Development of Regression Model for Visual Discomfort in Building Spaces: an Experimental Study

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Abstract

Visual comfort is an important parameter for evaluation of existing building spaces and for designing of buildings to be constructed. Any indoor environment is not comfortable or satisfactory if the illumination is poor. In this paper the authors have analyzed the data collected through experiments performed in various illumination settings in laboratory. Measured and calculated values of illumination level, position index, Unified Glare Rating (UGR) along with user based survey was used to perform regression analysis. The analysis was used to develop relationships between UGR and Illumination level with discomfort experienced by the users in same individual visual setting. The significance of discomfort glare along with illumination level in evaluation of building spaces has been discussed.

Keywords

Unified Glare Rating; Illumination; Buildings; Visual Discomfort; Regression

1. Introduction

When evaluating building spaces for various task based requirements, man-machine interactions are observed. Along with such interaction, environmental factors including illumination or visual comfort are also significant (Attaianese and Duca, 2012). Illumination is related to one of the five human sensations and is as important as any other environmental factors to be considered in evaluating building spaces (Chiang, et al., 2001). Unified Glare Rating is the most commonly used rating system to quantify the discomfort glare due to poor illumination in any indoor environment. The light intensity or illumination level contributes towards visual comfort/discomfort. Changes in moods and behavior have also been observed due to poor illumination and discomfort glare (Katzev 1992).

The ill effects of poor lighting affect the comfort as well as the productivity of the occupants or workers. In order to evaluate the building spaces it is necessary to consider illumination level as well as discomfort glare. There are various standards available for optimum illumination levels for respective requirements in building spaces and same is the case for glare also, but there is no such data or relationship available which can help in evaluating the visual discomfort on the basis of both glare as well as illumination level.

2. Literature review

Discomfort glare depends on brightness of the light source as well as the brightness of surroundings (Petherbridge and Hopkinson, 1950). If a single light source is used to create higher light intensity it will contribute towards discomfort glare. Whereas if the background or surrounding luminance is increased, with the same conditions the amount of glare produced can be decreased. The concept of Visual Comfort Probability (VCP) was developed to estimate the percentage of people experiencing discomfort due to glare (Levin 1975). Later another parameter that is the position index was included in calculation of discomfort glare along with VCP. Further the concept of Unified Glare Rating (UGR) was developed using position index solid angle and illumination levels in indoor spaces (Bedocs 1995).

Evaluation of building spaces based on percentage dissatisfaction was done including the illumination levels in the experimental data (Mui and Chan, 2005). Regression analysis was used to develop a relationship between illumination level and percentage dissatisfaction but discomfort glare was not included in the evaluation procedures. A multivariate-logistics model was used to develop an equation for overall acceptance of indoor environment quality which also included only illumination level and overlooked discomfort glare (Wong, et al., 2008). To develop a model for satisfaction of indoor environment quality, data was collected from two cities and about 500 occupants in china which also did not consider the effect of discomfort glare (Cao, et al., 2012). A study based on various environmental factors was done which included thermal comfort, air quality and visual comfort in building spaces (Chiang, et al., 2001). The study was conducted through quantitative analysis of collective effect of indoor environment factors and scores were calculated based on developed methodology. The research showed significant scores for illumination levels in physical environment of building spaces. In England a method of evaluating building spaces was developed based on percentage satisfaction which included light intensity along with other environmental factors (Ncube and Riffat, 2012).

A study was conducted to analyze the effects of energy efficient lighting on work efficiency (Katzev 1992). The study revealed that the lighting system which was installed varied the performance of workers in cognitive and comprehensive tasks under various indoor locations like office and labs. In an experimental work done to find out the effect of positioning of the light source, even with same type of light source, the glare can vary significantly (Bangali 2015). The experiments were done with the help of fluorescent and LED type light sources and various positions and patterns of light sources were set in order to calculate glare with the help of the software DIALux and UGR. In another experimental study done using conventional visibility tests and glare sensitivity tests found that the significance of background luminance is very high and it should never be ruled out while evaluating visual discomfort (Kim and Koga, 2004). The ability to signify background luminance was low in conventional tests as compared to glare sensitivity tests. Some experiments showed that the interrelation of the color of light and it intensity played a vital role in changing and maintaining the mood of subjects in building spaces (Knez 1995).

3. Methodology

To find the relation between significant factors affecting the visual discomfort it is necessary to record essential data. Light intensity or the illumination level was recorded using a lux meter at the location of observer for 18 experiments conducted. These experiments were conducted in ergonomics lab by repositioning the light source and light source type for various experiments.

Along with the light intensity level the position of the light source and observer was monitored and all the necessary angles were measured using a virtual environment in computer graphics software as shown in Figure 1. The position of light source and the occupant or user is essential in the calculation of the glare for the particular visual setup.

In order to calculate the glare it is important to record some basic measured values like illumination level, position of the light source and the background illumination. Glare was calculated with the help of Unified Glare Rating (UGR) as in equation 1.

$$UGR = 8\ \log\left[\frac{0.25}{Lb}\sum\frac{L^2\omega}{P^2}\right] \quad (1)$$

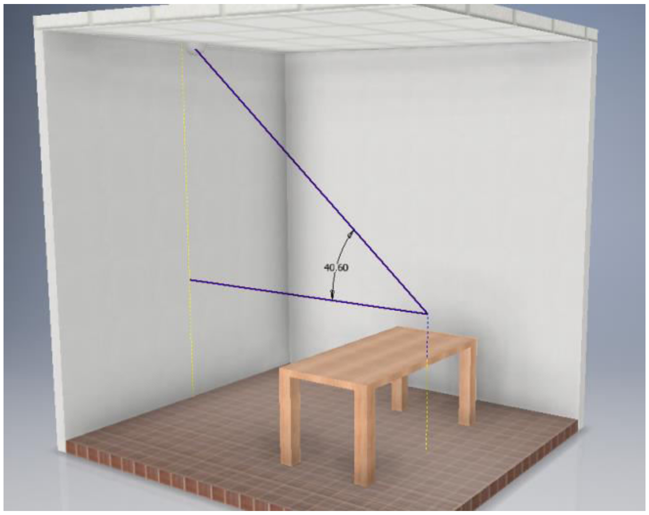
Where,

L	=	luminance of light source
ω	=	solid angle created to eye by light source
Lb	=	Luminance of background
P	=	position index

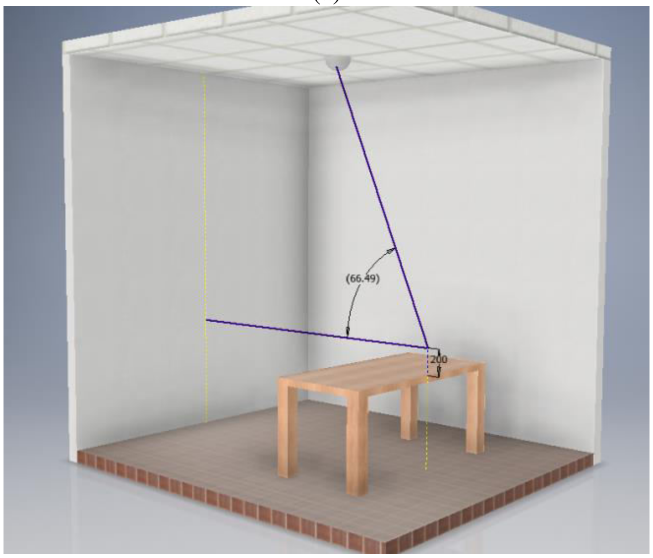
Guth position index is a function of two angels which are measured as per the positioning of the light source. Guth position index is mostly denoted by 'P' as in equation 2.

$$P = \exp[\left(35.2 - 0.31889\,\tau - 1.22e^{\frac{-2\tau}{9}}\right)10^{-3}\sigma + (21 + 0.26667\,\tau - 0.0029663\,\tau^2)10^{-5}\,\sigma^2] \tag{2}$$

Where:
τ = angle from vertical of the plane containing the source and the line of sight in degrees and
σ = angle between the line of sight and the line from the observer to the source.



(a)



(b)

Figure 1. Recreation of experimental setup in virtual environment
(a) Light source near front wall and middle of the ceiling
(b) Light source at center of the ceiling.

For eighteen experiments three positions of the light source were predefined on the basis of which the position index value was recorded using the computer graphics software. Three varieties of Light Emitting Diode (LED) were used as a light source, based on power consumption (7watts, 20watts and 27watts). The solid angle was calculated as per the dimensions of the room and the value of UGR was evaluated using the equation 1. The experimental setup was fixed for a single setting of position, light type and light intensity for Glare calculations as well as qualitative assessment of the discomfort experienced by the occupants. The occupants or users were asked to rate the level of discomfort on a scale of 1 to 4, 1 being the minimum or no discomfort and 4 being the maximum or intolerable discomfort. Twenty five volunteers contributed in discomfort data recorded for all eighteen experiments.

The experimental setup was arranged such that only artificial lighting contributed to the illumination level of the room whereas background luminance was assumed to be 3lx. The setup was maintained in the same settings for the participants to provide the ratings at the same position as in the quantitative data recording. The recorded data is shown in the Table 1.

The weighted average value of discomfort was calculated by multiplying the rating with number of votes towards that particular rating. The average discomfort rating was recorded and data considered in the article excludes the outliers, which may be due to rating or instrumental errors. The data was used to develop relationships between UGR and illumination level with visual discomfort using curve fitting method and regression analysis.

Table 1. Recorded Data

Exp. No.	Light intensity (lux)	UGR	Visual Discomfort rating
1	375	04.01	1.25
2	382	04.09	1.05
3	393	04.29	1.22
4	422	06.98	1.03
5	430	07.11	1.20
6	450	07.42	1.32
7	687	10.36	1.95
8	750	10.97	2.06
9	802	11.44	2.15
10	995	10.74	2.08
11	1071	11.25	2.08
12	1080	11.36	2.12
13	1368	12.96	2.72
14	1458	13.44	2.87
15	1498	13.59	2.91
16	1824	08.82	1.77
17	1851	09.01	1.75
18	1923	09.19	1.88

4. Results and Discussions

The data collected through measurements and calculations of position index, UGR, Illumination levels and discomfort ratings was subjected to regression analysis in order to develop a relationship between the significant factors for visual discomfort. The relationships developed were between UGR and Illumination level with visual discomfort. The analysis results are discussed in the following sections.

4.1. Unified Glare Rating and Visual Discomfort

The Unified Glare Rating is directly related to the discomfort experienced by the users. As the UGR increases the discomfort increases. Usually for value more than 10 for UGR the users start to experience discomfort. Equation 3 was developed on the basis of regression analysis for UGR with Visual discomfort data collected in during experimentation. The results of regression analysis were generated with R2 value of 0.96. and a quadratic equation was developed.

$$Visual\ Discomfort = 1.425 - 0.1486\ UGR + 0.01903\ UGR^2 \quad (3)$$

$R^2 = 0.96$

Fitted line plot as shown in figure 2 determines the scatter plot as well as the best fit of curve for the recorded data. The graph signifies that as the value of UGR increases, the visual discomfort experienced by the users also increases. A maximum discomfort rating of 2.91was observed for 13.59 value of UGR, whereas minimum discomfort rating of 1.03 was observed for 6.98 value of UGR. The minimum discomfort rating signifies least glare experienced by the users, which was for the case of 7watt LED light source. The maximum discomfort was experienced in the case of 27watt LED light source.

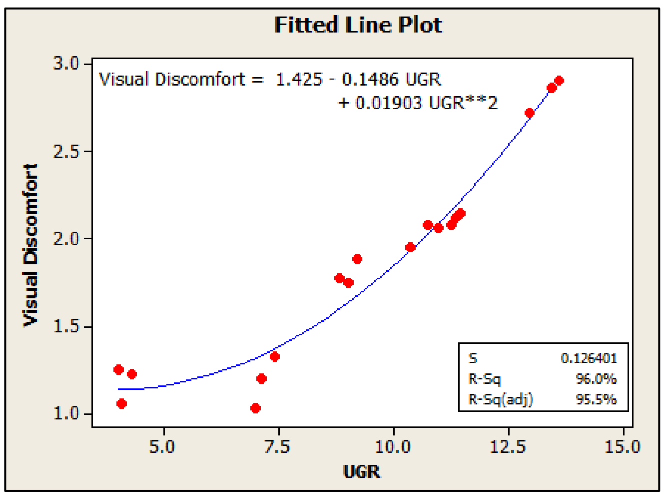


Figure 2. Fitted line plot of UGR v/s Visual discomfort

4.2. Illumination Level and Visual Discomfort

There is a perception that is the illumination level increases then the visual discomfort decreases. There are many standards related to acceptable illumination levels for various task or location based requirements. But the relationship developed through the regression analysis of Visual discomfort with Illumination level signifies a slightly different result as in equation 4 with R2 value of 0.844. There is a negative constant in the quadratic equation which signifies that the visual discomfort does not solely depend on the illumination levels.

$$Visual\ Discomfort = -0.3732 + 0.004469\ lx - 0.000002\ lx^2 \quad (4)$$

$R^2 = 0.844$

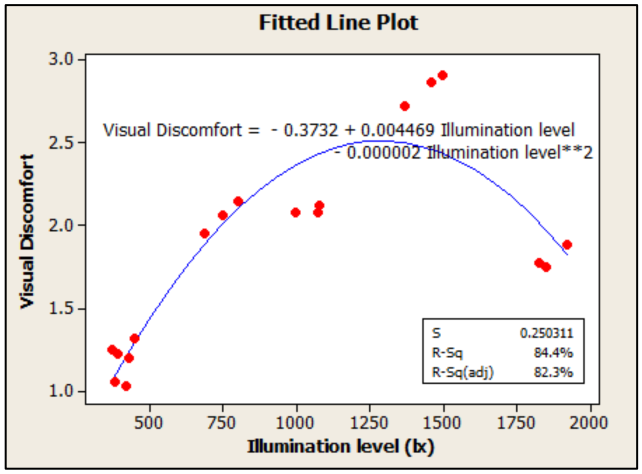


Figure 3. Fitted line plot of Illumination Level v/s Visual discomfort

The fitted line plot of Illumination level versus visual discomfort as shown in figure 3 signifies that the illumination level is not solely responsible for visual discomfort. The graph shows that even at low illumination levels the average visual discomfort is less and users are satisfied with the visual settings. Also the users feel low discomfort at high levels of illumination in the same environment but different position of light source.

5. Conclusions

The experimental study which was conducted was to mainly emphasize on the importance of light positioning and glare in user comfort in any type of building space. The subjective data which was based on visual discomfort, revealed that illumination levels are not solely responsible in comforting the users but glare and positioning of light source according to the background luminance plays a vital role too. Through the regression analysis of measured and collected data for eighteen experiments based on different settings of illumination levels, light source type and different positions, following conclusions were stated:

- Higher UGR results in increased visual discomfort for users and an effort to optimize the UGR or glare should be made in order to achieve maximum visual satisfaction of the users in building spaces.
- Irrespective of the optimum illumination level the users may experience discomfort due to poor positioning of the light source.
- Solely UGR or Illumination levels are not responsible for visual discomfort.
- In order to evaluate the visual discomfort/comfort in building spaces, glare should also be considered along with optimum illumination levels.
- The relationships developed through regression analysis may further be used to evaluate and provide scoring for building spaces in context of visual comfort/discomfort due to illumination and glare.

This study may fuel further studies based on visual comfort of users in building spaces. The ergonomic aspect of visual comfort cannot be overlooked and the discomfort glare along with other physical parameters might contribute towards overall assessment of comfort in indoor spaces.

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