# #381: The impact of shading devices on the visual comfort and energy consumption of office rooms

## A case study of the Ingenuity Building, Nottingham, UK

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*External shading devices on a building façade is a significant passive design strategy which can decrease direct solar radiation while controlling the direct daylight. While having an immense aesthetic impression, shading devices help to minimize the incident solar radiation and control daylight penetration, hence create a considerable effect on the building's energy performance. As energy conservation and efficiency are fundamental areas of focus in contemporary building design, the effect of shading devices on energy consumptions should be widely explored. The study of this paper evaluated the visual comfort and energy demand of a real case office building, the Ingenuity Centre; which is enveloped by an exceptionally distinct shading device. The purpose of this study was to understand the relation between daylighting and energy consumption of Ingenuity Building considering the impacts of shading device. Quantitative methodologies such as spot measurement and checking the rule of thumbs were undertaken to get a practical idea of the spaces. After analysing the physical model on Heliodon, a digital model was built in IES-VE, to analyse the annual average lux level and Daylight Factor of the office rooms during the active office hours. A significant observation of this study was that the existing shading devices were not providing optimum solutions to daylight inclusion, instead, there was a notable presence of glare causing visual discomfort. Moreover, there was no improvement in the overall energy consumption of the building with the existing shading devices. The proposed shading devices, which were suggested considering the building orientation and climate, improved the daylight level in the office rooms and reduced the energy load as well. The results showed that the annual average lux was increased by 4.5% with a significant reduction in glare with the proposed shading strategy. It was evident that an appropriately designed shading device could achieve higher energy efficiency, providing improved visual comfort. Further exploration is required in this matter with various orientations and building forms, the size and depth of the shading devices as well as materials.*

*Keywords: shading devices, daylight, office building, visual comfort, energy consumption*

## 1. INTRODUCTION

Shading devices, a fundamental part of the building envelope, function like a hat on a building. While performing as a protector of the inner spaces from the direct solar gain through openings, windows and large glazed surfaces, shading devices also influence positively towards energy efficiency in buildings (Lee et al., 1998, pp.47-63). The design and orientation of shading devices change according to different climatic region. For example, buildings in hot-humid climate demand shadings which can reduce the amount of solar radiation and sunlight penetration into the building. On the contrary, for cold climate, it is important to let the sunlight penetrate the building and let the envelope absorb the solar radiation to sustain the heat, hence working as a thermal mass to provide warmth during winter.

Energy efficiency is now considered as one of the fastest and most appropriate approaches to minimize any energy-related emissions associated with air pollution, global warming and climate change (Dincer, 1998, pp.427-453). Buildings all over the world are now expected to achieve energy efficient status by adopting several active or passive design strategies (Iqbal, 2007, pp. 2166-2177). Numerous approaches can be tried to reduce energy consumption in a building. A study in Hong Kong reported that 35% of total cooling demands could be saved by energy efficient envelope design (Chan, 1998, pp. 21-39). Another study confirmed that external shading devices, which can be made of building materials or plants, could reduce the indoor cooling load by 30%. This study also stated that shading devices are more effective in reducing cooling load compared with the use of high-performance glazing (Balaras et al, 2000, pp. 143-54).

## 2. The Ingenuity Centre, Nottingham

### 2.1. Building profile

The Ingenuity Centre is the latest addition to the University Innovation Park (UNIP) at Jubilee Campus. Located at the focal point of the UNIP, the Ingenuity Centre is a three-storied building providing office-based accommodation for technology-driven start-up businesses from the local business community and from within the University. Formerly the site of Nottingham's famous Raleigh bicycle factory, it also manufactured ammunition and armaments during World War II (Philpot, 2016, pp.17-21).

Completed in autumn 2016, the works of Ingenuity Building were managed by Robert Woodhead. The architect for the scheme was Bond Bryan, with Arup acting as services and structural engineer. The director of the Bond Bryan Architects, Mathew Hutton, claimed that the building was designed to appear as a hi-tech structure that would not look out of place in a sci-fi movie with a complex array of metal fins configuring a metallic bronze-coloured circular envelope (*Figure 71*). The curtain wall of the central core is glass and a black aluminium cassette cladding, while the support structure behind the blade cladding is also black (Hutton, 2017).

*Figure 71: The Ingenuity Building (source: author)*

The three-storey building is cylindrical, having a glazed core with an atrium space at the centre. The partitions for the spaces inside can be easily reconfigured to make smaller, cellular space and larger open spaces. There are

mixture of cellular and open-plan spaces at the first and second floors of the building. The ground floor level has more open, shared areas for social and public engagement including the atrium, seminar spaces and collaborative hub space (Hutton, 2017).

## 2.2. Background context

As stated by Hutton (2017), the main concept behind the architecture of the Ingenuity Centre was to reflect the local industrial heritage of the area surrounding the Innovation Park. The design was based on the shape of a tyre (*Figure 72*) to honour the Raleigh cycles factory, which dominated the Triumph Road site from the 1930s until the end of the 20th century (Hutton, 2017).

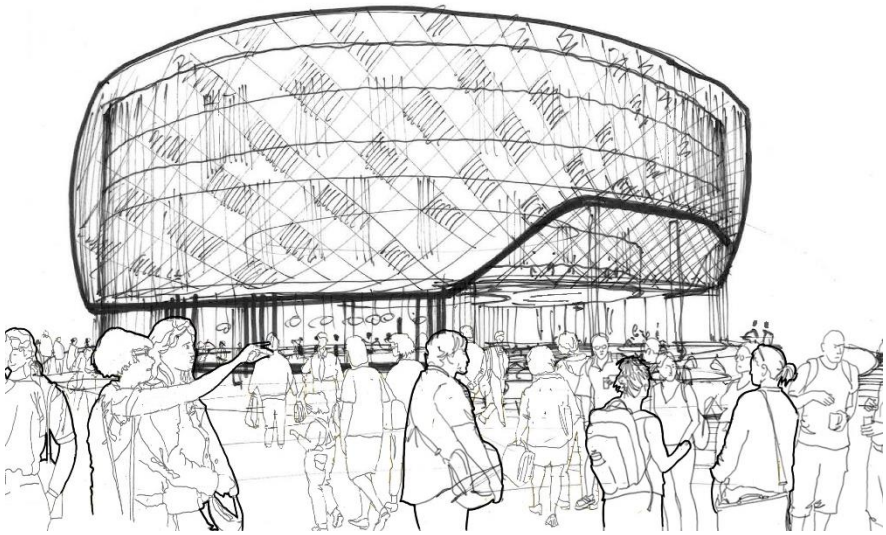

*Figure 72: Architects perspective (source: Hutton, 2017)*

The building was considered by the architect as a combination of hi-tech with heritage. In order for the building to resemble the Raleigh bicycle, which had its factory on the site, 1218 numbers of 350 mm wide x 50mm deep, angled, aerofoil-shaped fins were presented as shading devices (Philpot, 2016, pp.17-21).

The shading devices were constructed from anodised aluminium fins, with black concentric steel rings (*Figure 73*). This structure was mounted on vertical, curved hockey blade frames attached to the central cylinder. Each individual aerofoil blade was manufactured off-site but had to be cut to exact size by hand on site before installation (Philpot, 2016, pp.17-21).

*Figure 73: Shading devices of Ingenuity building (source: author)*

According to Hutton (2017), extensive modelling was carried out by the architects using Building Information Modelling (BIM) to ensure the effectiveness of the blade design. The aim was to design in such way so that the blades were neither obstructive nor oppressive while viewed from the inside and did not restrict the daylight entering the building at different times of year (Hutton, 2017).

## 2.3. Climate analysis

From *Figure 74*, it was understood that the average temperatures in Nottingham ranged from 10°C to 21°C in the summer season and from 2°C to 10 °C in the winter season. It was crucial to allow sun rays to get into the building in winter to lower the heating loads, whereas the opposite is required in summer.

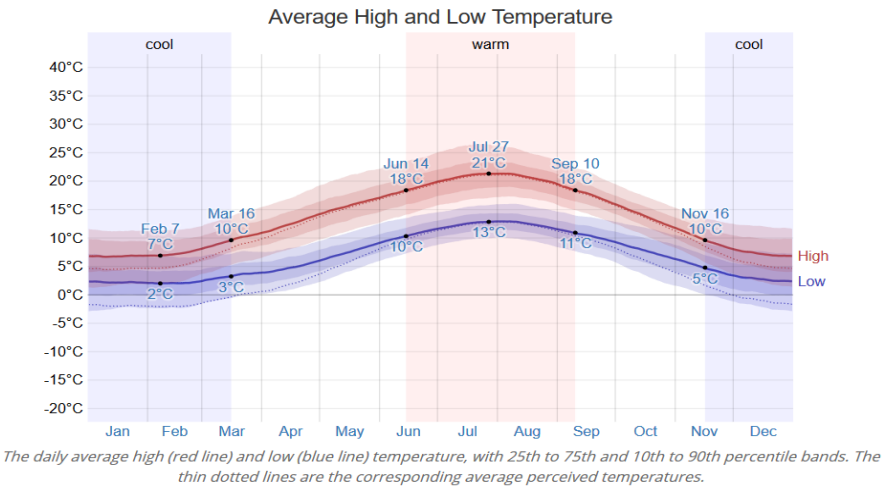


*Figure 74: Temperature graph of Nottingham (Source: weatherspark, 2018)*

Since summer has longer daylight hours (*Figure 75*), the building would be subjected to direct sunlight exposure for a long time, resulting in higher indoor temperatures in the building creating thermal discomfort. On the contrary, during winter, sunlight is appreciated, but the sun altitude is lower, increasing the probability of glare.

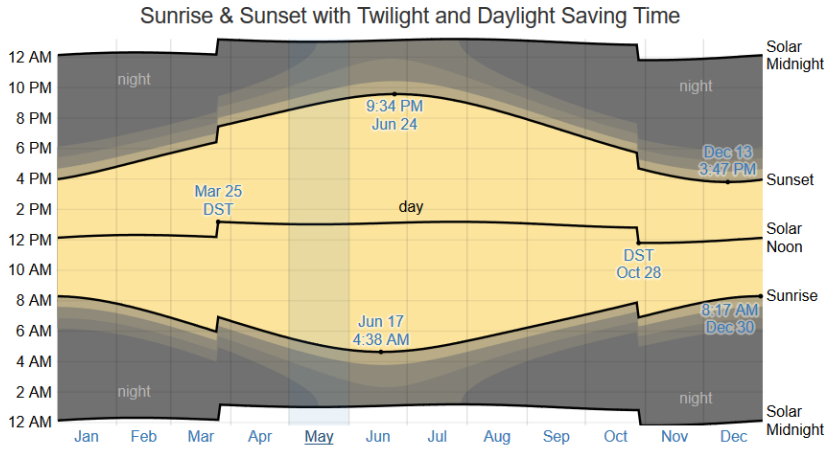


*Figure 75: Hours of daylight (Source: weatherspark, 2018)*

## 3. RESEARCH METHODOLOGY

In this paper, the author studied the performance of the shading devices focusing on daylight and energy consumption of the Ingenuity Building. The relationship between daylight and energy consumption was investigated, specifically on how the daylight levels change according to the shading device design and their influence on the performance of the building's energy consumption.

The initial investigation on daylighting and building energy consumption was carried out using Sefaira. Quantitative methodologies such as spot measurement and checking the rule of thumb were undertaken to get a practical idea of the spaces. After analysing the physical model on Heliodon, a digital model was built in IES-VE, to analyse the annual average lux level and daylight factor of the office rooms. Three separate analyses were conducted, comparing existing shading devices with no shading device, and finally proposing a shading strategy that responds to the limitations of the current design. The analyses was focused on two office rooms, both located on the first floor, one room facing the north and the other facing the south (*Figure 76*). Since the east and west sides of the building consisted of service facilities and circulations, there were no office rooms to compare with. Both the office rooms, located in the north and south, were almost identical in size, measuring 6.2m x 5.3m, having a ceiling height of 3.6m. The computer model simulations were run to achieve annual results during office hours, which was 9.00-17.00 from Monday to Friday.

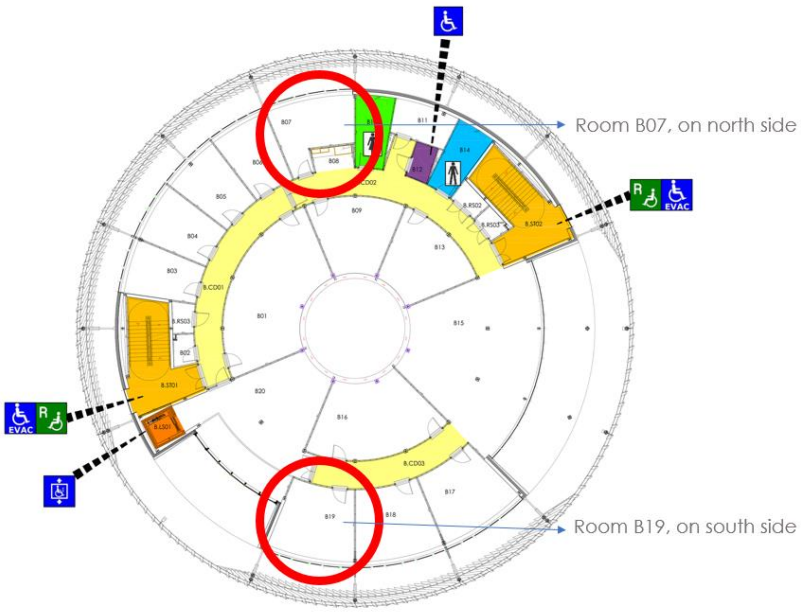


*Figure 76: Selected office rooms of Ingenuity Building on the first floor*

## 4. SHADING DEVICE ANALYSIS

The climatic condition and sun altitude play a vital role while designing a shading device. A well-designed shading device, which can be a part of a building or separately placed, can significantly reduce building heat gain and cooling requirements and improve the natural lighting quality of building interiors (Lee, 1995, pp.326-342).

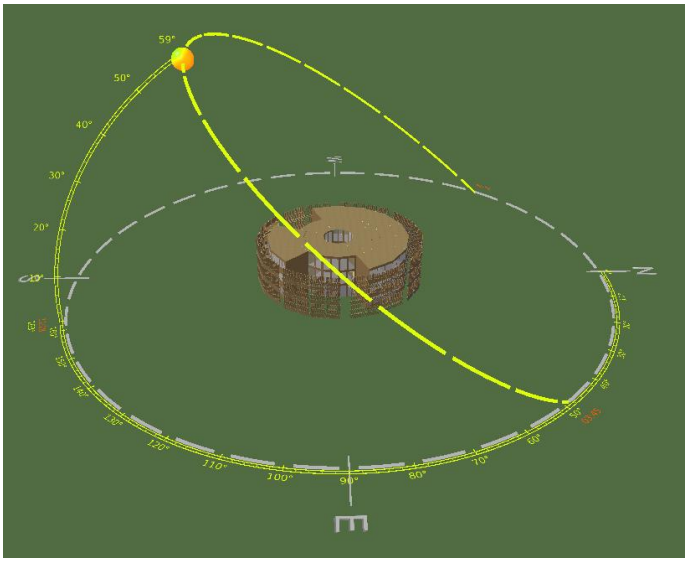

*Figure 77: IES model with yearly sunpath diagram for Ingenuity Building (source: author)*

The design of effective shading devices depends on the solar orientation of a specific building façade. From Figure 77, we can see the sunpath diagram of Nottingham with reference to the case study building. The sun rotates from east to west at a very low altitude, which indicates there will be no direct sunlight on the north façade. Any shading device on the north façade will only contribute to a reduction in daylight inclusion.

On the other hand, the sun altitude on the south façade varies from 14° to 59° through the year, meaning the shading devices should be designed in a certain way so that they can mitigate the solar radiation at this angle. During winter, when the sun is at a low angle, sunrays should penetrate the rooms, but the effect of glare would be a concern.

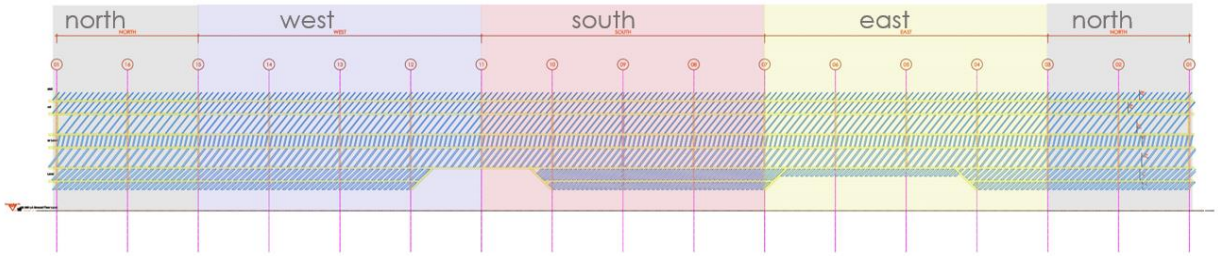


*Figure 78: Shading devices of Ingenuity Building*

While analysing shading devices of the Ingenuity Building, it was observed that they are all at the same angle all around the building (*Figure 78*). Since the sun altitude is different according to the sunpath diagram of Nottingham, the shading devices should have been oriented accordingly. After a detailed analysis of the sun orientation, horizontal shading devices were proposed with an inclination of 20°. They were 500mm in depth, also working as light shelves to provide light to the back of the room (*Figure 79*). The horizontal shades could replace the existing ones, creating the same exterior view from the entry side of the building (*Figure 80*).

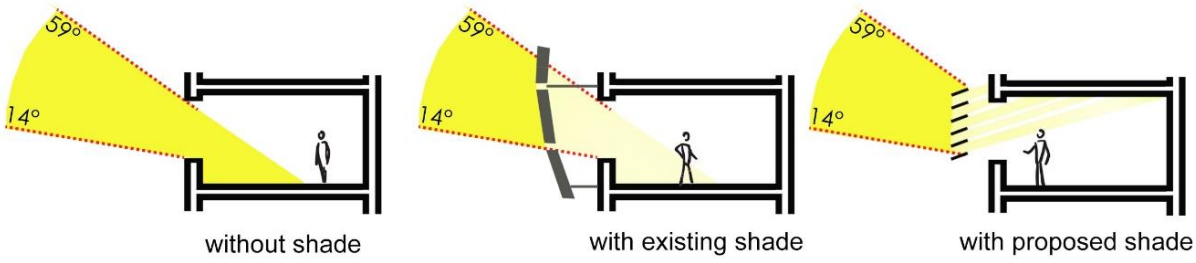


*Figure 79: Different shading orientation for the south room*

*Figure 80: author's proposal of shading devices, adopted from Hutton, 2017*

## 5. VISUAL COMFORT

In every environment, it is necessary for people to be comfortable whilst carrying out their works safely and properly. In an office building, the crucial elements are visual comfort and thermal comfort. The parameters to analyse the visual comfort of space are daylight factor, glare and illuminance. All these parameters were analysed for the two rooms in Ingenuity Building to understand the comfort level with existing shading, without shading and with proposed shading devices.

### 5.1. Daylight factor

Daylight factor (DF) is the ratio between the actual illuminance at a point inside a room and the illuminance possible from an unobstructed hemisphere of the same sky. DF is a constant, expressed as a percentage and always calculated on an overcast sky. As a rule of thumb, 80% of a floor area should have an average DF of 2% (Rennie, 1998, pp.39-52).

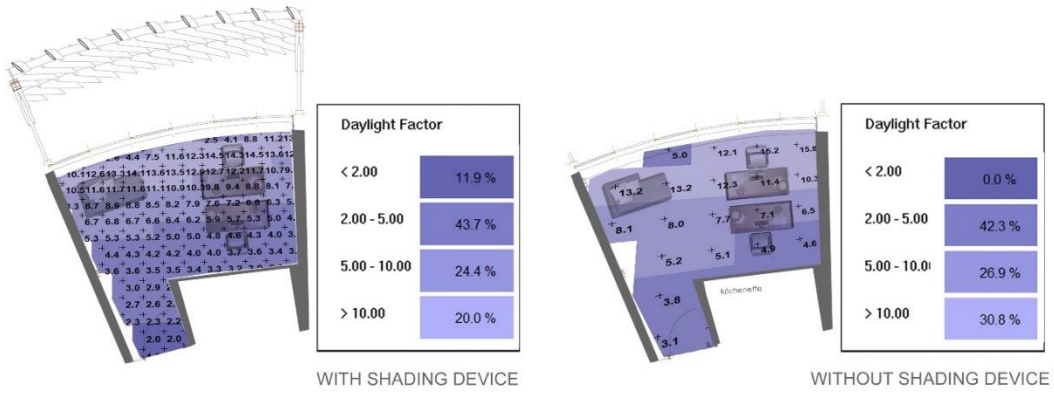


*Figure 81: Daylight factor distribution in the north room*

While running the simulation with the computer-generated model in IES-VE for the north room, the DF distribution was better without shading than with shading (*Figure 81*). As discussed in the shading device paragraph, the north side of the building did not require any shading, explaining why the DF level was reducing when shading devices were used (*Figure 82*).

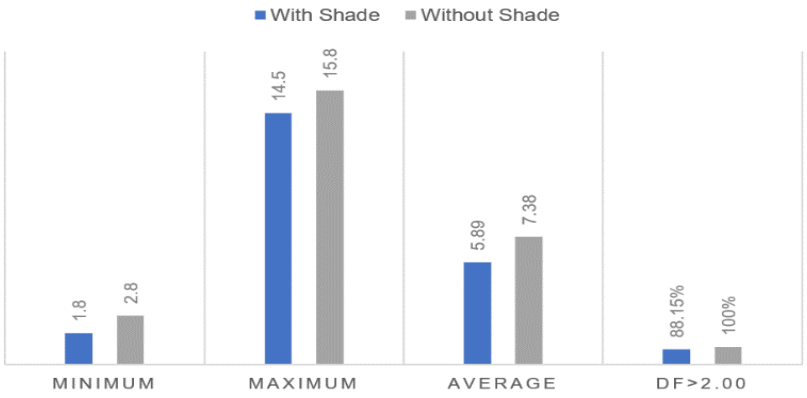


*Figure 82: Daylight factor levels of the north room*

The simulation of the south room showed that there was no improvement of DF level with the shading, as the room had angled vertical shading, rather than horizontal ones (*Figure 83*). But the proposed horizontal shading device could provide 92.31% of DF>2.00 which is required for a comfortable office environment (*Figure 84*).

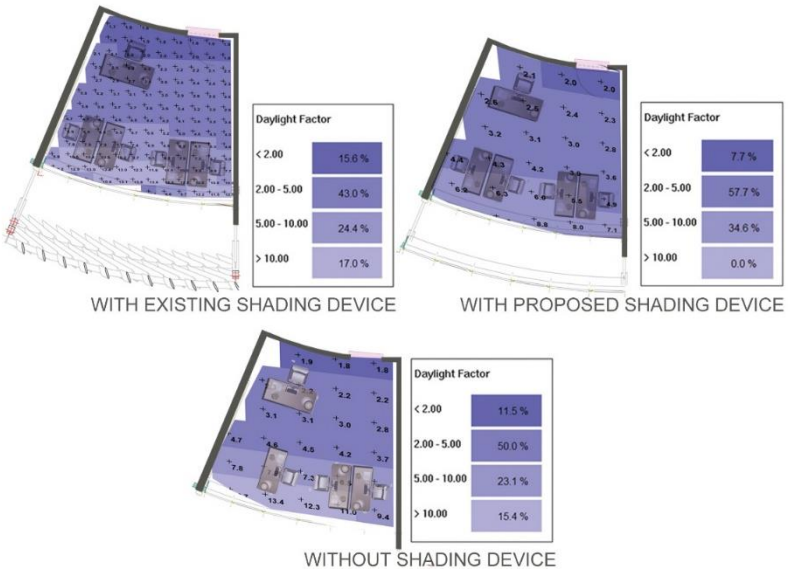


*Figure 83: Daylight Factor distribution in the south room*

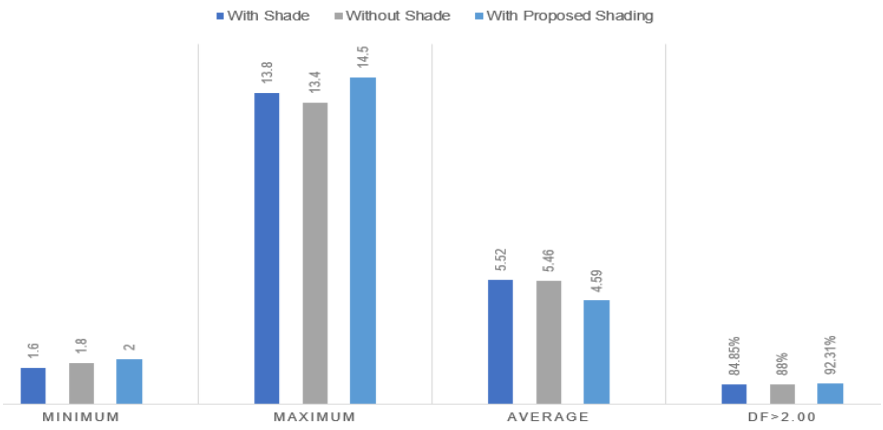


*Figure 84: Daylight factor levels of the south room*

From *Figure 84*, it was clear that the DF level improved with the new proposed shading. While the existing situation portrays an uneven distribution of DF, the proposed shading provided more stable DF all over the room.

## 5.2. Climate based daylight modelling

Climate based daylight modelling (CBDM) is the prediction of any luminous quantity (illuminance and/or luminance) using realistic sun and sky condition derived from standardized climate data. Unlike the conventional daylight factor approach, a climate-based analysis employs realistic, time varying sky and sun conditions and predicts hourly levels of absolute daylight illuminance. With the help of CBDM, the useful daylight illuminance (UDI) was simulated for both rooms. The UDI scheme measured how often in the year daylight illuminance with a range was achieved. According to the CIBSE lighting guide, it is compulsory to have a minimum of 300 lux of illumination for the office visual task lighting (CIBSE, 2006, pp.1-22). The following assumptions were considered while simulating the UDI: work plane height 0.85m, sky condition: overcast sky, occupancy hours: 9.00am-17.00pm, threshold lux level: 500 lux. The simulations were done for the 5 weekdays (Monday-Friday).

Illustrated in *Figure 85*, it was observed that the band of lux level 500-2500 decreased with the existing shading device for the north room. As there was no specific need for shading on the north façade, the shading was minimising the annual illuminance level. It was evident from *Figure 86* that the shading was reducing the illuminance level for the north room.

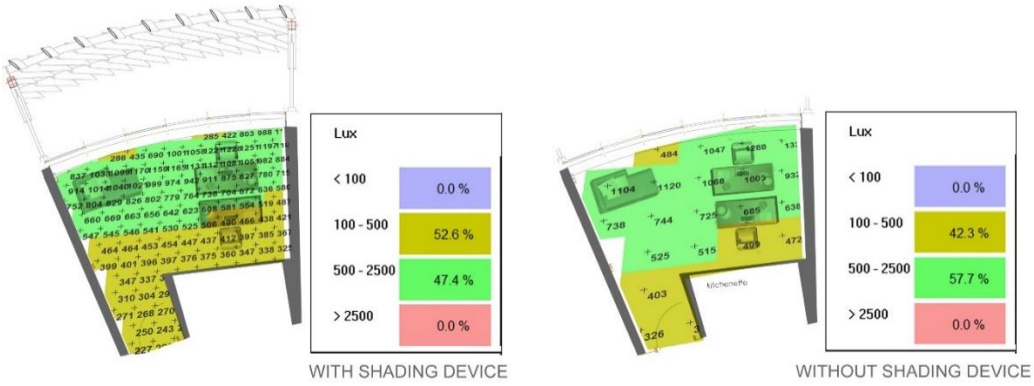


*Figure 85: annual illuminance level of the north room*

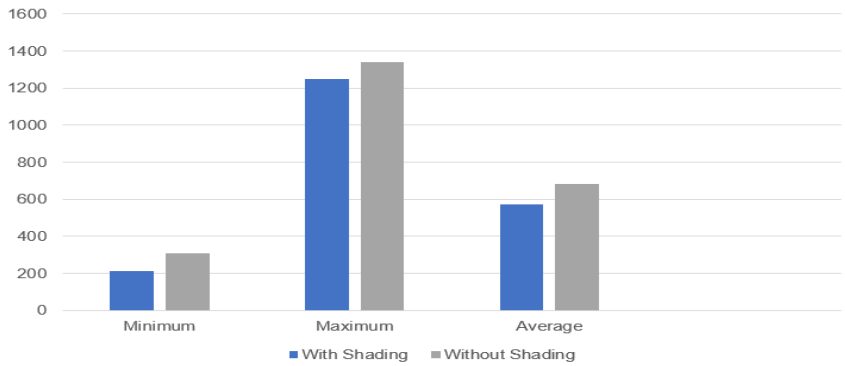


*Figure 86: Summery of annual illuminance level for north room*

While analysing the UDI for the south room, it was observed that the proposed shading had 6% more illuminance above 2500 lux, which was better than without shading (*Figure 87*).

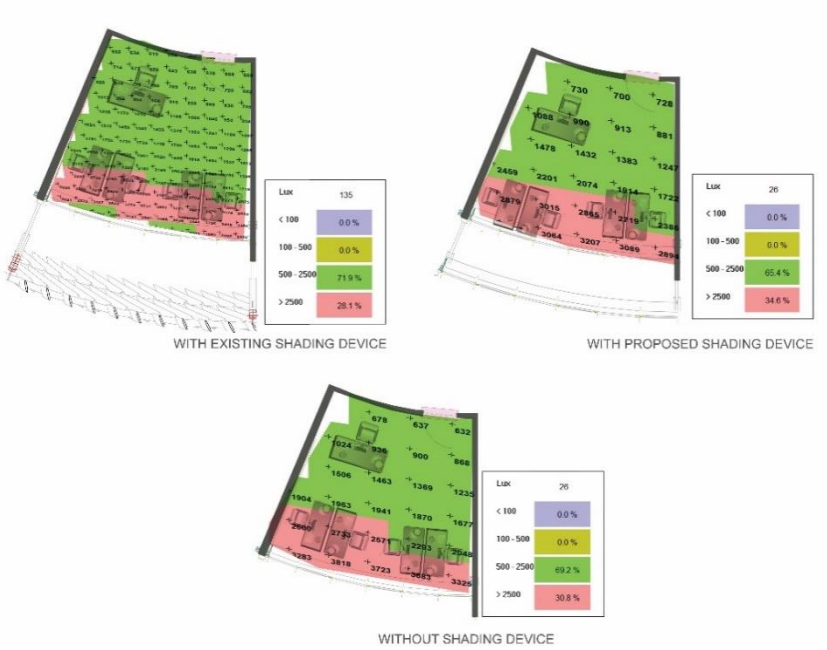


*Figure 87: Annual Illuminance level of the south room*

Also, from *Figure 88*, it was clear that, even though the maximum illuminance was lower for the proposed shading, the average illuminance was increased. This provided a better visual condition for the south room.

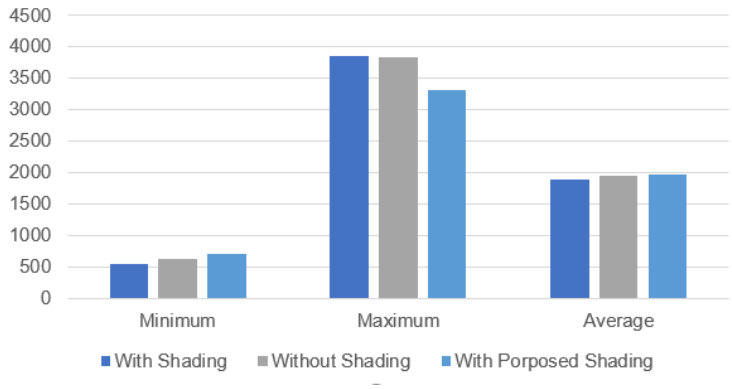


*Figure 88: Summery of annual illuminance level for the south room*

## 6. ENERGY CONSUMPTION ANALYSIS

To analyse the energy consumption performance of the Ingenuity Building, a digital energy model was built. All three cases were analysed by Sefaira to compare the simulations. The assumptions used on Sefaira were the following: office building in Nottingham, wall insulation 0.51W/m$^2$K, floor insulation 0.32 W/m$^2$K, roof insulation 0.18 W/m$^2$K, glazing U factor 1.80 W/m$^2$K, visible light transmittance 0.42, solar heat gain coefficient 0.4 SHGC, infiltration Rate 7.17 m$^3$/m$^2$h, ventilation rate 15 L/s person, equipment 25W/m$^2$, lighting 10 W/m$^2$. These values are accountable for the ASHRAE 90.1-2013 Baseline.

Surprisingly, the energy use of the whole building was the same as the existing shading and without any shading at 122 kWh/m$^2$/yr. But the energy breakdown showed that the heating load was increased with the shading and the cooling load was decreased (*Figure 89*), which meant that with the shading devices, less solar radiation could get into the building resulting in a higher heating demand. With the proposed shading devices, the energy consumption of the whole building was reduced to 121 kWh/m$^2$/yr. Though the heating load increased in that case, the cooling load was significantly decreased. As the solar radiation was shaded with better orientation, it resulted in less cooling demand.

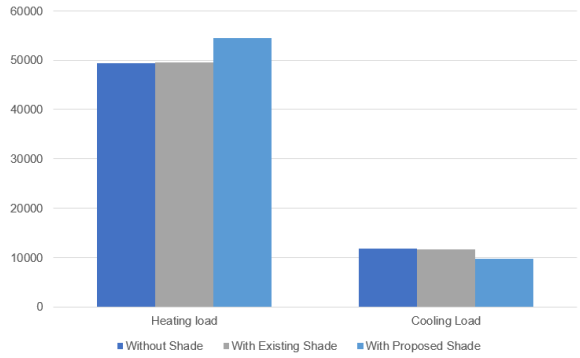


*Figure 89: Energy consumption of Ingenuity Building in kWH/m$^2$/yr*

## 7. CONCLUSION

The purpose of this study was to understand the relation between daylighting and energy consumption of Ingenuity Building considering the impacts of shading devices. A significant observation of this study was that the existing shading devices were not providing optimum solutions to daylight inclusion; instead, there was a notable presence of glare causing visual discomfort. Moreover, there was no improvement in the overall energy consumption of the building with the existing shading devices.

The proposed shading devices, which were suggested considering the building orientation and climate, improved the daylight level in the office rooms and reduced the energy load as well. The daylight factor above 2.00 of the

south office room was increased to 92.31%, whereas it was 84.95% with the existing shading devices. The annual average lux was increased by 4.5% with the proposed shading devices.

It was evident that appropriately designed shading devices could achieve higher energy efficiency, providing improved visual comfort. Further exploration is required in this matter with various orientations and building forms, with a range of sizes and depths of shading devices as well as materials.

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