An Investigation of the Luminous Environment in the Nottingham H.O.U.S.E

The effect of shading devices on a building with change of use

Double-blind review process

Do not include authors in the body text at this time

ABSTRACT: Daylight makes an important contribution to indoor quality and building occupants' wellbeing and productivity. Although it is well known that different spaces need different lighting quality in order for tasks to be performed effectively, the issue of change of use is rarely explored. This is particularly relevant now, not only because in many major cities where land is scarce and expensive building change of use is common, but also since the world is dealing with a major pandemic that has forced most people to start working from home for a significant period of time. Can homes provide good quality working environment?

The Nottingham H.O.U.S.E (Home with Optimised Use of Solar Energy) was designed for the Solar Decathlon Competition in Madrid in 2010 as a starter home. It has found its lasting place on the University of Nottingham campus where it provides office space. In this work, the authors investigated the luminous environment of the offices within the house and compare the findings to its designed targets. Onsite measurements, computer simulations and interviews with the users were undertaken and the findings suggest that the building has adequate daylight levels for task performance according to benchmarks. However, the aluminium shading device, essential from a thermal performance perspective, causes impairing glare that can affect the users' performance. The reflective properties of the device were studied and solutions were proposed.

KEYWORDS: Daylight , Nottingham H.O.U.S.E , Visual comfort, Glare, Shading device

1. CONTEXT/BACKGROUND

There is a significant and growing body of research on the benefits that effective daylighting in buildings can provide. Daylight contributes to the overall indoor quality in terms of user productivity, comfort and wellbeing, and energy savings; it is preferred over artificial lighting in working spaces [1]. Different spaces have different lighting requirements for functional task performance [1,6]. Effective lighting is particularly important for offices where more detailed tasks are conducted and, therefore, minimal lighting standards are specified. However, there could be potential drawbacks of daylighting like glare or overheating due to the type of glazing used in windows, shading devices, surface area of window discharging light and heat radiating through it.

In this paper, the authors investigated the luminous performance of the Nottingham H.O.U.S.E (Home Optimising the Use of Solar Energy) (Figure 1). The house was designed and built for the US Department of Energy Solar Decathlon competition in 2010, an international competition aiming to advance the knowledge of sustainable homes. Designed as a starter home for two adults and one child, the design of the house was focussed on offering a sustainable solution for the UK housing market. It was designed to meet the Passivhaus standards and the UK Code for Sustainable Homes Level 6 (zero carbon) [3].

Figure 1: The South Façade of Nottingham H.O.U.S.E, University of Nottingham.

Interestingly, as the competition was set to be held in Madrid, the designers had the task of making it perform to the climate requirements of both Madrid and Nottingham. In Nottingham (latitude 53 and longitude -1.2), the sky conditions are cloudy and overcast for about 50-70% of the year whereas in Madrid (latitude 40.4 longitude -3.7) it is mostly clear for around 30-70% of the year [2]. Currently, the Nottingham H.O.U.S.E. is used as an office for research and teaching staff. It is situated at the Creative Energy Homes hub, which is a project led by the University of Nottingham to explore the various technological developments in sustainable housing and energy efficiency [7]. The fact that the house is an environmentally efficient building, the transformed usage of the house from a home to an office building spurred the purpose of exploring the luminous environment.

The house consists of two floors, with a built-up area of 75 m^2. The ground floor consists of a lobby, kitchen, a living room (which is now an office area), dining space and a toilet (Figure 2). The upper floor consists of a bathroom and two bedrooms which have been converted into two single-occupant offices. The windows and roof light were designed for passive natural ventilation. The building also uses external aluminium blinds as a shading device on its southern facade(Figure 1). For this study, the office spaces within the house were reviewed, the issues that impact on adequate daylight were identified and potential solutions were proposed.

2. RESEARCH METHODOLOGY

The objectives of this research were to understand the luminous environment of the house and to analyse and propose solutions if any daylight problems were observed. To analyse the visual comfort from a user's perspective, the research staff working in the house were interviewed. The aim was to acquire feedback of the design of the house in terms of comfort, the materials of construction and technology. Also, onsite daylight measurements were recorded to analyse the daylight received on the work planes. However, to support the data collected from the onsite measurements and the interviews, a set of computer simulations were analysed and correlated. From the daylight visual comfort findings, it was inferred that there was a potential daylight problem occurring because of the external shading device, such as glare. Further computer simulations were run to analyse the glare occurred and plausible solutions were provided with supporting analysis.

The research methodology was divided into two parts, the first part was the assessment of the daylight performance of the house and the identification of any problems. The second part was the analysis of glare and proposal of solutions to minimize the effect of it without compromising the other elements of daylight performance.

2.1 Daylight analysis and visual comfort

The Nottingham HOUSE was divided into three zones and daylight performance was analysed at the task plane level (Figure 2). Zone 1 consisted of the open office on the ground floor with four work stations, an open to the sky dining area and a kitchen. This space consists of windows on the north, south and the east facades. The first floor was divided into Zone 2 (the room on the southern end) and Zone 3 (the room on the northern end) because they are two single-occupant offices.

Figure 2: The Nottingham H.O.U.S.E. zones

The main intent was to check if the daylight on the workstation planes satisfy the requirements for the task performance . Following an assessment done using rule of thumb calculations, the daylight factor (DF), uniformity ratio (UR) and the useful daylight illumination (UDI) for all the zones were investigated using the software, Integrated Environmental Solutions Virtual Environment (IESVE). The simulations were carried out using the following assumptions:

1. Sky conditions: overcast
2. Occupancy hours: 9:00 am – 5:00 pm
3. Threshold lux levels: 300 lux (task lighting)[6]
4. Simulated for the weekdays throughout the year (occupancy days)

The reason to run the digital model under the assumption of an overcast sky condition was to understand the luminous environment inside the built structure when there is minimal daylight availability. Also, the sky conditions in Nottingham are cloudy for 50-70% of the year.

To understand the daylight performance during the days with various sky conditions such as sunny and overcast day, on-site spot lux level measurements were recorded on the work plane at 3 different times of the day**,** 9:00am, 12:00pm and 3:00pm on the following days with the respective conditions:

1. An overcast day- artificial lights switched off and internal blinds 30% closed.
2. A clear sky day- artificial lights switched off with the internal blinds 100% open.

CIBSE (Chartered Institution of Building Services Engineers) comfort guidelines were used as a baseline for luminous standards and threshold criteria for office spaces. Various daylight parameters which measure the sufficient daylight levels on work planes were analysed. The following are the base guidelines:

1. DF- Minimum of 2% and an average of 5% [6]
2. UDI- 300-500 lux [6]
3. UR- More than 0.1 indicates borderline satisfied and more than 0.2 indicates good daylighting in the rear end of the room [10]
4. Glare- a) There would be an occurrence of glare if the DF is more than 5%
   b) The contrast ratio, measured in cd/m^2 of the task luminance: immediate surroundings: non - adjacent surrounding should be 1: 3: 10 [5 ,6]

2.2 Analysis of glare and shading device strategies

The results from the simulations and onsite measurements led to conclusions regarding the daylight performance of different zones. While correlating the data from the interviews, onsite measurements and the digital simulations it was inferred that there was an occurrence of glare in Zone 1 and Zone 2. Furthermore, frequent visits and a set of interviews were conducted to understand the visual comfort from an occupant perspective. The author visited the site every fortnight to record various data like onsite measurements, interview, to experience the space personally. The users were asked questions relating to their perception of the space, the daylight quality on various days, usage of the inner shading blinds and the frequency of using them. This led to the identification of experiential related issues like glare caused by the aluminium blinds used as an external shading device (Figure 1). Also, it was noticed that the inner blinds were used mostly to avoid the glare caused. As inferred from the interview and the daylight analysis, a set of digital analysis was carried out to understand the intensity of glare throughout the year by radiance mapping. The radiance mapping produces images which contain the glare components. The scope of the work presented in this paper was limited to only one component of glare, the daylight glare probability (DGP) because it is the most credible component which identifies the intensity of discomfort [11]. The Evalglare software was chosen to evaluate the DGP because it integrates radiance mapping to analyze it.

The probability of the occurrence of glare due to the shading device used in the southern facade in Zone 1 and 2 were identified in the occupant feedbacks and it was supported by the computer simulations. However, further analysis was required to measure the intensity of it. Zone 2 was simulated to arrive at various radiance mapping images to analyze the effect of glare. According to the CIBSE guidelines, if the DGP is higher than 0.35, it states that the glare occurred may cause discomfort but it is tolerable. However, with the aim of establishing solutions for a glare-free working environment, few shading device strategies were worked out to compare their DGP.

3. RESULTS AND DISCUSSION

The results are presented in this section, divided TO reflect the steps taken in the work.

3.1 Daylight analysis and visual comfort

The DF of the three zones as identified were analysed using Flucs DL, IESVE. As observed in Table 1, the average daylight factor received in Zone 1 is 6.9%, Zone 2 is 5.8% and Zone 3 is 5.1%. This shows that all the zones satisfy the minimum required DF conditions. However, there could be a probability of glare near the windows because DF near the windows, especially in Zones 1 and 2, is nearly 20% [6].

Even though the DF is satisfied in all the zones, the uniformity ratios from Table 1 infer that Zone 2 and 3 are uniformly lit whereas the Zone 1 is not because of its longer plan depth (Figure 2).

Table 1: Average DF and UR of Zone 1, 2, 3

Zone	Avg. Daylight Factor (%)	Uniformity Ratio (UR)
1	6.9	0.02
2	5.8	0.13
3	5.1	0.14

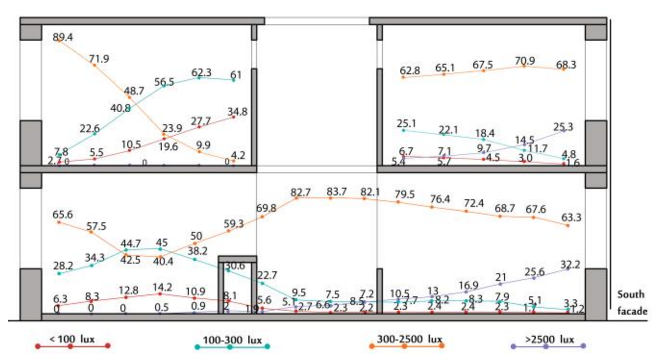

Figure 3: Section showing average UDI distribution throughout the year in all the zones

An in-depth climate-based daylight illumination renders were analysed to identify the UDI distribution in all the zones throughout the year as shown in the graph, Figure 3. The UDI range of 300-2500 lux, which is the sufficient natural daylight illumination for office task work, is satisfied in all the zones in the workstation areas for about 62%-89% throughout the year. It is clear that the house receives a part of direct daylight through the skylight window located at the centre of the building, providing ample daylight to the Zone1. The central space (dining /meeting area) gets acceptable daylight of 300-2500lux for around 70-84% annually. However, the kitchen receives daylight only for around 45-65% of the year because the window is orientated towards the north tends to receive diffused daylight**.** The workstation area in Zone 1 receives around 63-80% of acceptable daylight levels throughout the year. Although the work-plane in Zone 2 achieves required lux level requirement for around 63-69% of the year Zone 3 receives 4.2-89% of acceptable daylight because the window being on the north facade. However, as indicated in Figure 4 it is noticed that the high daylight illumination on the work plane in Zone2 is reduced because of the external shading device used. The present scenario proves that the existing shading device reduces the solar radiation, yet maintains the useful daylight illuminance. To further investigate the luminous performance a set of onsite multimeter measurements were recorded.

The occupants' feedback through interviews suggested there have been experiential problems like the occurrence of glare on their workstations during clear sky days and they tend to use the internal binds to avoid it. The external aluminium blinds used for shading increases the effect of glare due to their reflective properties. Also, the windows being on the southern facade are exposed to more solar radiation compared to other facades. This indicates more hours of daylight entering the workstation spaces. It is also clear from Figure 2 that a major number of workstations are on the southern end of the building, on the ground floor (4Nos.) and first floor (1No.).

The daylight illuminance was reviewed during the occupant hours: 9:00 AM – 17:00 PM on weekdays in the early summer season. During which it was observed that there was a high UDI ranging from 2600 lux- 4861 lux on the workstations in Zone 1 and 2 during noon on clear sky days (Figure 5). When the UDI is more than 2500lux and has exceeded the useful range of illumination it means that there could be a phenomenon of glare and overheating thus causing discomfort in the indoor visual factors [8].

It is clear from occupants' feedback that there is an occurrence of glare, however, there is an increased chance of occurrence of glare near the windows affecting the work-plane areas from the onsite measurements especially on sunny clear sky days. However, it is important to understand the intensity of glare caused. If this building was used as a house instead of an office the occurrence of glare wouldn't affect the occupants because the task would have been different. The next set of discussion would give more insight into the study on the intensity of glare.

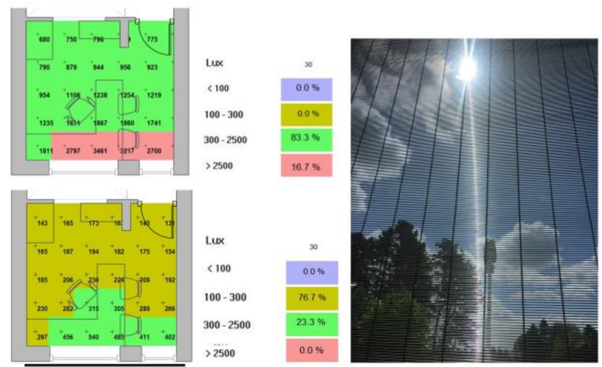

Figure 4: Average UDI of Zone 2, Base Case and Base Case + external shading measured in lux

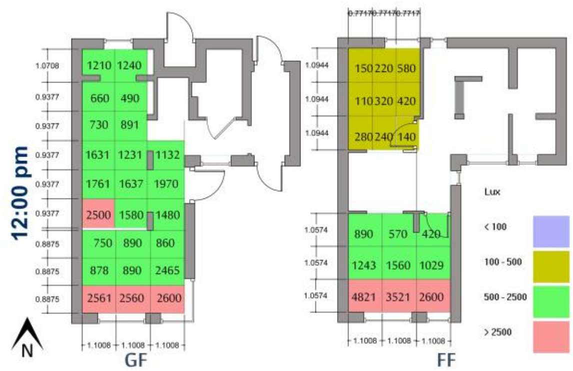

Figure 5: Onsite daylight illumination spotr measurements of all the zones on a clear sky day (10th April 2018 12:00pm)

3.2 Glare analysis

It was inferred from the occupant interview feedback that two types of glare that persist, disability glare and veiling glare. The disability glare, which was observed only in Zone 1 and 2 was caused by the aluminium shading device which is constructed of several cylindrical wire like blinds made of aluminium. However, this glare caused was majorly due to the field of vision that the occupant has been exposed to while working on their computers. Due to the reflective properties of the polished surface, the shading device reflects the daylight (Figure 4). Also, the veiling glare was caused due to the shadows of the blinds cast on computer screens resulting in reduced screen contrast. Generally, the occupants use internal blinds to avoid the glare but this would decrease the daylight entering the space and the view would get curtailed.

From Figure 4, it is inferred that Zone 1 and Zone 2 received the maximum illuminance of 2600-4821 lux near the windows thus indicating the occurrence of glare. To analyse the effect of glare due to the external shading device, Zone 2 was chosen for further findings. The digital model on IESVE was simulated to generate radiance luminance map images. A hemispherical image with the view position angle as shown in Figure 6 was processed to analyze the effect of glare. There is no measure of a threshold for glare to state if it is high or low because it is personal perseverance which changes according to the individual [2,4]. To evaluate the glare caused by the daylight, Wienold and Christoffersen developed a glare index, DGP and the formula for which is following:

$$DGP = 5{,}87 \times 10^{-5} \times E_v + 9{,}18 \times 10^{-2} \times \log\left(1 + \sum_i \frac{L_{s,i}^2 \times \omega_{s,i}}{E_v^{1.87} \times P_i^2}\right) + 0{,}16$$

Equation 1: Daylight Glare Probability [9]

Where, Ls is Luminance of source, ωs is the solid angle of the source, Lb is the background luminance i.e. adaptation luminance and Pi is the position index [9]. The following were the assumptions for simulations:

Sky condition: Overcast day /Sunny day

Task luminance: 180 cd/m^2

Simulation day: 21st June (Summer solstice)

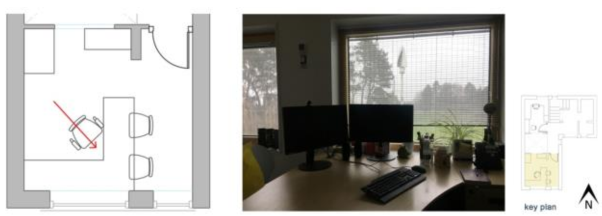

Figure 6: Zone 2 with the view position to analyse glare

The model was simulated on an overcast day without the shading device (Case 1) to analyze if there was an occurrence glare in this scenario. However, to analyze the current scenario the model was simulated on an overcast day and a sunny day to analyze the occurrence of glare (Cases 2 and 3). Further, the rule of thumb calculations and the DGP found from the processed images were analysed.

According to CIBSE, the contrast ratios, measured in cd/m^2, of the task luminance: immediate surroundings: non-adjacent surrounding should be within the ratio of 1:3:10 (180^0 Hemispherical view) [5]. The 3 cases were calculated using the rule of thumb from the digital image mapping from the IES VE radiance luminance image. The results for the respective cases were 1:3.6:13.6, 1:4.7:10, 1:2.8:27.3. The high contrast ratio between the visual task and the adjacent surface in Case 2 proved that the task was impaired by the glare. However, as inferred from the interviews and the high contrast ratios 1:27.3, Case 3 (sunny day) proves that the discomfort glare caused was due to the shading device.

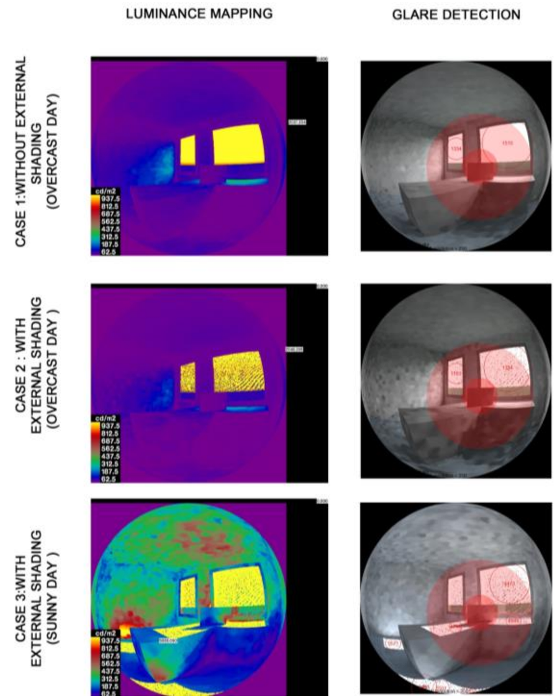

Figure 7: Luminance mapping and glare detection

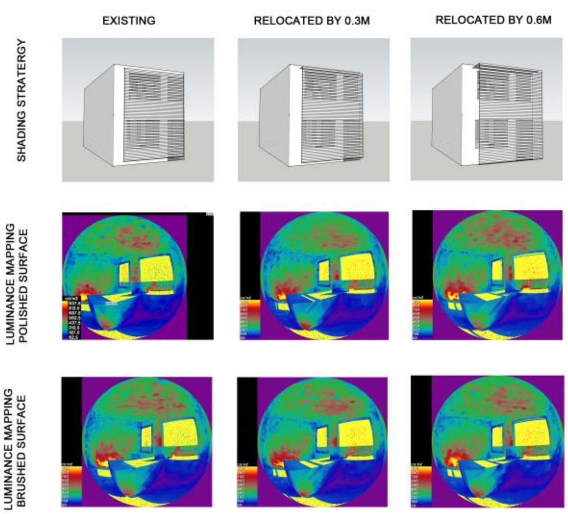

Figure 8: Shading device and Luminance mapping

Table 2: Aluminium finishes vs. their DGP and contrast ratios (SD Shading Device, PF Polished Finish, MF Matte Finish)

Finish		DGP	Uniformity ratio
Existing SD	PF	0.37	1: 2.8: 27.3
	MF	0.356	1: 3.0: 20.48
SD 2	PF	0.32	1: 2.4 : 21.47
	MF	0.311	1: 2.5: 20.43
SD3	PF	0.325	1: 2.4: 19.2
	MF	0.314	1: 2.2: 17.5

While simulating the luminance maps, a parallel High Dynamic Range (HDR) image was produced. Wxfalse colour application in DIVA was used to produce the luminance mapping from the HDR image. The luminance mapping as shown in Figure 7 helped in analyzing the DGP. The Evalglare software was used to determine the DGP once we code the Radiance image or the HDR image into it. The DGP for the Case 3 image was 0.37. This indicates discomfort but at tolerable levels. However, the study intended to achieve a glare-free work environment, and, therefore, various shading device strategies were tested.

It is important to understand the material properties and the finishes of a shading device during their application because we know that the reflective properties of the polished surface resulted in discomfort glare. The next set of analysis focused on altering the shading device's material properties and the distance at which it could be placed from the building. There are various grades of aluminium finishes available currently in the market. The more polished the surface is the more reflective they are. Figure 8 shows the shading strategy used and Table 2 is the comparison between the aluminium finishes and their contrast ratios and DGP (SD- Shading Device, PF- Polished finish, MF- Matte/ Brushed finish). Zone 2 was simulated with following shading strategiesand the different shading shown in Table 2:

1. Existing shading device

2. Existing shading device relocated 0.3 m away from the built structure

3. Existing shading device relocated 0.6 m away from the built structure

The reason for relocating the shading device was to explore whether that could help improve the results. Table 2 and Figure 8 show that the existing shading device portray the highest DGP and contrast ratios compared to the iterations. Also, it is evident that the surface finish of the blinds make an impact on the glare caused. The matte finished shading device simulations reveal a lower DGP and contrast ratios comparatively. However, it is also observed that the farther the shading device from the built structure, the lesser was the DGP. In the case of the third shading device strategy (matte finish), where the existing shading device was being relocated by 0.6 m from the building, it showed the lowest contrast ratio of 1: 2.2: 17.5, but it exceeded the ratio of 1: 10. However, in the case of shading device strategy 2 (matte finish), where the shading device was moved by 0.3m, it resulted in the lowest DGP of 0.311. Finally, it is inferred that the matte finish shading device yield better performance than the existing polished surface. It is important to note that the glare can be reduced by moving the shading device further away from the building in such a way that the principal shading strategy of reducing solar radiation was not affected.

4. CONCLUSIONS

It is important to evaluate the indoor comfort condition post-occupancy, especially when there is a change in building use as in the case with the Nottingham H.O.U.S.E. This can help in identifying any issues and the implementation of remedial measures. It is evident from the analyses conducted as part of this work that the Nottingham H.O.U.S.E satisfies the indoor daylighting requirements for the workstation task plane for 40-89% of the year. However, in the summer, especially during clear sky days the task is impaired due to visual discomfort caused by the glare due to the external shading device indoors. Given that the façade in question is orientated to the south, there would still be a need for a shading device to control daylight in the summer months. The reflective properties of the shading blinds have been causing the discomfort glare. It has been analysed that the glare can be avoided by changing the material finish of the shading device to a brushed or matte instead of polished finish. Also, by relocating the shading device further by 0.6m towards the south resulted in lower contrast ratios and a DGP of 0.311, which means the glare caused would be imperceptible. It can be observed that every building component that goes into the construction should be evaluated to understand the future impact of it. Especially the facade elements like the window, shading devices and the materials of their construction should be evaluated post-occupancy to decrease potential problems that might be caused by them.

REFERENCES

1. Osterhaus, W. (2009). *Design Guidelines for Glare-free Daylit Work Environments :* p.1-2.

2. *Weather spark*. (2018). Retrieved from Weatherspark: https://weatherspark.com/y/110123/Average-Weather-in-Chennai-India-Year-Round.

3. Guzman, G. (2014). An Exemplar of Low-Energy Offsite Manufactured Housing: Nottingham H.O.U.S.E.: p.2.

4. Julieta Yamin Garreton, R. R. (2016). Effects of perceived indoor temperature on daylight glare perception. *BUILDING RESEARCH & INFORMATION , 44* (8), pp. 907-919 :p-2.

5. CIBSE. (2009). *SLL Lighting Handbook.* Society of Light and Lighting.

6. CIBSE. (2006). *Guide A Environmental Design.* CIBSE Publications : p.1-20,21

7. Creative Energy Homes. (n.d.). *University of Nottingham*. Retrieved March 2018 from www.nottingham.ac.uk/creative-energyhomes/index.aspx

8. Gherri, B. (2015). *Assessment of Daylight Performance in Buildings Methods and strategies .* WIT Press.

9. Daniel overbey (n.d.). Retrieved from http://danieloverbey.blogspot.co.uk/2012/12/methodologies-for-glare-analysis.html

10. David Rennie, F. P. (1998). *Environmental design guide for naturally ventilated and daylit offices.* Construction Research Communications Ltd , BRE Ltd.

11. Christoph Reinhart, Shelby Doyle, J Alstan Jakubiec and Rashida Mogri (n.d). Retrieved from *Glare Analysis of Daylit Spaces: Recommendations for Practice.* http://web.mit.edu/tito_/www/Projects/Glare/GlareRecommendationsForPractice.html