Comparative Daylight Glare Analysis Between Measured and Computer Simulation Predictions

MARISELA MENDOZA[1].

[1]Nottingham Trent University, Nottingham, United Kingdom.

ABSTRACT: The importance of daylight design in buildings represents a crucial element to produce energy-conserving buildings providers of comfort to its users and visual acuity. This paper presents a comparative study between a physical daylight glare monitoring evaluation with that from a computer based tool (Ecotect/Radiance). Glare measurements were carried out using Ali Nazzal's daylight glare monitoring method. Computer simulations to predict glare were carried out using Ecotect software as an interface to perform calculations in Radiance.
Keywords: background luminance, daylight glare.

INTRODUCTION

Assessing users' visual comfort in regards to human sensitivity and task performance can be complex. Whilst human sensitivity refers to subjective and qualitative criteria related to the light source; task performance represents a more objective and quantitative approach. Glare is one of the major factors affecting visual comfort, especially due to its significant impact on both human sensitivity and task performance [1]. According to the CIBSE Lighting Code [2] good sight and visibility are achieved by: absence of glare, adequate quantity of light for a required task (illuminance levels) and uniform distribution of illuminance and luminance levels. Glare can be experienced as disability glare or discomfort glare and they may or may not occur simultaneously.

DAYLIGHT GLARE PREDICTION METHOD

Daylight glare predictions in this study were carried out following the daylight glare monitoring method developed by Ali. A. Nazzal [3]. Nazzal's method is based on the modification of the Cornell formula developed by Chauvel, et al. [4]. Nazzal's study considers daylight as a source of discomfort including direct and reflected sunlight. Based on the latter Nazzal's study introduces a new daylight glare index equation (DGI_N):

$$DGI_{N=} 8\ log_{10} 0.025 \frac{\left(\sum\left(L_{exterior}{}^{2} * \Omega_{pN}\right)\right)}{L_{adaptation} + 0.07\left(\sum\left(L_{window}{}^{2} * \omega_{N}\right)\right)^{0.5}}$$

Where, $L_{exterior}$ is the outdoor luminance, in other words the source luminance (cd/m^2), $L_{adaptation}$ is the luminance from the surroundings (cd/m^2), L_{window} is the window's luminance (cd/m^2), w_N is the apparent solid angle subtended by the window and Ω_{PN} is the corrected solid angle subtended by the source.

The room used to carry out the daylight glare measurements was a flat in one of the Halls of residence at Nottingham University, UK. Located on a second floor, this test room had two north-east orientated windows facing a courtyard and with no window obstructions. Fig. 1 shows a plan of the test room with the furniture layout.

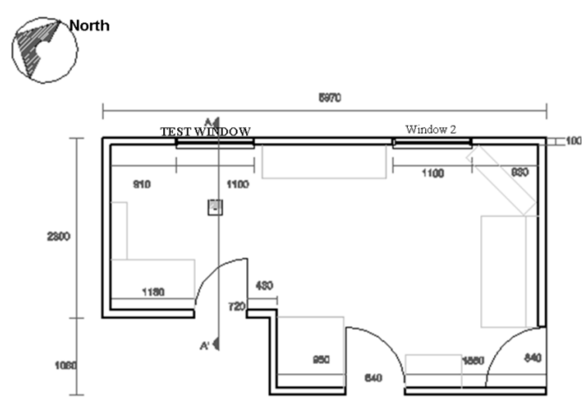

Figure 1: Plan of the test room showing the test window position and furniture layout.

Furniture in the room was not possible to be removed and therefore, all furniture in the room comprised by more than 2 different materials was covered with a white fabric of known reflectance. The latter was mainly to simplify the computer simulation in Ecotect.

The equipment used for this study included four single channel photometric sensors 'SKL 310' to measure illuminance (S00, S01, S02 and S03). Each one of the sensors operated independently containing a semiconductor diode and filter system that responds to light using a silicon photocell detector. All four sensors operated with cosine corrected heads. Also, the sensors were calibrated against a National Physical Laboratory UK reference standard light. A data logger was used to record the output of these sensors. External illuminance was measured using a sky light sensor (S00) and a displayed meter system (refer to in Fig. 2). External illuminance measurements were taken simultaneously to those on the data logger.

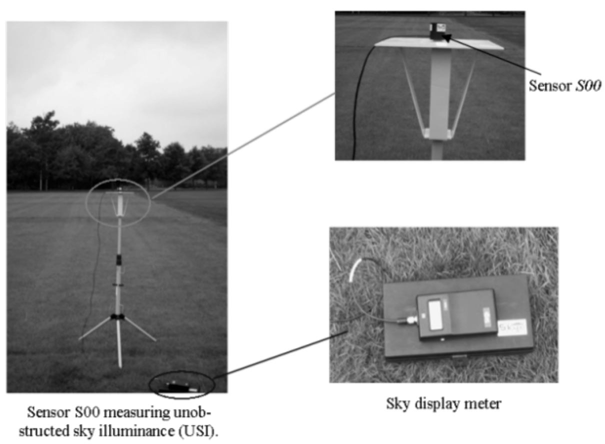

Figure 2: Sensor S00 measuring unobstructed sky illuminance.

According to Nazzal's daylight glare monitoring method, three illuminance sensors (S01, S02, and S03) had to be positioned vertically and in relation to three specific daylight areas in which the room is subdivided. These three daylight areas are named and identified as follows:

High daylight area, HdA, (refer to in Fig. 3). This area starts at the window pane and was obtained with the equation:

$$HdA = 2 * EWH$$

Where, $\mathbf{EWH} = {}^{\mathbf{abt}}/_{\mathbf{c}}$ and where **a** is the width of the window, b is the height of the window above the window sill, t is the light transmission factor of the window glass and c is the width of the facade containing the window. Sensor S01was located at the centre of the window and at 20 cm from the window pane (calculated as above).

Intermediate daylight area, IdA, (refer to in Fig. 3). This area starts at the border with the high daylight area and its depth is calculated with the equation:

$$IDA = 1.5 * EWH$$

Sensor S03 (measuring the window illuminance) was positioned at the level of the midpoint of the window, at the back of the intermediate daylight area and it was shielded by a box with black matt surfaces to be free of any reflection. The reason for shielding this sensor was to gather light, only, from the rectangular area of the window excluding light from the surroundings. Sensor S02 (measuring adaptation illuminance) was positioned at the opening end of the shield (box with black matt surfaces).

Low daylight area, LdA, (refer to in Fig. 3). This area is the remaining part of the room and was calculated with the equation:

$$LdA = test\ room\ depth - (Hda + IdA)$$

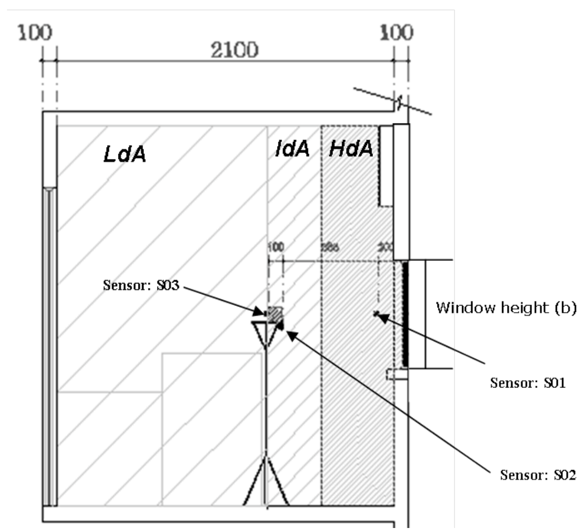

Figure 3: Test room section showing the three daylight areas.

The opening dimensions of the shield were obtained in relation to the dimensions of the window (refer to in Fig. 4).

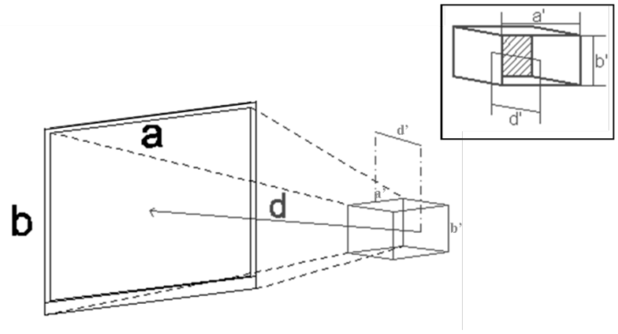

Figure 4: Dimensions of the shield (black box).

The following equations were used to obtain the dimensions of the shield:

$$\frac{a}{2d} = \frac{a'}{2d'}$$

$$\frac{b}{2d} = \frac{b'}{2d'}$$

$$\frac{a'}{a} = \frac{d'}{d} = \frac{b'}{b}$$

$$a' = \frac{ad'}{d}$$

$$b' = \frac{bd'}{d}$$

$$d' = \frac{db'}{b}$$

Sensors S01, S02 and S03, (measuring illuminance levels) were used to obtain the luminance parameters previously described in the DGI_N equation:

$$L_{window} = \frac{E_{v3shielded}}{2\phi_i\ \pi}$$

Where, L_{window} is the window luminance, $E_{v3shielded}$ is the average vertical shielded illuminance from the window (lux) and $2\phi_i\ \pi$ is the configuration factor from the observation point which is obtained as follows:

$$\phi_i = \frac{A_{\arctan B} + C_{\arctan D}}{\pi}$$

$$A = \frac{x}{\sqrt{1+x^2}}$$

$$B = \frac{y}{\sqrt{1+x^2}}$$

$$C = \frac{y}{\sqrt{1+y^2}}$$

$$D = \frac{x}{\sqrt{1+y^2}}$$

$$x = \frac{a}{2d}$$

$$y = \frac{b}{2d}$$

Where ***a*** is the width of the window, ***b*** the height of the window and ***d*** the distance from the observation point to the centre of the window.

$$L_{adaptation} = \frac{E_{v2\ unshielded}}{\pi}$$

Where, $L_{adaptation}$ is the luminance from the surroundings, $E_{v2\ unshielded}$ is the average vertical unshielded illuminance (sensor S02) from the surroundings (lux).

$$L_{exterior} = \frac{E_{v1\ unshielded}}{2(\pi - 1)}$$

Where, $L_{exterior}$ is the outdoors luminance, $E_{v1\ unshielded}$ is the average vertical unshielded illuminance (sensor S01) from outdoors.

The calculation of the solid angle of the window (ω_N) and source (Ω_{pN}) were calculated as follows:

$$\omega_N = \frac{ab\cos(\arctan(x)) * \cos(\arctan((y)))}{d^2}$$

$$\Omega_{pN} = 2\pi\phi_i$$

Data recordings were carried out according to a standard working day with Greenwich Mean Time (GMT) 9:00-17:00. During this time illuminance data were recorded hourly. The recording sessions were performed during the months of February, March and April. Two sessions were recorded for each month, under overcast and clear sky conditions. Special emphasis was put on ensuring that the sky conditions matched the description of the simulated skies: fully overcast (densely overcast with no sun) and clear sky (sunny sky conditions without clouds). However it is important to address that no moisture or turbidity conditions were considered.

ECOTECT/RADIANCE SIMULATION

These computer simulations were carried out in order to compare the daylight glare calculations with those obtained from the physical measurements. To select the software to be used in this study a brief survey into the available lighting simulation software was undertaken. It was noticed that some of these computer tools, offer more elaborated graphical user interfaces that can significantly facilitate and speed up daylight design and analysis process. Recent surveys such as that from the IEA: Lighting Design and Application [5] shows that these tools are increasing in number and use in architectural design. Within this survey two main categories of computer-based tools can be indentified based on the nature of their calculation methods: the radiosity method and the ray-tracing method.

The computer tool chosen for this study was Radiance which, amongst the ray-tracing methods, is considered one of the most accurate software tools for lighting simulations. Radiance has the advantage over other software to specify different sky conditions as well as the calculation of daylight glare. In addition Radiance allows displaying the simulation results as false colour images, numerical values and contour mappings. Radiance works under a Unix platform which may be quite complex for a non Unix user. The latter suggested looking for a tool that could work as an interface to use Radiance. Ecotect is user friendly and is software aimed for architects. Therefore, Ecotect was found a good alternative to use Radiance outside the Unix platform.

The main parameters considered to model the computer simulation were the same as those in the daylight glare prediction method. An exterior view of the test room modelled in Ecotect (refer to in Fig. 5).

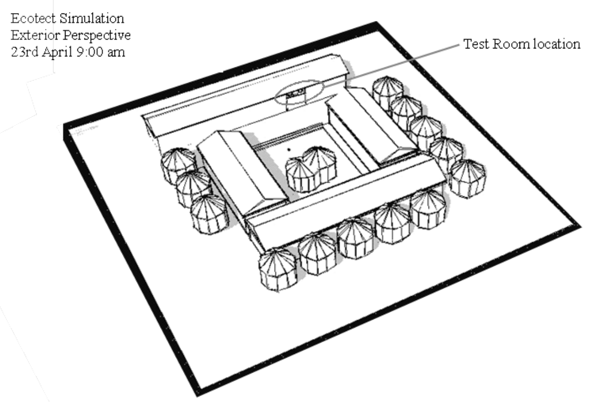

Figure 5: Exterior view of the test room Ecotect simulation.

The simulation of the optical properties of the test room surfaces such as reflectance, were obtained following the methodology applied by Fontoynont [6]. In addition, the methodology in the present study assumed that all materials were lambertian (all light was reflected diffusely). The reflectance of the known materials was calculated using the equation:

$$p_{Unknown} = p_{known} * \frac{L_{Unknown}}{L_{known}}$$

Where, p=reflectance, L=luminance. To obtain the luminance a Hanger Universal Photometer was used. Using a piece of a sample of fabric which reflectance was specified by the manufacturer and placing it above the surfaces which reflectance was unknown it was possible to measure luminance from the two materials (known and unknown) at a specific and equal point of observation. By applying this value in the previous equation, the unknown reflectance was obtained.

Two daylight glare calculations were predicted using this Ecotect modelling. The first one used Radiance to calculate illuminance at the position of every vertical sensor positioned in the test room exactly as Nazzal's method specifies. These illuminance results were used to calculate the new daylight glare index applying the DGI_N equation.

The second set of calculations was carried out in Radiance using the programs 'findglare' and 'glareindex' [6, 7]. In order to calculate daylight glare indexes using these programs it was necessary to set the Ecotect camera (simulating the observation point sensor S02) to capture hemispherical (fisheye) view which would allow to mimic the image produced by the observer's eye.

Unlike in 'findglare', background luminance, in Nazzal's daylight glare prediction method, considers both direct and indirect field luminance (including direct contribution from the source itself)

Each sensor (S00-S003) was modelled in Ecotect using a small analysis grid and positioned following Nazzal's daylight glare prediction method (refer to in Fig. 6). The grid average illuminance values were considered for calculations.

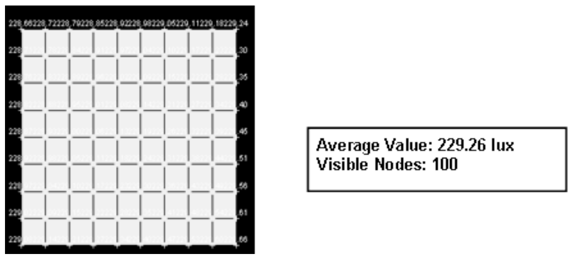

Figure 6: Analysis grid to simulate illuminance sensors

In addition at the position of each sensor an Ecotect camera pointing at the window's direction was positioned (refer to in Fig. 7).

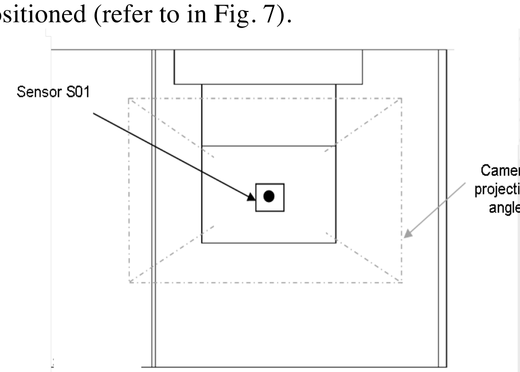

Figure 7: Front view of the square grid simulating sensor S01 and the camera position to capture images at the observation point.

These cameras were necessary in order for Radiance to calculate vertical illuminance and glare indexes. These cameras allowed to render different images in Radiance such as human-sensitivity images (refer to in Fig. 8).

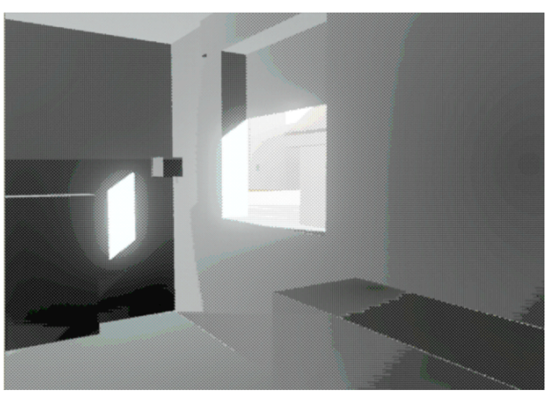

Figure 8: Human-sensitivity image rendered in Ecotect/Radiance

Also, it was possible to obtained false colour images showing illuminance levels on the surfaces (refer to in Fig. 9).

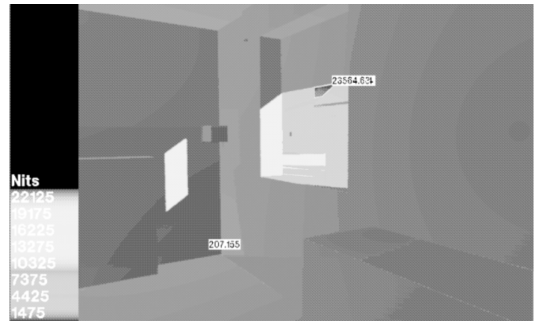

Figure 9: False colour image rendered in Ecotect/Radiance

Using Ecotect as an interface, the model was exported to Radiance where the modelling sky conditions were automatically set by 'gensky'. The gensky sky conditions for the present study were: Overcast Sky Model, which is based on the CIE overcast sky standard model. Clear Sky Model, based on the CIE clear sky standard model. Using these two skies it was possible to run the computer simulation to obtain the vertical illuminance levels for each simulated sensor.

ANALYSIS OF RESULTS

Three different sets of results of daylight glare indexes were obtained:

DGIN. – Physical prediction of daylight glare indexes using Nazzal's DGI_N equation and monitoring method.

DGI. Sim. - Prediction of daylight glare indexes using Ecotect model which followed Nazzal's positon of sensors. Vertical illuminance values of each sensor were obtained and further applied in Nazzal's DGI_N equation.

DGI. Rad.- Prediction of daylight glare indexes using the Ecotec model to carry out calculations in Radiance using 'findglare' and 'glarenx' tools.

Fig. 10 and Fig. 11 compare the daylight glare indexes results under overcast and clear sky conditions:

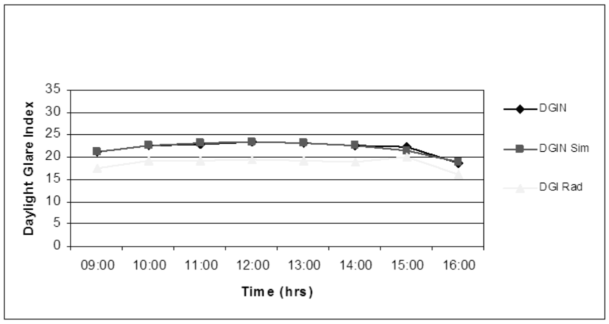

Figure 10: Predicted and simulated daylight glare indexes results. Overcast Sky (07th February 2005).

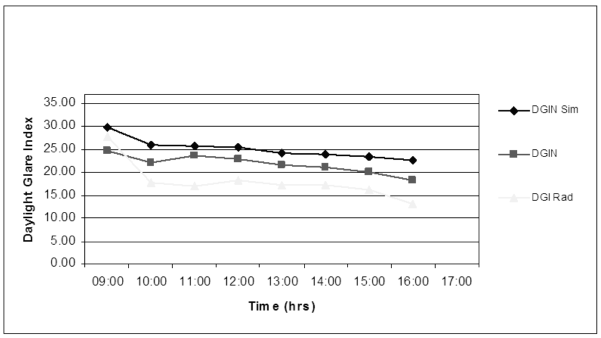

Figure 11: Predicted and simulated daylight glare indexes results. Clear Sky (18th February 2005).

It can be seen from Fig. 10 and Fig. 11 that the daylight glare index agreed closer under overcast conditions than those under clear sky conditions. The latter may be attributed to the limitations of 'glarendx' which uses indirect vertical illuminance as the background level excluding any direct contribution from the glare sources. Both figures also show the difference in daylight glare index results between those based in Nazzal's DGI_N equation and method and those based on the CIE glare index equation (DGI. Rad). Generally these results show that for both overcast and clear sky conditions, DGIN glare indexes are higher than DGIN. Rad.

CONCLUSIONS

Overall, predictions under overcast sky conditions had a better agreement in distribution and range values than those under clear sky. The latter may be attributed to the underestimation of direct illuminance levels in the calculations by 'glarendx'. The differences on daylight glare predictions may be also due to the discrepancy between simulated and naturally occurring sky conditions. The present study shows a rather small sample of physical predictions and further research should consider a larger sample of predictions before any general conclusions are drawn from this study. In addition further studies should consider the direct use of the DGI_N equation in Radiance to obtain glare indexes.

Also, it is important to consider in further research a monitoring method in which also subjects are included in order to validate the findings with those against users' perception.

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