingly, this suggest that the reason why daylight is so desirable as a main part of lighting from the point of people' satisfaction. This again implies that while considering the lighting design, people' psychological requirement are important, even sometimes people can not realise this themselves. Potential behaviour should be considered while designing, or the certain devices and systems can not achieve the expected result.

2 LIGHTING STUDIES IN A CASE STUDY BUILDING

This section of the paper is dedicated for lighting analysis and the studies carried out using a case study of a modern library building in Sheffield, UK in order to demonstrate some of the principles behind lighting design in relation to daylighting analysis in workplaces.

2.1 *Using Ecotect Programme*

Special computer programmes can calculate the light quantity and light distribution, and with the required computing input, able to also simulate the quality of the light atmosphere. In this study, the computer programme Ecotect is used for several lighting analysis focusing on Daylight Factor (DF) calculations.

Ecotect is a comprehensive and innovative building environmental analysis tool with a vast range of functions to help understand how a building design will operate and perform. The geometry of a space is composed of a few simple basic volumes of any number and at every scale. Any shape can be produced at the required degree of detail. The programme uses sky models that are employed to represent the light source from each situation from different locations across the world. Ecotect offers a range of lighting analysis and whilst its main focus is on natural lighting analysis, it also performs some rudimentary artificial lighting design functions. For more comprehensive lighting analysis, it also allows the user to output native files to other lighting applications such as Radiance (Autodesk, 2009).

Most natural lighting calculations are based on daylight factors. The Daylight Factor (DF) is simply a ratio of the daylight illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance, expressed as a percentage. Thus an unobstructed view of the sky would result in a 100% daylight factor. A point in the middle of a football pitch surrounded by stands may receive 70-80% whilst points in a room with only one window would receive considerably less, possibly as low as 1-5%.

The programme uses the Building Research Establishment's (BRE) Split-Flux methodology which is a widely recognised and very useful technique for calculating daylight factors. This method is based on the assumption that while ignoring direct sunlight, there are three separate components of the natural light that reaches any point inside a building; (1) Sky Component, (2) Externally Reflected Component and (3) Internally Reflected Component.

Using the daylight factor methodology, it is also possible to calculate the illuminance levels at any time of the day, any day of the year. Thus, it is possible to determine how often each point will be above a certain value. This is known as 'daylight autonomy' and is given as the percentage of time throughout the year that each point will need no additional light to maintain the selected level. Sky illumination at any time is calculated using the diffuse sky formula proposed by Tregenza in 1989 (Tregenza, 1989).

2.2 *Information Commons – A Case Study Building*

The Information Commons (IC) building is located in the heart of the University of Sheffield's urban campus. This 11,500 square metres building provides a 24/7 integrated learning environment for undergraduate and postgraduate students with 1,350 new study spaces where students can study individually or in groups, using print and electronic materials. It takes into account of current and future learning methods and technologies.

The IC building was designed as a modern style library and delivered in 2 phases through a design and build procurement route, and was completed in April 2007 by RMJM Architects. The main concept demonstrates the University's commitment to developing new styles of learning, teaching and research, and represents the biggest investment in learning support by the University since the opening of the Western Bank library in 1959, which was a traditional style library.

The footprint of IC building is a simple 'L' shape - west and east facade is longer than south and north. There is a central atrium which is located in the centre along with the circulation area going through first to forth floor with the top light full spans the length of the roof. The ground floor includes the reception and service area, VDT screens on the searching table, combine with a cafe. The cafe behaves as a buffer zone separates the library inside form outside, avoid the disturbing from the main road, keep the service and searching area quite and clean. The store and learning area start from the first floor, with offices and double height conference room around the building. Natural light from the roof window penetrates to the atrium in the middle of the building.

The building layout is arranged around a central rectangular atrium with open spaces located either side of atrium from second to forth floor. From the second to the third floor, the central atrium also separated the general learning space with VDT screens and quite study areas where is double floor height with the gallery. The atrium is provided with daylight via a rooflight that spans the length of the atrium; daylighting being allowed to penetrate downwards through the atrium to illuminate lower floors.

The learning area has a ceiling height of 3.8 meters and display the space in a daylight atmosphere similar to that outside, where one would expect to stay and work. The facade with large or ribbon windows lets filtered daylight into the building, the view and landscape out side the library recedes into a backdrop for the viewing. The main glazing areas are mainly facing north; this means the interior would receive most diffused and indirect daylight, which is better for working environments compare with more direct sunlight of south facing. However, this also means the building may not have enough daylight to support the certain brightness standard, and the artificial light may be used, which is not necessarily energy friendly for a building opening 24 hours and 7 days.

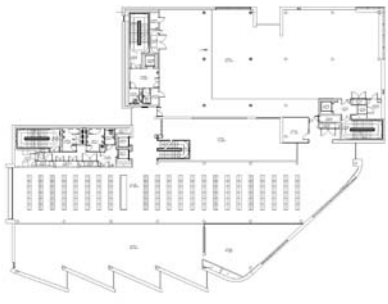

Figure 1. Information Commons building (left) and an Ecotect lighting modelling (right).

Figure 2: Typical floor plan of IC building

2.3 *Daylight Analysis in IC Building*

Generally, the reflectance of internal surfaces in IC building are quite low; one of the reasons behind this might be that there are direct and more diffuse light available, which also means decrease in direct light as means to reduce potential visual problems.

The calculation of daylight factors (DF) as well as the illuminance distributions is established on horizontal layers (working planes) across the study area on each floor using the height of 1 metre from the floor at 11:00 am on 21st August as the suggested hottest day average for Sheffield to illustrate the extreme situation under an overcast day (with 8500 lux sky illuminance). The climatic data and the daily conditions graph shown below (see figure 3) is clearly illustrating that there is clouds covering most of the day, and diffused solar is much higher than direct solar, also considering the fact that overcast situation takes nearly half proportion in Europe. Hence, the overcast sky model is chosen for the simulation.

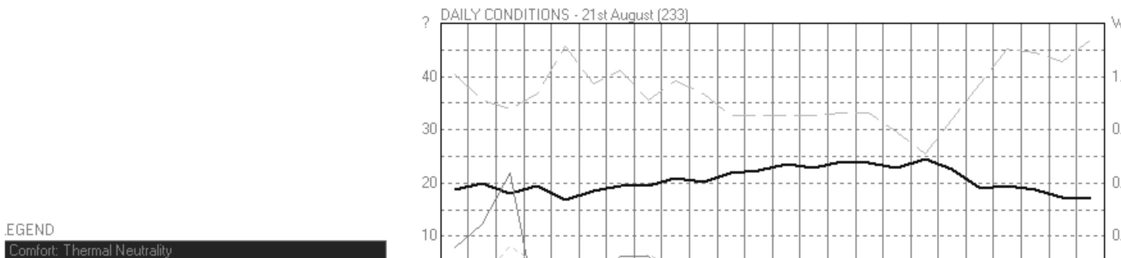

Figure 3: Climatic data for Sheffield, hottest day average, 21st August

The reflectance is one of the important aspects in lighting performance that also influences calculations during the computer simulation process. According to CIBSE guidelines, the internal reflectance range in ceilings, walls and floors are somewhere between 0.6-0.9, 0.3-0.8

and 0.1-0.5. The ceilings in IC building are different on each of the floors; normally with grey or white but matte (with texture) using low value of 0.6; the walls are mostly white but matte (with pattern) surface, so using the neutral value of 0.5; the floors mostly in dark blue carpet, therefore a lower value of reflectance 0.1 is used.

The daylight simulations have been carried out for all floor and also separated into each side of atrium space due to the different functions and window systems used within the building. East part area of atrium has mainly north facing windows with large glazing area; this large glazing area on the south facade is shaded by louvers. West part of the building is mainly designed as a quite study area, similar with the general open office layout, but the glazing area is more on the north and west facing facades, and again limited on the south. The typical floor plan is shown above (see figure 2).

2.4 *Floor by Floor Analysis*

The first floor is the bottom of the atrium with skylight on the roof as the function of general study with computer workstations. It also includes double height general study area in the east with large north facing glazing area, and small open general study area in the west. The analysis is completed separately for each of the floors as follows (see figures 4-9):

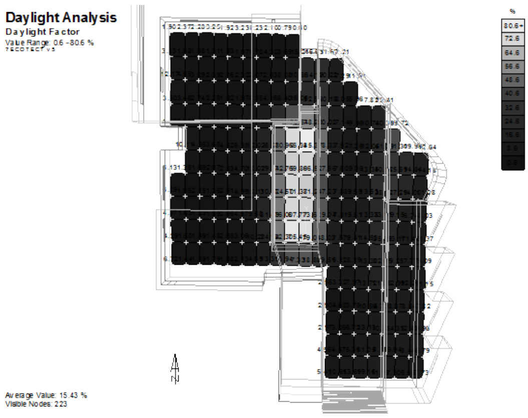

Figure 4: Daylight factors on the first floor

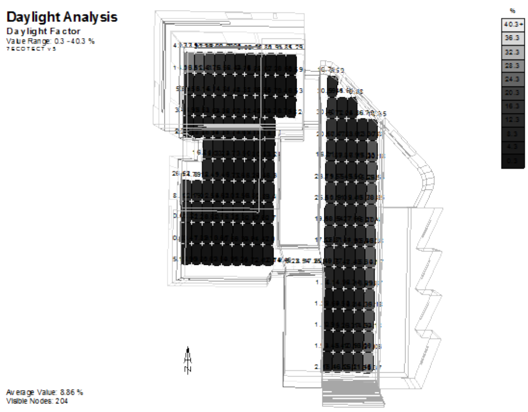

Figure 5: Daylight factors on the second floor

Figure 4 is showing the daylight factors on bottom of atrium which is extremely high compare to the surrounding area, with about 70% due to the skylight on the roof. This is the main problem of the skylight during summer season with high angle direct sunlight, and again this may cause visual discomfort, and therefore proper shading devices are needed. The area in the east with large north facing windows has higher daylight levels than in the west area with normal windows and limited south glazing (see figure 6, left and right).

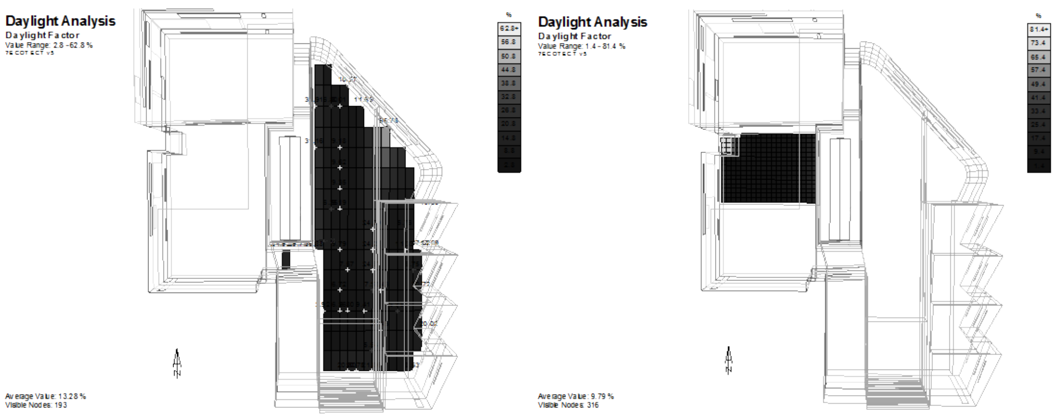

Figure 6: DFs in east part (left) and west part (right) of the building on first floor

The average daylight factor in east area with north light is 13.3% (see figure 6, left). Clearly, double height floor area near the windows has the higher brightness and distributed quite evenly. Brightness level reduced in single height floor in deeper area which is the store shelving located, the DF mostly around 6-9% which is still higher than the CIBSE guidelines (5%). The layout of shelving is parallel to the lighting source (east to west) allowing the light penetrates through the shelves. The light level in deeper area can be compensated by near the atrium space. On the first floor, only central part of west area is the general study area with storage shelving adjacent to the atrium space. The rest of the spaces are used as offices and circulation area and was not taken into account for the calculations. The average DF is 9.79% with illuminance of 832 lux. Natural light source comes from windows facing west and atrium, however due to non-shaded west windows, there may be a possibility of glare during afternoons (see figure 6, right).

The second floor has fairly even illuminance distribution compare with the first floor (see figure 5). General study area in east of atrium has the average illuminance of 1080 lux and DF of 12.7%. The shelving is located parallel to the light source also allowing the natural light to penetrate through (see figure 7, left).

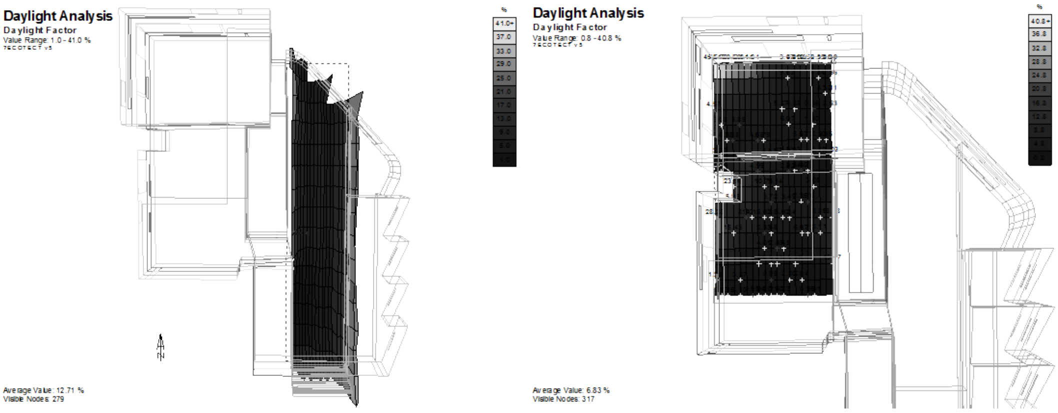

Figure 7: DFs in east part (left) and west part (right) of the building on second floor

Figure 7 is showing the quite study area facing west which has double height floor with gallery with the average illuminance of 580 lux and DF of 6.8%. Apart from the area adjacent the window, the DF is around 3-5%, rarely below 3%, just in the range of the CIBSE guidelines (see figure 7, right). Because of the fact that a quite environment was required in this space, the atrium was blocked, but the light still can go through in from the ribbon window on the atrium wall and compensate natural lighting into the area (with DF of about 8%).

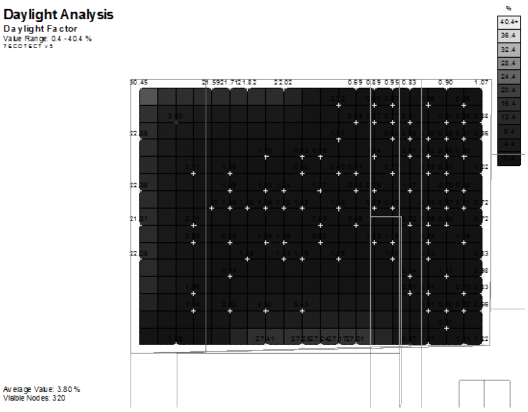

Figure 8: Daylight factors on the fifth floor

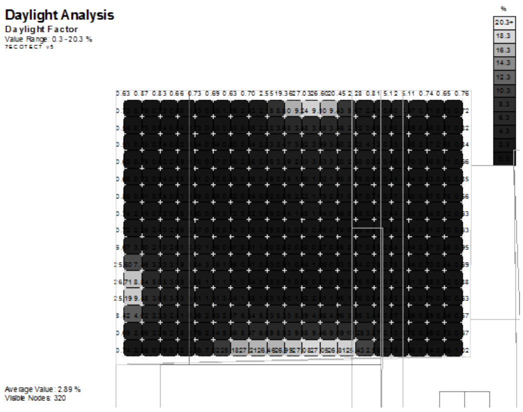

Figure 9: Daylight factors on the sixth floor

The fifth floor has a general open plan space and the calculations have shown the average DF of 3.8% with illuminance of 323 lux; one difference is that it has a bright ceiling (with reflectance of 0.9) instead of a matte one, and the DF has increased about 0.1% (see figure 8). This is also similar within the sixth floor space where the average DF is of 2.89% with illuminance of 245 lux, and the DF has increased about 0.06% (see figure 9). Hence, the inertial reflectance is important when performing such lighting simulations. In addition, although the average DF and illuminance level on fifth floor met the CIBSE guidelines, the large areas on both fifth and sixth floors are slightly below the 3% guidelines and therefore artificial lighting is needed. Daylight autonomy on sixth floor is only 27% and 31.5% on fifth floor.

2.5 *Walk-round Observations in IC Building*

In the double height area in IC building, an uplighter is used which is very smart technique. The luminaries are mounted on the wall, indirect lighting reflected off the reflector on the ceiling (see figure 10, left). Furthermore, the reflectors have a curved specular finish and it is spreading the light over a large part of the ceiling, and avoiding direct light into eyes. It also minimises the problem of casting excessively bright and direct light. In addition, from the maintenance point of view, the ceiling of double height floor is hard to reach but using this uplighter, it is much easier for people to only change the luminaries on the wall, and do the cleaning of the reflectors.

Figure 10: The uplighter used in double height floor area (left); dark grey and deep textured surfaces, which resulted in the 'hot spot' and the dark appearance of ceiling (right)

Most of the study areas in IC building use direct/indirect lighting system where its indirect lighting reflected off the ceiling and walls. It is a diffused even and soft lighting, and creates a comfortable ambience. However, the ceilings in IC building are dark grey and deep textured surfaces, and as a result, it creates the 'hot spot' and the appearance of ceiling being quite dark (see figure 10, right).

OVERALL CONCLUSIONS

In the Information Commons building, the brightness is reduced significantly as we go further away from window. The atrium can compensate and increase the central brightness levels by channelling through natural light. Some of the findings as a result of the lighting analysis undertaken during the study are summarised in the following:

- The arrangement of shelving in storage area is better placed parallel to the main lighting source like windows. This allowed the light to go through the deep areas.
- Double height floors have higher brightness levels due to the larger glazing areas.
- Clerestory windows can increase the lighting quality within the space, even though the thermal aspects should also be considered. However, in long term, it can be considered more important for improving the ambience which has more benefits for people and their satisfaction working in the building and using such workspaces created.

- Skylight on top of the atrium increases the brightness levels on the bottom area significantly, however due to reflectance glare effect may happen, and therefore proper shading devises may be also required.
- According to the simulations on third floor, the solely north light are not able to achieve sufficient daylight conditions to meet the CIBSE guidelines during overcast days, even with large glazing areas. This can be compensated by considerable planning, such as increasing the floor height, using a double height floor, or opening more windows facing other orientations.
- Most of the surfaces (walls and ceiling) in IC building are matte (with texture) or grey; this allows more diffused light in spaces, reducing glare and also other potential visual discomfort conditions. Although the grey ceiling seems too gloomy in some areas and reduces the whole brightness in spaces, the electrical lighting is needed at all times.

To conclude, human factor is the most important aspect in lighting design, the lighting quality and energy efficiency that can not be achieved without considering such conditions. Although the computer lighting analysis can simulate the light distribution with close accuracy and easy to use, lighting design guidelines can be more sophisticated and flexible, the design process should be based on the 'people's requirement' and fully understand the lighting design principles.

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