The Reduction of Discomfort Glare from Windows by Interesting Views

by

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A thesis submitted to the University of Sheffield
in partial fulfilment of the requirements for the degree of
Doctor of Philosophy

School of Architecture
The University of Sheffield

June 2006

Abstract

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. Both small and large source glare formulae are often poor predictors of the subjective assessment of discomfort glare and, in particular, Hopkinson's daylight glare formula. This suggests that window glare depends on more factors than the four embodied in the glare calculation: source luminance, source size, surround luminance and a position index. Several studies have suggested that interest in the glare source may reduce discomfort glare in various cases. This thesis investigated a general hypothesis that an increase in interest in a glare source is associated with a decrease in discomfort glare.

The investigations were performed in two main parts aiming to test the effect of interest in two cases of glare sources, a small projected screen image and a window. Indeed, a main focus of the thesis was to explore the effect of interest in the case of a window with a hypothesis that an increase in interest in a view is associated with a decrease in discomfort glare from windows. However, due to difficulty in settings and revealing the observed effect in real daylighting situations, this thesis began to see the effect of interest in the case of a small projected screen image under a highly controlled laboratory with a hypothesis that an increase in image interest is associated with a decrease in discomfort glare.

The findings of this thesis tended to support the general hypothesis. It has been found that an increase in interest in a glare source is associated with a decrease in the glare discomfort, both for a small projected screen image and a window. In addition to the interest effects, significant effects of the glare source luminance variations (RML) and some characteristics and contents in a glare source were also found in both cases of glare sources.

Acknowledgement

I am indebted to my supervisor Professor Peter Tregenza who provided very comprehensive advice and invaluable help throughout the duration of the thesis, and from whom I have learnt the most about lighting and scientific research methodology. It has been a great opportunity for me to be one of his students.

I would like to express my appreciation for the help of the generous office and all technical staff at the University of Sheffield. I also thank all my subjects for their help and participation.

My gratitude extends to my mother, my father, my sister and my brother for their great encouragement. Finally, my most special thanks to Wanarat Konisranukul for her greatest support and love.

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Chapter 1
Introduction

1.1 Introduction

Building occupants prefer windows in the spaces they occupy and believe that the presence of windows improves their productivity and their well-being. Beneficial qualities of having windows include view, daylight, sunshine and spaciousness (Collins, 1975; Collins, 1976; Hartleb Puleo and Leslie, 1991; Roessler, 1980). Daylighting delivered through windows provides a comprehensive package which can meet the requirements of good lighting by revealing both the task and the space clearly and by providing environmental stimulation by variation of lighting conditions in the space and a view out through the windows (Boyce, 2003). The use of daylight also affects the physiological need for light. Daylight maintains the daily rhythm of hormone production and influences melatonin suppression, a hormone that plays an important role in the regulation of the circadian sleep-wake cycle (Kuller, 1987; Cakir, 1991). Besides this, daylight utilisation can significantly reduce the energy consumption in rooms. Research has suggested that the use of daylight could save up to 50 % of electric lighting and cooling energy use (Parker *et al*, 1995, Galasiu *et al*, 2001).

Serious problems may occur however, when due to unrestricted use of daylight through windows, uncomfortable and glaring situations arise. If the effects of glare are not prevented, either their performance and visual comfort will be reduced (Boyce, 1981) or the lighting situation can be altered by providing more artificial lighting. The latter aspect has a significant influence on energy saving. Discomfort glare is therefore one of the main aspects that should be taken into consideration in the designing of a well day-lit space. If the problem of discomfort glare can be maximally reduced, not only will the lighting quality of the space be improved and physiological need might be satisfied, but also the savings in electric energy for artificial lighting can be increased due to the improved efficiency of daylight for the indoor illumination.

1.2 Problem Identification

Glare is the result of unwanted light in the visual field. It is usually caused by the presence of one or more sources of excessively bright light. There are two different aspects of glare. The first aspect relates to the extent to which a particular source of light interfering with a person's ability to perform a task, called "disability glare". The second one deals with the resulting discomfort caused by the light source, called "discomfort glare". Disability glare is the aspect of glare that causes a direct reduction in a person's ability to see objects within a visual field, without necessarily causing discomfort. This type of glare depends on the size of the glare source, the brightness of the source, the distance from the eye to the source, and the location of the source within the visual field. Discomfort glare includes, but is not limited to, the sensation of distraction, annoyance, and dazzle. This kind of glare seems to be compounded of two separated effects— the contrast effect and the saturation effect.

Both small and large source discomfort glare formulae are often poor predictors of the subjective assessment of discomfort glare and, in particular, Hopkinson's daylight glare formula showed a low correlation between the predicted value and the subjective response for discomfort glare from windows (Manabe, 1976; Stone and Harker, 1973; Boyce, 1981; Hopkinson, 1970; Hopkinson, 1972). This suggests that window glare depends on more factors than the four embodied in the glare calculation: source luminance, source size, surround luminance and position index. Hopkinson (1972), says that the outside view is undoubtedly a mediating or an enhancing factor. He notes, from comments by his observers, that a view with a great deal of interesting information extends his subjects' tolerance level of discomfort glare. Markus (1994 quoted in Boyce 1981; p. 313) that "people frequently sit for hours in front of a television set by free choice even though it should, according to the formula, be producing intolerable glare". Based on the above evidence, it can be seen that there are a number of authors who have pointed out that in many situations where a high luminance occurs, interest in the glaring source seems to modify the discomfort sensation. These phenomena indicate the psychological nature of the reaction to the interest in the source of glares, in different cases. Therefore, it would be reasonable to make a general hypothesis that, the higher interest in a glare source, whatever it may be, the lower discomfort glare people will report.

There have been studies of subjective responses to different types of view, in particular of the characteristics that could make the view through a window preferred. Heerwageen and Orians (1986) noted that views with dominant nature content are more pleasing than views dominated by built environment. Moreover, the general findings about the preference of views from studies conducted in Europe and the USA claimed that natural scenes are more preferred than those of the built environment and people preferred a complete view that contains part of every zone of the sky, the middle layer, and down to the ground near the window is preferred (Tregenza and Loe, 1998). Markus (1967a and b) examined the stratification of views; he argued that people tend to prefer views containing all three horizontal layers - sky, landscape or cityscape, and nearby ground – are preferred to views that include only one or two layers.

Most research on glare from windows has been devoted to developing prediction formulae based on the four parameters: source luminance, source size, surround luminance and a position index (Hopkinson, 1972; Chavel et al, 1982; Iwata *et al*, 1992a; Iwata *et al*, 1992b; Iwata and Tokura, 1998; Nazzal, 2000). Some other factors have been investigated (Boubekri and Boyer, 1992) Up until now, there is no record of a systematic study on the effects on glare of views through windows, in particular the relating the effect of sensation of interest in a view to discomfort glare.

It would be useful in both research and application to know whether an interesting view does reduce the sensation of glare from windows. It would, for instance, be evidence that even when examining physical comfort a purely psychophysical approach is insufficient; and the usefulness in practice of the window glare formula would be greatly enhanced if inclusion of view-related factors improved their predictive power. Moreover, the findings can be used as window design guidelines to optimize reduction of discomfort glare from windows. Not only could the lighting quality of the working place be improved as well as the occupants' physiological needs be satisfied, but also the savings from use of electrical energy for artificial lighting can be increased.

1.3 Research Hypothesis and Problem Solving Approach

This thesis considers the fundamental hypothesis of *"an increase in interest in a glaring source is associated with a decrease in discomfort glare"*

Due to limitation of time, this study tests this hypothesis with a limited number of cases of glare sources only. Based on the Hopkinson's supposition and the evidence and benefits mentioned above, this thesis mainly concentrates on testing the interest effect in the case of a window. A hypothesis in this case is that *"an increase in interest in a view is associated with a decrease in discomfort glare from windows"*. However, testing this effect in the case of a real window is certainly difficult particularly in terms of setting up an experimental environment and equipment and showing a measurable effect due to largely uncontrolled variables. Therefore, the thesis began by testing the effect of interest in the case of a small projected screen image under highly controlled laboratory conditions, a key test of the thesis. This is because it was easy to test and set up in terms of experimental environment and equipment. It was also believed that the effect of interest would be easier found in this test than other glare sources and other test conditions. Finally, it was expected that the similar conclusion to a small projected screen image would be drawn for the case of a window. In this case, the hypothesis is that *"an increase in interest in an image is associated with a decrease in the glare discomfort"*.

1.4 Outline of the Thesis

Chapter 1: The introduction to the thesis presents identification of the problem, the research hypothesis and problem solving approach, and the outline of the thesis. The literature review presents the main findings of the literature review conducted on the two main theories. A theory of discomfort glare is presented in **Chapter 2** and that of views through windows is reviewed in **Chapter 3**. These chapters conclude with the implications of the review's results for this research.

Chapter 4: Laboratory studies show three experiments using small projected screen images in a highly controlled laboratory situation. Firstly, the effect of interest in a screen image on discomfort glare was investigated. Secondly, some elements and characteristics in a screen image, such as water, sky and the naturalness of a screen image were also examined. Finally, the effect of Relative Maximum luminance of a screen image (RML_m) was explored in the last experiment.

Chapter 5: Studies in real day lit situations presents experiments using real views. Following from the results in the laboratory studies, the effect of interest in a view, some effects of elements and characteristics within a view, and the effect of relative maximum luminance of window were tested in this Chapter.

Chapter 6: Conclusions and discussion summarise the main findings for the general hypothesis. It also summarise the main findings from the main focus of the thesis and studies in the real daylighting condition. Based on these findings, it discusses the implications on both theory and practices. It also suggests areas of future research based on this study.

Chapter 2
Discomfort Glare and Development of Evaluation Systems

In Chapter 1, the general hypothesis was made that an increase in interest in a glaring source is associated with a decrease in discomfort glare. The thesis aims to see whether an increase in interest in a view is associated with a decrease in discomfort glare from windows, justified as a main focus of the thesis. Accordingly, a review of literature associated with this research is composed of two main subjects. The first one is the development of the evaluation systems for discomfort glare, which is reviewed in this Chapter. The second subject is related to views through windows, which is presented in the next Chapter.

As mentioned earlier, before investigating the effect of interest in a view on discomfort glare from windows, the thesis initially explores the effect of interest in the case of a small projected screen image under laboratory conditions, a key test of the thesis. Also, the development of the formulae for discomfort glare from windows, particularly in the early state, intrinsically relied on the evaluation systems of discomfort glare from small artificial light sources. Therefore, to establish a solid basis for underpinning the theory of discomfort glare from windows, this chapter begins with a description of the development and background of the major existing discomfort glare evaluation systems of glare from small source. Then, advantages and limitations of each system are discussed and identified and this leads to a selection of appropriate methods for the investigation of small projected screen images, carried out in the subsequent part.

In a second part of this Chapter, a review of the literature associated with the evaluation systems of discomfort glare from windows is presented. Similarly to the first part, the discussion is principally focused on the benefits as well as the problems associated with the evaluation and modelling of discomfort glare from windows. This discussion yields a selection of glare prediction methods to give a basis for investigation into the effect of interest in a view on glare from windows. Finally, the overall conclusion for this Chapter was drawn.

2.1 Introduction

Discomfort glare, as mentioned, is a sensation of distraction, annoyance and even pain from bright light. The cause of the sensation of discomfort glare seems to be composed of two effects— a contrast effect and a saturation effect. The contrast effect results when a light source is seen in an environment of much lower brightness. The saturation effect results when a light source that is seen contains such a level that the maximum possible rate of neural response from retinal elements is generated. In the case of a window, discomfort glare is normally a result of the contrast between the window and the adjacent walls and ceiling (Hopkinson *et al*, 1966). The development of the glare formulae for discomfort glare from windows began in late 1950s when the Cornell 1956 paper (Hopkinson 1957) raised a question of using the classical glare formula with glare from large sources. The study of Hopkinson and Bradley (1960) emphasised that the large sources generally subtends solid angle on the eye that exceeds 0.1 steradians, which led to increase the adaptation level of the eye. In this case, the discomfort glare sensation is reduced and therefore, the formula in the form given is no longer applied. The study also suggested that better evaluation of discomfort glare would be reached if the surrounding luminance was modified by the source luminance. This issue has been investigated in the field of the glare study and also sets the foundation for the development of the evaluation system of glare from windows.

As reasons noted above, this Chapter begins with the brief discussion of the four well-known evaluation systems of discomfort glare from small source, followed by the evaluation systems of discomfort glare from windows.

2.2 Evaluation Systems of Discomfort Glare from Small Sources

The pioneer study of glare began in the late 1920s by a group of American investigators, led by Holladay, Luckiesh and Stiles. Earlier works in this field were mainly involved with the study of glare from small artificial light sources. Luckiesh and Holladay (1925) were the first to apply psychological appraisal to glare. They developed a scale of comfort-discomfort, or degrees of sensation, from scarcely noticeable to painful sensations, while the study of Stiles went further to identify the different categories of glare sensation due to glare sources. Their works set the precedent for the division of national research interests in glare and provide a foundation for subsequent studies (Hopkinson, 1972). As more investigators in different countries pursued the studies and more refined techniques were employed, the concept of glare has extended far beyond the conclusion of the American work. Continued investigations by numerous significant researchers such as Hopkinson and Petherbridge (1950-1960s) in Great Britain; Luckiesh and Guth (1940-1960s) in United States; Sollner and Fischer in Germany (1963-1972); and Einhorn (1969), have lead to the establishment of the four glare evaluation systems.

2.2.1 The British Glare Index System

The first glare evaluation system was introduced in the 1961 IES Code which had been developed through the work of Hopkinson and Petherbridge during 1950s and 1960s. The system is based on certain assumptions about the factors which cause glare. To define magnitude of the discomfort sensation, four multiple criteria of discomfort glare: just intolerable, just uncomfortable, just acceptable and just imperceptible were used. On the basis of the two equations applied to a single glare source and multiple glare sources, tabular forms of glare index values were developed. The two proposed formulae are as follows:

Equation 1: basic formula for a single glare source

$$G = \frac{L_s^{1.6}\ \omega^{0.8}}{L_b\, P^{1.6}}$$

Where:

L_s = Luminance of the glare source (cdm^{-2})

P = Position index of the source which relates to its displacement from the line of sight

L_b = Luminance of the background (cdm^{-2})

ω= Solid angle of the source (sr)

Equation 2: summation equation for effect of multiple glare sources

$$\text{IES-GI} = 10\log_{10} 0.478\ \Sigma G$$

Collins (1962) indicated that the minimum reliable detectable change was one Glare Index unit and the least difference in Glare Index which makes a significant change in the degree of glare is three units. Applications and recommendations of the British Glare Index System were published in 1967 (IES-London) and revised in 1985 (CIBSE). The polarity of the scale in the British system is that larger GI's indicate increased glare sensation. The system is used in Great Britain, Belgium, South Africa, and in a modified form in Scandinavian countries (Sorensen, 1987).

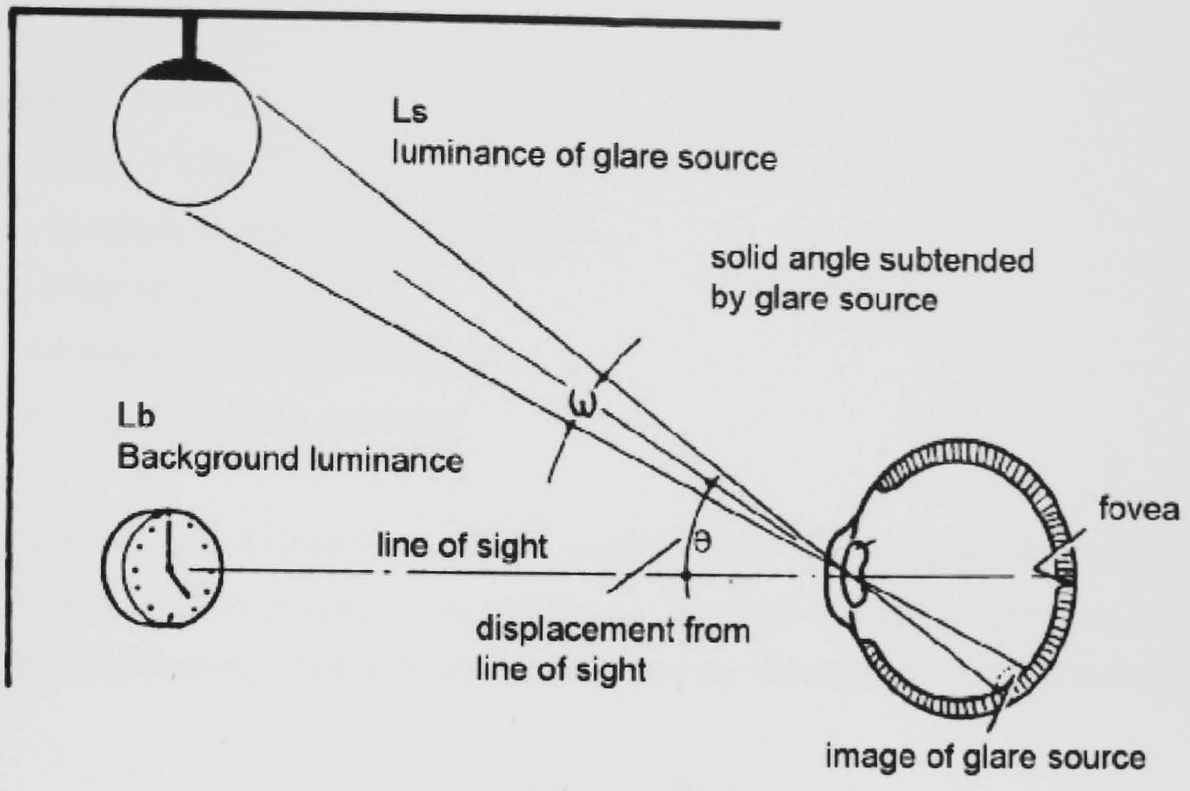

Figure 2.1: Main parameters in evaluation of discomfort glare

2.2.2 The American Visual Comfort Probability System

Following the same vein as Hopkinson and Petherbridge, Luckiesh and Guth (1949) carried out independent studies in the U.S. These investigations into discomfort glare were those that began the development of VCP system. The experimental technique was to evaluate the sensation of the glare source when the source was momentarily exposed to view in the uniform luminance background. It led to their development of the single criterion "Borderline between Comfort and Discomfort" otherwise called the BCD method. This subjective threshold measure has been equated with the "just uncomfortable" rating of the British Glare Index system. Continued through a series of investigations and modifications, Guth finally established the following relationship between subjective glare sensation and his experimental parameters:

$$M = \frac{0.5\, L_s\, Q}{F\, P^{0.44}}$$

Where:

$Q = 20.4\omega + 1.52\omega^{0.2} - 0.075$

L_s = Luminance of the glare source (cdm^{-2})

F = Field luminance (cdm^{-2})

P = Position Index for the source

ω = Solid angle of the source (sr)

As with the British Glare Index System, a calculation is made to obtain the glare level for a number of glare sources in an installation. The glare sensation values are generated using the following equation to obtain a value for the "Discomfort Glare Rating" (DGR):

$$DGR = (\Sigma_n M)^a$$

Where:

$a = n^{-0.0914}$

n = The number of glare sources.

A recommended procedure for computing Visual Comfort Ratings for interior lighting was published in the IES Lighting Handbook 1984 Reference Volume (Kaufman, 1984). The final form of the American system came out as "Visual Comfort Probability" (VCP). The DGR can be converted to VCP either by using a graph defined in the IESNA Lighting Handbook or by using the following equation:

$$VCP = \frac{100}{\sqrt{2\pi}} \int_{-\infty}^{6.374 - 1.3227 Ln\,(DGR)} e^{\frac{-t^2}{2}} dt$$

The figure represents the percentage of people who would accept the lighting as comfortable under the defined conditions. The IESNA recommends that an installation should be designed so that the VCP is 70% or greater. The system is largely used in United States.

2.2.3 The German Glare Limiting System

The development of the German Glare Limiting System was based on the several glare studies conducted by German investigators such as DeBoer (1958), Arndt, Bodmann and Muck (1959). They were convinced that the summations of individual glare sources used in the VCP and British Glare Index system were inaccurate. Sollner carried out a series of glare investigations by using one-third scale models (Bodmann, Sollner and Senger, 1966; Sollner, 1965; Bodman and Sollner, 1965) and 750 glare situations with different distribution of fluorescents. Appraisals were made by ten to fifteen observers using a seven-point glare rating scale of discomfort glare sensation ranging from no glare, glare between non-existent and noticeable, glare noticeable, glare between noticeable and disagreeable, glare disagreeable, glare between disagreeable and intolerable, and glare intolerable.

As a result, Sollner proposed the luminance curve method which expressed discomfort glare in terms of the curves shown the relationship between the luminance of the luminaries, their emission angle and the Mean Glare Rating. To avoid the difficulties in calculation of this method, Fisher transformed the luminance curve method to be a glare limiting method. This glare limiting system by Fisher (Fisher, 1972) specifies luminance limits for different quality classes of lighting situations.

The Glare Limiting system is fundamentally different from the British Glare Index and the VCP systems. There is no equation in this system that defines the relationship between glare sensation and the parameters influencing the glare sensation which infers that the Glare Limiting system is more restricted in use than the British Glare Index and the VCP systems. However, seen as a practical system, the Glare limiting system is exploited in a number of countries including Australia, France, Germany, Israel, Italy, Japan, the Netherlands, and Switzerland.

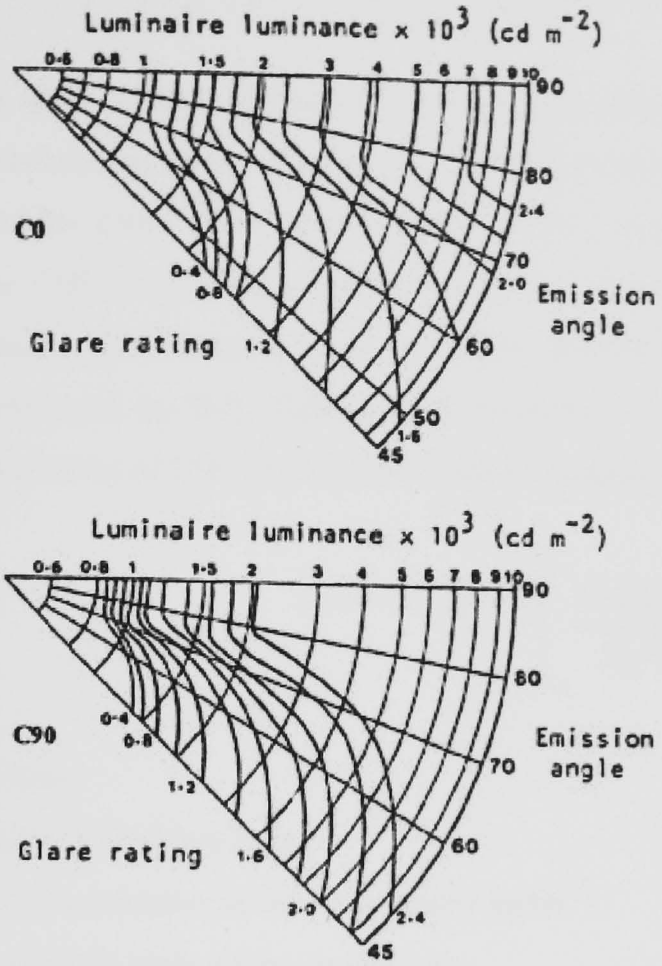

Figure 2.2: Sollner's original glare limiting curve set for C0 (longitudinal viewing) and C90 (transverse viewing)

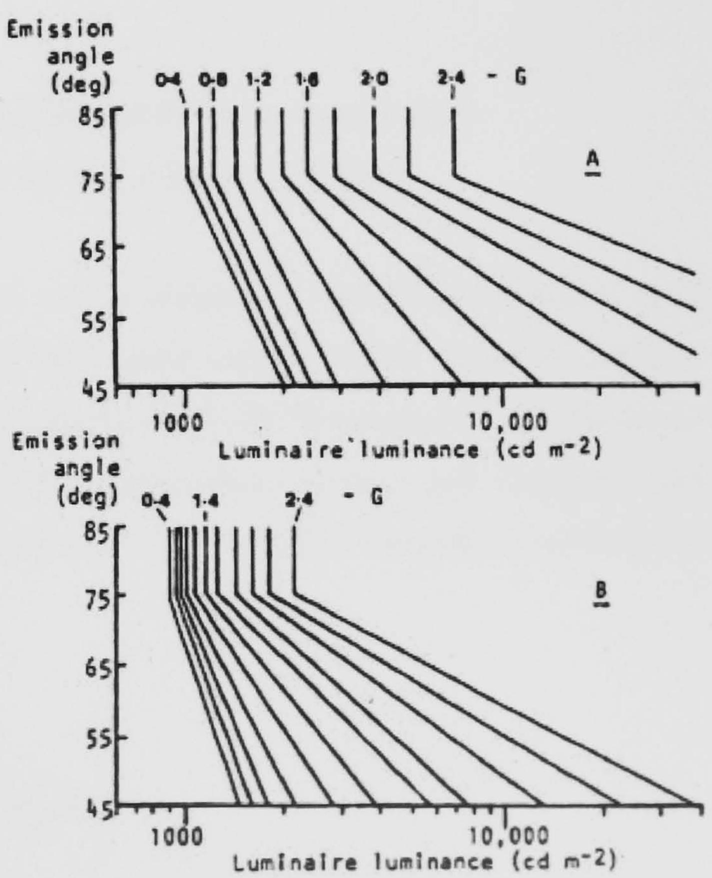

Figure 2.3: Sollner's glare limiting curves after modification by Fischer

2.1.1.4 The CIE UGR Glare Rating System

In spite of these differences in approach several studies showed reasonable agreement between the glare sensations predicted by the three methods- the VCP, the Glare Index, and the mean Glare rating (Manabe, 1976, Aleksiev and Vasilev, 1978). It is, therefore, the CIE (Commission Internationale de l'Eclairage), which has engaged in producing a unified glare formula incorporating the known facts. The CIE Glare Index (CGI) formula developed by H.D. Einhorn, was published in CIE publication No. 55 (CIE 1983). The final form of CIE Glare Index equation proposed by Einhorn is as follows:

$$CGI = 8 \log_{10} 2 \left(\frac{1+E_d/500}{E_d+E_i} \sum \frac{L_s^2 \omega}{P^2} \right)$$

Where:

CGI = CIE Glare Index

L_s = Luminance of the glare source (cdm^{-2})

ω = Solid angle of the source (sr)

P = Position index of the source

E_d = Direct vertical illuminance at the eye from all the glare sources (lux)

E_i = Indirect illuminance at the eye from the rest of the sources (lux)

Although at that time, the CIE formula was considered a significant milestone, many difficulties have been found in setting up a glare index method from this formula. Accordingly, in 1987, the CIE formed Committees TC-25 "Fundamentals of Discomfort Glare" and TC 3-13 "CIE Discomfort Glare Evaluation system" and adopted a new evaluation formula proposed by Sorensen (1987). This new CIE formula, a Unified Glare Rating (UGR) is as follows:

$$UGR = 8 \log_{10} \left(\frac{0.25}{L_b} \sum \frac{L_s^2 \omega}{P^2} \right)$$

Where:

UGR = CIE UGR Glare Index

L_s = Luminance of the glare source (cdm^{-2})

L_b= Luminance of the background (cdm^{-2})

ω = Solid angle of the source (sr)

P = Position index of the source

On the basis of the UGR formula, the "CIE Unified Glare Rating System" has been developed. Applications and calculation procedures within the UGR system were codified in CIE technical report 117: Discomfort Glare in Interior Lighting (CIE, 1995). In this report, three main methods for glare predictions are included. These are the glare calculation derived by using the UGR formula, UGR calculated using a tabular method and a rough estimate of discomfort glare by using the luminance limiting curve method. The scale of UGR values range from about 10 and 30 for typical applications. Higher values indicate increased discomfort glare. Responding to the CIE' s intention, the UGR system has enabled lighting practitioners, architects and interior designers to carry out glare calculations that can be carried across national boundaries and understood without the need for translation from one system to another. Accordingly, it could be regarded as the "International Standard of Glare Prediction Methods".

Although each glare evaluation system has its own advantages and disadvantages and the international standard for glare prediction method was reached, all the systems shared a similar limitation in terms of a large variance in subject response. Many studies on discomfort glare have showed wide scatters in glare ratings and low correlations between the predicted values and subject response for all of these evaluation systems (Manabe, 1976; Stone & Harker, 1973; Boyce *et al*, 1979; Boyce, 1981).

2.3 Evaluation Methods of Discomfort Glare from Windows

As stated, there have been doubts expressed as to the validity of the evaluation of glare from large sources through the classic glare formula from time to time. At the same time, the increasing tendency of a general movement towards higher standards of comfort in all aspects of life has increased demand for a wider context regarding visual discomfort. The study of discomfort glare has moved away from small windows and small light fittings towards very large sources of light— in particular windows. Following the symposium held at Cornell University in 1956, aimed at developing evaluation methods, a number of research programmes were set up to investigate the phenomenon of glare from windows. The work at the Building Research Station and Cornell began in 1960 and has led the way forward in the development of the formula for discomfort glare from large sources and the possibility of producing a glare index which could be useful in lighting practice. Through almost half a century of continuing study, daylight glare formulae have been developed and incorporated into a code of good lighting practice. In this section, four recognised evaluation methods of discomfort glare from windows are reviewed and discussed.

2.3.1 Daylight Glare Index (DGI)

The early stage of the study of glare from large sources at the Building Research Station in England and at Cornell University in United States made it clear that a different formula is needed for evaluating glare from large sources (Hopkinson, 1963). The combined work of these two research centres resulted in a general glare equation known as the Cornell formula. It is a modified version of the BRS Glare Index formula, where the modification has been based on results of experiments with large sources.

In the laboratory, a bank of closely packed fluorescent lamps whose light was diffused by an opal plastic screen was set as a large surface of uniform brightness. The multiple-criterion method (Hopkinson, 1940) was used to evaluate the glare sensation. In control of the source luminance, trained-observers were asked to slowly raise the brightness of the source, allowing a necessary period of adaptation, until a certain degree of discomfort glare was reached. Four degrees of glare sensation criterion were consisted of:

- just perceptible glare (Criteria D),
- just acceptable glare (Criteria C),
- just uncomfortable (Criteria B), and
- just intolerable glare (Criteria A)

Based on the results, the glare formula existed at that time (the BRS formula) is no longer valid in the form given for two reasons. The first one is about the position of the glare source. When the glare source is very large, it can no longer be taken as a point source with a single defined position in space. The part of the large source remote from the direction of view will give less glaring than the part along the line of sight. Therefore, a correction has been applied to account for different positions in the field of view (Hopkinson and Bradley, 1960). The second reason is about the adaptation level of the eye. As a large glare source occupied a large part of the field of view, the adaptation level is influenced by the source itself and is determined partly by the surround. Therefore, the surround luminance is modified by the source luminance. Based on the findings, the BRS formula was modified and the degree of glare can be expressed through a daylight glare index (DGI):

$$\text{Daylight Glare Index} = 10\log_{10} 0.478 \sum \left(\frac{L_s^{1.6}\,\Omega^{0.8}}{L_b + (0.07\omega^{0.5} L_s)} \right)$$

Where:

L_s = Luminance of the glare source (cdm^{-2})

L_b = Luminance of the background without the luminance of glare source (cdm^{-2})

ω = Solid angular subtense of the glare source (sr)

Ω = Solid angular subtense of the glare source, modified for the effect of its position in the field of view by means of position index P (sr)

The glare criteria were established based on the mean glare index generated from the responses of people tested for various lighting situations (Robbin, 1986). It represents a degree of discomfort glare, as shown in Table 2.1 below.

Table 2.1: Glare Index for the Evaluation of Daylight Glare

Glare Criteria	**Glare Index (GI)**
Just imperceptible	10
	13
Just acceptable	16
	19
Just uncomfortable	22
	25
Just intolerable	28

Source: Hopkinson, 1971

The use of the equation to predict glare due to daylight has been accepted since 1960 and is supported by field studies that were reported in the 1970s (Hopkinson 1971; 1972). According to the reports, the validation studies were conducted in two stages.

The first stage was intended to make suggestions for limiting values of Glare Index for daylight environments. Accordingly, the observing team consisted of three small groups who were asked to study a wide range of daylighting situations and then make judgements on the degree of the discomfort glare as well as the acceptability of the prevailing level of discomfort glare for the purpose of the space. In this field study, the variation of the real daylighting conditions such as a wide range of sky luminance conditions, a large number of buildings to visit and the inherent different conditions of places reveal gaps in the data, since the Glare Index were never experienced or were only experienced on rare occasions. These circumstances have led to some adjustments of the Cornell large-source glare formula.

The second stage of this field study was to validate these proposed limiting Glare Index values. In this process, the same groups of observers were asked for further sets of judgements in real environments. Indeed, they had to judge whether they agreed or not with the recommendations according to the proposed limiting glare index. For example, the observer would be taken to a test location where the proposed limiting glare index obtained from the modified formula was 20. He would be told that he was looking at a lighting situation which had a glare index of 20. The observer then had to give judgement as either agreeing or disagreeing with the recommendation. The results of this study showed that there is greater tolerance of mild degrees of glare from real daylight situations than from comparable artificial lighting sources. However, the degree of tolerance does not extend to severe degree of glare. In this way, the scale of Glare indices was adjusted and a Code of Recommended limiting Daylighting Glare Indices was proposed as follows:

Daylight Glare Index = 2/3 (GI+14)

Table 2.2: Comparison of Glare Index and Daylight Glare Index

	IES Glare Index (GI)	**Daylight Glare Index (DGI)**
Just imperceptible	10	16
	13	18
Just acceptable	16	20
	19	22
Just uncomfortable	22	24
	25	26
Just intolerable	28	28

Source: Hopkinson, 1971

The recommended limits for Glare Index in day lit interiors were obtained in this study. The limiting values finally selected were published in the IES Code 1973 and again in 1977 (Chauvel *et al*, 1982) and have been widely used to evaluate glare from daylight until the present day. However, a continuing study on glare from windows in real environments has revealed some limitations within the system, particularly the low correlation between predicted Glare Index for a particular environment and the degree of glare discomfort experienced (Hopkinson, 1970; 1971, 1972). When correlation coefficients were computed between the DGI and subject appraisals, the resulting 0.35 – 0.55 leave a significant amount of variance unexplained. The study of Hopkinson (1972) suggested that this could be caused by a number of factors including the interesting view outside. Similar to Hopkinson, Boubekri and Boyer (1992) pointed out that appealing and pleasant views could have significantly influenced these glare assessments. Indeed, these findings become a reason for this research.

The DGI formula is the most cited model for prediction of discomfort glare from windows (Fisekis *et al*, 2003). However, some other studies highlight the insufficiency of the DGI in predicting glare discomfort from daylight. This has led to either the modification of the DGI or the creation of other glare evaluation methods. In the next section, these available methods will be explained.

2.3.2 Chauvel's Modification of the Cornell Formula

The study of daylight glare through real windows by Chauvel *et al* (1982) asserts a difference between the glare experience from real windows and the glare experience from large artificial light sources. This difference was interpreted as a result of psychological differences in the visual content of the field of view. The study of Chauvel *et al* led to their modification of the Cornell large source formula. Instead of taking into consideration the source luminance and the background luminance as the Cornell large source formula does, Chauvel' s modified version takes source luminance, the window luminance, and the background luminance to be parameters. See below:

$$\text{Daylight Glare Index} = 10 \log_{10} 0.478 \sum \left(\frac{L_s^{1.6} \Omega^{0.8}}{L_b + (0.07 \omega^{0.5} L_w)} \right)$$

Where:

L_s = Luminance of the patch of visible sky, of the obstructions and of the ground seen through the window (cdm^{-2})

L_b = Average luminance of the interior surfaces of the room (cdm^{-2})

L_w = Average luminance of the window (cdm^{-2})

ω = Solid angular subtense of the glare source (sr)

Ω = Solid angular subtense of the glare source, modified for the effect of its position in the field of view by means of position index P (sr)

The work of Chauvel has largely contributed to the development of discomfort glare studied, however some limitations seem to be remained. Nazzal (1998a), points out that the weight of background luminance is too large in both Hopkinson's Cornell formula and Chauvel's Cornell formula. In addition, instead of calculation, many parameters used in modified version of Chauvel are presented in the form of diagrams and, importantly it is difficult to identify the difference between the source luminance and the window luminance as defined in the modified version. On this basis, Nazzal proposed the new evaluation method for discomfort glare from windows called DGI_N (Nazzal, 1998a; Nazzal and Chutarat, 2000)

2.3.3 New Daylight Glare Index (DGI_N)

The new modification of the DGI (DGI_N) method was developed based on Chauvel's modification of the Cornell large-source glare formula (Nazzal and Chutarat, 2000). In general, the equations for evaluating glare in Chauvel's modified version and the DGI_N are quite similar as both methods take into consideration the same fundamental parameters: size of glare source, luminance, and position of the glare source in the field of view. The difference between these two formulae, however, is that the DGI_N discards the background luminance. According to Nazzal (1998a), a large source such as a window covers too large area on the retina to be clearly distinguished from the background. Thus, it is irrational to include the luminance background in the calculation. Based on several previous studies, the immediate surrounding luminance has more impact on the discomfort glare than the background luminance, therefore the term of adaptation luminance was introduced in this new calculation method. Moreover, in the new DGI_N evaluation method, the apparent solid angle ω_n subtended by a window, and the solid angle Ω_{pN} subtended of the source are modified to include the effect of the observation position and configuration factor. This new DGI_N formula is shown as follows:

$$DGI_N = 8 \log_{10} \left(0.25 \frac{\Sigma (L_{exterior}^{2} \times \Omega_{pN})}{L_{adaptation} + 0.07(\Sigma(L_{window}^{2} \times \omega_N))^{0.5}} \right)$$

Where:

L_{window} = Window luminance: the source luminance (cdm^{-2})

$L_{adaptation}$ = Adaptation luminance: the luminance of the surroundings including reflections from the internal surfaces (cdm^{-2})

$L_{exterior}$ = Luminance of the outdoors, caused by direct sunlight, diffuse light from the sky and reflected light from the ground and other external surfaces (cdm^{-2})

ω_N = Solid angle subtended by the glare source (window) to the point of observation (sr)

Ω_{pN} = Solid angular subtended of the glare source, modified for the effect of its position in the field of view by means of position index P (sr)

The three parameters the above equation are calculated as follows

$$L_{window} = \frac{E_{v3\ shielded}}{2\phi_i \times \pi}$$

Where:

L_{window} = Average vertical luminance of the window, calculated from the reading of the sensor with the shielding pyramid (cdm^{-2})

$E_{v3\ shielded}$ = Average vertical illuminance from the window at the sensor with the shielding pyramid (lux)

ϕ_i = Configuration factor of window

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

Where:

$L_{adaptation}$ = Average vertical luminance of the surroundings, calculated from the reading of the sensor without shielding (cdm^{-2})

$E_{v2\ unshielded}$ = Average vertical illuminance from the surroundings at the sensor without shielding (lux)

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

Where:

$L_{exterior}$ = Average vertical unshielded luminance of the outdoors, calculated from the reading of the sensor without shielding (cdm^{-2})

$E_{v1\ unshielded}$ = Average vertical illuminance from the outdoors at the sensor without shielding (lux)

Based on their works to validate of this new method, Nazzal and Chutarat (2000) report that the new DGI_N procedure appears to yield sensible and consistent glare values even in the direct sunlight and this should lead to the great improvement of daylight glare calculation. However, at present, this calculation method seems to be new and there has not been much evidence yet provided to asserted its ability to evaluate glare in lighting practice.

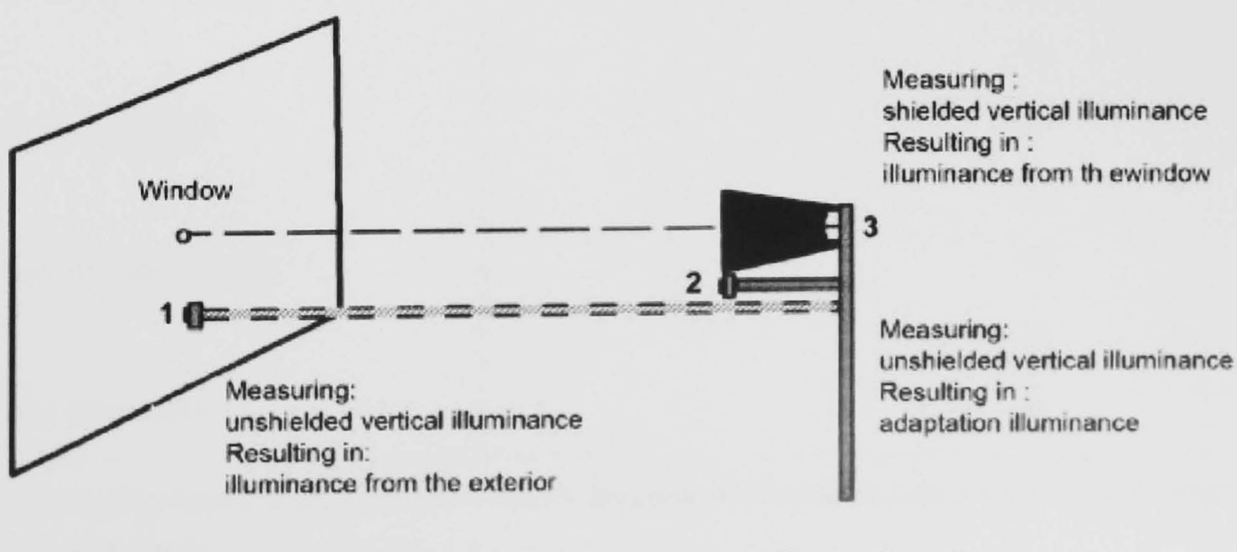

Figure 2.4: A set of three vertical sensors to evaluate discomfort glare

2.3.4 Predicted Glare Sensation Vote

The Predicted Glare Sensation Vote was developed by a group of Japanese researchers. The series of experiments were conducted both in laboratory settings using a simulated window and in a room with real windows. In their study, the research team modified Hopkinson's glare sensation criterion to use as a continuous scale called the Glare Sensation Vote (GSV) as shown:

Just perceptible	=	0
Just acceptable	=	1
Just uncomfortable	=	2
Just intolerable	=	3

The corresponding of GSV to DGI values is as follows:

Table 2.3: Comparison between GSV and DGI for the Evaluation of Discomfort Glare

Degree of Perceived Glare	**GSV**	**Daylight Glare Index (DGI)**
Just imperceptible	0	16
		18
Just acceptable	1	20
	1.5	22
Just uncomfortable	2	24
		26
Just intolerable	3	28

The relationship between DGI and GSV can be demonstrated by the equation GSV = (DGI-16)/4 (Tokura *et al*, 1996)

The experiment was conducted under 120 conditions and deployed more than two hundred subjects (Iwata *et al*, 1992a; Iwata *et al*, 1992b; Tokura *et al*, 1996). In the first experiment, using a simulated window, the results indicated a good correlation between the Glare sensation vote and DGI in central vision. This relationship between DGI and GSV leads to the assumption of the research team, Iwata and her colleague, that like Hopkinson's study, the GSV acquired in laboratory with simulated windows should reflect the subjective evaluations under real sky conditions. However, the results from the second experiment, conducted in rooms with real windows, led to the research team's conclusion that the DGI was insufficient in predicting glare sensation in all conditions. Therefore, a new prediction method should be developed. Based on data from the experiments, Iwata and her colleague proposed the new predicted method of glare, the Predicted Glare Sensation Vote:

$$PGSV = 3.2 \log_{10} L_{wp} - 0.64 \log_{10} \omega + (0.79 \log_{10}\omega - 0.61) \log_{10} L_b - 8.2$$

Where:

$$L_b = \left(\frac{E_v/\pi - L_{wp} \times \phi_w}{1 - \phi_w} \right)$$

Where:

E_v = Vertical illuminance at the eyes (lux)

L_{wp} = Luminance of a window (cdm^{-2})

L_b = Luminance of the background (cdm^{-2})

ω = Solid angular subtense of the source (sr)

ϕ_w = Configuration factor of a window

As the PGSV was introduced based on glare assessment using simulated windows, further investigation was carried out in order to examine how applicable the new method was in a real sky condition. In this process, the PGSV was compared with the GSVs obtained from a real window results. According to Tokura *et al* (1996), the results indicated that the calculated value of the PGSV is relatively higher than the actual glare sensation vote, however it gives a more plausible value of glare sensation than the DGI does.

The researchers also derive from the experiments with a uniform light source, that the PGSV discards the effect of the luminance distribution of windows, thus the equation might not be applicable in the situation that realises the non-uniform luminance distribution. In addition, it was found out that the value of PGSV becomes independent of the background when the size of the source increases to match the whole visual field. In this case, the study demonstrated that the PGSV would be applicable to sources larger than 1 steradians (Iwata and Tokura, 1998).

2.3.5 Modified Daylight Glare Index (DGI_{mod})

The DGI_{mod} is a modified version of Hopkinson Cornell large-source formula based on the experiments under the conditions of natural light (Fisekis *et al*, 2003). Ten subjects were asked to evaluate glare from window in the two test rooms with three sky conditions. Based on the suggestion of Nazzal (1998a) and Nazzal and Chutarat (2000) in that a large glaring source such as a window covers a very large area on the retina that makes it impossible to clearly distinguish it from the background, another representation of the background luminance has also been used to avoid this limitation in their studies. It is an average luminance of the entire field of view including the glare source: L_a (cdm^{-2}) given by:

$$L_a = \frac{E_{un}}{\pi}$$

Where:

E_{un} = the vertical illuminance measured by an unshielded at the point of interest

On this basis, Fisekis *et al*, 2003 investigated the daylight Glare Index (DGI) substituting L_a for L_b (Fisekis *et al*, 2003) and compared overall performance of the two formulae—DGI-L_b and DGI-L_a. The result from the experiment asserts the application of the equation to calculate glare using either background luminance (L_b) or average luminance (L_a). Using L_b had led to achieve a better overall performance, however mild degrees of glare can be predicted with relative accuracy while using the average luminance (L_a). The prediction of DGI-L_a beyond the just acceptable criterion is considered to be underestimated. Based on this research finding, Fisekis and his colleagues explain that, due to the saturation process, the influence of the average luminance in the adaptation function has a declining effect when the source luminance increases. Therefore there is a need to modify the formula by raising L_a to an exponent (χ <1). On the basis of the data obtained from the experiment, the modification of Cornell large source formula is as follows:

$$DGI_{mod} = 10 \log_{10} 0.478 \sum \left(\frac{L_s^{1.6}\, \Omega^{0.8}}{L_a^{0.85} + (0.07\omega^{0.5} L_s)} \right)$$

According to Fisekis *et al* (2003), the modified DGI gives a better overall performance with increased accuracy of glare assessment. Certainly, the work of these researchers has made a valuable contribution to the debate about background and source luminance as well as the investigation of the effect of a glare source's luminance to an observer's adaptation luminance (Osterhaus in Fisekis *et al*, 2003). However, as commented by the researchers themselves, more work is required in order to arrive at generic conclusions.

2.4 Conclusion

In conclusion, this review of literature addresses and discusses advantages and limitations of the existing glare evaluation systems for both small source glare and large source glare. This has led to the selection of glare prediction methods to be based in two main investigations in the subsequent sections: an investigation of interest in an image on glare in laboratory studies and a study of the effect of interest in a view on glare from windows in real daylighting conditions. In the first part of this Chapter, the discussion of the four well-known systems for the prediction of small source glare, the British Glare Index (IES-GI), the Visual Comfort Probability (VCP), the German Glare Limiting System, and the Unified Glare Rating (UGR) demonstrates the variety of concepts and criteria used as well as the calculation methods among these systems. Two prediction systems were chosen to be the basis in an investigation of the effect of image interest on discomfort glare in the thesis, the IES-GI and the UGR. These two prediction systems have been selected based on two main reasons. As a pioneer glare evaluation system, the IES-GI has a strong development background and has been employed previously in a great number of glare studies. This makes it easier to access useful information required for this research. The UGR formula was chosen based on the fact that it is the newest development formula and it is considered to be an international glare evaluation system. Whilst the review emphasises the strong development of an evaluation system for small source glare, an evaluation system for large source glare, particularly windows, demonstrates more limitation. Although a number of studies on large source glare have made a very useful contribution to the development of evaluation systems for glare from windows, it is the Hopkinson DGI-Cornell large source formula that offers a complete glare index system and, as earlier stated, it is also the most cited model for prediction of discomfort glare from windows. On this basis, the Hopkinson DGI formula is selected to be a basis for investigating the effect of interest in a view on glare from windows.

Moreover, the review of literature shows problems associated with a large variance in subject response and the low correlation between the existing evaluation systems and subject appraisals for both the small-source and large-source systems. Based on this review, since the effect of interest may be small, in order to found this effect easily, controlling methods would be employed in experiments in this thesis to try to control many extraneous variables as possible. For example, a pretest period containing procedures for controlling some extraneous variables, such as the meaning of glare and its criteria would be added in experiments for this purpose. Also, in an investigation of interest of a view in real daylighting condition, an aim is to carry out the experiment in test rooms without furniture arrangements and no tasks for subjects to perform.

Finally, the review of literature also indicates that most of the researches on glare from windows have been largely focused on the development of prediction formulae based on the four parameters discussed previously. Whilst the effect on glare of the interesting views through a window have been pointed out since the development of the DGI in the earlier state and some other factors have been investigated, there is no evidence of a systematic study on the issue of the effect on discomfort glare of either interest in a view or other view-related factors. In the next Chapter, a literature review relating to views through windows would be presented and discussed.

Chapter 3
Views through Windows

3.1 Introduction

As mentioned earlier, there is evidence implying a possible effect of interest in a view through windows on discomfort glare. Indeed, a view with a great deal of interesting information or meaning might have an important effect on discomfort glare (Hopkinson, 1972). This forms the main focus of the thesis—to investigate the effect of interest in a view on a sensation of glare discomfort. After investigate the interest effect, this thesis also intend to further investigate effects of view content on glare, which could be carried out in the final part of the thesis. Given this basis, this section aims to review literature concerning views through windows. Two particular attempts were made in this section are 1) to discuss on the subject of views through windows regarding the meanings to the main focus of the thesis and 2) to establish a based knowledge for identifying factors relating view content. This not only contributes to the investigation of the effects of view content on discomfort glare, but also helps to assert the potential of effect of interest in a view on the sensation of discomfort glare. In fact, as the relation between features within a view and the sensation of discomfort glare is expected in this thesis, the literature review on effects of view content and classification could provide essential information for further investigation of this relationship.

In all, the review of literature is composed of four main parts. It begins with a brief introduction of windows and view out, followed by the description of view out and the discussion about its importance regarding various perspectives. This includes the explanation of the benefits and effects from view to outside. It continues with the review of view content and classification. Then, an analysis of the interest in a view was carried out. Finally, a conclusion illustrating the meanings of the literature review to the main focus of the thesis and the investigation of the effects of view content was drawn.

3.2 Windows and View Out

As previously discussed, windows are considered as a potential source of glare, however they have various functions and provide many benefits to the building occupants. A number of pieces of research have demonstrated that daylight is preferred to artificial light (Keighley, 1973a; Heerwagen and Heerwagen, 1984; Wells, 1965; Wotton and Barkow, 1983). Furthermore, there is ample evidence that people nonetheless consider windows to be an important element of a comfortable office (Heerwagen and Orians, 1986).

Accordingly, several research studies on the windowless environment have demonstrated, in most cases, the desire for windows (Collins, 1975, Cuttle, 1983; Butler and Biner, 1989; Stone, 1998). The reason for a desire for windows is related to not only to their illumination and spectral qualities but also to the view which is usually associated with the daylight (Manning, 1965). The result of the social survey carried out by the Co-operative Insurance Society Building, Manchester showed that 90 percent of the 2500 respondents agreed that it was important to be able to see out of the office (cf. Tregenza and Loe, 1998). Indeed, this indicates that another essential function of a window is the provision of a view of the outside world.

Although relatively little is known about the nature of visual requirements in relation to view, a view to outside is believed to be a good "visual rest centre", which permits the eye to re-focus at distant scenes in contrast with the typical close work found in offices (Manning, 1965). In addition, it has also been suggested that the necessity of views through windows to the users is related to psychological reasons. Whilst most views through windows are acceptable, there is some evidence that views with high information content are preferable (Collins, 1975). Likewise, Markus (1967a and b) pointed out that the information content of the view might be one of important factors to window design.

Through recent decades, there is an increase in the recognition of effect of view out. A number of researchers have concentrated on investigating the role and function of view out and its benefits. The works of these researchers not only emphasis the effect of view out on building occupants but also provide an explanation for the desire of window and view out. In order to lay the foundation for the main focus of the thesis and the exploration of effects of view out on discomfort glare, the review of functions and benefits of view out is presented in the following section.

3.3 Functions and Benefits of View Out

As the important characteristics of windows appears to be their provisions of a view, view out is simply referred to the scene beyond the window (which does not limit to some sort of beautiful landscape, scene) (Collins, 1975). Instead, it can be defined according to its information content (Markus, 1967a and b). Accordingly, view can be good or bad, beautiful or ugly depending on the information it contains and the attitude of an observer. Whilst windows have many functions and window design has been dominated by the need to provide adequate daylight and ventilation, in a windowless environment, the provision of a view seems to be a main reason driving the building occupants' desire for windows (Manning, 1967; Markus, 1967a and b; Collins, 1975; Ludlow, 1975). According to his study investigating subjective responses to the lighting installation in an office building, Wells (1965) found that 89 percent of the surveyed respondents considered it was desirable to be able to see outside even when there was abundant artificial lighting in the interior.

This situation is further supported by the study for daylight design of Jackson and Holmes (1973a and b). In the issue related to an importance of the view for an office worker, Jackson and Holmes (1973a and b), comment that people look out of the window for release in the form of movement compared with their static situation inside. It is the way that people reassure themselves that life is still going on in the real world outside (Ibid). Similarly, Christoffersen *et al* (2000), based on their study of daylighting and window design, reported that the ability to see the view outside and weather conditions was the most positive aspect of windows agreed by more than 1800 office workers. All these findings stress the fact that there is the psychological need to link with outside world as Manning (1967; p. 20) point out "people within buildings seem to need some contact with outside world".

In some particular circumstances, the relative importance of view out in the working environment might be less than the other factors such as immediately effective environmental features, temperature, lighting, and noise (Boyce, 2003). The desire for windows could also be lessened by other psychological needs, for instance the need for privacy and security (Roessler, 1980). However, in most building environments, the desire to be able to see outside seems to be overwhelming as Jackson and Holmes, 1973b point out, "there is some indication that information content can be quite small, even a brick wall six feet away outside a window is much preferable to a brick wall at the same distance inside the same room". Similarly, the study of Cooper *el al* (1973) shows that the presence of a view was not rated as the most important aspect of an office, however, they did suggest that "most people will be will satisfied, provided they can see out, even if the view is restricted". These comments were also supported by the study of Ludlow (1975), the functions of windows in buildings. Through his assessment of view qualities, Ludlow concluded that a view of any quality is better than if there is no view at all.

Although the desire for a view out appears well established, the knowledge about the purpose that is served by the view outside seems to be limited. Among the studies that have dealt with this issue is one by Heerwagen (1990), who suggested that the people's response to windows may be largely unconscious and related more to a psychological aspect than previously believed. Accordingly, she highlighted four general psychological benefits from the ability to see through a window which includes an access to environmental information, access to sensory change, connection to the world outside, and restoration and recovery. In order to establish a verifiable explanation of view function, further discussion on these four psychological benefits of a view through windows is carried out as follows:

3.3.1 Access to Environmental Information

The need to access the environmental information has its own obvious as well as perhaps deeper and unconscious significances as it links to the evolution and existence of human race. According to Heerwagen (1990), environmental data such as weather conditions and time of day have a profound effect on the health and survival of the primitive man. For example, information obtained on daylight and weather changes is critical to daily decision-making such as finding food and a place to sleep.

In the present day, the role for environmental information seems to be less crucial than the past. However, the evidence from the window and view studies asserts that a requirement for such information has continued. Many people make decisions about their daily activities based on a glance through the window. Manning (1965) highlighted that one of the main reasons for a desire of windows is the ability to know about the weather and the time of day. Likewise, the study of Butler and Biner (1989) shows that the provision of a view outside that allows people to keep track of time and weather is one of the key factors influencing window preferences. In his study, Markus (1967a and b) suggested that the view could be analysed in terms of its information content which largely related to its ability to provide psychological benefit. As a dominant source of light, the sky, sometimes with visible sun, is not only helpful people to find out the weather, time of day and seasonal change but also has "probably become a symbol for life, energy, fertility growth and all mankind's basic needs" (Markus, 1967a; p. 60). Clearly these psychological benefits could not be fulfilled in the windowless environment. Besides, in some cases, the lack of opportunity to access environmental information might lead to a negative outcome as the poor recovery of patients in windowless intensive care units has been witnessed (Wilson, 1972; Keep *el al*, 1980).

3.3.2 Access to Sensory Change

An interaction between man and environment involves a process of gathering and interpreting environmental stimuli sensation and perception. Sensation refers to the human sensory system reacting to environmental stimuli, whilst perception involves the gathering, organising and making sense of information acquired through the sensory system, vision, hearing, smell and touch (Carmona *et al*, 2003). A number of studies emphasise that this sensing and interpreting the environment is important to the survival of organism. Indeed, there is the need to stimulate the organism by variety of experience and exposure to information (Prak, 1977). According to Platt (1961) sensory change is fundamental to perception and may well be essential for the efficient functioning of the brain. Evans and Piggins (1966) highlighted that the preference for the new or the changing environment is an essential mechanism of a system which is to survive for long in the physical world. The importance of the sensory change was stressed by the result found in research probing into the negative effects of the absence of it. According to Lozano (1988), several psychological studies reported perceptual disturbances, such as boredom, restlessness, lack of concentration and hallucinations, when people were subjected to monotonous, unchanging environments. This shows that sensory change is necessary for psychological development and maintaining the mental well being of man.

Although the sensory stimuli are usually perceived and appreciated as an interconnected whole, the vision seems to be the dominant sense (Carmona *et al*, 2003). It offers more information than the other senses combined as Porteous (1996; p. 201) pointed out, 'vision is active and searching: we look; smells and sounds come to us'. Accordingly, while most interior environmental factors such as temperature, ventilation rate, artificial lighting, furnishings, and colours are kept constant and unlikely to provide any source of change, view out may become the only available source of variable environmental stimulation (Heerwagen, 1990). This conjecture is supported by the study of Wyon and Nilsson (1980). Based on their survey of almost 500 people working in various kinds of jobs in both windowed and windowless environments, it was found that people who held inactive jobs tended to present their desire for windows more than those who worked at active jobs that allowed them to move around their work place. Likewise, Collins (1975) also suggests that a restricted workspace and a sedentary or routine job may have increased the dislike of the windowless situation of office workers. The lack of change and stimulation was also one of the major complaints by the employees who worked in several underground offices as surveyed by Sommer (1974).

In general, the significance of sensory change attaches great importance with its ability to offer clues about the world around us (Bell, 1973) as well as to provide a pleasurable quality independent of the information it imparts (Heerwagen, 1990). The need for these benefits offers an explanation of the desire for a window and view out.

3.3.3 Connection to the Outside World

The need for psychological connections with the outside world should be considered crucial, as it has been proved already by various pieces of research and experiments (Roessler, 1980; Heerwagen, 1990). In fact, the opportunity to have a view of the external world is frequently cited as a primary benefit of windows. Markus (1967b) pointed out that the fundamental function of a window is to act as a visual aperture enabling building occupiers to remain liked to the external world. Similarly, Roessler (1980; p. 65) claimed: "to establish the visual connection between interior and exterior has made windows indispensable for human well-being."

Although the realization of the centrality of this benefit arose in the context of window and view out preferences, as discussed in the previous section, there are sound theoretical grounds for believing that this requirement would be necessary to the survival of an information-based organism. As Morgan (1967) argued "ordinary man might therefore define the function of the window as the medium through which he maintains contact with his environment, with life, which enables him deed in his subconscious to know that he is a free man"(cf. Collins, 1975, p. 34). In this sense, windows provide the building occupants an access to witness and involve in the changing events in the world beyond walled boundaries. As Manning (1967) suggested, the use of large windows in hospital might be the most suitable construction to prevent feeling of ostracism or separation from the outside world. The study of Ne'eman and Hopkinson (1970) showed that the window preference was dependent on the visual information provided by the view outside rather than by the amount of daylight or the level of interior artificial lighting. Accordingly, they explained that attention to the outer world is essential to relieve the sense of enclosure. It gives a feeling of freedom to communicate with the world outside. This is also a reason that obstructed views have always been least favoured. In addition, in the context of privacy, view out in most cases responds to the need for a feeling of privacy without being isolated from the out side world.

3.3.4 Restoration and Recovery

Apart from the benefit of view as a "visual relief and relaxation" (Wineman, 1982), the view has believed to provide a "psychological relief" (Goodrich, 1986; Heerwagen, 1990). In this context, relief is defined as an easing of pain, discomfort or oppression or as anything that lessons tension or stain or offers pleasing change as to the mind or eye (Webster, 1982 cf. Heerwagen, 1990). The results from various studies provide strong support that the window, as a source of a view out, affords a wide range of restoration and recovery benefits. Although the mechanism that makes a view out serve these functions seems to be complicated, studies on the benefits of windows suggest that views containing natural content are more restorative than others.

The investigation of the patient reaction to windowless intensive care units by Wilson (1969) shows that the absence of windows led to increased patient stress. Wilson gave an explanation that windows provide some sort of necessary psychological escape form the grim realities of surgery. Similarly, in a study by Ulrich (1984), it was found that surgery patients who had a view of deciduous trees from their rooms had fewer complaints of nausea and headaches, required fewer analgesic doses, and had shorter lengths of stay than similar patients whose rooms looked on a brick wall. Accordingly, Ulrich (1984; p. 421) suggested, "the natural scene had comparative therapeutic influences". The "psychological relief" from an access to nature through window was also asserted by the study of Kaplan and Kaplan (1995). In this study, the participants were asked to evaluate the effect of a view out regarding their view from their desks. The findings showed that employees with a view containing natural elements felt that their jobs were less stressful and were more satisfied with their jobs than others who had no outside view or who could see only built elements from their window. In addition, the result also indicated the therapeutic value of view out as the respondents with nature views reported fewer ailments and headaches.

Understanding these four psychological benefits should help to reveal the principles underlying the human requirement for windows. Although the traditional role of windows as the source of daylight remains, as discussed, the desire for windows has been greatly attached to their provisions of views. The presence of view out in a room seems to be necessary and have great benefits to occupants inside. This has led to an increase in an attempt to establish criteria for view out and incorporate them with other significant criteria for window design presently. Several studies relating to the effect of views show that there is a link between the features of view content and subjective sensation. Thus, aimed to explore the effects of view content on the sensation of discomfort glare, a consideration and perhaps identification of features of view content would be essential in this thesis. Indeed, it will help to establish a based knowledge for identifying factors to an investigation of effects relating to view content on the sensation of discomfort glare. A further discussion on the view content and its classification is continued through the following section.

3.4 View Content and Classification

If interest in a view does affect discomfort glare, and it is also known from other works that interest in a view is influenced by the inclusions of specific factors in a view, then we would expect that these factors would also affect discomfort glare. This assumption forms a link between the view content and discomfort glare and, based on this link, possible factors affecting the sensation of glare discomfort regarding view content can be deduced. This section began by the discussion of effects of factors in a view obtained from previous studies. It, then, followed by view classification, in which an aim is to summarize approaches and define factors relating view content that have been identified from the past. Finally, the issue of interest in a view was also discussed.

3.4.1 View Content and Its Effects

Apart from the psychological benefits obtained from a provision of view out, much literature reveals the investigations of effects of features in the view content, in particular, on window dimensions (Keighley, 1973a and b; Ne'eman and Hopkinson, 1970; Roessler, 1980; Ludlow, 1976). Keighley highlighted the influence of the view content on the observers' choice of preferred window shape and location. He deduced that "view requirements appear to be the best satisfied by horizontal apertures, the dimensions of which are determined primarily by the elevation of the skyline" (Keighley, 1973a, p. 319). In the subsequent study, Keighley (1973b) investigated a number of window arrangement varying in for example size, shape and number of apertures. In agreement of his previous study, He found that satisfaction of window height was dependent on the view and the visibility of the skyline. Ne'eman and Hopkinson (1970) investigated the minimum acceptable window size in an office environment, as a function of a wide range of variables. They found that the view content was the most important factor in determining the minimum window width. They also indicated that close views required wider windows than distant views. Ludlow (1976) explored the optimum window size and shape. He indicated that the preferred size and shape of windows are related to horizontal stratification in a view and determined essentially by the variation in sky/ground ratio.

Although there is much evidence relating to effects of features in a view on window dimensions, little information on the effects of features in a view on subjective sensation. In their initial pilot studies, Markus and Gray (1973) showed that satisfaction with windows in residential environments was related to specific features of the view content. They found that the amount of greenery and nature elements visible, and the amount and kind of activity occurring in a scene affected the general feeling of satisfaction. In contrast, dissatisfaction was influenced by the numbers of buildings and man-made elements visible in a view. Similar to the previous study, the final findings from a subsequent study confirmed that visual satisfaction was strongly related to what was seen outside.

Through the above literature review on view content and its effects, there is no direct record of particular features and elements of view content on interest in a view. However, the above previous researches support the assumption that there is an effect of view content on the subjective sensation especially to the satisfaction with window. Accordingly this seems to suggest that the features of view content could also affect the interest in a view. In exploring the effects of view content on discomfort glare, identifying characteristics and physical elements that is likely to have an effect on interest in a view is considered essential. Before doing this, it is important to firstly understand how views are classified, particularly according to their content. The review of view classification will help to demonstrate the way other researchers have used to classify views, which could be served as guidelines for the classification of view content in this thesis.

3.4.2 View classification

Although, the effect of view content on observers has been established, the study of characteristics of a view out itself seems to be limited. In fact there is no systematically categorized typology of a view out. Only one obvious and systematic source of this information in terms of view outside is from the study of Markus (1967a). Through his investigation of the significance of sunshine and view for office workers, Markus (1967a) suggested that the view should be analysed according to its information content—the amount of sky, land or cityscape or ground which it contains. Most related studies on the issue of content and classification have been carried out in the field of environmental psychology in terms of landscape scenes, particularly in environmental aesthetics and environmental perception which, therefore, becomes a main source of information discussed in this review of literature.

As previously defined, "view out" refers to the scene beyond a window that generally contains different sorts of information. From the aspect of environmental studies, view out is represented by landscape scenes which vary in characters ranging from absolute nature to all urban scenes. Whilst there are very few studies on the view out and its content, research into landscape preference and assessment application is a very active field particularly in regard to the issue of landscape quality. With the main aim of investigating quality and preference, many researchers in this field have made an attempt to define physical-landscape variables thought to influence the perception of landscape quality (Fenton and Reser, 1988). Several of these studies provide essential information for examining the content of views through windows. Accordingly, the discussion of view content and classification in this section is made with reference to these studies.

The term landscape refers to an expanse of natural scenery seen by the eye in one view (Webster's New World Dictionary, 2nd College Edition). It clearly focuses upon the visual properties of the environment. According to Daniel and Vining (1983), the studies on landscape scene and its quality have been mostly conducted based upon two distinctive purposes: to determine the character of the landscape—its elements and attributes and to justify the quality dimension of the landscape scene. In their views, the latter approach can give a good explanation as to why some landscapes provide more pleasure to the senses than others. In addition, with respect to the classification of landscape assessment model by Daniel and Vining (1983), landscape scenes can be identified according to five significant assessment methods: ecological, formal aesthetic, psychophysical, psychological, and phenomenological.

In brief, the ecological models give primary concern to naturalness and views are classified regarding the natural features contained. In the formal model, scenes are classified based on the formal properties of the landscape which refer to basic forms, lines, colours and textures and their interrelationships. The landscape scenes are therefore justified or categorised in terms of the aesthetic value of their basic elements. In contrast, the psychophysical model seeks to determine mathematical relationships between the physical characteristics of the landscape and the perceptual judgments of observers, the scene thus categorized according to physical features such as topography, vegetation, water, etc. In the psychological model, the assessment of views depends upon the feelings and perceptions of the people who view landscapes. The landscapes are identified according to their ability to evoke feelings or reactions either positive or negative such as relaxation, warmth, cheerfulness or happiness, stress, fear and constraint. Finally, in the phenomenological model, views are identified based on individual subjective feelings and interaction with the landscape, for example the individual experiences and impressions on the issue of emotions related to space— destinations and disorientation.

Likewise, the discussion of Fenton and Reser (1988) on the issue of landscape quality and assessment contribute to the identification of view content. According to these researchers, the defining of physical-setting variables of landscape are generally seem to follow two main streams of thought, termed objective and judgmental. Evidently, there has been the continuing debate between researchers taking a cognitive approach, assuming that "environments could not be characterized independent of either human perception or human action" (Wapner *et al*, 1973) and those focusing on the study of the objective physical environment. On the basis of these two research polarities, three main approaches have been adopted in order to define physical—landscape variables thought to influence the perception of landscape quality: the objective quantification, normative judgments, and phenomenological descriptions (Fenton and Reser, 1988).

As Fenton and Reser (1988) described, objective quantification is the landscape-preference technique that refers to the objective measurement of physical-setting variables. This technique has been used to predict landscape quality through a number of objectively quantifiable landscape variables. Based on this technique, the content of views or landscape scenes can be classified by their physical elements and composition such as sky, land, and water. In the study of Shafer *et al* (1969), for example, ten landscape zones were defined as sky, stream, waterfall, immediate, intermediate and distant areas of vegetation and non-vegetation.

With different direction, instead of direct measurement of physical features of the landscapes, normative judgments refer to the use of judges' ratings to define landscape variables with a clear environmental reference (ibid). Through this technique, the variables of landscapes could be described according to either physical attributes or characteristics of the objective environment. For instance, in his research, Linton (1968) described physical landscape in geographical terms such as landform (mountain, bold hills, hill country etc.) and land use (wild landscape, rich varied farming landscapes, forest and moorland, etc., whilst R. Kaplan (1973) and Kaplan and Kaplan (1989, 1995), adopt the more subjective terms of variables such as complexity, coherence and mystery. The phenomenological description is also one of the techniques employed for describing the physical-landscape attribute discussed by Fenton and Reser (1988). As previously discussed, in this approach, landscape variables are defined through cognitive domains of individuals, thus the content of scene is often described in terms of subjective response such as crowded, barrenness, and lack of open space. However, as the psychologically dominant technique, the phenomenological approach has been least employed in the field landscape assessment.

The attempt to classify landscape scenes is also presented in the study of Steven Kaplan (1975) and Rachel Kaplan (1983). Through the procedures they used in constructing their model of environmental preference, S. Kaplan and R. Kaplan classified and evaluated the characteristics of landscape scenes. In this process, referred to in their studies as Category-Identifying Methodology [CIM], the researchers asked the respondents to classify a large number of photographs of various landscapes according to certain schemes. In this way, they derived the way to categorize the landscape scene in terms of two major types, the environmental content and spatial configuration. Kaplan and Kaplan (1995) described that the landscapes in content-based categories have as their theme or common characteristic that they deal with specific objects or elements, such as water and vegetation. This makes it possible to identify or categorize the landscape scene. Dissimilarly, spatial configuration categories are based on the way the elements are arranged in the implied space of the scene. As highlighted by Kaplan and Kaplan (1995) the scene should be examined based on spatial configuration categories, when content is not the distinguishing characteristic. Undoubtedly, this study has contributed highly to the classification of landscape scenes as well as the justification of their qualities.

A review of literature shows that there are different approaches in scene classifications and many variables in terms of content in landscapes have been identified in the past. It also emphasised that although there is no precise or systematic way to classify views outside, either the psychophysical model or normative judgment system of assessment seem to be adopted later by researchers whose studies related to an assessment of views through windows such as Ludlow (1972) Markus (1967a and b) and Ulrich (1979, 1984). In all, the attempts of many previous researches to classify views out and landscape scenes have helped to establish based knowledge for the later studies in the issues relating to view content and its effects. This review of view classification is also become principle underlying the preparation and categorisation of small projected screen images and views in this thesis.

With regards to the exploration of effects of view content on discomfort glare, as the above literature reviews shown no record of features of view content affecting interest in a view, the relationship between view content and interest in a view is further discussed in the next section. The main focus is to define "interest" and identify characteristics and physical elements that are likely to have an effect on interest in a view.

3.4.3 Interest in a View

As mentioned earlier, the general hypothesis was proposed that an increase in interest in a glare source is associated with a decrease in discomfort glare. According to Humphrey (1972) "interest" refers to active inquiry, where the observer is concerned to derive what information he can from the stimulus and discern it's meaning. According to the Oxford dictionary (2002), "Interest" refers to a feeling of curiosity or concern. Since interest is subjective, this sensation of the observers can vary with the situation they are in. Therefore, interest in a glare source depends not only on the stimuli but on people and on the circumstances. Therefore, it is necessary to define interest for a particular group of people to a specific stimulus in a particular circumstance. "Interest in a glare source" in this thesis was defined as the sensation of curiosity in subjects to a glaring source in an experimental situation in which the subjects rated the glaring source. Also, interest in a view refers to this sensation in a view of subjects in an experimental circumstance. It has been noted in the previous section about the link between the inclusions of specific factors in a view and discomfort glare. To provide criteria on view selection and to further investigate effects in a view to make thesis findings more beneficial in terms of practical implications, the review of literature below aims to establish a foundation of knowledge for identifying the elements and characteristics in views that can affect the interest in a view.

Although there is a strong notion that a view out is desirable, as earlier stated, what particular characteristics or physical elements in a view affect interest in a view is virtually unknown. In general, environmental preference appears to have some relationship with those environments that satisfy information needs. In the field of landscape perception, preference seems to take its dominant role as the indicator for aesthetics. Interest and preference in an environment leads the observer to maintain his contact. In most cases, it is undeniable that something that arrests the attention is preferred. Although the distinction between interest and preference has not been stated explicitly, it is known that when something is excessively difficult to recognize— strange or unusual things— the high interest may no longer be accompanied by preference. Studies in environmental aesthetics and perception defined and treated interest and preference in a scene as two separated factors. Much evidence in this field also indicated that interest and preference in an environment are related (Humphrey, 1972; Appleton, 1975; Kaplan, 1982). In accordance with this, view preference seems to be related to the interest of the observer to a view. A number of researchers on view out attempted to identify view-related factors that seemed to influence preference in a view. Reviewing these studies, therefore, could help to clarify the possible pertinent view-related variables that affect the interest in a view.

Markus (1967a), one of the first researchers who conducted a systematic study relating to window and view out, assessed the view preferences of 400 office workers in large open-plan offices in England. He suggested that about 88% of subjects preferred views of the distant city and landscape, while only about 12% preferred a view of buildings at ground level or of the sky. In this study, Markus also emphasised that the information content of view is critical in determining the satisfaction with the window of the subjects and one the most important characteristics of views that affected viewer preference is the horizontal stratification, the layers of ground, city or landscape, and sky. Likewise, Keighley (1973a and b), in his study of visual requirements and reduced fenestration in offices, noted that it seems to be a general requirement to be able to see a wide lateral view of the skyline or horizon together with a margin of sky above and a margin of ground below this, the depth of which depended upon the elevation of the skyline.

Through their continuing exploration of various aspects of view through windows, Markus and Gray (1973) highlighted that views containing natural features such as grass, trees, plants as well as open space were desirable. Moreover, the satisfaction was also related to the view of other buildings. Indeed, the fewer buildings, the more satisfaction of view out. Heerwageen and Orians (1986) also noted that views with dominant nature content are more pleasing than views dominated by built environment. Moreover, the general findings about the preference of views for visual pleasure and relaxation from studies conducted in Europe and the USA are consistent with the above studies. They claimed that people preferred views of natural scenes rather than those of the built environment and a complete view that contains part of every zone of the sky, the middle layer, and down to the ground near the window is preferred (Tregenza and Loe, 1998).

Factors which could affect preference in a window-view have been pointed out, but there are also many studies in scenic-quality or preference ratings focusing on identifying factors influencing preference in an environment. These factors provide information on additional view-related factors that could also have an effect on view preference and hence are reviewed below.
According to their studies, R. and S. Kaplan, pioneered research into landscape aesthetics, and developed the landscape preference model. This preference model is based upon four important variables: complexity, coherence, mystery, and legibility. They also pointed out that complexity offers enough information to promote interest. Ulrich (1979) restated Kaplan and Kaplan's findings as he argued that visual landscape preference is a response in favour of scene which relates to two main factors: legibility and mystery. In his terms, legibility has four components: complexity, focality (coherence and unity), ground texture, and depth.

With a similar approach and stimuli to R. and S. Kaplan, investigations of aesthetics and affective responses to outdoor environments carried out in Europe and North America, have shown a strong tendency of preference towards natural scenes over urban views that lack of natural environment (Wohlwill, 1973; Ulrich, 1979, 1981, 1983, 1984, 1986). Similarly, S. Kaplan, R. Kaplan and Wendt (1972) used fifty-six slides to investigate preference ratings of undergraduate students and also found seemingly consistent laboratory evidence that natural scenes are preferred to urban scenes.

In addition to factors describing characteristics in a view, many studies also suggested some factors in terms of physical elements in a view that could have an effect on view preference. The possible effect of the presence of water in a view was emphasized by many studies on window-view. Ludlow (1976) claimed in his study that "inclusion of any natural elements improves assessment of view and this includes sky, natural vegetation and water even if only a small amount". Likewise, in the study of Heerwagen and Heerwagen (1984), assessing the reaction of solar glazing, he showed that occupants with the view of trees, water or distant views rated their views as more cheerful than those whose view was without these features. In studies on environmental aesthetics and perception, although negative affective responses can be elicited by some water phenomena, for example, a storm sea or a lake dotted with chemical foam pollution, a consistent finding in the experimental literatures is that scenes with water features usually are accorded especially high levels of preference or pleasantness (Bruch and Palmer, 1979; Shafer *et al*, 1969, Zube *et al*, 1975). Hubbard and Kimball (1967) also claimed that water may enhance landscape preference by serving as a focal element and possibly increasing subjective depth.

In general, the works of these researchers provide a basis for expecting an underlying commonality in preference across individuals. It helps to identify a class of view-related variables that seem to be effective in the prediction of view preference. A summary of these factors drawn from the above studies, as an inference of the view-related factors that could influence interest in a view, are as follows:

1. The naturalness of a view (Markus, 1967, Kaplan, 1978; Markus and Gray, 1973; Ulrich, 1979, 1981, 1983; Heerwagen and Heerwagen, 1984; Heerwageen and Orians 1986; Kaplan and Kaplan, 1989).
2. The horizontal stratification in a view (Markus, 1967a and b; Keighley;1973a and b; Tregenza and Loe, 1988)
3. Factors in a view relating to landscape preference variables: complexity, coherence, mystery, and legibility in a view (Kaplan, 1972, 1978; Kaplan and Kaplan, 1989; Ulrich, 1979).
4. The presence of water in a view (Ludlow, 1976; Heerwagen and Heerwagen, 1984; Bruch and Palmer, 1979; Shafer *et al*, 1969; Zube *et al*, 1975; Habard and Kimball, 1967)

3.5 Conclusion

This chapter reviews literature on the subject of views through windows beginning with the investigation of windows and view out. It is, then, followed by view functions and its benefits. Finally, the content of the view out and its classification was explored including the issues of view content and its effects, view classification, and interest in a view.

As mentioned in the previous Chapter, a systematic study of the effects on discomfort glare of either interest in a view or other view-related factors has been virtually non-existent. This Chapter revealed much literature stressing the importance and psychological advantages of the provision of views through windows on building occupants. The literature review on view content and its classification showed that many features of view content have been explored for their effects on window dimensions and other subjective sensations. The discussion on this issue also indicated that, through past studies on related fields, there is a solid basis on classifications of content in scenes or landscapes and many variables in terms of content in landscapes have been identified and studied on their effects. This situation not only emphasizes that view out is not just a scene beyond a window, as described in its definition, but also gives a strong support that the presence of a view could have important effects on the sensation of discomfort glare from windows. The situation particularly stresses the possible effect on glare in terms of both interest in a view and factors relating to view content.

With regards to issues in the literature review of view content and its classification, while the discussion on view content and its effects shown no direct record of features in a view affecting the degree of interest, the review on interest in a view summarizes many possible view-related factors affecting interest in a view, which could possibly be factors affecting discomfort glare as noted above. This review serves a foundation for the two main processes of the thesis. The first process is when the selections of small projected screen images and views were made in preliminary tests in experiments, which attempt to relate the screen images and views to interest scores. The factors identified become basic criteria to select the images and views that could be interesting. The second process is when a study of the effect of interest in the cases of both a small screen image and a window on discomfort glare shows significant results. In this case, the review of literature would also provide knowledge basis for further investigating effects on glare relating to image and view content.

Overall, based on the literature review of these two subjects, it is undeniable that the effect of interest in a view on discomfort glare from windows is appropriate for investigation.

Chapter 4

Laboratory Studies

4.1 Introduction

A general hypothesis was proposed: *"an increase in interest in a glaring source is associated with a decrease in discomfort glare"*. The main focus of the thesis is the interest effect on glare in the case of a window. However, the experimental work begins by testing the effect of interest using a small projected screen image[1] under highly controlled laboratory conditions. There are three reasons for this. Firstly, testing the effect of interest in the case of real windows seems to be difficult in terms of setting up an experimental environment and equipment, while it is relatively easy both to set up and to manipulate investigated variables using small projected screen images under laboratory conditions. Secondly, there is evidence that glare sources containing information are often objects of interest (Markus quoted in Boyce, 1981; Hopkinson, 1972.) It is also easy to control extraneous variables under laboratory condition for increasing the potential significance of findings by reducing the variance. Hence, it was believed that if the effect of interest was not found in this test, it is very unlikely that this effect would be measurable in other glare sources and other test conditions. Finally, there is also much literature available in environmental aesthetics and perceptions which show the use of small sized colour slides projected by a slide projector to represent real scenes (Ludlow, 1972, 1976; Roessler, 1980, Keighley, 1973a and b). On the subject of validity of substituting simulated views for real views, Ludlow (1972, 1975), investigated the attributes used by people to assess a view represented by small sized colour slides. He reported that observers did evaluate real views along similarly to those the slides of views. In this way, it was believed that if an increase in interest in a small projected screen image is associated with a decrease in discomfort glare, similar conclusions could be drawn

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[1] 'A small projected screen image' refers to what was used as a stimuli glare source in this thesis. It is an image that was projected by a computer projector on to a screen, with a visual size less than 0.1 steradians (a small glare source). This was also sometimes called in this thesis as ' a small screen image' and ' a screen image'

for the effect of interest in a view on perceived glare. This initial laboratory experiment is a key test of the thesis. A positive outcome would be a primary indicator of the effect of interest in glare sources, but if no relationship between interest and glare could be found in this test it is very unlikely that the effect would be measured in a real window.

The first investigation described in the Chapter is this key test. However, the experimental findings suggested that there were, in fact two distinct effects on glare: factors contained within the image, and variation in the luminance of the image. Hence, two further laboratory experiments were performed to investigate these. The three experiments carried out in this part were, therefore:

1. to test whether an increase in interest in an image is associated with a decrease in discomfort glare;
2. to investigate what content of an image affects glare;
3. to examine the hypothesis that an increase in Relative Maximum luminance in an image leads to an increase in the glare discomfort.

4.2 Methodology

4.2.1 Experimental Settings

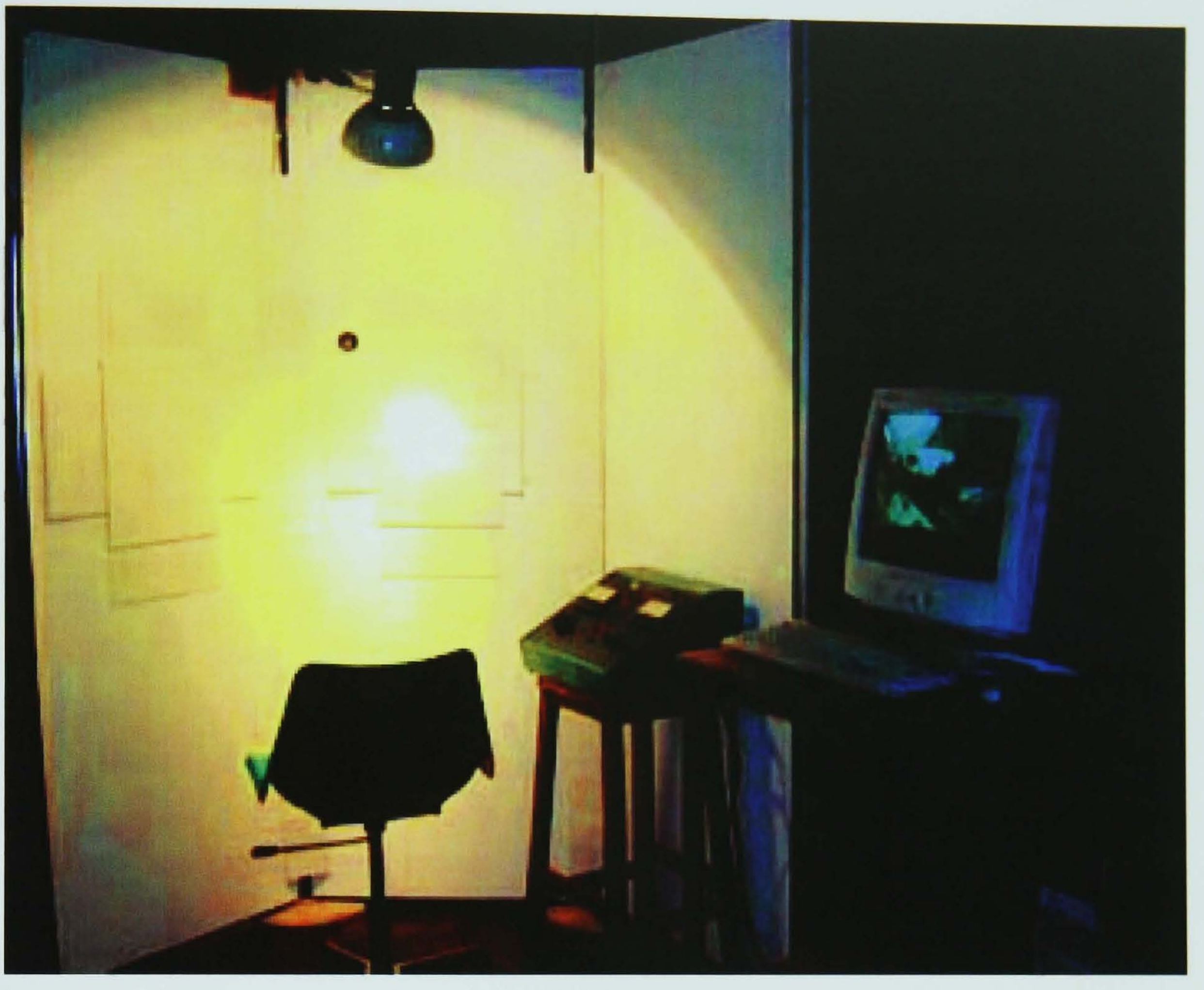
4.2.1.1 The Overview

All three experiments were conducted within a specially constructed chamber in the School of Architecture, University of Sheffield. The apparatus consisted of a reference glare source and two back-projection screens set in the walls of a cubicle. This was half-hexagonal in plan and painted matt white. There was a movable 100W tungsten halogen which illuminated the walls. Figure 4.1 and 4.2 illustrate a view of the experimental settings within the chamber. Figure 4.3 illustrates the lay-out of experimental environment. Three glare sources can be seen. The first glare source is a reference glare source. It was a 100W opal incandescent lamp seen through an opening and located about the centre of the partition at 16° above and 10° horizontally deviated toward the right from the line of sight. It was connected with dimmer control located near the subject's seating. The second and third glare sources are the screens with a series of image stimuli. There are two computer projectors located behind the partition. Both of them were used to project the image stimulus on to a tracing paper screen. They were able to produce image stimuli as glare sources, with starting luminance of 1,000 cdm^{-2} up to a maximum luminance of 150,000 cdm^{-2}. Both projectors were connected with two computers preset to automatically administer the stimuli to the two screens.

4.2.1.2 The luminous Environment and Background Luminance

The subject sat in the centre of the cubicle at a distance of 0.60 m from the projection screens. The size and shape of the cubicle were chosen to cover a visual field 30 degrees vertically above and 60 degrees vertically below the line of sight, and 65 degrees horizontally on the right and left relative to the line of sight (Kaufman, 1984). Gaps at the junction of the walls were covered to prevent other light entering. The background luminance was provided by reflecting light off the surfaces in the subject's field of view and was held constant throughout all experiments at approximately 65 cdm^{-2} average luminance of the entire visual field excluding the glare source. This level was chosen because it is in the range of luminances commonly found in interior spaces (CIBSE, 1994). As the lamp used unfiltered mains supply and was movable, check measurements were made both before and after each test. Any extraneous light was only a very small percentage of the background value.

The first experiment used only one projection screen as a glare source, and this, during an experimental run, was varied across a large proportion of its total range of operation, from the starting luminance up to a maximum luminance of 150,000 cdm^{-2}.



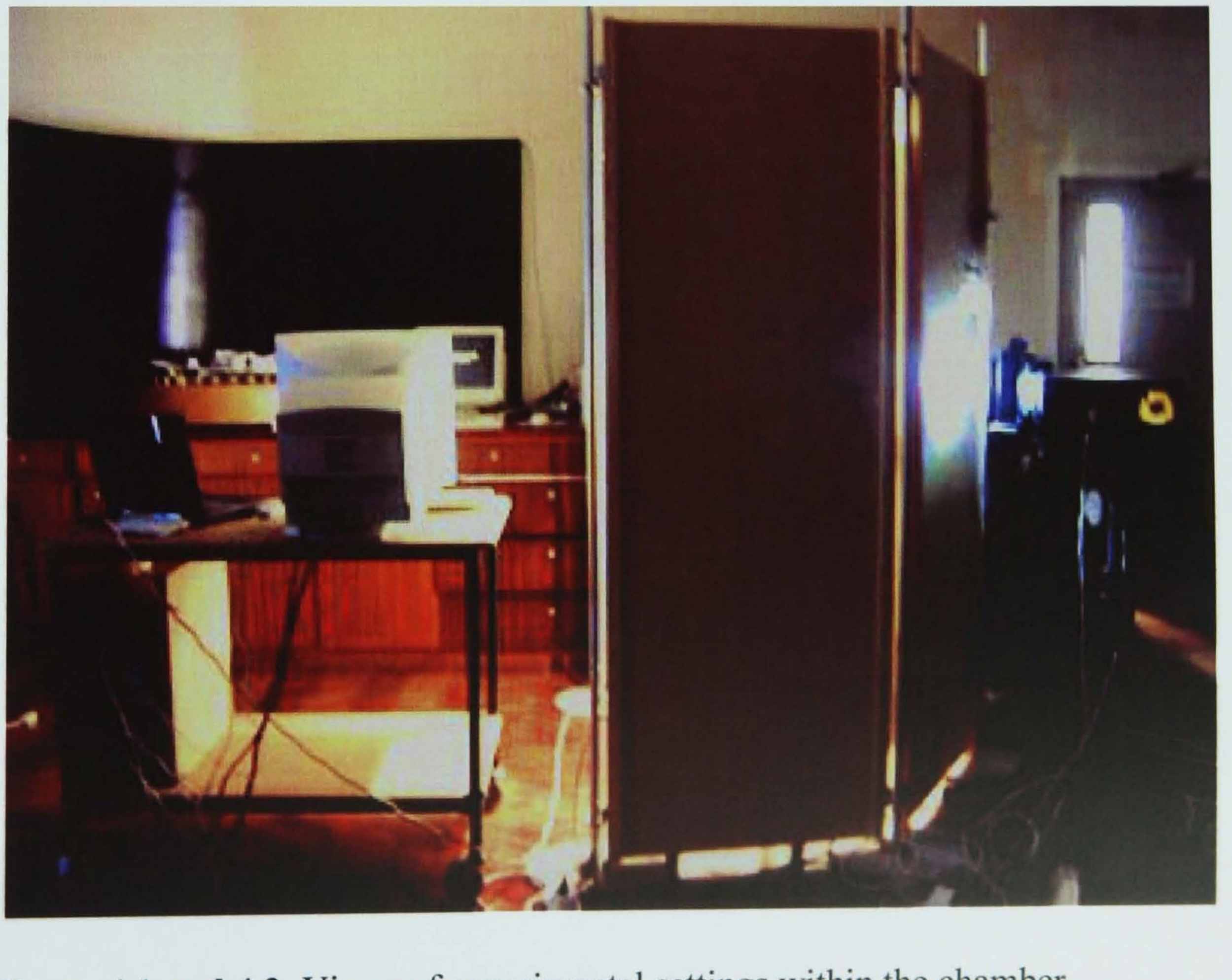


Figure 4.1 and 4.2: Views of experimental settings within the chamber.

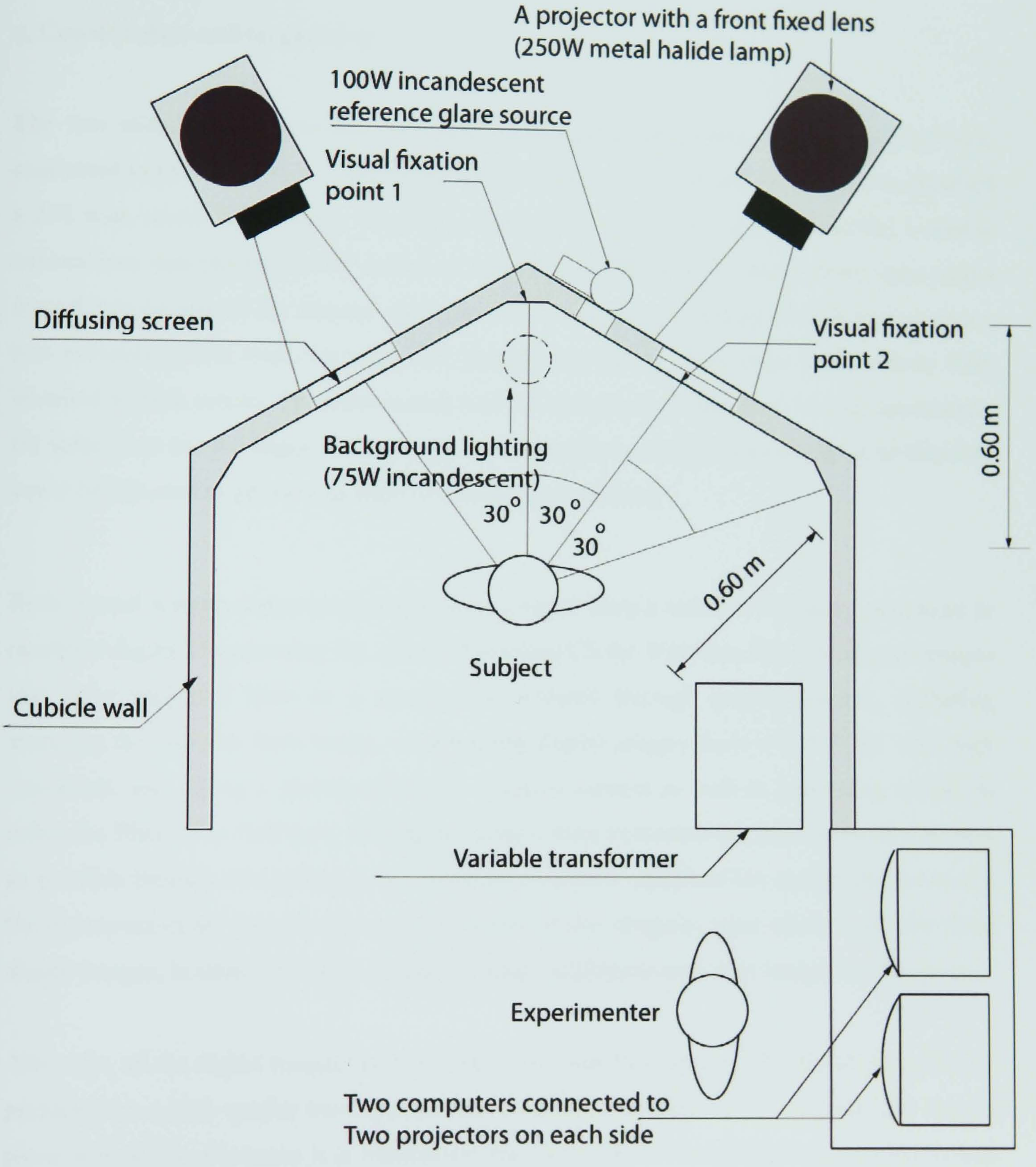


Figure 4.3: Lay-out of experimental settings in laboratory.

4.2.1.3. The Stimuli Glare Sources

a. Construction and Generation

The two stimuli were provided by modified computer projectors, with front-fixed lens, connected to two computers. Each projector consisted of a power unit in which was installed a 250 watt, metal halide lamp. To produce luminance values as high as possible, a double convex lens was placed at 0.05 metres in front of each projector to concentrate light output from the projectors on the screens, made up with tracing paper. In front of each tracing paper, two movable panels made up with matt paper mounted ¼'' thick foam board sheets were installed to each screen. The foam boards had beveled edges so that there was no opportunity for subjects to see the edges of the foam cores. These foam boards were movable so that they could be adjusted to get various sizes of stimuli glare sources.

Both neutral screens and screen images, were created from a series of computer generated or modified digital images using the Adobe Photoshop CS for Windows XP. The digital images that were projected later on a screen were created through several sources, including scanning the pictures from books, downloading digital images from a CD-ROM with high resolution, and taking a photograph using a digital camera as well as generating solely by using the Photoshop Software. All digital images were corrected for their properties as best as possible through this program. To create all proposed variations for screen images to suit the objectives of the experiments, many features of this program were taken to modify these digital images, in terms of both a change in image brightness and other image modifications.

After that, all the digital images were put into Microsoft Powerpoint. The digital images were projected on a high-quality tracing-paper screen to become glare source stimuli. The tracing paper was selected because it is translucent and diffusing, with consistent properties. It was mounted over openings in the partition, and thick white paper was back-mounted at the edges to avoid the tracing paper becoming wrinkled. The projector was adjusted to obtain the best quality of the projected images seen from the fixed view in position.

b. Glare Source Calibration

There is variability in luminance output produced by computer projectors due to a number of factors, such as using metal halide lamps. Therefore, to achieve the 'precision' of the instrument[2], the two computer projectors were calibrated before the real experiment was conducted. The data of one screen image with an average luminance of 7,500 cdm^{-2} and a visual area of 0.009 m^2 was used as the calibration data for these glare sources. The calibration was drawn from a value of average luminance of the reference screen image and the brightness value of the digital image given by the Photoshop program or called in this study 'relative brightness'. The brightness option in the Photoshop program is shown in Figure 4.4. For this option, at the position where every image was first imported, the brightness value was set to 0. This is not an absolute value representing an actual value of the degree of luminance of the stimulus screen image, but it represents there is no change in overall brightness of the digital picture. For example, a stimulus screen image with an average luminance of 2,000 cdm^{-2} would have a relative brightness value of 0 in Photoshop, when a digital image of this stimulus was firstly imported. This relative brightness could be varied towards negative values as low as -100 to obtain a darker image and towards positive values up to +100 to obtain a brighter image. Further increases or decreases could be made by setting the last modified brightness image (+100 or -100 value) at a value of 0 again and varying the brightness using the same process.

[2] 'Precision' has been defined as the ability of an instrument to produce the same output for repeated applications for a given input (Ray, 1988)

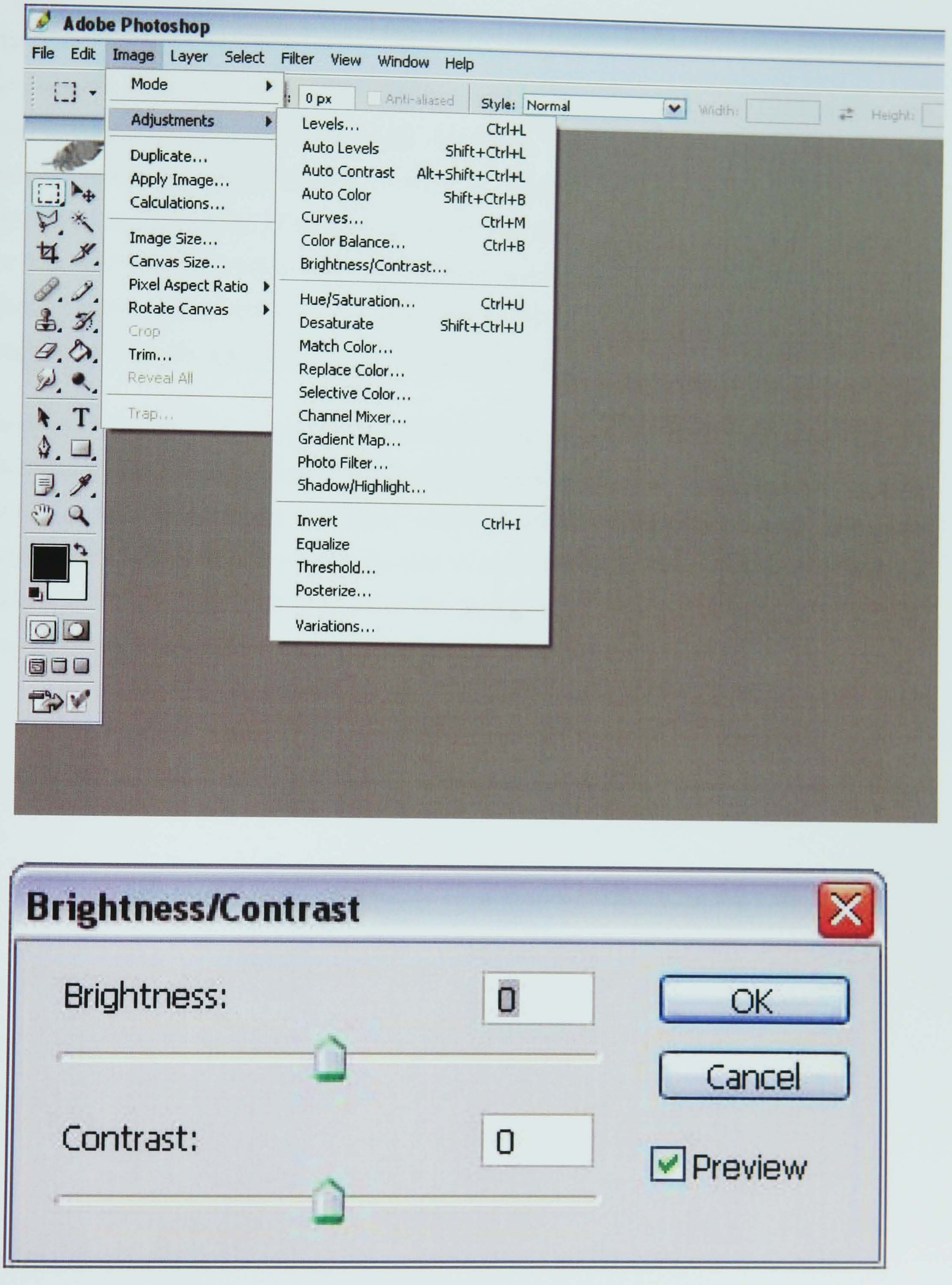


Figure 4.4: Brightness option in Photoshop program

The relative brightness values of the digital image, numerical values given in the brightness option, were set at -200, -150, -100, -50, 0, 50, 100, 150, 200. Three measurements for each relative brightness value were taken. The calibration of this reference screen image for the glare luminance source as a function of the relative brightness values of the digital image for the background luminance of 65 cdm^{-2} is shown in Figure 4.5. The logistic functions fitted to the data were used to quickly obtain interpolated values between the calibration data points. They were also subsequently used to derive the relative brightness values on the Photoshop programme when the apparatus was during experimental runs.

These two stimuli glare sources were calibrated by measuring their luminances using a reference screen image for a range of the relative brightness values. The instrument used for measurement of glare source luminance was a Minolta T-10 illuminance meter. The glare sources were calibrated only once at the start of each experiment. However, glare source and background luminances were checked at the beginning and the end of every experimental run, thus keeping a running check on the luminance calibration.

$$Y = 1 / (1 + 8.868e^{-0.9712X})$$

Fit Standard Error = 0.03175; F Statistic = 379629.9

Adjusted $r^2 = 0.9993$

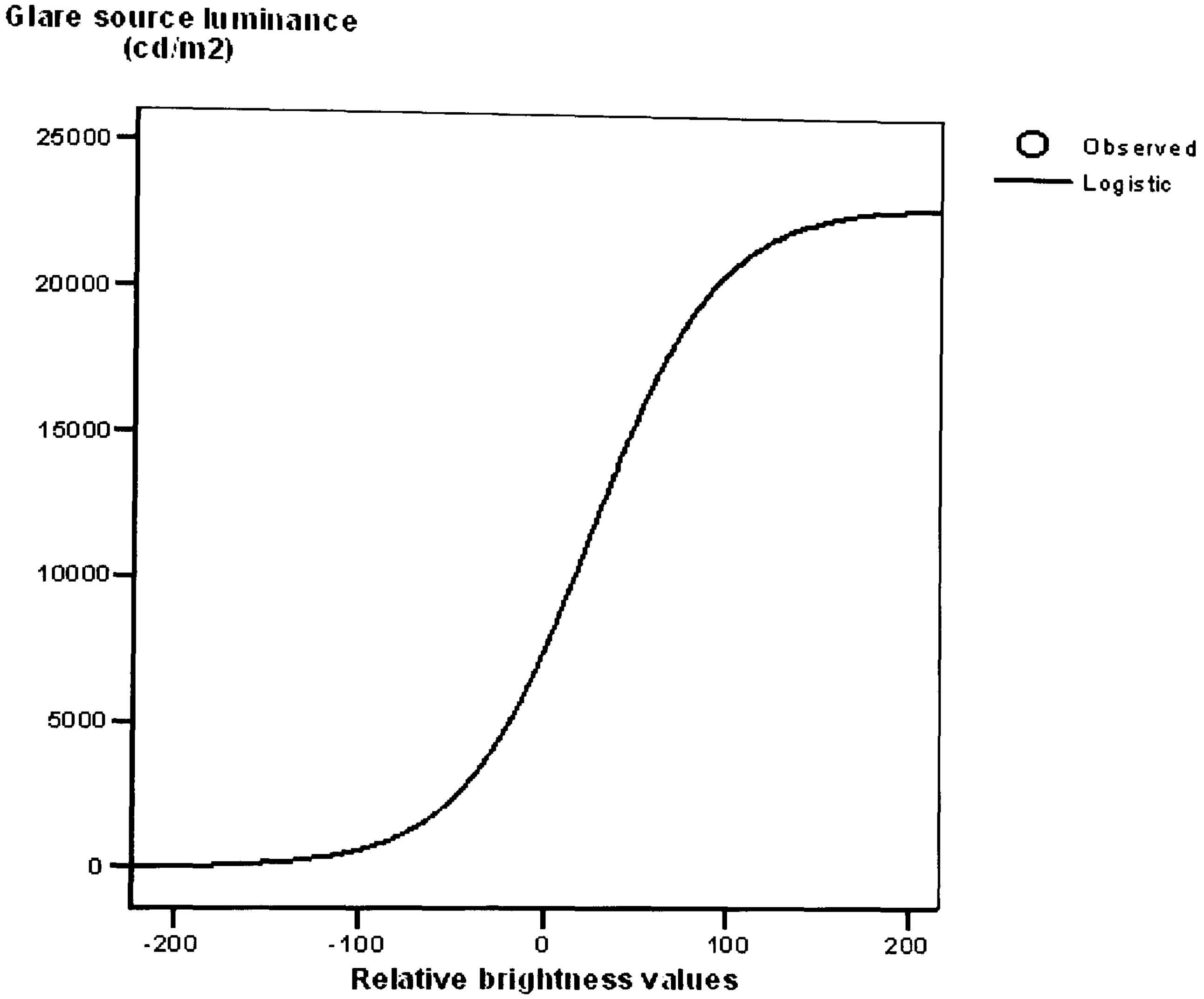


Figure 4.5: Glare source luminance calibration of reference image with an average luminance of 7,500 cdm^{-2} when the value of relative brightness is 0 in the Photoshop. The vertical axis shows the luminance of the source and the horizontal axis shows the relative brightness values of the brightness option in Photoshop.

4.2.1.4 The Positioning of Subject and Fixation Point

The subject was positioned with his or her eyes 0.60 metres away from, directly in front of, and at the same elevation as, the stimuli. This was ensured by an adjustable-height chair. The chair was cushioned and had a straight back to keep the subject's posture as constant as possible. There were two fixation points with respect to the line of sight. The first one was horizontal perpendicular to the eye on the centre of the panel between two screens. This fixation was used in the second experiment (part 1). The two screens were deviated ten degrees from this fixation. The fixation was marked by a square-tape and the subjects were required to fixate on this mark before the presentation of the stimuli and when the stimuli were presented, the subjects were required to continue fixating on this point while evaluating discomfort glare from the stimuli. The second fixation is at the centre of the right stimuli glare source. This fixation is used in the first, the second (part 2) and the third experiments. The subjects were adjusted to keep them looking at the centre of this glare source by a piece of equipment before an experiment was started and were also required to keep the same posture and fixation when evaluating the glare.

4.2.1.5 Measurement Equipment

There were two pieces of equipment used for the photometric measurement. The first was a Minolta LS-110 luminance meter (Serial No.79013010), mounted on a tripod. Measuring range for this device was from 0.01-299,999 cdm^{-2} and its measurement angle is 1^{o}. The error is +2% or + 1digit of value display. It was calibrated on June 15, 1992 (Calibration certificate No.9229-1876-21).

The second was a Minolta T-10 illuminance meter (Serial No. 31021014), mounted on a tripod. Measuring range was 0.01-299,999 lux and the error is +2% or + 1digit of value display. It was calibrated on June 19, 1998 (Calibration certificate No. 9245-1977-11)

4.3 Image Interest and Glare Tolerance

4.3.1 Introduction

This first experiment examined the effect of image interest on glare, using small screen images as a glare source ranked on "interest" by an independent subject group. In this experiment, the discomfort sensation of many interesting screen images and a neutral screen was evaluated on some representative discomfort scales. Prior to this test, a preliminary study for quantifying 'interest' was carried out.

4.3.2 Experimental Objectives

The hypothesis of this experiment is that an increase in interest in an image is associated with a decrease in discomfort glare. This hypothesis implies that, for a given level of glare sensation, as image interest increases, a subject tolerates an increased degree of physical glare, as indicated by the glare indices. This forms the working hypothesis of the experiment.

4.3.2.1 Quantifying 'interesting' screen images

As mentioned in Section 3.4.3, "Interest" is subjective and depends not only on the stimuli but on people and on the circumstances people are in and it is better to be defined for a particular group of people regarding a specific stimulus and a particular circumstance. For this experiment, the interest in an image was defined as a sensation of curiosity of the subjects to a small projected screen image in the circumstance of the experiment in which they rated the screen image (the preliminary test of this experiment). This sensation begins from no interest to extraordinary high interest, quantified by the scores from five-point rating scales given by an independent group of subjects. Thirty-one screen pictures were selected covering a wide range of image content. Then, these selected images were presented in random order on a 15 x 20cm screen to eight subjects, all university students in architecture but who differed in nationality and social background. The pictures were ranked by their mean score as shown in Table 4.1. The most highly ranked score was a picture showing a man with a baby in an exotic interior, while the least interesting ranked picture is showed building with an untidy metal-construction façade.

4.3.2.2 Defining Glare Indices

As per the reasons mentioned in Section 2.4, in this study, "the glare indices" are defined using the following two formulae— the British Glare Index (IES-GI) and the CIE UGR Glare Index (UGR). They are shown as follows:

$$\text{IES-GI} = 10 \log_{10} 0.478 \sum \left(\frac{L_s^{1.6} \times \omega^{0.8}}{L_b \times P^{1.6}} \right)$$

$$\text{UGR} = 8 \log_{10} \left(\frac{0.25}{L_b} \sum \frac{L_s^2 \, \omega}{P^2} \right)$$

Where:

L_s is luminance of the glare source (cdm^{-2}); L_b is luminance of the background (cdm^{-2}); ω is solid angle of the source (sr); and P is Position of the source relative to the line of sight: position index (sr).

Picture	Interest scores		Pictures	Interest scores		Pictures	Interest scores	
	Mean	SD		Mean	SD		Mean	SD
	4.75	0.46		3.85	0.83		3.50	0.53
	4.63	0.52		3.85	1.13		3.50	0.93
	4.50	0.53		3.85	0.53		3.50	0.93
	4.38	0.52		3.75	0.46		3.45	1.19
	4.25	0.46		3.75	0.46		3.45	0.41
	4.25	0.88		3.68	0.88		3.30	0.51
	4.13	0.99		3.68	0.88		3.25	0.88
	4.00	1.07		3.63	0.52		3.25	1.04
	3.88	0.99		3.63	0.74		3.13	0.35
	3.88	0.99		3.60	1.06		3.10	1.13
							2.75	1.28

Table 4.1: Thirty-one screen images used in the preliminary test of the first experiment and their interest scores

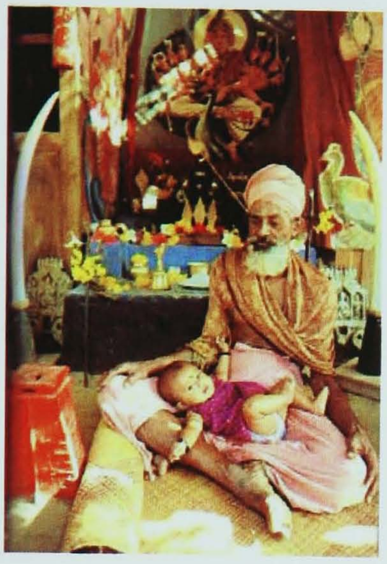
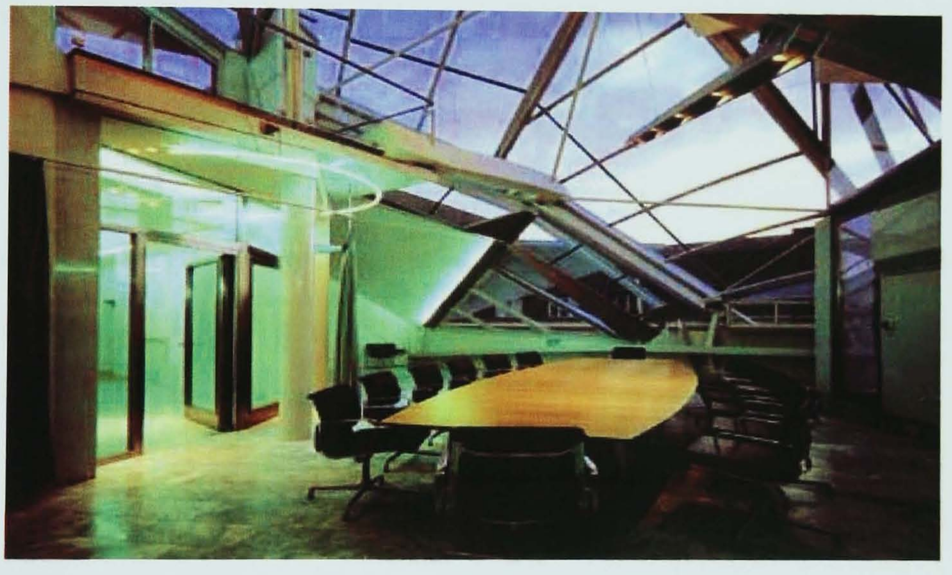


Image A **Image B**



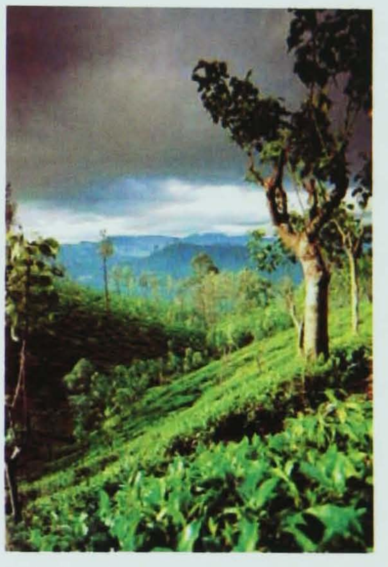


Image C **Image D**

Figure 4.6: The highest four interesting screen images that were used in the first experiment. Image A is the most interesting; Image B is the second most interesting; Image C is the third most interesting; Image D is the fourth.

4.3.3 Methodology

4.3.3.1 Stimuli Variations

In the process of quantifying interest, the scores of the degree of interest in each screen image were obtained. An image normally contains some information that might create interest, while the neutral screen seems to have no information. The final four highest-scoring pictures were compared with four neutral screens containing no image. These neutral screens were taken to represent screen images of zero interest. Each of these had the same size as one of the projected images found interesting, either 4 x 8cm or 4 x 5.5 cm, subtending angles at the eye of 0.009 and 0.006 steradians. In total, there were eight treatments in this experiment, consisting of four interesting screen images and four neutral screens. The four interesting screen images are shown in Figure 4.6.

Instead of using a dimmer to control the luminance of the glare sources, since the projectors were connected to the computers, luminance of all stimuli, both blank screens and screen images, were adjusted using the brightness option in the Photoshop program. The use of this option is similar to that described in Section 4.2.1.3. However, when overall brightness of the screen image stimulus was adjusted using this option to achieve very high or low levels of luminance values, colour, contrast and some characteristics of the screen image would probably have been distorted. The distortions of screen image might affect the degree of interest in such a screen image. To ensure that the screen images were not affected from this brightness adjustment process, one screen image as a representative for all screen stimuli images was tested in this pilot study. The objective was to find the range of relative brightness for which interest in a screen image was not different from those obtained from a non-distorted screen image, where its relative brightness was equal to 0. From the results of a Chi-square test, the goodness of fit test, this range of the relative brightness was between –170 and +200. Accordingly, the brightness of each screen image was adjusted to get very high or low values of luminance within the limited values. The picture of the screen image that had been used is shown below.

Figure 4.7: A reference screen image that had been used in the pilot test

4.3.3.2 Experimental Measurements

To determine the glare indices, four parameters were measured. These parameters are the luminance of the source, the background luminance, the solid angle of the source, and the position of the source relative to the line of sight or the position index.

a. The Measurement of the Luminance of the Source

In the process of producing the variation in source luminance for all stimuli, measurements of the source luminance for each increment and decrement were also taken. Firstly, the ratios between luminance and vertical illuminance were measured at the subject's seating point for the neutral screen of visual areas of 0.006 and 0.009 steradians, and taken to be constant. The measurements of luminances were taken first by a luminance meter, a Minolta LS 110 with a measurement angle of 1^{o}. The measurements of vertical illuminances were then taken by using a illuminance meter, a Minolta TM 10. To obtain proposed source luminances: the brightness option in the Photoshop program was incrementally altered to achieve illuminance levels (measured using illuminance meter at subjects seating point) which corresponded with the proposed source luminances according to the formula ratio $R=L_s/E$, where R=the ratio constant, L_s = source luminance and E = Vertical illuminance measured at a subject's seating point. The values of relative brightness in Photoshop corresponding to the proposed source luminance were tabulated. Finally, in the real experiment, when the source luminance was increased and each subject reported that they had reached the three levels of glare sensation, the relative brightness of these three levels was recorded. By using the table of relative brightness corresponding to the proposed source luminance, the source luminance for the three levels of glare was obtained.

b. The Measurement of the Luminance of the Background and Other Physical Values

The background luminance measurements were conducted using a luminance meter, a Minolta LS-110, mounted on the tripod at the subject's seating point. Seventeen points around the visual fixation were measured. These points were selected because they covered the whole range of luminance values found within the visual field. Then, all the measured values were averaged. Average background luminance values are tabulated in Table 4.2. All locations of point measurements are shown in Figure 4.8. The background luminance measurements were checked both before and after each experiment was carried out.

Table 4.2: Background luminance values of the first experiment in laboratory

Points	Background Luminance values
1	90.4
2	92.7
3	103.0
4	90.6
5	87.5
6	60.0
7	62.5
8	63.0
9	62.0
10	57.5
11	38.6
12	40.4
13	42.2
14	38.0
15	35.0
16	112.5
17	30.0
Average	**65.0**

The values of the solid angle subtended at the observer eye by the glare source and the position index were held constant and were measured by a tape measure. The visual size of each stimulus was either 0.009 or 0.006 steradians and the distance from the centre of the stimulus to the eye was held constant at 0.60 m. After collecting all physical values, the glare indices were calculated based on two formulae: the IES-GI and CIE UGR.

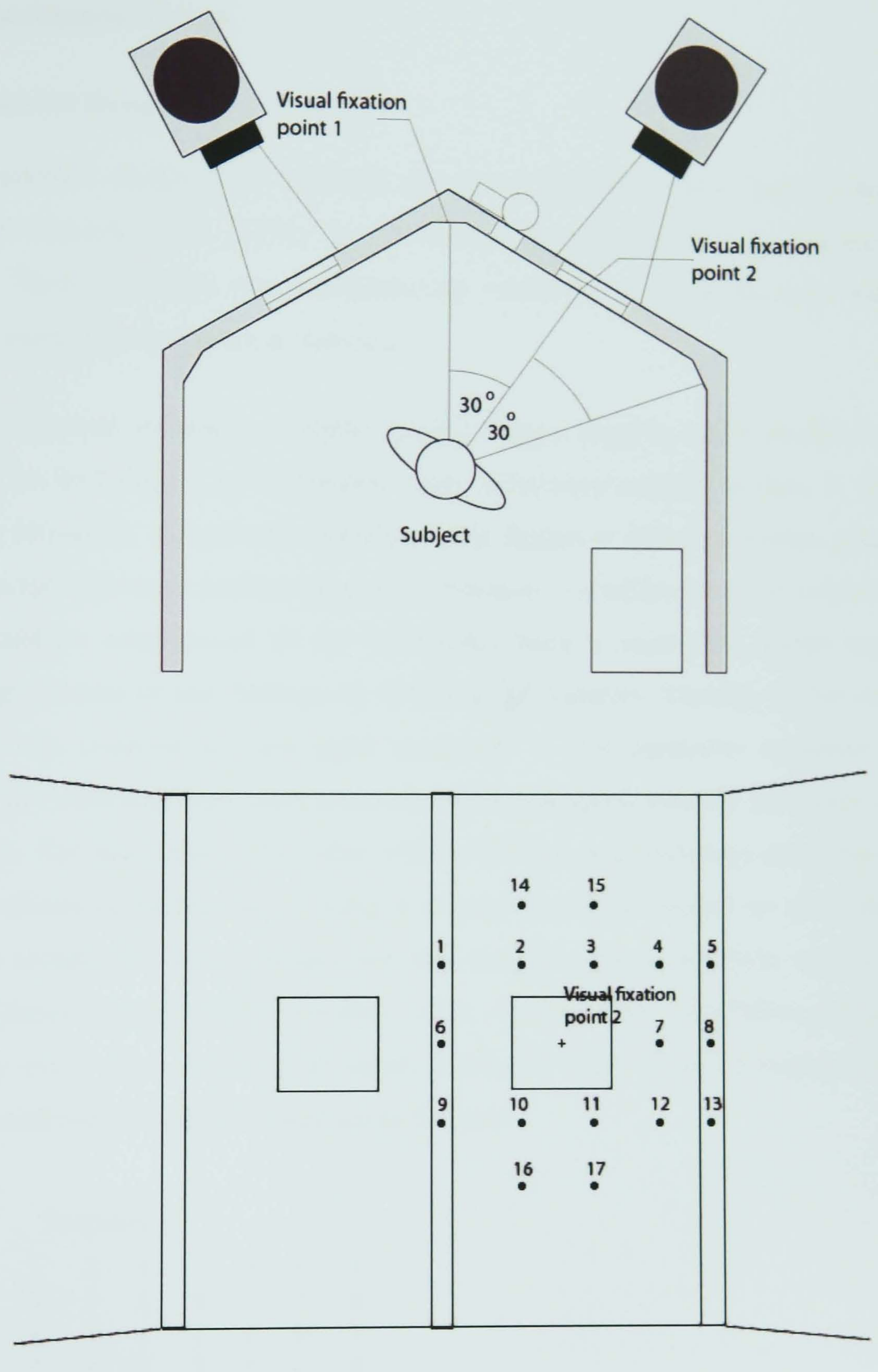


Figure4.8: Background luminance points with two screens in presentation position and a visual fixation (the centre of the right screen)

4.3.3.3 Experimental Design

a. Experimental Design

The experimental design is a repeated measures Balanced Latin Square design, with reference to Edwards, L.A. (1972). In this design, the same subject experienced all eight treatments. Each treatment was systematically randomly assigned to each subject. The reasons for using this design are as follows:

Firstly, the repeated measures or within-subject design requires much smaller numbers of subjects to be included in an experiment than a between subject design. It is not time-consuming. Secondly, the greatest benefit of this design is that it provides guards against both known and unknown confounding and extraneous variables from the subjects, because the same subjects experienced all the treatments. Such a controlled design increases the potential significance of any findings by reducing the variance. Thirdly, in this design, each of subjects was required to view eight treatments in one particular sequence. For each sequence, each treatment from eight total treatments was systematically randomly assigned to each subject. For this reason, the order effects (fatigue and learning) and other unknown carry-over effects occurring due to using a repeated measures would be controlled. In this design, the criteria for this technique are that each treatment condition appears an equal number of times in each ordinal position. Also, each treatment condition precedes and is followed by every other condition an equal number of times. A set of sequences for eight-treatment-condition having been used are as follows:

Subject	Sequence							
1	1	2	8	3	7	4	6	5
2	2	3	1	4	8	5	7	6
3	3	4	2	5	1	6	8	7
4	4	5	3	6	2	7	1	8
5	5	6	4	7	3	8	2	1
6	6	7	5	8	4	1	3	2
7	7	8	6	1	5	2	4	3
8	8	1	7	2	6	3	5	4

b. Testing Procedures

As mentioned in Section 2.4, most studies on discomfort glare showed large scattering in the results and this thesis is trying to control as many extraneous factors as possible. For this reason, a pretest period was added into this experiment. There are two parts to this experiment, a pretest period and a real experiment period.

Pretest Procedures

In the pretest period, upon arrival, each subject was first provided with the explanation of study/informed consent form. In this process, an explanation form was given to each subject containing a description of the aim of the experiment and the overall procedure. After signing the informed consent form, the subject was asked to complete a pre-study questionnaire for the purpose of obtaining their general information. The subject was then positioned in the chair, which was adjusted to the appropriate height so the subject's back was straight and his/her head was positioned correctly. Then, the appropriate instructions were read to the subjects (see a full questionnaire in Appendix B). This included the definition of glare, the meaning of criteria and the procedure trial which would be used in both the pretest period as the real experiment period. Thus, the effect of instruction on the subject was controlled by using identical instructions.

Markus (1974) cited that glare was an abstraction that corresponds to no unitary experience. These results do suggest that a clear definition of glare is needed by anyone attempting to measure it. Likewise Markus, Perry (1991) also noted that few, if any, of the studies have resulted in a rigorous definition of discomfort glare. Thus, the interpretation of the meaning of each criterion, which might not appropriately represent the sensations being rated, was to a great extent left to the observer. This suggests that the subjects may not define and understand the response criteria in a common manner and contributes to large variance of the results in glare experiments. In order to control of the effect of meaning of glare and its criteria in this experiment, apart from the use of the rigorous definition of discomfort glare and clearly identical descriptions of each criterion, two methods were employed in the pretest period for this purpose. The first method was that after the instructions were read to the subjects, the experimenter showed an example trial similar to those employed in the real experiment. This technique gave the subjects a definition of discomfort glare by demonstrating to them directly and has been used in many glare studies (Hopkinson and Bradley, 1960; Bennet 1977). The second method is that subjects performed one example trial. In the demonstration by experimenter in this experiment, a neutral screen with a visual size of 0.006 sr. was used for demonstration by the experimenter. As the luminance of a neutral screen was increased, the experimenter had to choose the source luminance which corresponds to three levels of glare thresholds: just noticeable, just uncomfortable, and just intolerable and these values were recorded. After the demonstration by the experimenter, subjects had to choose the source luminance of the neutral screen corresponding to the three criteria with a similar procedure as shown by the experimenter. The levels of luminance for each glare criterion of subjects were recorded. The benefits of these methods were not only that the effect of meaning of glare and other unknown effects could be controlled, but also ensuring that the methodology was understood and ability of the subjects to do all the procedures in the real experiment was verified. However, if the experimenter showed her choice of source luminance to the subjects, there might be a possibility that, during the real experiment, the subjects would choose the level of source luminance to close to those of the experimenter shown in this pretest period rather than reflecting their own real perceptions. Normally, the experimenter is a lighting expert, who is more sensitive to glare than the subjects. Therefore, when all the data of source luminance was converted to glare indices, the glare indices of the subject for each criterion, obtained through this method, would be lower and these values would be related to the glare indices of the experimenter. The effect of the demonstration by experimenter on the results in real experiment requires investigation. As mentioned above, in this experiment, the neutral screen with a visual size of 0.006 sr. was used in the pretest period and it was also used as treatment 1 in the real experiment. To investigate the effect of the demonstration by experimenter on the results, the data of glare indices for the neutral screen of the experimenter in the pretest period and those of the subjects in the real experiment were used for this investigation and the results are shown in Section 4.3.4.

In the final part of this pretest period, the subjects would relax for about 10 minutes. This provided a time for a subject to adapt to the experiment environment and relax in order to minimize the effect of subject anxiety level. Then, after he or she finished this period, the real experiment trial was started.

Real Experiment Procedures

After the period of pretest, each subject was seated at the seating point at 0.60 m. from the right screen. He/she was told to fix eye position at the fixation point. This was done to control the effect of position of the source relative to the line of sight and the presence of the visual task. Also, the solid angle of the glare source was held constant for each pair of blank screens and interesting screen images. The background luminance was held constant at 65 cdm^{-2}. The first treatment was to be presented automatically beginning from the lowest luminance level until the highest. The subject was asked to judge three criteria beginning from just noticeable level. When the subject's sensation had reached each level, the subject would verbally indicate the level, for example, "just noticeable" and so on. The relative brightness of the pictures selected, preset on the computer screen, were recorded. After each subject finished the judgement of each criterion for each treatment, the experimenter would not present stimuli anymore until they indicated that afterimage effect had gone. This was done in order to minimize the afterimage effect. Then, another level of judgement would follow on. After he/she finished the judgement for each treatment, the experimenter would not present stimuli anymore until they indicated that the after image effect had gone. With randomized allocation treatment, the subject would go on. The subject sent the signals for each level of sensation in the same sequence and procedure as the first treatment. All the procedures were repeated until the eighth treatment. After that, another subject was introduced to the experiment and the same procedures were repeated from first subject through to last. All the sequences of the treatment were systematically randomized.

By comparing the recorded values of relative brightness of the pictures with the table of relative brightness corresponding to the proposed source luminance mentioned in Section 4.3.3.2(a), all the data of luminance of the source for the three levels of glare were summarized with other measured physical values. It should be noted that a continuous exposure was selected to be used in this experiment in order to control the effect of the duration of exposure (intermittent or continuous). The reason for this is that, in normal glare situation, glare sources, surroundings, and stimuli are continuously presented.

c. Subjective Assessment of Discomfort Glare

When the subjects were required to judge the glare, three criterion steps were used. These criteria were adopted from the Glare Sensation Vote (GSV) which has been used in many glare studies (Iwata *et al*, 1992a, Iwata *et al*, 1992b, Iwata and Tokura, 1998)[3]. However, most previous researches on discomfort glare used these rather abstract criteria without any descriptions and left subjects interpret to them by themselves. To help all subjects better understand these criteria and to give the subjects guidance in the selection of source luminance corresponding to one of these categories, these glare categories were connected to a clear description with an approximate time. A corresponding time-span was also used in glare experiments, such as studies by Osterhaus (1998) and Velds (2002). Each subject was instructed that he could report when the luminance of the glare source reached a point at which it produced a sensation corresponding to one of the following specified three glare thresholds:

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[3] The Glare Sensation Vote is a modified form of Hopkinson's original criteria in such a way that it could be used as a continuous scale (Hopkinson, 1940). There are four glare categories, just perceptible glare, just acceptable glare, just uncomfortable glare, and just intolerable glare. Instead of using four steps, three criteria are introduced in this experiment, which are just noticeable glare, just uncomfortable glare, and just intolerable glare. It was found in the pilot test that when all these criteria connected with the time span there is no difference in meaning between just perceptible glare and just acceptable glare. The subjects reported that they firstly perceive glare, when they can tolerate the lighting condition for about 1 day, which corresponds to a description of just acceptable glare in other glare studies and our later experiments.

"Just noticeable glare" refers to the point where the subjects could tolerate the discomfort sensation for approximately 1 day, when working in someone else's room. But, they would require a change in lighting condition if they were to work there for longer periods of time.

"Just uncomfortable glare" refers to the point where the subjects find the source could create the discomfort or annoyance sensation, which they could tolerate for approximately 15-30 minutes if the work had to be carried out. But it would require a change in lighting condition for any longer period.

"Just intolerable glare" refers to the most intense sensation of glare at which the subject feels that the glare source create the discomfort sensation until they can't stand anymore. They would immediately change the lighting condition.

These three thresholds were described to all subjects. Also, it was suggested to them to think that they have to pursue some visual tasks in the working environment while evaluating these criteria of discomfort glare. This method could help the subjects to better understand what discomfort glare is. Therefore, it helps to control the effect of the meaning of discomfort glare and its criteria. In addition to these glare categories, if the subjects felt they had difficulty in making judgements, they were asked to make some comments and reasons in a blank space in their questionnaires (see a full questionnaire in Appendix B).

d. The Observers

To minimise cultural differences in interest, this first experiment used a subject group tightly controlled in cultural background, university students of Thai nationality. The same eight subjects sampled experienced all treatments. They were initially recruited from the population of university students in the University of Sheffield. Their ages all ranged from only 18-30 years. To reduce bias of the results, there were four females and four males. There was an equal balance between subjects with spectacles and those without them. Also, spectacles were worn by 50% of both men and women. In order to obtain the most accurate data and avoid some visual effects, the subjects were all self-certified as not having other eye problems and having no colour-vision deficiency. The sample size in this experiment was based on using an operating characteristic curve method. This technique has been described in a book by Montgomery (2001) — Design and analysis of experiments, 5th edition. In this method, to obtain the number of subjects, five parameters need to be defined:

1. A detectable difference of luminance (μ_i-μ_i) between any two treatments
2. Number of treatment levels
3. The error variance of the population (σ_ε^2)
4. The probability of a Type I error (the probability of rejecting the null hypothesis when the null hypothesis is true; α)
5. The probability of a Type II error (the probability of accepting the null hypothesis when the null hypothesis is false; β)

In general, the population error variance is unknown. It is possible to make a reasonable estimate of the population error variance on the basis of a previous glare experiment or a pilot study. From a previous study of glare by Waters (1993), an estimate of the population error variance (σ_ε^2 = 4,337,139) was already identified. The numbers of treatment levels are eight. Then, the experimenter defined the probability of a Type I error (the probability of rejecting the null hypothesis when the null hypothesis is true), α of 0.05, and the probability of a Type II error (the probability of accepting the null hypothesis when the null hypothesis is false), β of 0.10. Also, a detectable difference of 750 cdm^{-2} was proposed because it was determined within the capability of the apparatus and the experimental design and was based on the results of Waters. By using an operating characteristic curve method based upon all of these parameters mentioned above, a minimum of seven subjects were required to be included in this experiment to provide a detectable difference of 750 cdm^{-2}. The Balanced Latin Square design requires a number of subjects which is an equal multiple of the number of treatment sequences for completing counterbalancing. The final number of subjects, therefore, was adopted to be eight.

4.3.3.4 Statistical Analysis

In order to see whether, for a given level of glare sensation, as image interest increases a subject tolerates an increased degree of physical glare, as indicated by the glare indices, there was a need to compare the results of the sample mean ($\overline{X}$) of glare indices for both the IES-GI and the UGR between the two treatments-the blank screens and interesting screen images of four pairs. Therefore, a Paired-samples *t*-test was used in an SPSS Program. The decision was made to use a Paired-samples *t*-test due to the fact that it is more sensitive than any tests of mean comparisons and that the same subjects were experienced in all treatments. It is also a Parametric test which is more precise than Non-parametric Test. After using the Paired-samples *t*-test, we looked at the *p*-value. If the *p*-value of the results is less than the significant level (p-value < 0.05), we can say that there is a statistically significant difference of the sample mean ($\overline{X}$) of glare indices between the blank screen and interesting-screen image treatments.

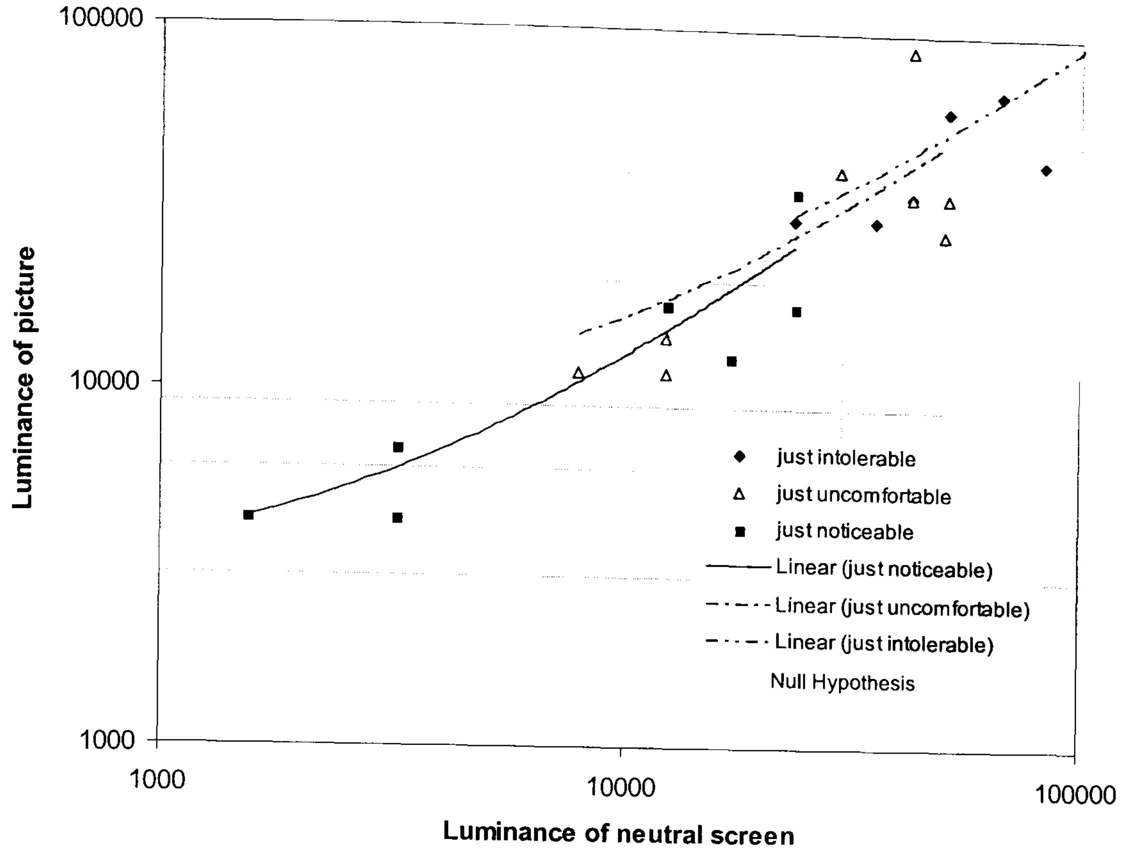
4.3.4 Results and Conclusion

Table 4.3: Mean and standard deviation of glare indices associated with levels of glare discomfort from screen images and neutral screen

	IES-GI				UGR			
	Neutral screen		Screen Image		Neutral screen		Screen Image	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Image A								
Just Noticeable	20.2**	7.26	29.1**	3.97	22.2**	7.23	31.1**	3.97
Just Uncomfortable	26.3*	7.79	34.2*	3.28	28.3*	7.80	36.2*	3.30
Just Intolerable	32.6*	5.68	38.0*	4.30	34.6*	5.69	40.0*	4.30
Image B								
Just Noticeable	26.5**	6.49	33.0**	3.50	28.5**	6.49	35.0**	3.50
Just Uncomfortable	34.1**	5.58	38.5**	3.30	36.2**	5.56	40.5**	3.32
Just Intolerable	41.3*	3.29	42.5*	2.88	43.3*	3.31	44.5*	2.88
Image C								
Just Noticeable	27.1*	5.32	29.5*	4.54	29.1*	5.33	31.5*	4.54
Just Uncomfortable	34.8	3.08	34.6	4.29	36.8	3.08	36.6	4.29
Just Intolerable	40.0	2.45	39.7	3.78	42.0	2.45	41.7	3.76
Image D								
Just Noticeable	23.7*	7.22	25.9*	5.26	25.7*	7.22	27.9*	5.26
Just Uncomfortable	31.4	5.23	31.7	5.13	33.4	5.23	33.7	5.13
Just Intolerable	37.1	3.89	36.9	4.06	39.1	3.89	38.9	4.06

** indicates the difference between pair of mean values is highly significant (*prob*<0.01) in a paired *t*-test
* indicates the difference between pair of mean values is significant (*prob*<0.05) in a paired *t*-test

Table 4.3 shows the mean and standard deviation of the two glare indices for all four screen images and their equivalent neutral screens. The glare index at which a threshold was reported tended to be higher when the source was a screen image than when a matching neutral screen. A matched-pair *t*-test finds this difference to be significant across all degrees of glare threshold in the two screen images ranked highest in interest; in three of the six cases the result was highly significant ($p<0.01$). With the other two screen images there was a significant difference only at the 'just noticeable' level. This numerical outcome implies that there were significant differences between glare sensations from the two screen images ranked most interesting and the sensations from neutral screens of the same mean luminance. These results suggested that an increase in interest in an image is associated with a decrease in discomfort glare.



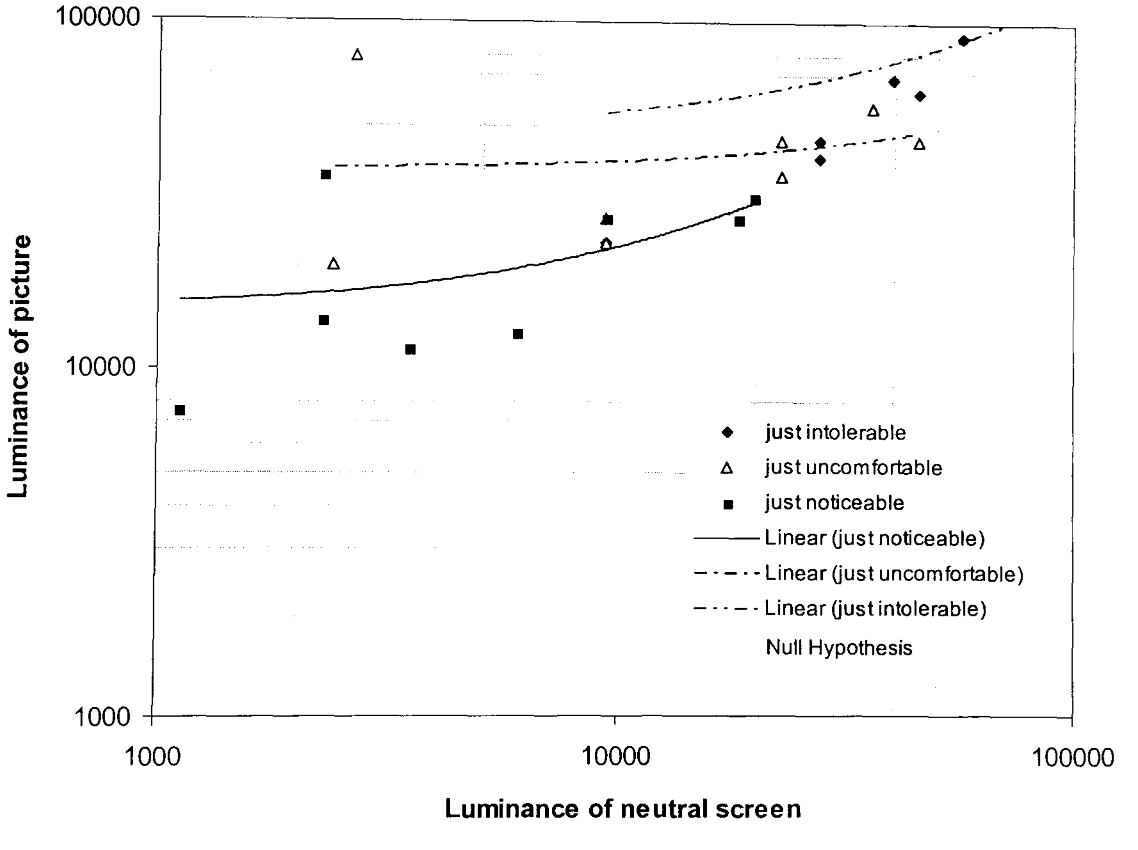


Figure 4.9: Comparison between luminance of blank screen causing glare and luminance of screen image causing the same level of discomfort glare. Upper graph, screen image D (ranked 4th in 'interest'; lower graph, screen image A (ranked highest).A high value on the y-axis (screen image) indicates a high glare tolerance.

Figure 4.9 plots the screen image luminance at which each subject reached a threshold (y-axis) against the neutral screen luminance (x-axis) at which the subject reported the same degree of discomfort glare. The upper graph represents screen image D, ranked fourth in interest; there is greater tolerance of the image than the blank screen at lower luminances but at higher values the screen image and neutral screen values converge strongly. The difference between screen image luminance and blank screen luminance is much stronger in the lower graph, screen image A, which ranked highest in the preliminary test. The trend lines of the three glare levels are almost horizontal at low luminance, indicating that the UGR and the IES-GI would be a poor predictor of glare discomfort in this case.

We also note some factors specific to this experiment that affect interpretation of the results mentioned above. Firstly, a uniform source was compared with one that varied in luminance and colour. If a small uniform screen is compared with a screen image of the same size and same mean luminance that varies in brightness across the surface, both glare formulae predict that the non-uniform image would produce a higher glare index because L_s has a higher exponent than ω. Waters *et al* (1995) confirmed this experimentally for sources on which the subject's eyes were fixated (as in this case) but found the opposite effect with peripheral sources. The differences in Table 4.3 between screen image and blank screen glare IES-GI and UGR values are likely therefore to be conservative. Secondly, although the eight stimuli (4 screen images, 4 neutrals) were presented in random order, the thresholds were determined with each source increasing incrementally in luminance. This was done to control adaptation across the pairs to avoid error occurring from very bright source and low luminance sources being seen in succession. It was also the procedure used by Hopkinson (1940) and Hopkinson and Bradley (1960). The UGR and IES-GI thresholds found are not necessarily those that would be found in other presentation sequences but this does affect the conclusions. Finally, it is also noted that the use of a larger number of subjects in this experiment might have yielded more significant cases. Therefore, the result might have been much stronger than those found in this experiment.

When the data from observers' comments were analysed, it is of particular interest to note that recording all observers' comments in this experiment yielded another possible effect on discomfort glare of a small projected screen image. Most subjects complained that they were bothered by the elements in screen images, which contained the degree of maximum luminance. They felt that these elements caused additional discomfort and they commented that the higher maximum luminance lead to their higher glare perception. Nonetheless, no clear conclusion was drawn for the effect of the luminance variation within the glare source on discomfort glare from previous discomfort glare studies. This effect was not, therefore, taken into account in this experiment. However, since this effect was most frequently mentioned in the comments, it seems that the effect is likely strong. It is a factor, therefore, that should be controlled in subsequent experiments and will be further systematically investigated later.

As mentioned earlier in Section 4.3.3.3(b), the demonstration of an example trial made by experimenter in the pretest period may influence the results in this experiment. To see this effect, the relationship between the data of the glare indices of the experimenter in the pretest period and the data of glare indices of subjects for treatment 1 in the real experiment (a neutral screen with a visual size of 0.006 sr.) were investigated. The Kendall's Coefficient of Concordance (W) was calculated for this investigation. It is based on an assumption that if glare indices of subject relate to those of experimenter, a relationship would exist between a difference between the glare indices of experimenter and the reference glare indices[4] and between the glare indices of subject and the reference glare indices. As the requirement of using the Kendall's Coefficient of Concordance (W), the data to be used in this test must be ordinal scale (ranking). Therefore, only values of IES-GI were explored because the similar ordinal data to those from IES-GI were obtained from the UGR. The data of IES-GI from the experimenter was subtracted by the reference IES-GI for each subject and a real difference was drawn. A similar method was done to values of IES-GI from each subject. Then, the relationship of these differences was tested as to whether it was significant. In order to

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[4] Reference glare indices are the glare indices for a given level of discomfort glare as reference to the IES glare index system (IES Technical Report No. 10)

compute the coefficient (W), the real value of difference between IES-GI of the experimenter and the reference IES-GI was transformed to be nominal scale (categories), A, B, and C. Also, the value of real difference between IES-GI of each subject and the reference IES-GI were transformed to be ordinal scale (ranking), 1, 2, and 3. The results are shown below.

Table 4.4: The Kendall's Coefficient of Concordance (W)

	Experimenter		
N	A	B	C
k	Ranking		
Subject 1	2	1	3
Subject 2	3	1	2
Subject 3	3	2	1
Subject 4	2	1	3
Subject 5	3	1	2
Subject 6	1	2	3
Subject 7	3	1	2
Subject 8	1	2	3
R_j	18	11	19

Labeled R_j gives the sum of ranks assigned to each category N. Computing the value of the Coefficient of Concordance (W) is 0.297, when S=38, N=3 and k=8. According to χ^2=k(N-1) and df=N-1, the value of χ^2 = 4.75, and df=2. Consulting to the Table of the Chi-square distribution (Cohen and Holladay, 1982), the critical value for χ^2= 5.99 when df= 2 and α= 0.05, and the critical value for χ^2= 9.21 when df= 2 and α= 0.01. The obtained values for χ^2 do not exceed the critical value of χ^2 where α= 0.05. No relationship existed between the IES-GI of experimenter and the IES-GI of subject. It can be concluded that the demonstration by experimenter in the pretest period has no influence on our results. This method would be, therefore, used to make a more controlled situation for subsequent experiments in this thesis.

In summarising, this experiment shows that an increase in image interest is associated with a decrease in glare discomfort. The effect of image interest on discomfort glare varies with source luminance. The effect at low luminance seems to be much stronger than at high luminance.

4.4 Image Content and Discomfort Glare

4.4.1 Introduction

In the previous investigation, it was shown that an increase in interest in a small projected screen image is associated with a decrease in discomfort glare. The main focus of this thesis is to investigate the effect of interest in a window-view on glare. After test the interest effect, this study also aim to explore effects on glare of view content. Since findings in terms of image content could be use as indicators for effects on discomfort glare of view content in the investigations of window-views, it would be interesting and useful to investigate further from the finding from the previous investigation in terms of image content in this Chapter.

As already mentioned about the link between view content and discomfort glare, it is irrefutable that this link is also true between content of a small projected screen image and discomfort glare. The assumption which forms this link for the case of a small projected screen image is— if interest in a screen image affects the glare discomfort and image interest is influenced by specific factors of image content, then it is expected that these factors would also affect discomfort glare. The literature review in Section 3.4.3 emphasised that view preference and interest could be related and view-related factors affecting the preference could be possible factors affecting the interest in a view. Accordingly, preference in a screen image seems to relate to image interest and physical elements and features in a screen image affecting the preference could also be factors affecting interest in a screen image. Based on view-related factors reviewed in Section 3.4.3, this second experiment used matching pairs of bright screen images to examine glare from scenes containing physical elements or characteristics that tend to have an effect on image preference. The main aim of this experiment was to see what content in a small projected screen image affects discomfort glare. As already noted above about the main focus of this thesis and benefits of image content's results, instead of using a wide range of screen images, the screen images that have been used in this experiment represent real scenes that can be seen through a window (view outside).

There are two parts in this experiment investigating discomfort glare from small screen images. The first part aims to explore the effects of some important characteristics and physical elements in screen images— the naturalness of an image and the presence of some elements in the screen images of natural scenes— sky, water, and ground. The second part of this experiment aims to evaluate the effect of image stratification on discomfort glare.

4.4.2 Glare and Images of Natural Scenes

4.4.2.1 Introduction

As it can be seen from Section 3.4.3, one of the factors that seems to be important as it was emphasised by many researchers about the effects on preference in a view and in an environment, is the naturalness of a view (Kaplan, 1978; Markus and Gray, 1973; Ulrich, 1979, 1981, 1983; Heerwagen and Heerwagen, 1984; Heerwagen and Orians, 1986). On this basis, the naturalness of an image was chosen with the aim of investigating whether an image of natural scene gives less glaring than an image of urban view.

Moreover, in a preliminary test of this experiment, subjects were asked to score fifty projected screen pictures of various views in terms of interest. An aim of the test was to find factors in the screen image that could have an effect on the interest in order to be used to explore their effects on discomfort glare in the main test of this experiment. The fifty screen images were selected based on the criteria that they contained physical elements and features that tend to have an effect on image preference as suggested by previous studies on window-view and environment, and are reviewed in Section 3.4.3. These screen images were also presented in random order on a 15 x 20cm screen to twenty-four subjects, university students in architecture but differing in nationality and social background. They were asked to assess the degree of interest in each screen image using questionnaires with eleven-point rating scales[5]. The screen images were ranked by mean scores as shown in Table 4.5. The results in the preliminary test shown the top six highly ranked screen images were natural scenes containing some form of water and the sky. Based on these results, within the natural scene context, it would be interesting to see whether the presence of water and sky in the scene induced less glaring that those without them.

In addition, as it can be seen from Section 3.4.3, the presence of ground in a view has been advocated, often to ensure that a scene contains three strata of preference— nearby ground, middle distance and sky (Markus, 1967a and b; Keighley, 1973a and b; Tregenza and Loe, 1998). In this way, the presence of ground in a screen image was thus also chosen to see whether a screen image of natural scene with ground gives less glaring than those without.

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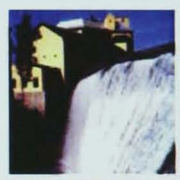
[5] The five-point rating scale was used in the preliminary test for the first experiment in the laboratory, while the eleven-point scale was employed in this test. This is because the preliminary test for the first experiment was the first test and, thus, we used a simple method. However, we employed the different scale later because there was complaints from some subjects in the first test that five-point scaling was not comprehensive enough to describe their subjective feelings.

Pictures	Interest scores		Pictures	Interest scores		Pictures	Interest scores	
	Mean	SD		Mean	SD		Mean	SD
	8.88	0.73		7.20	0.93		6.92	1.27
	8.58	0.53		7.20	1.05		6.67	0..73
	8.58	0.73		7.20	054.		6.67	1.00
	7.50	0.78		6.96	0.90		6.39	0.59
	8.70	1.05		6.96	0.67		6.39	1.09
	8.63	0.50		6.96	0.67		6.38	1.01
	7.50	0.50		6.96	0.88		6.38	1.01
	7.50	0.87		6.92	0.61		6.13	0.93
	7.21	0.60		6.92	1.00		6.13	1.13

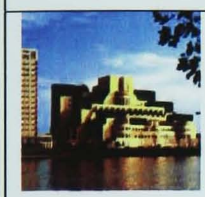
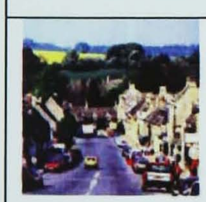
Pictures	Interest scores		Pictures	Interest score		Pictures	Interest scores	
	Mean	SD		Mean	SD		Mean	SD
	6.13	1.13		5.00	0.88		4.46	1.20
	5.83	1.00		5.00	1.05		4.21	1.00
	5.29	0.67		4.79	1.00		4.17	1.22
	5.20	0.88		4.79	0.81		3.63	0.59
	5.21	1.17		4.79	0.50		3.63	1.24
	5.00	0.88		4.70	1.17		3.63	0.88
	5.00	0.88		4.70	0.97		3.63	1.01
	5.00	0.88		4.46	0.97			

Table 4.5: Fifty screen images used in the preliminary test of the second experiment and their interest scores

4.4.2.2 Experimental Objectives

The following four factors were tested as to whether they can reduce the degree of glare discomfort:

1 An image of a natural scene instead of an urban or man-made environment
2 The presence of water in an image of a natural scene
3 The presence of visible sky in an image of a natural scene.
4 The presence of nearby ground surface in an image of a natural scene.

These four factors are defined as follows;

1. "The naturalness of an image", in this study, refers to the combined amount of natural elements and man-made elements in a small screen image. This factor depends on how much in the way of natural elements and man-made elements were within the screen image. If the amount of natural elements within the screen image is equal, an increase in amount of man-made elements would decrease the naturalness of the screen image. Tennessen and Cimprich (1995) classified views out in to four categories according to the naturalness in a view, which are all natural, mostly natural, mostly urban and all urban views. In this study, five levels of the naturalness of an image were employed, which are images of all natural, mostly natural, neither natural nor urban, mostly urban, and all urban views. The image category of neither natural nor urban view was added because it seems that there may also be a balance between natural elements and man-made elements in a scene. An image of all natural view refers to a screen image that contains all natural elements and features, for example, trees, grass and bushes with no human influences. It should be noted that 'natural elements' in this study do not include sky and water. An image of mostly natural scene refers to a screen image that contains mostly natural elements and features and has some man-made elements in the screen image. And, if there is an equal balance between natural elements and man-made elements in a screen image, it would be defined as an image of neither natural nor urban scene. On the other hand, if the majority of what could be observed in a screen image was built, including

buildings, parking lots, but with some natural components such as a few trees and bushes, it was defined as an image of mostly urban scene. An image of all urban scene refers to a screen image that contains all man-made elements and has no natural elements. Only two extreme levels were chosen for study, which were images of all natural and all urban scenes.

2. "The presence of water in an image" refers to being able to see water in a small screen image. "Water" in this study refers to all different categories of the water, classified regarding their natural characteristics.

3. "The presence of sky in an image, in this study, refers to whether or not sky can be seen in a small screen image. "Sky" in this study refers to all different categories of the sky, classified regarding typical weather characteristics, for example, cloudy sky and clear sky.

4. "The presence of ground in an image", in this study, refers to the presence of ground within a small screen images. "Ground" refers to all the different categories of ground, both natural and man-made ground. The natural ground refers to ground with nature elements and no human influence consisting of, for example fields, meadows, woodland, unpaved roads, flowers. Man-made ground refers to ground with human influences consisting of, for examples many types of hard man-made surfaces, streets and concrete roads.

4.4.2.3 Methodology

a. Stimuli Variations and Selection of Screen Image Samples

There are two processes to select a sample of all screen images to be investigated in terms of discomfort glare in this experiment. Firstly, all screen images for treatment 2 in each session were selected (ten screen images for each session). It should be noted that only ten categories of natural scenes, water, sky and ground were chosen to investigate. The selected categories were as follows:

For the effect of the naturalness of an image, ten kinds of screen images were meadow scenes, grassy stretches, dense foliage, mountain scenes, tropical evergreen forest, coniferous forest, swamp forest, beach forest, and canyon. For the water collection, ten kinds of water were selected to study, including river, lake, sea, canal, light rain, waterfall, flood, shower, creek, and swamp. The ten types of sky selected for the study were cloudy sky, partly cloudy sky, clear sky, sunny sky, rainy sky, storm sky, sky with sunrise, sky with sunset, sky with rainbow, foggy sky. Since the effect of the naturalness of an image has to be controlled (all natural), only natural grounds were used to study. Ten types of natural grounds were hay field, soil ground, soil road, green field, rock, unpaved road, beach, colorful wild flowers, sun flower field, and river bank.

Secondly, after all test screen images (treatment 2) for each session were selected, all control screen images (treatment 1) were selected or modified using the digital images used for test screen images (treatment 2). The control screen image (treatment1) were selected or modified regarding the consistency with the test screen image (treatment 2) of as many as characteristics and elements as possible as criteria. These are, for example, their complexity, distance, colour, and picture clarity as well as the luminance range of the images. Particularly, in order to control the effect of luminance range of the screen image for each pair, maximum luminance within each pair of screen image was checked by visual inspection to ensure that each pair contains a similar value. All screen image stimuli were shown below.

Figure 4.10: Screen images for session 1- the effect of the naturalness of an image

Treatment 1:
Images of urban scenes

Treatment 2:
Images of natural scenes

Treatment 1:
Images of urban scenes

Treatment 2:
Images of natural scenes

Figure 4.11: Screen images for session 2- the effect of the presence of water in an image

Treatment 1:
Images of natural scenes without water

Treatment 2:
Images of natural scenes with water

Treatment 1:
Images of natural scenes without water

Treatment 2:
Images of natural scenes with water

Figure 4.12: Screen images for session 3- the effect of the presence of sky in an image

Treatment 1:
Images of
natural scenes
without sky

Treatment 2:
Images of
natural scenes
with sky

Treatment 1:
Images of
natural scenes
without sky

Treatment 2:
Images of
natural scenes
with sky

Figure 4.13: Screen images for session 4- the effect of the presence of ground in an image

Pair
Treatment 1:
Images of
natural scenes
without grounds

Treatment 2:
Images of
natural scenes
with grounds

Pair
Treatment 1:
Images of
natural scenes
without grounds

Treatment 2:
Images of
natural scenes
with grounds

b. Experimental Equipment and Measurements

All the photometric measurements were taken with by similar method as those in the first experiment. In this experiment, the source luminance was held constant at 8600 cdm^{-2}. The background luminance was held constant at 65 cdm^{-2}. Average background luminance values were taken for locations shown in Figure 4.14. The values of the solid angle subtended at the observer eye by the glare source and the position of the source were also held constant. The area of each stimulus was 8 cm x 8 cm. with the distance from the centre of the stimulus to the eye being 0.60 m.

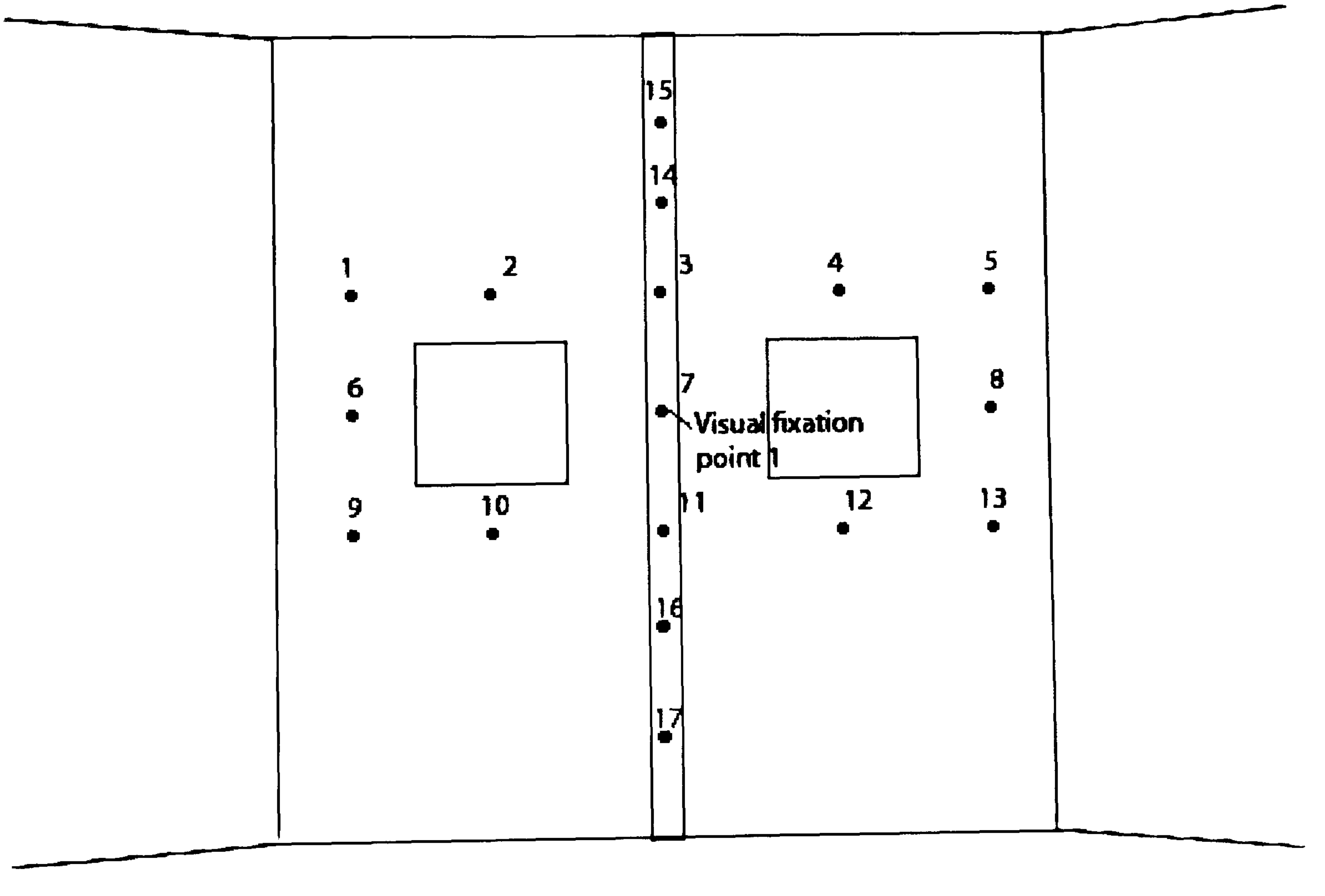


Figure 4.14: Background luminance points with screens in presentation position and a visual fixation (the centre of the presentation wall)

c. Experimental Design

Experimental Design

As the results in the first experiment showed a large scattering of data, the paired comparison technique has been used in this experiment. This method was used in many lighting studies (Flynn *et al*, 1973; Flynn, 1977; Houser *et al,* 2002; Houser *et al*, 2004). In this experiment, the technique was done side by side. There are four sessions in this experiment each of which investigates each variable. In each session, there were 10 pairs of screen images to be compared. This required 10 images projected on the right screen and 10 images on the left screen. Each subject would have to choose which screen image produced more discomfort than the other— left or right. By this method, other nuisance variables from subjects could be minimized, such as age and gender. The sequence of sessions and the presentation of each pair of screen images in each session were randomized. The positions of the images (left or right) were randomly placed. By using randomization, the effects due to people comprehending the experiment, fatigue and other nuisance variables would be minimized.

Testing Procedures

As in the first experiment, there were two periods in this experiment. Before the real experiment study started, the pretest period took place. In this period, each subject was first provided with the explanation of study/informed consent form with the aim and overall procedure described. Then, they were asked to complete a pre-study questionnaire and were positioned in the chair, which was adjusted to a correct position. Then, the experimenter read instructions to the subjects including the definition of glare, the meaning of the criteria and the procedure trial used in both the pretest period and the real experiment. Then, the experimenter showed the subject an example of comparing discomfort sensation between the two glare sources and subjects then made their own example comparison. For these example comparisons, a series of 10 pairs of screen images, which were different from those employed in the real experiment, were used. Then, the subjects compared each screen image against another screen image in the same manner as it would be done in the real experiment.

Finally, the subjects were allowed to relax for about 10 minutes and the experimenters then took their positions in front of the two computers to enable the real experiment.

Four sessions of comparisons in the real experiment were then begun. Each session lasted approximately 5-10 minutes. In each session, the presentation order of treatments was randomized for each subject in each study. The positions of all the images (left or right) were also randomized. The sequence of sessions presented to each subject was also randomized.

First, the presenter asked the subject. "Are you looking at the mark at the centre of the presentation wall?" When the subject responded affirmatively, the presenter instructed the subject to, "continue to look at the mark and there are two little openings containing images. They are quite bright. I would like you to indicate as to which one causes more discomfort than the other, the screen image on the left, or the right." This forced choice method has been used in many studies (Flynn *et al*, 1973; Flynn, 1977; Houser *et al*, 2002; Houser *et al*, 2004). Each pair of image stimuli was presented for about three seconds. The subject responded left or right. Three seconds was used due to the fact that this method has been employed by many previous glare studies (Guth, 1959, 1963; Waters, 1993). The experimenter recorded the subjects' response. The image stimuli were then changed by the experimenter. Comparisons continued until completing ten comparisons. Then, two openings were closed. Also, the subject was told to re-adapt his/her eyes until the effect of after image had gone.

Subjective Assessment of Discomfort Glare

As earlier stated, due to the wide range of responses during the use of multiple criteria, the paired comparison method was devised to find an individual response. Using the raw data collecting sheet, the raw data from the comparisons were placed in an order to be associated with an image stimuli number. At the end of the experiment, the numbers of subjects that chose such a stimulus screen image to be *more* discomfort than the control screen image were counted. Then, these numbers were converted to be the numbers of subjects that chose such the stimulus screen image to be *less* discomfort than the control screen image and those that chose the control screen image to be *less* discomfort that the test image (see Table 4.7).

Table 4.6: An example of raw data of each subject's response

Subject no. 1

Image pair	1	2	3	4	5
Stimuli Label	City1	City2	High1	House1	House2
Response L/R	L	L	L	R	L
Image pair	6	7	8	9	10
Stimuli Label	House3	School	Square	Street1	Street2
Response L/R	L	L	L	L	L

Note: L =LEFT, R=RIGHT

Table 4.7: The numbers of the subject's response in each comparison

Stimuli Label	City1	City2	High1	House1	House2
Number of A	2	3	1	3	2
Number of B	10	9	11	8	10
Stimuli Label	House3	School	Square	Street1	Street2
Number of A	3	1	2	4	5
Number of B	9	11	10	8	7

Note: Number of A is the number of subjects who found the control screen image to be of *less* discomfort than the test screen image. Number of B is the number of the subjects finding the test screen image of *less* discomfort than the control screen image.

The Observers

The subjects were recruited from students at the University of Sheffield. Twenty-four subjects took part in this study during the 1st and 2nd of June 2004. The number of 30 observations devised by Bechtel (1987) to obtain a statistically robust distribution of scores was not reached in this experiment. However, significant results can be obtained with these numbers. The reasons that made it difficult to reach the high numbers of the subjects are the fact that in a glare experiment, the subjects have to be exposed to a bright glare source. There is also the necessity of ensuring the proper understanding of particular words used, so this requires the subjects to be trained before doing the real experiment. These tasks are not only a time-consuming process, but also made subjects wonder about their risks. Furthermore, the experiment took place at the end of the summer university term, corresponding to the exam period for the students, reducing the potential of getting the larger samples. The total number of subjects in this experiment was thus twenty-four.

The subject sample consisted of males and females between 20 and 30 years of age. There was an equal balance between males and females. There was also a balance between subjects with spectacles and without spectacles. Spectacles were worn by 50% of both men and women but no other eye defects and no colour-blindness were included in the experiment. Subjects were compensated for their participation.

d. Statistical Analysis

To assess the acceptability of each hypothesis mentioned above, two statistics were performed. The first one is a Chi-square test (χ^2) and the second one is a Binomial Test. To give a basic ideal of the difference between each set of results, a Chi-square test (χ^2), the goodness of fit test, was used. For the more important test, allowing a drawing of conclusion regarding the hypothesis, the Binomial test was carried out. The decision was made to use this test due to the fact that the data has a binomial distribution. The binomial distribution is the sampling distribution of the proportions that we might observe if random samples are drawn from a two-class population such as male/female, pass/fail, etc. In this experiment, these are right/left. Two hypotheses for each set of comparisons were set:

Null hypothesis $H_0: P_1 \leq P_2$

Alternative hypothesis $H_1: P_1 > P_2$

The Z value was given by the formula as follows:

$$Z = \frac{(x \pm 1/2)-1/2N}{1/2\sqrt{N}}$$

Where,

P_1 is a total probability of subjects detecting t less discomfort in test screen images than the control screen images for 10 pairs.

P_2 is a total probability of subjects detecting less discomfort in control screen images than test screen images for 10 pairs.

X is the total number of subjects detecting less discomfort in test screen images than the control screen images for 10 pairs.

N is the number of trials. In this case, it is the total number of trials for 10 pairs.

The alternative hypothesis (H_i) is that the total probability of a numbers of the subjects in detecting test screen images less glaring than the controls is more than those in detecting control screen mages less glaring than test screen images. A one-tailed test was used because this alternative hypothesis is a directional hypothesis. Then, values of Z and p-value were obtained.

4.4.2.4 Results and Conclusions

In the Binomial test, there were significant differences in glare response between test screen image and control screen image in three of the four sets. These are shown in Table 4.8, which gives the number of subjects who chose each screen image.

Table 4.8: Screen images chosen as less glaring in paired comparison test of screen images with and without a given feature

Image pair	Number of subjects (out of 24)							
	Natural	Urban	Natural with water	Natural without water	Natural with sky	Natural without sky	Natural with foreground	Natural without foreground
1	*23*	1	*16*	8	*15*	9	*17*	7
2	*11*	13	*21*	3	3	21	*16*	8
3	5	19	*16*	8	*17*	7	12	12
4	*22*	2	12	12	12	12	*14*	10
5	7	17	*19*	5	*11*	13	*24*	0
6	6	18	9	15	4	20	*21*	3
7	*22*	2	*22*	2	*21*	3	11	13
8	*20*	4	*14*	10	*15*	9	11	13
9	*18*	6	7	17	*13*	11	8	16
10	*20*	4	*20*	4	*19*	9	*19*	5
Total	154**	86	156**	84	131	109	153**	87

** indicates highly significant results (*prob*<0.01) on the binomial test with number of trials 10x24.
* indicates significant results (*prob*<0.05) on the binomial test with number of trials 10x24. Italics indicate test image greater than the control.

In a χ^2 test, the results from all four sets indicate a highly significant difference from the null hypothesis of equal probability ($p<0.01$). More important is the one-tailed test of the total of each set against the cumulative Binomial distribution. The Binomial test indicates whether, over all the pairs of screen images in the set, the number of choices for the screen image with the specific feature differs from the null hypothesis. For three sets, natural: urban scene, the presence of water and the presence of ground, the result was highly significant (p<0.01). For the presence of sky set, the result was just below significance (p= 0.0869).

According to the result, it could be concluded that images of natural scenes evoke less discomfort than images of urban scenes and in the with regard to natural scenes, the presence of some elements like water and ground alleviate the sensation of discomfort glare. We note that the screens lay outside the subjects' central visual field and peripheral effects of non-uniform illuminance may have occurred; but because the number of subject-choices in each set was large (24) and the views were presented randomly in pairs, this is unlikely to have systematically affected the outcome. It is noted that although at the beginning of the experiment, each pair was selected based on consistency of maximum luminance and average luminance between each pair, the effect of this ratio was checked again to ensure that it was sufficiently controlled in this experiment. By using Chi-square statistics, the goodness of fit test, the test shows that the control was achieved – there was no significant effect of this ratio on the outcome.

4.4.3 Horizontal Stratification of an Image and Discomfort Glare

4.4.3.1 Introduction

Markus, a pioneer in studies on window-views, stated that one of the important characteristics of almost all views is their horizontal stratification (Markus, 1965; 1967a and b; Lynes, 1974). Markus (1967a and b) and Lynes (1974) claimed that this characteristic of view consists of three elements and each of these elements has its obvious as well as perhaps deeper and unconscious significance as follows:

First, the upper layer is the sky, the primary source of light. It also permits the keeping track of the time of the day, the state of the weather and perhaps the seasonal changes. The presence of the sun itself, visible or implied by the sky, probably plays a key role in that as accompanied source of heat and light it has become a symbol of life, energy, fertility and growth" (Markus, 1967b; p.103). Secondly, the middle layers of "predominantly upright objects, such as trees or buildings" (Lynes, 1974; p. 285). This view of the landsscape or the city is the one that gives most information about the distant and inanimate environment (Markus, 1967b). Thirdly, the bottom layer is the foreground. "This downward view of the ground and activities such as traffic, rivers, play-ground, parks, streets-comprises the basic human, social portion of the view" (Markus, 1967b; p.103).

It has been stated earlier that factors in a small screen image affecting image interest seems to affect the glare discomfort. As it has also been mentioned in Section 3.4.3, several studies indicated that stratification in a view could have an effect on view preference and this characteristic could be a possible factor affecting the interest in a view (Markus, 1967a and b; Keighley, 1973a and b; Lynes, 1974). In this way, it implies that the horizontal stratification element in a small screen image could have an influence on the glare discomfort. Moreover, in the previous section, the significant effect of a presence of nearby ground in a screen image was found. The effect of a presence of sky in a screen image was also just below significant. As mentioned above, in terms of window-view, amount of sky and nearby ground in the view are important elements affecting view stratification. Through the variations of amount of sky and ground in a screen image, these previous results hence imply that the variation of horizontal stratification in a screen image could affect discomfort glare. However, the results could not yield to a certain conclusion of the effect of image stratification on discomfort glare yet. And, there are a number of aspects of image stratification that need to be further studied. For example, there is a question of whether a screen image of sky alone is less glaring than other scenes, even though the previous results suggested a reduction of glare due to a presence of sky in an image of natural scene. It is also uncertain as to which of two-layer images, a screen image with a sky and a middle layer or that with a middle layer and a nearby ground, may give less glaring effect. even if the previous experiment shown the significant effect of grounds but not for the sky effect.

Based on all of the reasons mentioned above, the discomfort glare from many small screen images with different degree of horizontal stratifications is assessed and detailed conclusions on the effect of image stratification on glare were drawn up in this part.

4.4.3.2 Experimental Objectives

A hypothesis of this part is that the stratification of an image affects discomfort glare.

Markus (1967a and b) defined the characteristics of the three horizontal layers of the view out as stratification. In this study, "stratification of an image" refers to the characteristics of three horizontal layers in a small screen image. Similarly to what is described as the three layers of window-view as noted above, these three horizontal layers in an image, in this study, are the upper layer of sky, the middle layers of "predominantly upright objects, such as trees or buildings", and the bottom layer which is analogous to being the foreground.

4.4.3.3 Methodology

a. Stimuli Variations and Selections of Screen Image Samples

Varying the characteristic of stratification of a screen image in terms of the visible amount of each layer appears to be a rational way to investigate subjective feelings. Normally, with an increase in height of building, the window-view appears more distant and has a higher ratio of sky to ground. Since the results in this experiment could be seen as a preliminary indicator for the effect of stratification in a view on discomfort glare, which could be studied later, the classification of screen images in this experiment should be also correspond to the window-views as seen from different levels of a building. By taking the ratio of visible amount of sky to cityscape and ground within the view as a physical measure and regarding the views that can be seen through windows according to an increase of the height of the building in reality. This classification could correspond to views as seen from different levels of a building: basement, ground floor, mid-floor and high floor. According to this, six types of images representing six levels of image stratification are as follows:

1. An image contains only one upper layer, the whole sky. This corresponds to a view with a very high floor.
2. An image contains only foreground. This scene can be found on the basement of the building where the views out is a slope of grass or a car park ramp for example.
3. An image contains only a middle layer of cityscape or landscape. This scene can be found on a middle floor, where a window that we look through is confronted with a building or gardens only.
4. An image with one-third of sky and two-thirds of cityscape/landscape. This scene could be found on the mid floor.
5. An image with two-thirds of the cityscape/landscape and one third of ground. This scene could also be found on the mid floor, at a level a little lower than the fourth type.
6. An image with one-third of sky, one-third of cityscape, and one-third of ground. This corresponds to a view that can be seen at the high level of a building.

Due to time constraints, screen images representing only four real scenes that can be possibly seen through a window were selected to study. These scenes were a high-rise office building scene, a residential scene, a mountain scene, and a garden scene. The reasons for choosing these four contexts were due to the fact that they were scenes most commonly found through windows. To investigate the effect of image stratification on discomfort glare, all six levels of image stratification, one of which contains four scenes, are studied as follows: Treatment 1 represents images with only one layer, the whole of which is sky. Treatment 2 refers to images where there is only one layer— foreground. Treatment 3 is images with only one middle layer. Treatment 4 is images with one-third of sky and two-thirds of cityscape/landscape. Treatment 5 is images with two-thirds cityscape/landscape and one-third of ground. Treatment 6 is images with one-third of sky, one-third of cityscape, and one-third of ground.

To obtain all screen images used in this experiment, there were two steps. Firstly, four screen images containing all three horizontal layers (treatment 6) were selected to represent the four real scenes mentioned above. To control the effect of luminance range, suggested by evidence from the first experiment (the effect of interest in an image on discomfort glare) that it might have an effect on discomfort glare, all the screen images were also chosen so that they have an equal maximum brightness distributed evenly across each screen image. Finally, these four screen images containing three horizontal layers were modified to get the other five levels (treatment 2-6) using Photoshop. The final 24 screen images, four screen images for each level of image stratification, were used in this experiment and they are shown below:

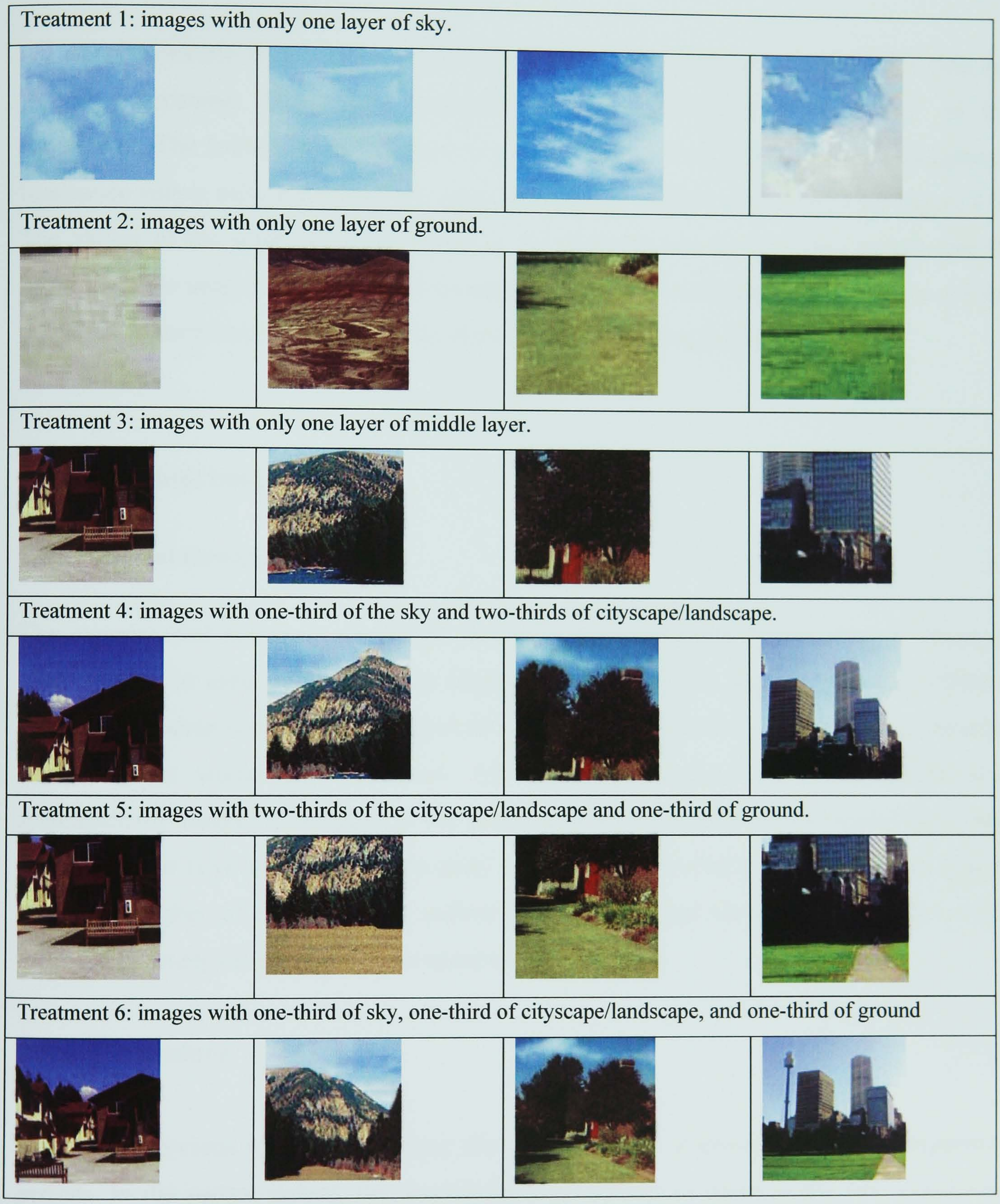


Figure 4.15: Twenty-four screen images that have been used in the second part of the second experiment

b. Experimental Equipment and Measurements

All the photometric measurements were taken by similar methods as those in the first and second experiment. The source luminance is held constant at 12,000 cdm^{-2} in this experiment. The background luminance was held constant at 65 cdm^{-2}. Average background luminance values were taken from the same locations as the first experiment (see Figure 4.8). The values of the solid angle subtended at the observer eye by the glare source and the position of the source were also held constant. The area of each stimulus was 8 cm x 8 cm. with the distance from the centre of the stimuli to the eye being 0.60 m.

c. Experimental Design

Experimental Design

The experimental design is a repeated measures Balanced Latin Square design. There are four pictures in each treatment. This requires each subject to view twenty-four different images. The same subjects experienced all treatments so that the effects of other variables from subjects would be minimized. All the stimuli images to be presented were systematically randomly assigned to the subjects. A set of sequences for twenty-four-image conditions that have been used in this study are based on the criteria that each image appears an equal number of times in each ordinal position and that each image precedes and is followed by every other condition an equal number of times.

Testing Procedure

Like other previous experiments, there are two periods— a pretest and a real experiment periods. In the pretest period, the procedures were similar to those in the first experiment, obtaining the explanation of the study and completing informed consent form; completing pre-study questionnaire; and getting instructions. Then, one example trial using screen images, which were different to those employed in the real experiment, was made and shown by an experimenter and then subjects did their example trials. Finally, the subjects relaxed for ten minutes. After the period of pretest, each subject was told to fix the eye position at the fixation point— the centre of the right screen. The first image was presented automatically and the subject was asked to rate perceived discomfort glare by marking on GSV scales. The subjects had to complete this process within three seconds for each stimulus until they finished all twenty-four screen images. This was done in order to control the effect of the duration of exposure. Whenever the subjects indicated any after image effect, the experimenter would not present stimuli anymore until they indicated that the effect had gone. This was done in order to minimize the afterimage effect. All the sequences of treatments were also systematically randomly assigned to each subject. After each subject had finished the experiment, another subject was introduced to the experiment and the same procedures were repeated until the last subject.

Subjective Assessment of Discomfort Glare

Discomfort glare in this study was determined by subjective glare rating using a continuous scale with four criteria called 'the Glare Sensation vote' (GSV) (Iwata *et al*, 1992a; Iwata *et al*, 1992b; Iwata and Tokura, 1998). Like the first experiment, these glare categories were connected to a clear description with an approximate time. This allowed subjects not only to understand each threshold by the given definitions, but also to imagine meanings of an interval between demarcations. The subjective glare ratings and their descriptions were also related to numerical scales and are shown below:

"Just (im)perceptible glare[6]": The point where glare discomfort is first noticed by the subjects. This level was defined by the point at which you feels that the glare source is just irritating or noticeable, but causing no great annoyance. Below this level, you are aware of the glare source as a patch of light, without suffering any annoyance from it.

[6] Within the original criterion 'just imperceptible' (Hopkinson, 1940; Hopkinson, 1963) is being used, as well as 'just perceptible' (Hopkinson, 1972); the Predicted Glare Sensation Vote uses 'just perceptible', based on a study of Matsuda *et al* (cited in Iwata *et al*, 1992a)

"Just acceptable glare": This level was defined by the point at which the subject felt that the glare source was just irritating or noticeable and they could tolerate the discomfort sensation approximately 1 day, when working in someone else's room. But, they would require a change in lighting condition if they were to work there for longer periods of time.

"Just uncomfortable glare": The point where the subject found the source could create the discomfort or annoyance sensation, which they could tolerate for approximately 15-30 minutes if work had to be carried out. But it would require a change in lighting condition for any longer period. This is the borderline between noticeable and uncomfortable glare.

"Just intolerable glare": The most intense sensation of glare at which the subject felt that the glare source created a discomfort sensation which they can't stand anymore. They would immediately change the lighting condition. It is the borderline between uncomfortable and intolerable glare.

These four criteria were described to all subjects. It was also suggested that they think that they have to pursue some visual tasks in the working environment while evaluating these criteria of discomfort glare. A vote could be made by marking a tick at any point on the line of the continuous scale. The Glare sensation vote (GSV) value is defined as the value marked by subjects on this scale. For data analysis, numbers were assigned as follows:

GSV 0: just perceptible
GSV 1= just acceptable
GSV 2= just uncomfortable
GSV 3= just intolerable

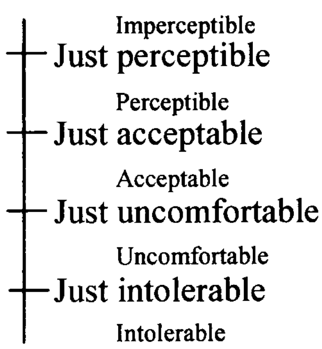


Figure 4.12: The Glare Sensation Vote (GSV) used in the subjective assessment of this experiment. We considered the criterion to be equal intervals because the corresponding values of the Glare Indices have equal intervals.

The Observers

Twenty-four subjects took part in this study during the 3rd and 4th of June 2005. The number of 30 observations devised by Bechtel (1987) was not reached in this experiment for the same reasons as those in the first part. However, significant results can be obtained with this number of subjects. The subject sample consisted of males and females between 20 and 30 years of age. There was an equal balance between males and females and a balance between subjects with spectacles and without spectacles. Half of men and half of women wore spectacles. The subjects were recruited from students in the University of Sheffield and were paid for their participation.

d. Statistical Analysis

The hypothesis being tested in this part is that image stratification affects the glare discomfort. To test this hypothesis, the sample mean $(\overline{X})$ of the GSV between the four treatments, four pictures for one treatment, are compared. A one-way repeated measures analysis of variance (ANOVA) was used in an SPSS Program. The decision was made to use Parametric test due to the fact that it is more precise than Non-parametric test. Two hypotheses were set: Null Hypothesis (H_0) and Alternative hypothesis (H_1) as follows:

Null hypothesis $\quad H_0$: $\mu_1 = \mu_2 = \mu_3 \ldots\ldots = \mu_k$

Alternative hypothesis $\quad H_1$: $\mu_i \neq \mu_j$

After using One-way ANOVA, if the *p*-value of the results is less than the significant level (p-value < 0.05), it would be said that there is statistically significantly difference of the sample mean $(\overline{X})$ between any two treatments. The null hypothesis would be rejected and the alternative hypothesis would be accepted. Then, it would be concluded that the effect of image stratification on discomfort glare was found (p-value < 0.05). After that, a Sidak *t*-test for multiple-group comparisons was used to see between which treatments that their sample means $(\overline{X})$ were statistically significantly different.

4.4.3.4 Results and Conclusion

Table 4.9: Mean and standard deviation of glare assessments (GSV) from images with different degree of stratifications and the significance levels (*p*-value) of the ANOVA analysis

Image categories	Mean	SD
Images only one layer of the whole sky (L1)	2.33	0.61
Images where there is only one layer of foreground (L2)	2.19	0.55
Images with only one middle layer (L3)	2.10	0.62
Images with one-third of sky and two-thirds of cityscape/landscape (L4)	1.89	0.68
Images with two-thirds of the cityscape and one-third of ground (L5)	1.60	0.76
Images with one-third of sky, one-third of cityscape/landscape and one-third of ground. (L6)	1.27	0.54
p-value	0.000**	

** The mean difference is highly significant (*prob*<0.01) in a one-way repeated measures ANOVA
* The mean difference is significant (*prob*<0.05) in a one-way repeated measures ANOVA
NS No significant difference in a one-way repeated measures ANOVA

Table 4.10: Difference between mean of glare assessment (GSV) from pairwise comparisons for images with different stratifications

Image Categories	L1	L2	L3	L4	L5	L6
L1	0. 000					
L2	0. 141	0. 000				
L3	0. 236	0. 096	0. 000			
L4	0. 448**	0. 307**	0. 211	0. 000		
L5	0. 734**	0. 594**	0. 498**	0. 084**	0. 000	
L6	1. 064**	0. 923**	0. 827**	0. 089**	0. 078**	0. 000

** The mean difference is highly significant (*prob*<0.01) in a Sidak *t*-test
* The mean difference is significant (*prob*<0.05) in a Sidak *t*-test

Table 4.9 shows the results of mean and standard deviation of glare assessments (GSV) and the ANOVA from images with different stratifications. The ANOVA shows overall difference among the glare assessments of six types of images. The results, as can be seen in Table 4.9, show the effect of image stratification was highly significant ($p<0.01$). Further analysis of multiple comparisons between means by the Sidak t-test , as can be seen from Table 4.10, indicates that images with two-thirds of cityscape and one-third of ground and images with three layers are significantly less glaring than all images with one layer— either with sky alone, foreground alone, or with only middle layer ($p<0.01$). Similarly, it also shows that images with one-third of sky and two-thirds of cityscape/landscape are significantly less glaring than images with a one layer of sky and one with foreground only($p<0.01$).

With regards to two-layer images, images with two-thirds of cityscape/landscape and one-third of ground are also significantly less glaring than images with one-third of sky and two-thirds of cityscape/landscape ($p<0.01$). These results are consistent with the previous investigation showing the stronger effect of the presence of ground in an image of natural scene than the presence of sky. Moreover, as it can be expected, images with three layers are significantly less glaring than images with one-third of sky and two-thirds of cityscape/landscape ($p<0.01$). The remaining significant difference occurs between images with three layers and images with two-thirds of cityscape/landscape and one-third ground. It was found that images with three layers are significantly less glaring than images with two-thirds of cityscape/landscape and one-third of ground ($p<0.01$). The finding in this section leads to the conclusion that image stratification affects discomfort glare.

In summarising, the main aim of this second experiment is to see what content in a screen image affect discomfort glare. The overall findings for this experiment indicated that the sensation of glare discomfort is influenced by some characteristics and physical elements in a screen image. These factors are the naturalness of an image, the presence of water, the presence of ground in an image and image stratification.

4.5 Discomfort Glare and Luminance Variation in an Image

4.5.1 Introduction

As already stated in Section 4.3.4, most subjects complained about the effect of luminance variation within screen images, used for the first experiment (effect of interest in an image on discomfort glare). Indeed, they complained that as maximum luminance in images got higher, they were more glaring. In their study of glare discomfort from small source stimuli, Waters and his colleagues showed that non-uniform surfaces can cause more discomfort than uniform light sources when positioned at the line of sight (Waters *et al*, 1993). Velds (Velds, 2000) investigated the impact of non-uniform source luminance distribution on the perception of glare using a normal window and windows with different daylighting systems. He found that the perception of glare from non-uniform sources— windows with daylighting systems, either a window with mirrored louvers or that with Venetian blinds, is higher than that of a glare source with an identical average source luminance— a normal window. Following on from this, they implied that the luminance variation within the glare source is particularly important and could affect discomfort glare.

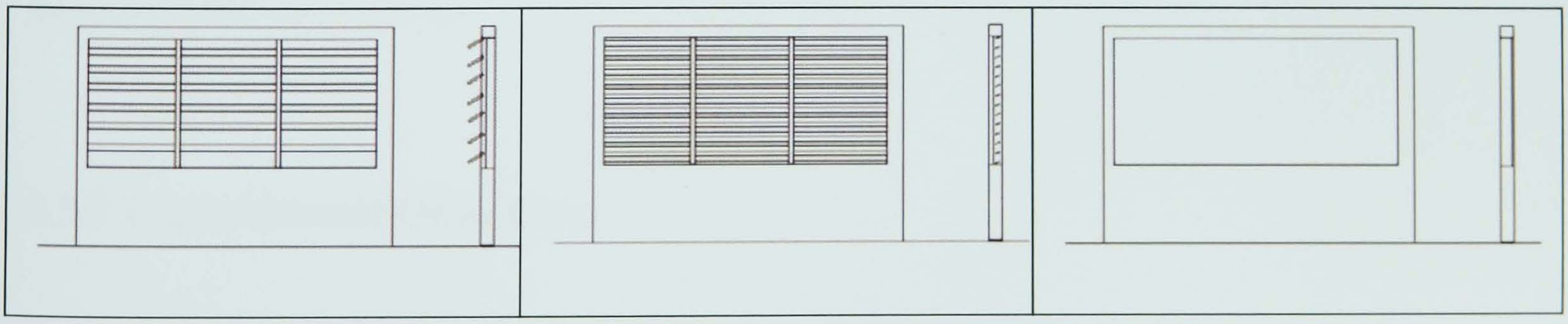


Figure 4.16: Windows with daylighting systems used in the study of Velds. Left: a window with mirrored louvers. Middle: a window with Venetian blinds. Right: a normal window.

This idea is also supported, theoretically, when we take both the UGR and BRS-GI formula to calculate the glare from two sources. These two sources are equal in an average luminance. The first one is non-uniform source—some parts are very bright while the rest are dark. Another one is uniform in luminance. To calculate the glare from non-uniform source, the source was divided into several bits and each bit has the same luminance. Instead of using an average luminance of the glare source to calculate the glare as the uniform source, the calculation of the glare from this source was done by taking the summation of glare calculation of individual bit. It was found that glare calculations for both the BRS-GI and UGR obtained from non-uniform source is higher than glare calculation from uniform source.

The above researches implied the effect of luminance variation within the glare source in different cases. On the basis of the evidence, another general hypothesis could be made that the ratio between the maximum luminance and average luminance of the glare source affect the glare discomfort. In this thesis, the ratio of maximum luminance to average luminance within the glare source was defined as "Relative Maximum Luminance within the glare source or RML" In other words, the general hypothesis for the relationship between discomfort glare and RML is that *"discomfort glare increases with the Relative Maximum Luminance within the glare source"*. Since the effect of RML that can be observed comes from the results of the first experiment (the effect of image interest on discomfort glare) which used small projected screen images as a source of glare, and due to simplicity and continuity in terms of experimental set up, this study began to test this effect in the case of a small projected screen image.

4.5.2 Experimental Objectives

A hypothesis in this experiment is that an increase in Relative Maximum luminance in an image (RML_m) is associated with an increase in discomfort glare. In this experiment, 'Relative Maximum luminance of an image' (RML_m) is defined as the ratio between maximum luminance (L_{max}) to an average luminance within a small screen image (L_s).

4.5.3 Methodology

4.5.3.1 Stimuli Variations

Due to the fact that the first experiment in this Chapter demonstrates that interest in an image affects the sensation of glare discomfort, it is necessary to control this effect in this experiment. Thus, before the real experiment was started, a preliminary test was carried out for this purpose. In fact, in order to control the effect of image interest, this preliminary test was aimed at finding which screen image subjects found equally interesting as the blank screen (no interest)[7]. Normally images of geometric patterns contain less information and could be less interesting than images of real scenes. Instead of using screen images representing window-views like previous experiments, the screen images of geometric patterns were used in this experiment. Thirty different screen images of geometric patterns generated by a computer using combinations of various patterns of light, grey and dark elements were projected by a projector on a 15 x 20cm screen. All of these screen images were paired with a blank screen. In total thirty paired screen images, a blank screen and a test screen images, were presented in random order to eight subjects. Subjects were required to choose which screen image was more interesting than another one by saying 'the first or the second'. Then, the numbers of subjects who found such a screen image more interesting were counted. On χ^2 test, it showed a significant difference in interest between neutral screen and screen image in twenty-two screen images. Thus, there were eight screen images representing the same interest as the neutral screen. Then, among these eight screen images, a screen image with the most RML_m value was used to test in the main experiment. The test screen image was modified by keeping the mean luminance of image constant and increasing the maximum luminance within the image to obtain two other levels of RML_m values. There are four treatments in the main experiment. Treatment 1 is the control— a neutral screen with RML_m of 1. Treatment 2 is a screen image with RML_m of 6.6 (the original image). Treatment 3 is a screen image with RML_m of 6.8. Treatment 4 is a screen image with RML_m of 8.0.

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[7] The blank screen was used as a control treatment to be compared with other screen images. It represents a screen image with zero interest as well as the lowest value of RML_m: RML_m=1.

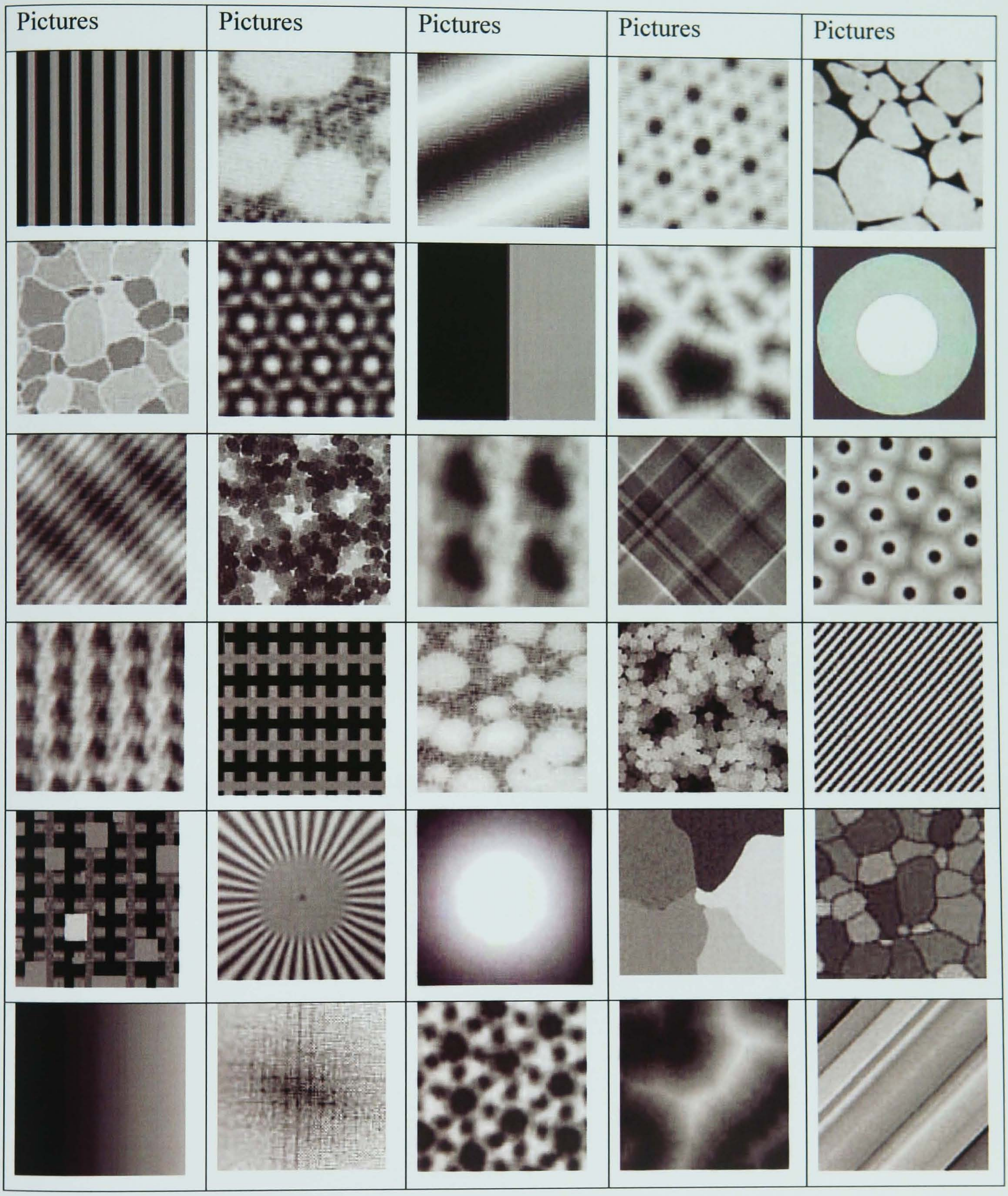

Figure 4.17: Thirty screen images used in the preliminary test of the third experiment

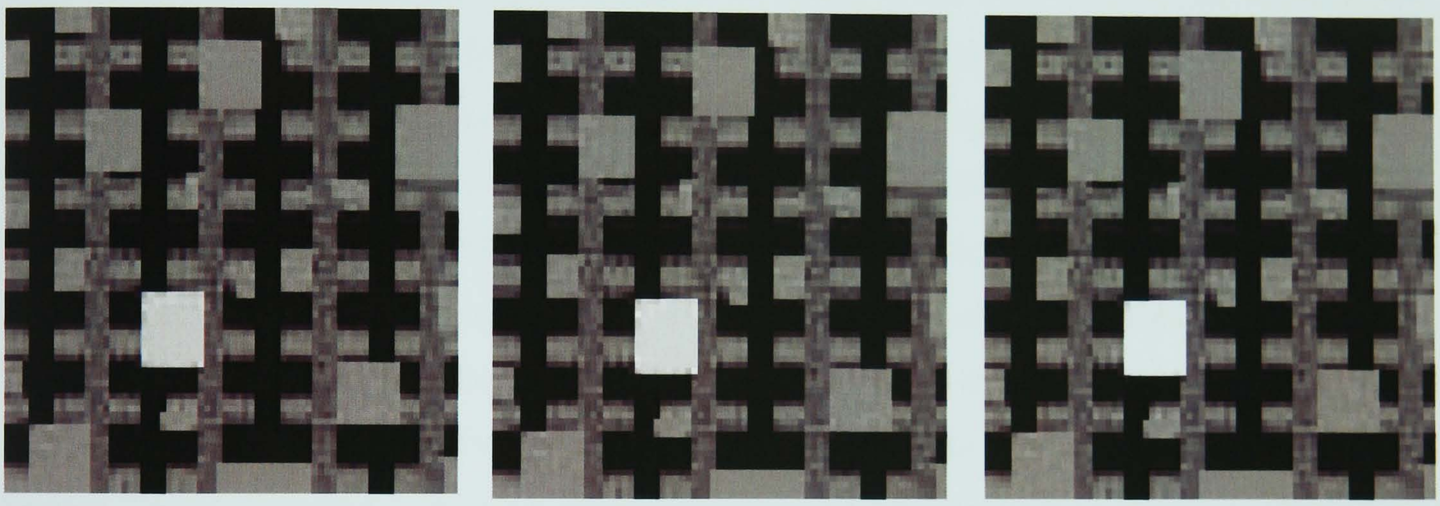

Figure 4.18: Three screen images to be tested in this third experiment. From left to right, a screen image with RML_m of 6.60, a screen image with RML_m of 6.80, and a screen mage with RML_m of 8.0.

4.5.3.2 Experimental Equipment and Measurements

There are two parameters to determine the degree of relative maximum luminance of a small screen image (RML_m): a maximum luminance (L_{max}) and an average luminance of a screen image or source luminance (L_s). Before the preliminary test started, the degrees of RML_m of all thirty screen images used in the preliminary test were measured in our laboratory. In this experiment, we use the right screen for the purpose of this measurement. The maximum luminances within thirty screen images were measured using a luminance meter, a Minolta LS-110, mounted on the tripod at a seating point aiming at the right screen. The Minolta has a measurement angle of 1°. Measurement of an average luminance of these images was also conducted using the luminance meter, mounted on the tripod the same procedure as mentioned in previous experiments. For the measurement of RML_m of the test screen images used in the real experiment, after modifying to get three versions, the maximum luminance and average luminance of these test images were collected using similar methods as stated above. The average luminance of all test screen images in the real experiment was held constant at 12,000 cdm^{-2}. The visual fixation in this experiment was at the centre of the right screen. The background luminance measurements were also conducted using the luminance meter, mounted on the tripod using the same procedure and locations as mentioned in the previous experiment. Average background luminance value was taken and it is held constant at 65 cdm^{-2}. The values of the solid angle subtended at the observer eye by the glare source and the position of the source were held constant and were measured by a tape measure. The area of each screen stimulus image was 8 cm x 8 cm. The distance from the centre of the stimulus to the eye was 0.60 m.

4.5.3.3 Experimental Design

a. Experimental Design

The experimental design in this experiment is, again, a repeated measures Balanced Latin Square design. The same subjects experienced all treatments. Four treatments were presented in systematic random orders. A set of sequences for four-treatment-conditions that have been used is based on what is described in Section 4.3.3.3(a).

b. Testing Procedure

The same methods as those used in the investigation of the effect of image stratification were employed again in this experiment. In the pretest period, the procedures began by getting the explanation of the study and completing informed consent form; completing the pre-study questionnaire, followed by the giving of instructions; seeing an example demonstration of one trial by the experimenter; doing an example trial; and relaxing for 10 minutes. In the real experiment, each subject was told to fix the eye position at the fixation point—the centre of the right screen and was asked to rate perceived discomfort glare by marking their subjective rating on a GSV within three seconds for each treatment until completing four treatments. All the sequences of treatments were systematically randomized. The same procedures were repeated for the first subject through to the last subject.

d. The Observers

Thirty-two subjects took part in this study during the 3rd and 4th of November 2004. There were equal numbers of men and women, all university students between 18 and 31 but varying in nationality and cultural background. Spectacles were worn by 50% of both men and women but no other eye defects and no colour-blindness was reported by any subject in this experiment. The subjects were paid for their participation.

4.5.3.4 Statistical Analysis

The hypothesis for this part of the experiment was that an increase in the Relative Maximum luminance in an image (RML_m) is associated with an increase in discomfort glare. To test this hypothesis, a one-way repeated measures analysis of variance (ANOVA) was used with the same reasons as stated in the second part in the second experiment. It was followed by a Sidak *t*-test for multiple-group comparisons.

4.5.4 Results and Conclusion

Table 4.11: Mean and standard deviation of glare assessments (GSV) from four treatments with different degree of Relative Maximum luminance in an image (RML_m) and the significance levels (p-value) of the ANOVA analysis.

Image categories	Mean	SD
A uniform blank screen with RML_m of 1 (L1)	0.916	0.86
An image with RML_m of 6.6 (L2)	1.305	0.51
An image with RML_m of 6.8 (L3)	1.617	0.72
An image with RML_m of 8.0 (L4)	1.795	0.98
p-value	0.000	

** The mean difference is highly significant ($prob<0.01$) in a one-way repeated measures ANOVA
* The mean difference is significant ($prob<0.05$) in a one-way repeated measures ANOVA
NS No significant difference in a one-way repeated measures ANOVA

Table 4.12: Difference between mean of glare assessment (GSV) from pair comparisons for four treatments with different degree of Relative Maximum luminance in an image (RML_m)

Image Categories	L1	L2	L3	L4
L1	0. 000			
L2	0. 399	0. 000		
L3	0. 702**	0. 313	0. 000	
L4	0. 880**	0. 491	0. 780	0. 000

** The mean difference is highly significant ($prob<0.01$) in a Sidak t-test
* The mean difference is significant ($prob<0.05$) in a Sidak t-test

Table 4.11 shows the mean and standard deviation of glare assessments (GSV) from four screen images with a different degree of Relative Maximum luminance (RML_m) and the significance levels (*p*-value) of one-way repeated measures ANOVA analysis. The ANOVA indicates the effect of Relative Maximum luminance within a screen image was highly significant ($p<0.01$). From Table 4.12, the Sidak *t*-test shows that a screen image with RML_m of 6.8 is significantly more glaring than a neutral screen ($p<0.01$). A screen image with RML_m of 8.0 is also significantly more glaring than a neutral screen ($p<0.01$).

In conclusion, the results in this experiment suggested that an increase in Relative Maximum luminance within an image (RML_m) is associated with an increase in discomfort glare.

4.6 Conclusions and Discussions

The investigation of the effect of interest in a small projected screen image on discomfort glare through the laboratory experiments lead to the findings that not only assert the influence of interest in an image and their contents on discomfort glare sensation but also identify the effect of luminance variation within the image. Importantly, the results supported the general hypothesis of the thesis that *"an increase in interest in a glaring source is associated with a decrease in discomfort glare"*

In brief, the results show that an increase in interest in a small bright screen image is associated with a decrease in discomfort glare. In terms of image content, by investigating discomfort glare from screen images of various window-views, it was found that images of natural scenes invoke less glare discomfort than images of urban scenes. Also, simple descriptors like 'water', 'ground', and 'image stratification' are likely to decrease glare sensitivity. Conversely, the results from the last experiment in the laboratory suggested that the discomfort glare increases with the Relative Maximum luminance within a small screen image (RML_m). Apart from the main findings for each experiment, the result of the preliminary tests in the first and second experiments seems to be important and need to be further discussed. As a whole, all of these findings have raised three pertinent issues discussed in this section. They consist of 1) Subjective identification of interesting screen images; 2) Effect of the interest in an image on discomfort glare; and 3) Effect of luminance variation in an image (RML_m) on discomfort glare.

4.6.1 Subjective Identification of Interesting Screen Images

By observing interest scores of small screen images in two preliminary tests, those for the first and second experiments, some pertinent issues are certainly further discussed. The relatively narrow scatter in the results obtained from subjects in these preliminary tests provide evidence that, young educated adults, university students in architecture, with differing nationality and social background share some interest in relation to certain visual aspects of screen images. In general, the result offers a basis for expecting an underlying commonality in interest in scenes across individuals.

Although the influence of culture on peoples' relationship with the physical environment has long been recognised, a number of studies concerning environmental aesthetics and preference provide support for the results found in these two tests. Berlyne and his colleagues, for examples, found that there were "impressive similarities in the way in which people with markedly different cultural backgrounds respond to the same visual material" (Berlyne *et al*, 1974 cf. Altman and Wohlwill, 1983; p. 108). Likewise, Ulrich (1983) pointed out that there is possibility of similarity between the preferences of people with different background for visual environments. In his point of view, there are general principles underlying the way people respond to the visual environment. He also argued that the differences between groups of individuals seem to exist in such variations as the public and certain professions rather than among groups defined on the basis of such traditional variables as income and social background. Furthermore, the results of the first experiment also provide support for this line of argument. Interest as evaluated by the preliminary group also affected the level of discomfort glare in the real experiment group. In the preliminary test, architectural students of differing nationality and social background assessed screen images in terms of interest. The subjects from the Thai student group used in the real experiment reported a significant reduction in glare when individually treated with the images selected as the top four most interesting by the preliminary group.

Regarding the scores of interest in an image in the first test as seen from Table 4.1, whilst the interest in thirty-one screen images containing a wide range of contents were ranked by architectural students, it was found that two out of the four ,most interesting images, were dominated by architectural content[8]. Similarly, it is possible that the professional background of subjects had influenced their interests. Nonetheless, this does not mean that all that is

[8] See Table 4.1

architecture makes architectural students interested since, based on the findings, the majority of screen images containing architectural contents were not included in the top ten interest scores for both tests. The challenge then is to determine what differentiates the images that are more favoured from those that are not. Examining and analysing of the results, particularly the contents of screen images considered as highly interesting images,[9] seems to give some insight into this concern.

In fact, the result from this empirical study suggests some potential variables that might be used to predict the interest in a small screen image. Firstly, the interest seems to be intimately related to certain characteristics of screen images. Secondly, some physical elements within a screen image also seem to have an effect on the degree of interest. Drawn from the results, there is a strong implication that complexity, mystery and, in some aspects, incongruity, seem to be major factors influencing the interest in an image.

For the three most interesting images in the first test and the top ten most interesting images for the second test, complexity was generally presented in terms of variations of colour, shape, orientation and form. The results are consistent with much of the evidence suggested by researchers on environmental aesthetics and perception. By using stimulus patterns of visual scenes in his early experiment, Berlyne (1971; p. 212) indicated that "complexity is confirmed as an outstanding determinant of pleasingness and interestingness" and Rappoport and Kantor (1967; p. 210) claimed in the context of architecture that "high complexity can hold much of attention of the perceivers".

Another dominant characteristic of the most interesting images identified by subjects is mystery, defined by Kaplan (1973, 1987), Kaplan, S. and Kaplan, R. (1982) as an element that increases interest and involvement in a scene by providing the promise of further comprehensive information. According to Ulrich (1983), mystery could be elicited when the line of sight in a natural or urban setting is deflected or curved, which he called defected

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[9] The screen image with interest score higher than 4 (based on a five point rating scale from 1-5) in the first test and screen image within the top ten interesting images in the second test.

vista, signalling that new landscape information is just beyond the visual bounds defined by the observer's position. This characteristic seems to be demonstrated in both screen images ranked as second and third most interesting in the first test as well as three out of the top-ten most interesting images for the second test[10].

Another characteristic that seems to have an effect on interest is incongruity in an image. Incongruity is defined by a mismatch between stimulation and neuronal model of expectations (Berlyne, 1957). According to the subjects' comments, this effect seems to be strong in the screen images that gained high interest scores in the first test. The most interesting image in the first test made the subjects doubt about its meaning as one stated, "the picture seems to be very peculiar." Similar responses were also made when some subjects noted that they were eager to identify the strange object located in the middle of the image, later found as the second most interesting image in the first test. The results provide support for the findings of Berlyne (1958) and Berlyne and McDonnell (1965), which showed that the attention of adult subjects is attracted by incongruous pictures, such as a camel with a lion's head.

Furthermore, in terms of physical elements in a screen image, the results from these two tests suggested that the subjects were more interested in images of natural scenes than images of built environment. As can be seen in the first test that all images of natural scenes were judged as highly interesting images, and, in the second test, nine out of the top ten most interesting images are images of natural scenes. It is likely that the images containing vegetation especially tree green shrub, and grass gained more attention from the subjects than those without. Moreover, the presence of water and sky in a screen image may be considered one of the potential factors making images interesting. In fact, their effects seem to be stronger in an image of natural scene because it can be ascertained from the result of the second test that the top six ranked in interest are images of natural scenes with water and sky.

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[10] See Table 4.1 and Table 4.3

In addition, the findings also implied the influence of stratified layers in a scene on the interest in an image. As demonstrated in Table 4.1 and Table 4.3, images of natural scenes with three layers always got higher marks than the ones presented with two layers—middle and sky— for both tests. Specifically, the images containing all three layers, foreground, cityscape/landscape, and sky, seemed to be more interesting than those with one or two layers. The interest in images of urban scenes seems to be emphasised by layers presented in the scene also. According to the results of both tests, images of urban scenes with three layers were likely to get higher interest scores than those with one or two layers.

In conclusion, almost all factors which could have an effect on image interest as mentioned above were suggested by previous researchers in environmental aesthetics and perception as well as window-view in that these tend to have an effect on preference in a screen image. For instance, Kaplan and Kaplan (1989, 1995) stated that environmental preference depends on four factors, which are coherence, complexity, mystery, legibility. Many studies have also emphasised the preference of natural scenes over urban views or built environments (e.g. Kaplan and Kaplan, 1995; Ulrich, 1981, 1983). In addition to this experimental evidence, screen images in the second tests were selected based on things that could affect image preference and, in most cases, screen images that seemed to be highly preferred got high scores in interest. In this way, the results seem to give a strong indication that interest in a screen image could be related to the preference.

It should be noted that the result of this study was based upon only one independent group of subjects. The findings are, in several particular aspects, likely to be consonant with other research on environmental aesthetics and perception. The main aims of these two preliminary tests were to select interesting images and to find some factors that should be investigated for their specific effects on discomfort glare. The identification of variables regarding interest in an image was quite limited because the amount of images that were used was small. Using a wider range of image contents would lead to more profound results.

4.6.2 Effect of Interest in an Image on Discomfort Glare

The findings of the first and second experiments have raised many important issues regarding discomfort glare assessment. As a subjective assessment, the discomfort glare seems to be influenced by the interest in a small projected screen image. Indeed, an increase in interest in a small projected screen image is associated with a decrease in the glare discomfort. The results provide further evidence that there was a direct relationship between the interest in a small projected screen image and the subject's tolerance of discomfort glare as the effect of the two images ranked most interesting on glare sensations tended to be stronger than the other two images ranked third and fourth. The findings imply support for Hopkinson's (1972) and Markus' (1974 cited in Boyce 1981) suggestion that a view with a great deal of interesting information or meaning might have an important effect on the sensation of discomfort glare.

This effect of the interest in an image on discomfort glare reflects the psychological needs of humans highlighted by S. Kaplan (1978) and Kaplan and Kaplan (1989, 1995). According to these researchers, human functioning depends on information provided by the immediate environment and humans "often seek information even when having it makes little discernible difference" (Kaplan and Kaplan, 1995; p. 51). Based on this theoretical point of view, it is probable that the interest in an image encouraged the subjects to pursue for additional information, thus they tended to be less sensitive to glare discomfort.

The expected effect of the degree of naturalness of an image and the presence of some particular elements— sky, water, and ground, in an image was supported by the results obtained from this study. Specifically, the high degree of naturalness represented through the images of natural scenes and the presence of water and ground were shown to significantly alleviate the sensation of discomfort glare. As previously mentioned in Section 3.4.3, view preference seems to be related with interest in a view. This assumption could be also applied for the case of a small projected screen image. Therefore, as earlier stated, interest in a small projected screen image could be associated with the preference. Based on this assumption, the results are congruent with a number of researchers who work in the field of environmental perception (e.g. Herzog, 1988; Kaplan and Kaplan, 1989; Orland, 1988; Ulrich, 1983). In fact, it was found that natural scenes are more preferable than built environments. In this way, with the lower degree of naturalness, the urban scenes or the presence of human influences in otherwise "natural" scenes dispose subjects to perceive them as relatively less interesting than a purely natural image. Consequently, the subjects seemed to experience more glaring.

Likewise, the significant effect of the presence of water on discomfort glare sensation is also consonant with the preference to water in landscape scenes asserted by earlier studies. Water has been described in a number of literatures as a visual element that is high in aesthetic and symbolic values, and that also evokes positive feelings such as tranquility (Ryback and Yaw, 1976). As earlier mentioned in Section 3.4.3, Hubbard and Kimball (1967) noted that the presence of water in landscapes evokes preference and aesthetic pleasantness in a scene. Accordingly, images of nature scenes with a presence of water seem to be more interesting than those without, and therefore, made the subjects more tolerant to glare discomfort.

As mentioned earlier, the presence of the nearby ground had significant effect on discomfort glare, whilst the effect of sky was below significant. These findings were emphasised by the result obtained from the further investigation of the effect of images' stratification as it appeared that images with two-thirds cityscape and one third of ground are less glaring than images with one-third sky and two-thirds cityscape. This is hardly surprising. Earlier studies have also found the presence of foreground in the landscape scene may strongly influence interest of observers (Craik, 1970; Ulrich, 1973, 1977; Wohlwill, 1973). According to Gibson (1958), the characteristics of ground texture profoundly affects the accuracy of depth estimates. Specifically, it can play a very important role in defining depth and helping the observers to comprehend element relationships in three dimensions (Ulrich, 1977, 1983). In this way, more information can be extracted and therefore influence the interests and/or pleasure of observers. This may also give an explanation as to the relationship between images' stratification and discomfort glare. Based on its characteristics, images with three layers demonstrate the clearest three-dimensional space of the landscape. Thus, they provided more information that could attract the interest of the subjects. On the other hand, when depth in the images was restricted or could not be perceived, the scenes seemed to stand ambiguously in two dimensions and appraisal was also essentially limited. Accordingly, images with one layer, either sky or ground, with the most restricted depth appeared to give highest glare to the subjects.

Finally, the results from the second experiment showed significant effects of some factors in a screen image in reduction in glare discomfort. As emphasized in Section 4.4.1, these factors were believed that they tend to have an effect on image preference. Based on what we already mentioned in the previous section that interest and preference in a screen image could be related, the results in this part implied that an increase in image preference is associated with a decrease in discomfort glare.

4.6.3 Effect of Luminance Variation in an Image on Discomfort Glare

The results from the last experiment in the laboratory studies investigating discomfort glare from small projected screen images with a different luminance ratio (RML_m) supported another general hypothesis that discomfort glare increases with an increase in Relative Maximum Luminance within the glare source (RML). This experiment tested this hypothesis in the case of a small projected screen image. It has shown that, with the same degree of interest provided, subjects found the non-uniform stimuli image gives more discomfort than uniform stimuli image. Specifically, an increase in Relative Maximum Luminance within a small screen image (RML_m) is associated with an increase in the glare discomfort.

The effect of Relative Maximum luminance of an image (RML_m) on discomfort glare found in this study tends to be consistent with the works of some prior investigators. Waters and his colleagues show that non-uniform surfaces can cause more discomfort than uniform light sources when positioned perpendicular to the line of sight (Waters *et al*, 1995). Likewise, Velds (2000), found that windows with different daylighting systems are more glaring than a normal uniform window. However, as the mean luminance of each glare source was held constant, this effect of non-uniformity in this study could be considered as the effect of the luminance variation across the screen images, indeed, the maximum luminance within a glare source.

Although the effect of non-uniform sources on discomfort glare is not clearly understood, there is much common ground between the general causes of discomfort glare and the effect of non-uniformity, in this study, caused by the Relative Maximum luminance within an image (RML_m). As was commonly established, discomfort glare is associated with high and excessive luminance contrasts in the visual field. According to Hopkinson *et al* (1966), the physiological cause of this sensation of discomfort glare appears to be a compound of two effects. "One is a contrast effect, which results when a light source, possibly only of moderate brightness, is seen in an environment of much lower brightness and so causes glare by contrast. The other is a saturation effect, which results when any part of the retina, even the whole retina, is stimulated by light at such a level that the maximum possible rate of neural response from the retinal elements is generated" (Hopkinson *et al*, 1966; p. 212). This phenomenon of glare could provide an explanation as to the relationship between non-uniform luminance of glare source and discomfort glare found in this study.

According to Perry (1992), the high luminance contrast is very visible. The screen images with high RML_m tended to produce high luminance contrast that became noticeable for the subjects. In this way, the area containing maximum luminance could be perceived by the subjects as an actual glare source instead of a whole scene. Although, there is no clear evidence indicating how this process affects the discomfort sensation, one of the most obvious works responding to this issue was presented by Perry (1992). As a result of his study, Perry (1992) argued that discomfort glare is involved in the saturation of contrast detection mechanism. In this process, the high contrast signals described in Perry's study tend to drive the contrast detection mechanism towards saturation. This saturation effect could possibly lead to the subjective response of discomfort.

Similarly, in this study, the high contrast signals due to the highest luminous elements in the non-uniform images would add significantly to the high contrast information present in the visual field and therefore this made the subjects more glaring from the non-uniform images than the uniform blank screen. Likewise, it could be assumed that the higher the maximum luminance in a screen image, the higher the degree of contrast of information, hence the more glaring the subject reported. This might be a reason why an increase in RML_m between non-uniform screen images could lead to an increase in the glare discomfort. Furthermore, as the maximum luminance for each screen image in this study was a minimum of 132,000 cdm^{-2}, it could be plausible that this luminance level had reached the level that the maximum possible rate of neural response from the retinal elements is generated. Accordingly, the subjects reported more glaring with the sources which contained high RML_m than the uniform source and as the maximum luminance in the screen image increases, the glare increases.

4.6.4 Conclusion

The results in this Chapter showed that an increase in interest in a small projected screen image is associated with a decrease in discomfort glare. It follows that some characteristics or physical elements in a screen image also relate to a decrease in glare discomfort. On the other hand, this sensation increases with an increase in Relative Maximum luminance a screen image contains (RML_m). The results not only support the two general hypotheses of the thesis, but they also emphasis the two more factors affecting discomfort glare— the interest in an image and the Relative Maximum luminance in an image (RML_m). In the condition where a small glare source contains some information, like projected screen images, the existing standard glare index formulae seem not to apply and, hence, a modification for the glare formulae would be required to include these two additional factors.

The results still do not imply any particular mechanism for discomfort glare; in particular there is no indication that the effect of interest is peculiar to small screen image glaring sources. The results in the laboratory showed an association between image interest and glare in highly controlled situations. It would be likely that real windows in daylighting condition would also show a similar effect. The strength of the results therefore strengthens the hypothesis that the interest in a window-view is a factor affecting the sensation of discomfort from windows— the main focus of the thesis. As a key test of the thesis, this finding also emphasises a fundamental assumption that the effect of interest is likely to be found in other cases of glare sources.

While the patterns of the results are consistent and their implications are important, it is necessary to note three particular limitations of the experiments in this Chapter. Firstly, the results of these experiments remain contingent on the range of screen images investigated for each experiment. Secondly, the subjects participating were only university students, a group of the subjects with similar in age range but distinctive in educational backgrounds. Finally, the stimuli in the laboratory studies were small projected screen images and were not real windows, and the setting was artificial. Extension of the results into those in the case of a window in a real daylighting situation remains conjectural. These provide a clear programme for the next stage of research— studies in real daylighting conditions.

Chapter 5
Studies of Real Daylighting Conditions

5.1 Introduction

The presence of a realistic view and the appearance and design of the window seem to have an effect on judgements of discomfort glare under daylighting conditions (Hopkinson, 1970; 1972; Boubekri and Boyer, 1992). The results in the previous investigation showed the significant effect of interest in a small screen image on discomfort glare. These results fortify the possibility of the effect of interest in the case of a window. When a glare source is a window, the glare source is large. Thus, the adaptation level of the eye was influenced by both the surround and source luminance. People also tend to shift their focus towards distant objects in the view through the windows, relaxing their eyes. There are components of real daylighting situations which might have an important effect on whether the condition is assessed as uncomfortable. This situation forms the question of whether the effect of interest that has been found in the case of a small screen image under a highly controlled laboratory still shows a similar effect in a case of a real window. As the main focus of the thesis, the hypothesis was that an increase in interest in a view is associated with a decrease in discomfort glare from windows.

In Section 4.5.1, another general hypothesis was proposed that discomfort glare increases with the Relative Maximum luminance in a glare source (RML). The results of the laboratory tests indicated the significant effect of Relative Maximum luminance within a small screen image (RML_m) on discomfort glare. It would also be interesting to see whether this effect would lead to a similar conclusion when using view-windows as glare sources compared with using small projected screen images. The results for this part would support this general hypothesis in another case of glare sources. The results in the laboratory also suggested significant effects of some features of image content on glare. In terms of practical implications of thesis's results on window design guidelines, it would be useful to document the effects of other factors on discomfort glare regarding view content. It would be interesting also to see whether these factors would show similar effects to those found in laboratory tests. In this Chapter, two experiments were carried out, using real windows as sources of glare in the daylighting situation. Initially, an investigation into the effect of interest in a view on discomfort glare was carried out. Based on the findings in the laboratory and the effect of view interest as well as evidence from the related readings on window-views and environmental aesthetics and perception, another experiment was performed investigating effects of view content on discomfort glare from windows.

5.2 View Interest and Glare Tolerance

5.2.1 Introduction

The main focus of the thesis was intended to be investigated in this section, using real views ranked on "interest" by an independent subject group. Since the effect of luminance variation within a window could be studied at the same time as the interest effect, this section also attempts to test another general hypothesis that discomfort glare increase with the Relative Maximum Luminance within the glare source (RML) in the case of a window. Furthermore, before the real experiment was started, a preliminary test was also taken to quantify interesting views.

5.2.2 Experimental Objectives

There are two hypotheses in this experiment. The first hypothesis is that an increase in interest in a view is associated with a decrease in discomfort glare from windows. The second hypothesis is that discomfort glare from windows increases with the Relative Maximum luminance of a window (RML_w).

5.2.2.1 Quantifying 'Interesting' View

Similar to the process within the first experiment in laboratory (effect of interest in an image on discomfort glare), "interest" was defined for a particular group of people to a specific stimulus in a particular circumstance. For this experiment, interest in a view was defined as a sensation of curiosity of subjects in response to a view in the experiment situation in which they rated the view (this preliminary test). Ten real views were selected based on the criteria that they contained physical elements and features that previous researches on window-view and environment suggested tend to have an effect on preference in a view, as reviewed in section 3.4.3. All the selected real views were randomly viewed in real rooms by twenty university students in architecture but differing in nationality and social background. The subjects were asked to assess the "interest" of each view using questionnaires with eleven-point rating scales. The views were ranked by mean score. The least interesting view was a view of a concrete wall with monotone colour. The most interesting view had three strata containing full of information with a balance between natural and man-made elements and variety in many aspects, like colours and materials.

5.2.2.2 Defining Daylight Glare Index

As already discussed in Section 2.4, "daylight glare index" in this study refers to the Hopkinson Cornell formula, the most cited large glare source formula defined as follows:

$$DGI = 10 \log_{10} 0.478 \sum \left(\frac{L_s^{1.6} \Omega^{0.8}}{L_b + (0.07\omega^{0.5} L_s} \right)$$

Where: L_s is luminance of the source (cdm^{-2}); L_b is luminance of the background (cdm^{-2}); ω is solid angle of the source (sr); and Ω is solid angular subtense of the source, modified for the effect of the position of the source relative to the observer: position index (sr).

5.2.2.3 Defining Relative Maximum Luminance of the window (RML_w)

'Relative Maximum luminance of the window' (RML_w) is defined as the ratio between maximum luminance (L_{max}) to an average luminance within the window (L_s).

View	Interest scores		View	Interest scores	
	Mean	SD		Mean	SD
	5.56	1.07		3.86	1.19
	5.22	0.88		3.83	0.88
	4.31	0.99		3.76	1.13
	4.07	1.07		2.54	0.54
	3.90	1.28		1.83	0.54

Figure 5.1: Ten views used in the preliminary test of the first experiment and their interest scores

5.2.3 Methodology

5.2.3.1 Experimental Settings and Conditions

As mentioned earlier in Section 2.4, in this thesis, it was attempted to control as many extraneous variables as possible. For this purpose, instead of using real rooms, the experiment was, therefore, conducted within two identical test rooms without typical furniture arrangements and no task was required for subjects to perform. The rooms were located at the Faculty of Architecture, University of Sheffield, UK at latitude 53° 27'N, longitude 1° 484'W. Each test room was 4.00m deep by 3.00m wide and 3.00m high and accommodated four tall windows with a frame on each one. There were Venetian blinds in front of each window to control the light from outside. To ensure that there was no bright area in a subject's field of view except from the view outside that could be seen through the test window, all the blinds were completely closed except those in front of a test window. The blind in front of the test window was closed until the position of the window frame so that the window area was considered only below the frame and therefore, the actual size of test window was 0.80m wide and 1.00m high. Moreover, behind all the blinds, think matt-opaque papers were mounted covering all the windows until the position that the blinds were shut— the window frame for the test window and the window sills for the rest.

All rooms were furnished identically. The ceiling was matt white with reflectance p(R) =0.8, the walls p(R) = 0.6, and the floor p(R) = 0.2. The subjects were seated facing the test window at the distance of 2.00 m from the window plane to evaluate discomfort glare. The weather condition in this experiment was a mixed weather, with periods of both rain and sunshine. Figure 5.2 illustrates the view of experimental settings within the test room. Figure 5.3 illustrates a lay-out of experimental settings.

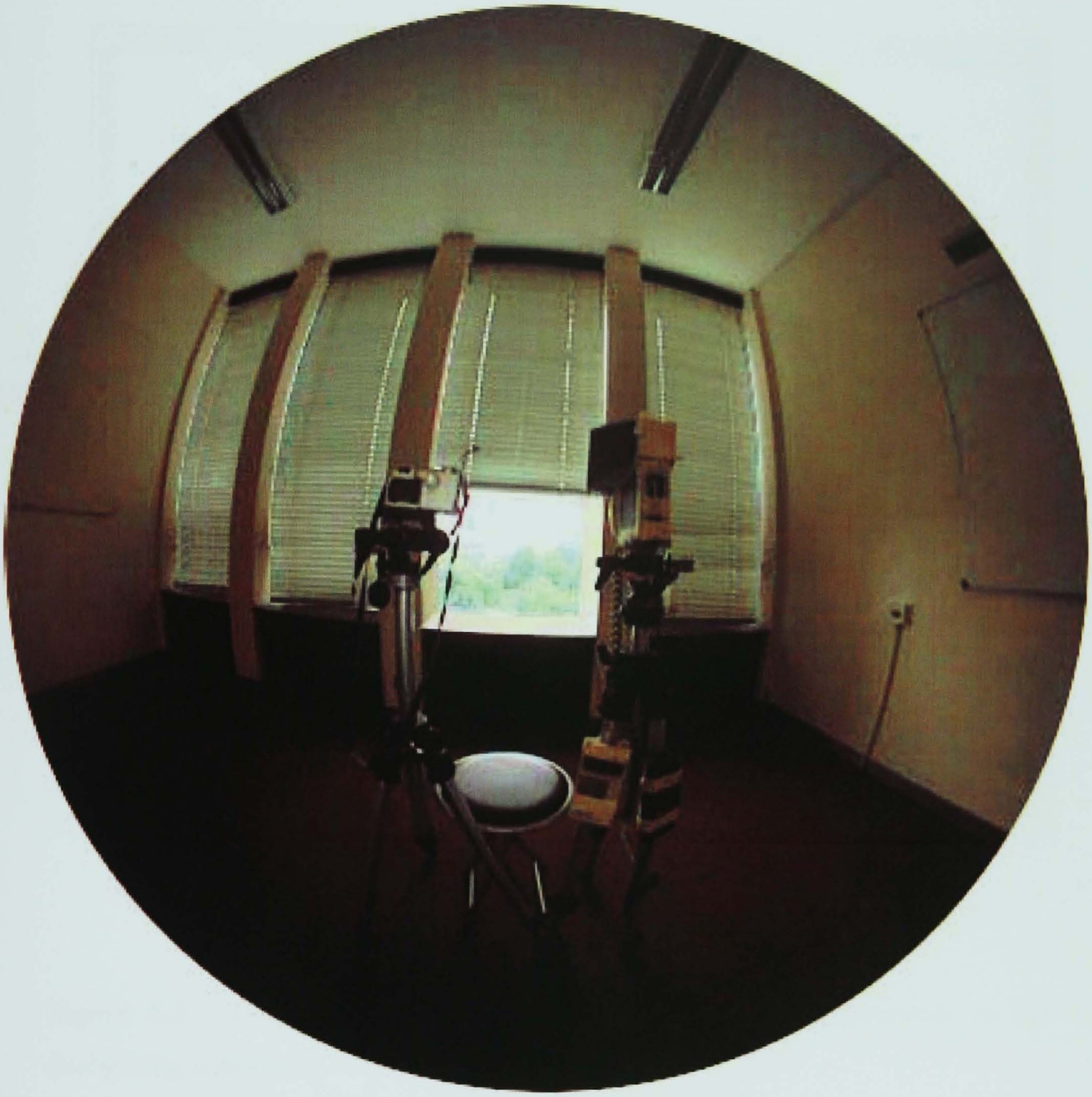

Figure 5.2: View of experimental settings of experiments in the real daylighting conditions

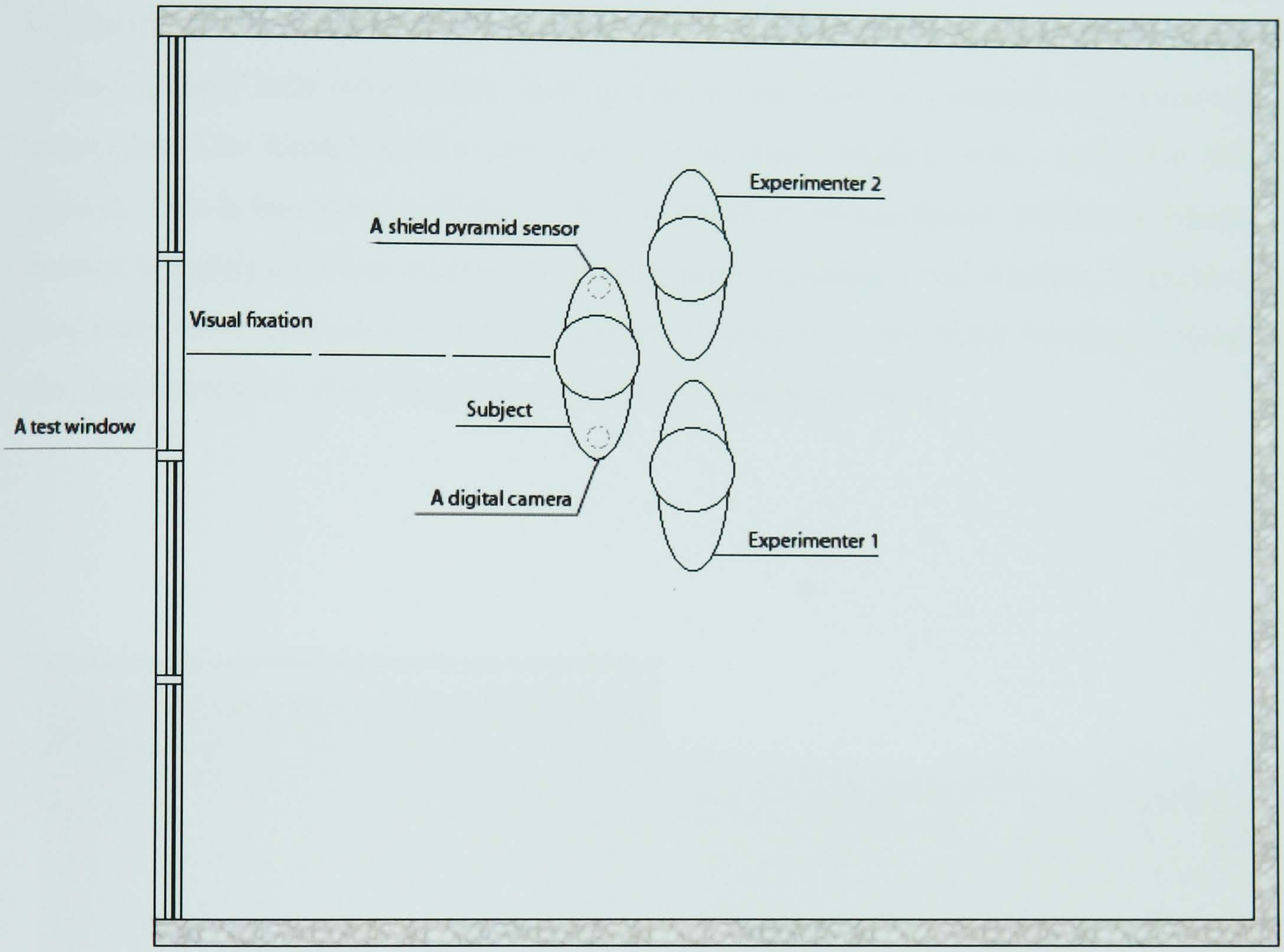

Figure 5.3: Lay-out of experimental settings of the first experiment in the real daylighting conditions.

5.2.3.2 Stimuli Variations

In the process of quantifying interesting views, the degree of interest in each view was obtained. The two most extreme interesting views were used in the experiment – the most interesting and the least interesting views. In general, a view through a window, even those containing very little information, such as a brick wall view or a concrete wall view could be interesting. The blank window was used to represent a window with a real view with zero interest. This is because a real view with zero interest was not found. The blank window was created by using a diffuse translucent tracing paper covering a real window. Therefore, three treatments were presented in this experiment. Treatment 1: the blank window. Treatment 2: the least interesting view. Treatment 3: the most interesting view.

Figure 5.4: Views that were used in the first experiment in the real daylighting conditions. Left picture is the least interesting view and right image is the most interesting view.

For the effect of Relative Maximum luminance of the window (RML_w), only two views, the least interesting view and the most interesting view were explored. This is because there was shown to be a variation in the Relative Maximum luminance (RML_w) within these two stimuli due to sky conditions and the time of day. The blank window was excluded because in this stimulus there was no variation in the Relative Maximum luminance within a window (RML_w). This value was measured at the same time that the subjects evaluated the glare.

5.2.3.3 Experimental Equipment and Measurements

There are two main photometric measurements: 1) DGI value measurement, 2) Relative Maximum luminance value measurement.

a. DGI Parameters Measurements

To identify the value DGI, all physical values were monitored and calculated following the methodology proposed in the IEA SHC Task 21 'Daylighting in Buildings' work programme[11] (IEA SHC Task 21/ ECBCS ANNEX 29, 2000, Aizlewood, 1998).

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[11] Task 21 is one of the Research Tasks carried out by IEA SHC researchers, the International Energy Agency Solar Heating and Cooling Programme (IEA SHC). There are two main aims of Task 21. The first aim was to advance daylighting technologies. The second aim was to promote daylight conscious building design. Important elements in the task are: 1) established international procedures for evaluation of the performance of conventional design solutions and innovative daylighting systems as well as performance of daylight responsive lighting control systems; 2) established international procedures and protocols for monitoring the daylighting performance of real buildings including the assessment of users' opinion of their working environment.

Source Luminance

Rather than attempting to make a difficult series of frequent spot luminance measurements in the test rooms, measurements of the luminance of the window (L_s) was derived from the vertical illuminance (E_s) measured by an illuminance meter covered by a shield in a pyramid shape, so that it only received light from the window source as follows:

$$L_s = \frac{E_s}{\pi \Phi}$$

Where:

E_s is the vertical illuminance measured by a shielded iluminance meter at the point of interest.
Φ is the configuration factor of the glare source with respect to the measurement point. According to Siegel and Howell (1972) and Nazzal and Chutarat (2000), it is calculated as follows:

$$A = \frac{X}{\sqrt{1+X^2}} \qquad B = \frac{Y}{\sqrt{1+X^2}}$$

$$C = \frac{Y}{\sqrt{1+Y^2}} \qquad D = \frac{X}{\sqrt{1+Y^2}}$$

$$\Phi = \frac{A\arctan B + C\arctan D}{\pi}$$

$X = a/2d$

$Y = b/2d$

Where: a is the width of the window (m)

b is the height of the window (m)

c is the distance from the observation place to the center of the window area (m)

The shape of the shield was calculated according to window dimensions and the distance between source and meter (see the position of the pyramid below). The illuminance meter was located at the center of the pyramid.

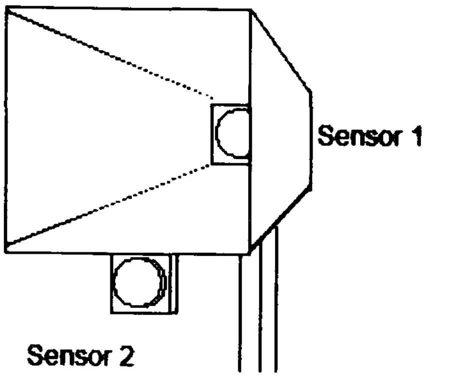


Figure 5.5: A pyramid of black card (shielded/unshielded sensors) to be used to calculate the DGI

Background Luminance

The background luminance, L_b, is the average luminance of interior surfaces of the room, which contributed to the visual field of the observer. It is defined as the luminance of the whole surroundings which produces the same illuminance on a vertical plane at the observer's eye as the visual field under consideration excluding the glare source. L_b is derived as follows:

$$L_b = \frac{E_{un}-E_s}{\pi\,(1-\Phi)}$$

Where:

E_s is the vertical illuminance measured by a shielded iluminance meter at the point of interest

Φ is the configuration factor of the glare source with respect to the measurement point

E_{un} is the vertical illuminance measured by an unshielded iluminance meter at the point of interest. The unshielded illuminance meter was placed below the pyramid (see Figure 5.5).

These two meters were Minolta T-10 illuminance meter, Serial No. 31021014 for the shielded one and Serial No. 36721015 for the unshielded sensor. Measuring range is 0.01-299,999 lux and the error is +2% or + 1digit of value display. The unshielded meter was calibrated on June 15, 1992 with a Calibration certificate No. 9229-1876-21. The shielded meter was calibrated on Sept 20, 2002 with a Calibration certificate No. 9882-1136-22.

The solid angle subtended by the window, modified by the position index (Ω)

According to the IEA SHC Task 21, the solid angle subtended by the window, modified by the position index of the window is calculated using:

$$\Omega = \sum [d\omega_i \, . \, P_i]$$

Where:

ω_i are the solid angles of elements of the window

P_i are the position indexes of those elements

There is no advice in the literature as to how many segments of the window should be divided into when calculating Ω . The window was therefore divided into twenty segments in a 5x4 arrangement. The solid angles of elements of the window (ω_i) and the position indexes (P_i) were calculated from the equations in Luckiesh and Guth (1949) and Petherbrige and Longmore (1954) respectively.

The solid angle subtended by the glare source to the point of observation (ω)

The total solid angle can be calculated both by summation of twenty segments of divided window and by an undivided windows. However, as the number of segments is large, there is an essential influence of the number of segments on ω. Many researchers suggested using the calculation for whole windows (IEA SHC Task 21/ ECBCS ANNEX 29, 2000, Aizlewood, 1998). The calculation for a whole window was thus used using the equation:

$$\omega = \frac{A \cos \theta . \cos \varphi}{d^2}$$

Where:

A is the window area (m^2).

d is the distance from the viewpoint to the center of window area (m).

θ, φ are the angles between the line of sight and the centre of the window area.

To avoid an error due to the frequent fluctuation of daylight which is much higher than an error due to position deviations, the measurement was conducted at the same time the subject evaluated discomfort glare instead of right after subject evaluation. It is impossible to record the values at the same position as the subject's seating point— 2.00m. perpendicular to the centre of window with 1.20 m. above the floor. The position of this pyramid of black card was at 10 cm. to the right from a seating point and pointing towards a window (the shape of the pyramid was calculated regarding this point). However, there might be an error in the DGI recorded at this position. We carried out a test assessing whether vertical illuminance recorded at 10 cm deviation to the right (using unshielded sensor) is different from those at the subject's seating point (using another illuminance meter). The results from *t*-test showed no significant difference and hence, there should not be significant error of the DGI regarding this position of the measurement. After collecting and calculating all physical values obtained from the pyramid, daylight glare index for an individual assessment was calculated based on the Hopkinson-Cornell large-source formula.

b. Relative Maximum Luminance of Window Parameter Measurements

There are two parameters in determining Relative Maximum luminance value (RML_w) of the window: its maximum luminance (L_{max}) and average luminance (L_s). The average luminance of window (L_s) could use the same data as those measured to calculate the DGI. However, as a result of different patterns of luminance distributions across the window according to fluctuating daylighting conditions, it is impractical to represent the maximum luminance within the window with measurements conducted with luminance spot meters. This limitation is due to the difficulty of setting a specific position for recording maximum luminance at a time the subject evaluates the glare. A CCD digital camera, used in conjunction with a specific software— Photolux— converts signal level to be an actual luminance, is the proposed method in this study to record maximum luminance values for each evaluation. This method has been proposed and widely used in both lighting research and commercial mapping of luminance values and calculating lighting measures, such as the maximum and average luminances of the scenes, within a short time span (Coutelier, 2002).

Experimental Equipments

The digital CCD camera that has been used in this study is a Nikon Coolpix 990. It was fitted with a 'fish-eye' lens, model FC-E8, allowing a 180° representation of a scene centered on the optical axis of the digital camera. The Nikon Coolpix 990 with a FC-E8 fish-eye lens was used because it is one of a range that can be used in conjunction with the Photolux software, for example Coolpix 5000; Coolpix 5400 ; Coolpix 990, and was available at the School of Architecture in the University of Sheffield. This digital camera has a 3.34 Million pixels CCD sensor and delivers images with a resolution of 2048 by 1536 pixels. The camera saves images using an extension of the TIFF format called EXIF (for Exchange Image File). This format allows saving of all the settings information with the image and particularly the exposure value, essential for when we want to use the camera as a luminance-meter. These pictures were saved on a CompactFlash™ card as TIFF files. For the most accuracy, the camera was calibrated with the Photolux software. Due to both time and cost limitation of this study, it was not possible to send the camera to be calibrated. However, without this calibration, the possible errors of the data are very small and certainly less than 10%. The errors of the data were also checked indicating that the errors were much less than experimental effects in this experiment (the errors for the next experiment were also checked showing the errors were much less than experimental effects as well).

Figure 5.6: Nikon Coolpix 990 CCD Camera

The software that has been used in this study is called Photolux, version 1.3.5. It was developed by the Lighting Research Group of I'Ecole Nationale des Travaux Publics de l'Etat (ENTPE), in Lyon, France. The Photolux software produces luminance maps from the pictures of the camera and presents luminance values using a colour code. It can also calculate minimum, maximum, average values of luminances and its standard deviations of real scenes, as well as their resulting illuminance. To produce all the measures, the software is based on calibration functions of the pixel brightness levels of the digital image taken through a digital camera and the actual luminance values of this scene. The calibration and the validation of the Nikon Coolpix 990 were described elsewhere (Coutelier and Domortier, 2002; 2003). This software allows recording and to reproduction of luminances from 10 cd/m^2 to 100,000 cd/m^2.

The quantity of light, which reaches the CCD of the camera, depends not only on the brightness of the scene but also the settings used to take the pictures: the aperture and the time during which it was opened (shutter speed). The combined influence of both settings is often expressed using an index called the "Exposure Value (EV)". The aperture is proportional to the square of its value: $1/f^2$, when focal length is constant and if v is the shutter speed, the quantity of light reaching the CCD is proportional to v/ f^2. Thus, if the sensitivity and the gain of the sensor are constant, the information provided by the CCD only depends on this ratio. This function is shown below:

$$EV= 3.32 \log 10 (f^2/v)$$

The relationship between the pixel brightness levels and the actual luminance values differs with the exposure value. To cover all the ranges of luminances that would possibly occur in the real scene taken through the Coolpix 990, for example the sky luminance in a bright day, it is necessary to take different pictures with different exposure values for each evaluation. Based on an exposure a Table of Coolpix 990, these exposure values (EV) are set for 9 different values. All the pictures were recorded with a resolution of 2048 by 1536 pixels and stored on the memory card of the camera. The pictures were then transferred to the computer on which the Photolux software had been installed. The software combines all the pictures of the same scene to produce a luminance map and all statistics values. An example of luminance map and statistics values of a view that has been used has shown in Figure 5.7. By this method, the maximum luminance within the investigated window can be obtained.

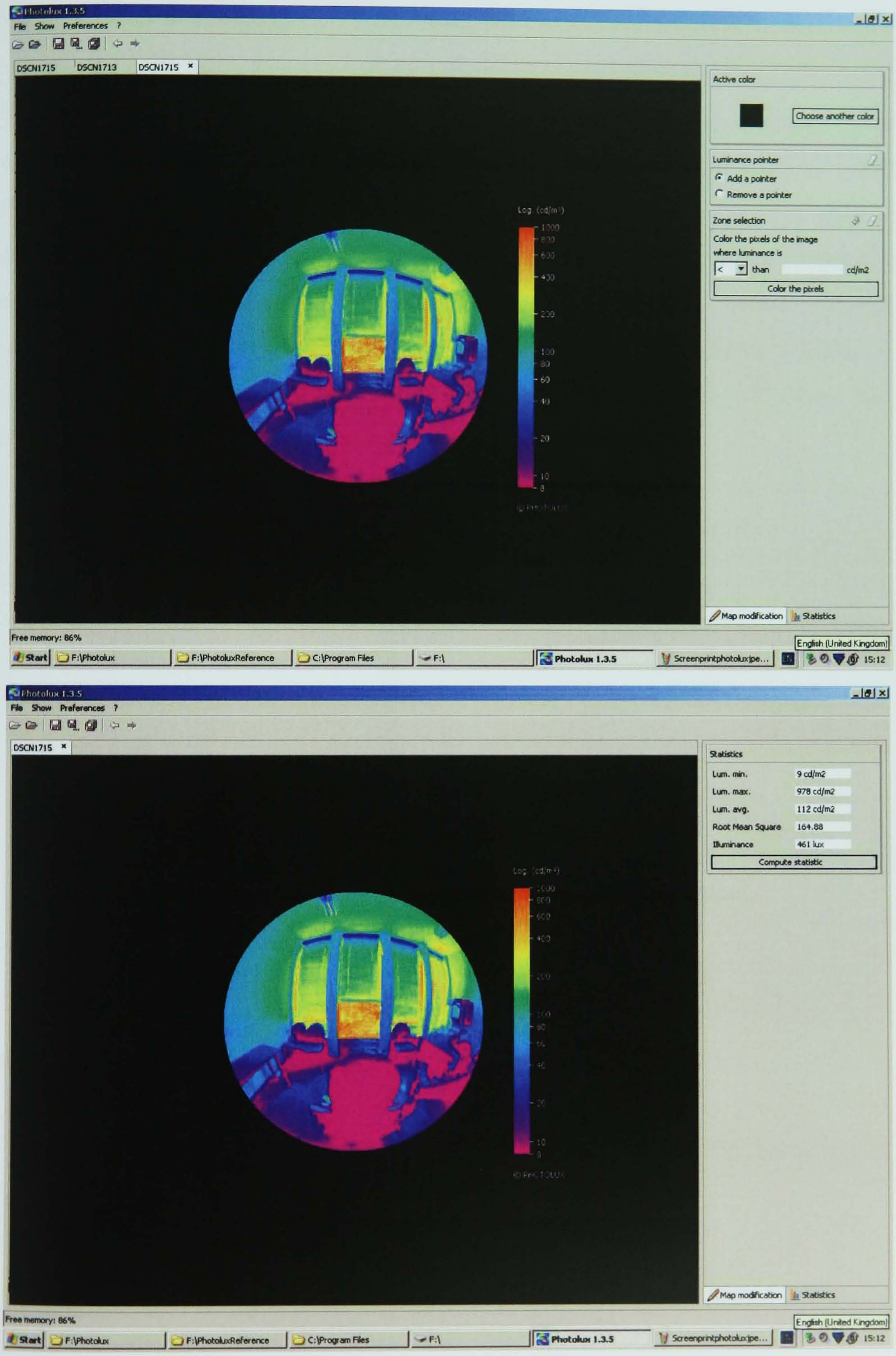


Figure 5.7: luminance maps and statistic values obtained from Photolux

Measurement Procedures

The photograph was taken with the use of a tripod stand to ensure a perfect horizontal and vertical level of the lens. Similar to the measurement for the DGI, to avoid an error due to the frequent fluctuation of daylight which is much higher than an error due to position deviations, the measurement was conducted at the same time the subject evaluated the degree of discomfort glare instead of right after subject evaluation. The camera with fish-eye lens was therefore placed on a tripod as near to the subject seating point as possible— 10 cm. to the left from a seating point and pointing towards a window. The position of the camera is shown below.

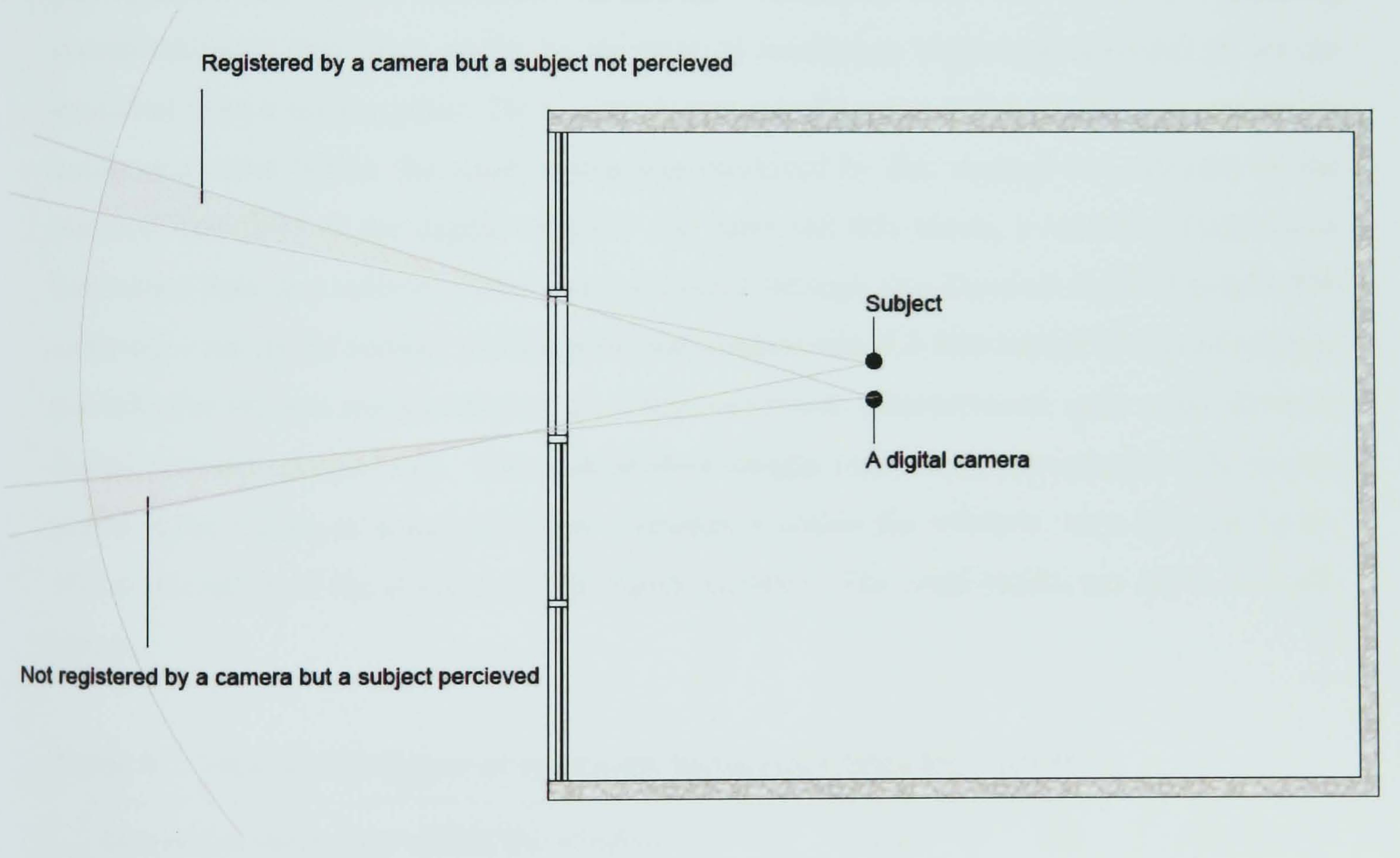


Figure 5.8: Plan illustrating positions of subject seating point and a CCD camera

According to the position of the camera, there are two issues that need to be considered. As it can be seen in the figure above, the first issue is that there were some areas in the view as perceived by subjects, which might contain a maximum value of luminance which could not be registered by the camera. Also, there were some areas in the view outside that are registered by the camera, but were not seen by the subjects. With a viewing distance of 2.00m from the windows, these areas were few in potential. A check was also carried out before the experiment began that there were not any bright elements located within these areas.

The different positions of a digital camera used to record a photograph of the views may result in different brightness of the pictures hence alter their actual luminance values. The photograph may show different luminance. Therefore, the second issue requiring consideration is that there might be an error in maximum luminance recorded at 10 cm deviation from a seating point. Thus, a check was carried out to assess whether the maximum luminance value within the window that was produced by this method was affected by the position deviation of the digital camera. To carry out this check, a test set of maximum luminance data in a reference view was measured through two identical digital Coolpix 990 cameras— one at the subject seating point and another one at 0.10m beside this point towards the left. For the test measurements, the thirty luminance measurements were made for both digital cameras concurrently. Two independent sample *t*-tests were performed on the data to assess if the values of actual maximum luminance within the window were affected by the 10-cm deviation of the position of the digital camera. The *t*-test results are given in Table below.

Table 5.1: *t*-test for the degree of maximum luminance within the window

Maximum luminance within the window	Mean	SD	*p*-value
Subject seating point	12300.49	13668.89	0.994
10-cm deviation	12273.41	13662.92	

** indicates the difference between mean values is highly significant (*prob*<0.01) in a two-sample *t*-test
* indicates the difference between mean values is significant (*prob*<0.05) in a two-sample *t*-test

The results have shown that there is no significant difference between the maximum luminance at the seating point and that at the 10-cm deviation to the left, even at the 10 % significance level. This confirms that there is not significant error of maximum luminance when we position a digital camera at this point to take a photograph.

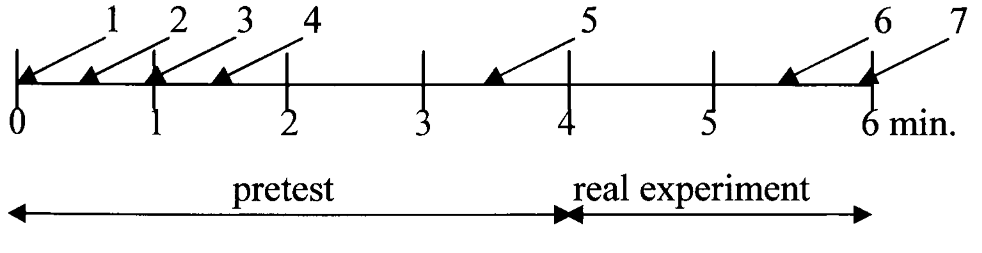
5.2.3.4 Experimental Design

a. Experimental Design and Testing Procedure

The experiment took part during three weeks of May 2005. Since this period was a term-time period, each room could not be used for this experiment at the same time and it was possible to get only very few numbers of subjects to come to all the treatments. Therefore, the experiment was designed to let one subject experience only one treatment and to use a randomization method. In each week, twenty-four subjects took part in each treatment. The experiment began with treatment 1 in the 1st week of May until treatment 3 in the 3rd week. Subjects were randomly selected from students in the University of Sheffield. Then, the subjects were randomly assigned to treatments. By using randomization, subject variables and other effects due to people comprehending the experiment, fatigue and other unknown nuisance variables could be minimized. It should be noted that, even with randomization, there might be a possibility that some subject variables affecting discomfort glare, gender and the use of spectacles, were distributed unevenly across treatments, and therefore affected our results. The effect of gender and the use of spectacles were checked in this experiment and the results of this check are shown in Section 5.2.4.

There are two periods in this experiment, the pretest period and the real experiment. In the pretest period, the procedure was similar to that described in all experiments in the laboratory but with a different aim (see Appendix E). This process began by getting the explanation of the study and completing informed consent form. Then, each subject was required to complete the pre-study questionnaire. This was followed by the giving of instructions containing the definition of glare, the meaning of criteria and the procedure trial used in the pretest period and the real experiment period. The experimenter then demonstrated her own evaluation on a test window and subjects performed one trial of their evaluation with a similar procedure as the real experiment. They were required to do five evaluations of discomfort glare from a test window and each evaluation had a 30 second interval. Then, they were asked to relax for about two minutes.

In the real experiment period, two experimenters were ready to take photographs and record light levels, positioned behind the camera and a pyramid of black card (shielded/unshielded sensor). Firstly, the subject was asked to look at the centre of the window containing the outside view. After 30 seconds of adaptation, the presenter asked the subject to evaluate the glare level on the GSV scale on the questionnaire as well as send a verbal signal by saying 'yes' to the two experimenters. Concurrently, one experimenter took photographs with nine different exposures and another experimenter recorded light levels— the shielded and unshielded illuminance values. One evaluation took about 6 minutes. All the procedures used in this experiment are shown below.



1. A subject entered the chamber and took a seat.
2. The subject got an explanation form, completed an informed consent form, and general information. Then, all procedures were described to the subject.
3. An experimenter demonstrated her own evaluation on a test window.
4. The subject made five evaluations of discomfort glare from a test window.
5. The subject relaxed for about two minutes.
6. The subject was asked to fix eyes at centre of window and adapts to luminance of the environment for 30 seconds.
7. The subject completed questionnaire.

b. Subjective Assessment of Discomfort Glare

Like laboratory experiments, a glare sensation vote (GSV) connected to an approximate period of time for which the degree of discomfort glare is tolerable was used. Subjects were provided written descriptors for each of these sensations and did an example test in the pretest period. Also, the keywords of each sensation were displayed in all recording sheets. A vote could be made by marking a tick at any point on the line of the continuous scale. The Glare sensation vote (GSV) value is defined as the value marked by subjects on this scale. For a full description of the scale, please see in Appendix E. After the GSV was recorded, all the data was converted to be the same scale as the DGI scale. In this study, this converted GSV data was called 'GRV' or 'Glare Response Vote'. This is more logical and makes it easier to see an effect of the variable investigated by taking the relationship of GRV against DGI, which is the same unit as DGI[12]. According to Tokura et al. (1996), converting from the scale of GSV to the same scale DGI scale uses the data of corresponding DGI values tabulated below:

Table 5.2: Degree of discomfort glare and corresponding GRV and DGI

Degree of discomfort glare	GSV	DGI
Just (im)perceptible	0	16
		18
Just acceptable	1	20
Borderline between Comfort and Discomfort	1.5	22
Just uncomfortable	2	24
		26
Just intolerable	3	28

Therefore, GSV can be converted into the DGI scale using the following equation: GSV= (DGI-16)/4. GRV was derived as follows: GRV= 4GSV+16.

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12 The data would be used later to make a modification to an existing daylight formula by taking the additional effects of interest in a view and the Relative Maximum luminance in a window (RML_w) (see Appendix A).

c. The Observers

Seventy-two subjects involved in this experiment. All were university students between 18 and 31 but varying in nationality and cultural background. Forty of them were men and thirty-two were women. Spectacles were worn by twenty men and fifteen women. Other eye defects or colour-blindness were not reported. All subjects were paid for their participation.

5.2.3.5 Statistical Analysis

a. Statistical Analysis for Tests of Significance for Difference in Regressions Lines

To test the hypothesis that an increase in interest in a view is associated with a decrease in discomfort glare from windows, comparisons between the regression lines of the relationship between the DGI and GRV were made. The data was fitted using a Linear Regression analysis and a one-way between subjects analysis of covariance (ANCOVA) was used to see whether these lines are significantly different. The ANCOVA was used instead of ANOVA. This is because in this experiment the Relative Maximum luminance within a window (RML_w) can not be controlled. By using ANCOVA, the Relative Maximum luminance within a window (RML_w) was analyzed as a covariate and this effect can be eliminated from our results. After that, a Sidak *t*-test for multiple-group comparisons was also employed.

b. Statistical Analysis for Measure of Association and their Tests of Significance

To test the hypothesis that discomfort glare increases with the Relative Maximum luminance of window (RML_w), three steps are necessary. Firstly, we assume that if discomfort glare increases with an increase with the Relative Maximum luminance in window (RML_w), a relationship would exist between an increase in the Relative Maximum luminance of window (RML_w), and an increase in the ratio between GRV and DGI. Then, the ratio between GRV and DGI for individual assessment was taken. Finally, the relationship between the Relative Maximum luminance within window (RML_w) and the ratio between GRV and DGI was drawn up and a Pearson correlation coefficient (r) was determined and tested as to whether the correlation was significant.

5.2.4 Results and Conclusion

The ANCOVA showed a highly statistically significant difference among three regression lines ($p<0.01$). This means that the effect of interest in a view on discomfort glare from window was significant. The Sidak t-test revealed that the most interesting view is significantly less glaring than a blank window ($p<0.01$). It also showed that the least interesting view is significantly less glaring than a blank window ($p<0.01$). The results have shown not only that a highly significant difference was found between view treatments and the control treatment, but it also shown that the most interesting view is significantly less glaring than the least interesting view ($p<0.01$). Figure 5.9 shows the relationships between DGI and GRV for three treatments.

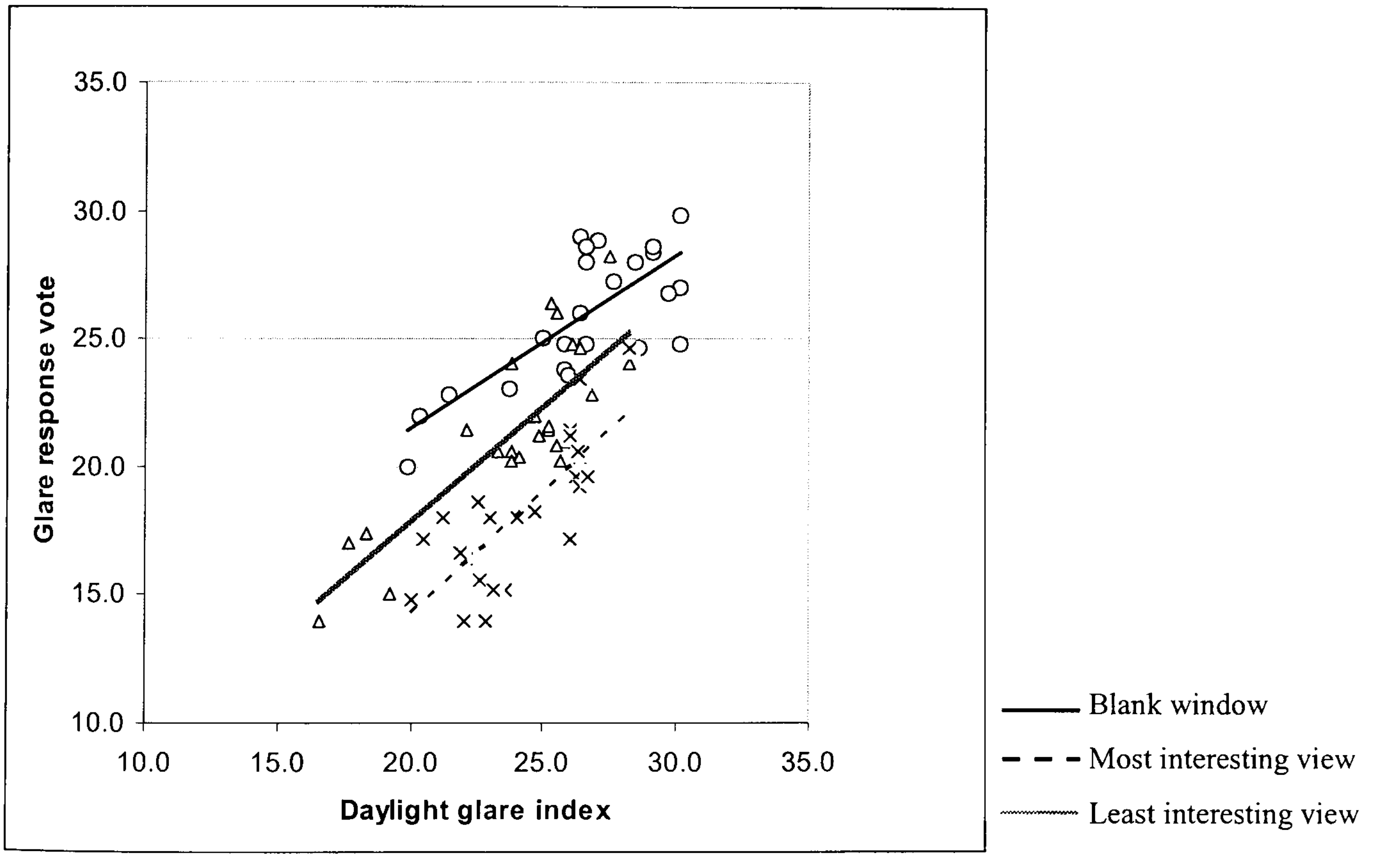


Figure 5.9: Daylight glare index (DGI) calculated versus glare response vote (GRV) judged by subjects for a blank window, least interesting view, and most interesting view. The horizontal axis represents the calculated daylight glare index, the vertical axis represents the Glare response vote reported by subjects (GRV). ○ uniform blank window, Δ window with least interesting view, × window with most interesting view. The lines are trend lines of the fitted function.

Table 5.3: Correlation coefficients, r, between Relative Maximum luminance of a window (RML_w) and the ratio of GRV and DGI (GRV/DGI) for two views.

Treatment	N	r
Least interesting view	24	0.863**
Most interesting view	24	0.721**

** Correlation is significant at the 0.01 level (one-tailed)
* Correlation is significant at the 0.05 level (one-tailed)

The correlation between RML_w and the ratio of GRV and DGI for both views are highly significant ($p<0.01$). It can be concluded that discomfort glare increases with the Relative Maximum luminance of the window (RML_w).

It should be noted that this experiment took place in test rooms under clear sky and overcast sky conditions, and no direct sun was perceived by the subjects. The colour temperature of the sky could not be controlled in this study. However, there is still no clear conclusion drawn the effect on discomfort glare of colour temperature of the sky. Hence, the above effect is not taken in to consideration in this thesis.

As mentioned in Section 5.2.3.4(a), in order to ensure that the effect of gender and use of spectacles can be controlled by the use of randomization, these two variables were checked as to whether these two factors were distributed evenly across treatments. A Binomial statistic and Chi-square, goodness of fit test, were used to see whether there is a significant difference between male and female subjects and between subjects with and without glasses or contact lenses in each treatment. The results are shown below.

Table 5.4: A Binomial Statistics for the effect of gender in the first experiment

Gender	Treatment		
	Blank window	Least interesting view	Most interesting view
x	13	13	14
p-value	1.458	1.458	1.692

** The binomial test showed highly significant results (two-tailed)
* The binomial test showed significant results (two-tailed)

Table 5.5: A Chi-square Statistics for the effect of gender in the first experiment

Treatment	E	O	$(O-E)^2$	$(O-E)^2/E$
Blank window	12	13	1.00	0.08
Least interesting view	12	13	1.00	0.08
Most interesting view	12	14	4.00	0.33
χ^2				0.50
p-value				NS

** The test was showed highly significant difference from a Chi-square test
* The test was showed significant difference from a Chi-square test
NS The test was showed no significant difference from a Chi-square test

Table 5.6: A Binomial Statistics for the effect of the use of spectacles in the first experiment

The use of spectacles	Treatment		
	Blank window	Least Interesting view	Most Interesting view
x	11	11	13
p-value	0.838	0.838	1.458

** The binomial test showed highly significant results (two-tailed)
* The binomial test showed significant results (two-tailed)

Table 5.7: A Chi-square Statistics for the effect of the use of spectacle in the first experiment

Treatment	E	O	$(O-E)^2$	$(O-E)^2/E$
Blank window	12	11	1.00	0.08
Least interesting view	12	11	1.00	0.08
Most interesting view	12	13	1.00	0.08
χ^2				0.25
p-value				NS

** The test was showed highly significant difference from a Chi-square test
* The test was showed significant difference from a Chi-square test
NS The test was showed no significant difference from a Chi-square test

Entering a table of Binomial distribution (Seigal, 1956) at a value of x in each treatment and N=24, the critical values for each treatment were obtained and it was found that all of them are not less than 0.05. Moreover, for the Chi-square test, by consulting the table of the Chi-square distribution (Cohen and Holladay, 1982), the critical value for $\chi^2 = 5.99$ when df= 2 and $\alpha = 0.05$, and the critical value for $\chi^2 = 9.21$ when df= 2 and $\alpha = 0.01$. The obtained values for χ^2 do not exceed the critical value of χ^2 where $\alpha = 0.05$. By using the two statistics, no significant difference was found between male and female subjects and subjects with and without glasses or contact lens in each treatment. This means that in this experiment the use of randomization is enough to control these two factors.

In summary, it can be concluded that an increase in interest in view is associated with a decrease in discomfort glare from windows. On the contrary, discomfort glare increases with Relative Maximum luminance within the window (RML_w).

5.3 View Content and Discomfort Glare

5.3.1 Introduction

In the previous experiment, it was shown that an increase in interest in a view is associated with a decrease in discomfort glare. It would be interesting and useful to know what content of a view affects the glare discomfort as this information would benefit to window design guidelines for reducing discomfort glare from windows. As already mentioned in Section 3.4, it appears that there is a strong link between inclusion of features and physical elements in a view and discomfort glare. If interest in a view does affect discomfort glare, and interest in a view is influenced by some specific factors in a view, then these factors would be also expected to affect discomfort glare. Thus, this experiment aims at exploring the effects of content of a view outside that could have an effect on view interest. It can be seen in Section 3.4.3 that there are many view-related factors which could have an effect on interest in a view. Due to limitation of the time of study, only two factors were investigated, the naturalness of a view and the horizontal stratification of a view. These two factors were chosen to be investigated because, with regards to view content, these two factors seem to have important effect on discomfort glare. It can be seen by the results in the laboratory that by using small projected screen images that the naturalness of image and the horizontal stratification of an image are associated with a highly significant reduction in glare.

Another aim in this experiment is to explore the effect of Relative Maximum luminance within a window (RML_w) on the sensation of glare discomfort. The result from the first experiment (effect of interest in a view on discomfort glare) suggested the question of whether a similar conclusion could be drawn with different contents within scenes.

5.3.2 Experimental Objectives

Two main aims in this experiment have been identified. The first is to investigate whether a natural view is less glaring than an urban view and whether a view with three stratifications is less glaring than a view with one middle layer as well as whether there is an interaction effect between the naturalness of a view and view stratification. The second is to investigate whether discomfort glare increases with Relative Maximum luminance within a window (RML_w).

For the first aim, two factors were defined as follows:

1. The naturalness of a view, in this experiment, refers to the total amount of combination between natural elements and man-made elements in a view. This factor depends on how much the view is made up of natural elements and man-made elements. Like the laboratory experiments, five levels in the degree of the naturalness of a view have been defined, which are all natural, mostly natural, neither natural nor urban, mostly urban, and all urban view. All the definitions of each category of view were similar to those in the experiment investigating the effect of naturalness of an image on discomfort glare (Section 4.4.2.2). For example, all natural view refers to a view that contains all natural elements and features, with no human influences. In this experiment, only two extreme levels were chosen for study, which are all natural view and all urban view.

2. Markus (1967a and b), defined the characteristics of these three horizontal layers of the view as stratification. In this study, stratification of a view refers to the characteristics of three horizontal layers of a view. As it is already described in Section 4.4.2.2, Markus (1967a and b) and Lynes (1974) claimed that this characteristic consists of three elements— the sky, the middle layer of cityscape/landscape, and the foreground.

Similarly to the investigation of the effect of image stratification on glare, the variations of stratification of a view in terms of the variation of the visible amount of each layer were employed. The classification corresponded to the views as seen from different levels of a building. This process was done by taking the ratio of visible amount of sky, cityscape and ground within the view. Six levels of view stratification have been proposed, which are a view with only one layer of a whole sky; a view with only ground, a view with only a layer of middle layer; a view with one-third of sky and two-thirds of cityscape/landscape; a view with two-thirds of the middle layer and one-third of ground; and a view with one-third of sky, one-third of cityscape/landscape, and one-third of ground. In this experiment, only two types of views were selected to study, which are a view with only the middle layer of cityscape/landscape and a view with three parts with the same amount. The reason for this is that a view made entirely up of middle layer may contain urban and natural information and such a view is relatively easy to find from the experiment building, while a view with the sky only is believed to be of little informative value and the view of the ground only is difficult to find from any building. The view has three layers chosen because it is believed to have the best characteristics of view as stated by Lynes that a balanced view should include balanced portions of all three layers (Lynes, 1974).

For the second aim of this experiment, similarly to the definition given in the previous experiment, 'Relative Maximum luminance of a window' (RML_w) is defined as the ratio between maximum luminance (L_{max}) to an average luminance in a window (L_s).

5.3.3 Methodology

5.3.3.1 Experimental Settings and Conditions

The experiment was conducted within four identical test rooms without furniture arrangements and no task was required for subjects to perform. The rooms were located at the Faculty of Architecture, University of Sheffield, in Sheffield, UK. Each test room was 4.00m. deep by 3.00m. wide and 3.00m high and accommodated four tall windows with a frame on each one. All rooms were furnished identically, with reflectance for the ceiling

$p(R)$ =0.8, the walls $p(R)$ = 0.6, and the floor $p(R)$ = 0.2. They were set with Venetian blinds and mounted with think matt-opaque papers with the same characteristics as the first experiment. The subjects were seated facing the test window at the distance of 2.00 m from the window plane to evaluate discomfort glare. The weather condition in this experiment was a mixed weather, with periods of both rain and sunshine.

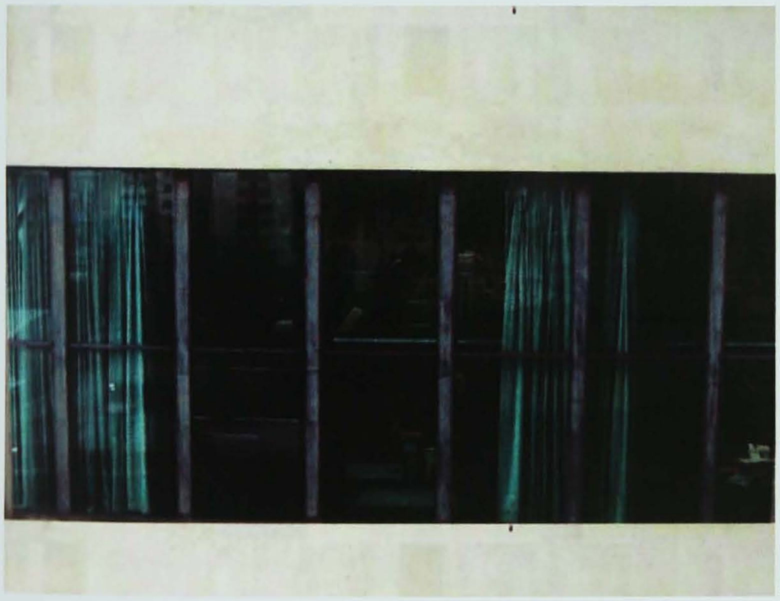
5.3.3.2 Stimuli Variations

As earlier stated, for the effect of the naturalness of a view (A), only two extreme levels were chosen which are all natural and all urban. For the effect of view stratification (B), only two levels were chosen, which are a view with only one layer of the middle layer (cityscape or landscape) and a view containing all three layers. These variables combine to make 4 possible treatments as follows. Treatment 1 contains a single layer and this view is all natural (a natural one-layer view). It does not contain any urban information, only natural. Treatment 2 is a natural three-layer view. This view contains only natural elements as well and has all three strata. Treatment 3 is an urban one-layer view. This view contains only man-made elements. Treatment 4 is an urban three-layer view. This view contains only man-made elements and has all three strata. All views that were investigated in this experiment are shown in Figure 5.10.

For the effect of Relative Maximum luminance of a window, all four views were explored. This value of Relative Maximum luminance in the window was measured at the same time the subjects evaluated the glare.

Picture A

Picture B



Picture C

Picture D

Figure 5.10: Views that were used in the second experiment in the real daylighting conditions. Picture A is a natural one-layer view. Picture B is a natural three-layer view. Picture C is an urban one-layer view. Picture D is an urban three-layer view.

5.3.3.3 Experimental Equipment and Measurements

Two main photometric measurements, the measurement of DGI value and the measurement for the Relative Maximum luminance value (L_{max}/L_S) used the same equipment and procedures as those described in the first experiment in this Chapter.

5.3.3.4 Experimental Design

a. Experimental Design and Testing Procedures

Twenty-four subjects for each treatment took part in this study from the 1st to 4th week of June 2005. The experiment began from treatment 1 for the 1st week until completing treatment 4 in the 4th week. Similarly to the previous experiment, individual subjects took part in only one treatment and a randomization was used. The subjects were randomly selected from students in the University of Sheffield and they were randomly assigned to treatment conditions. It should be noted that, even though the randomized assignment was employed, there might be a possibility that two specific factors affecting discomfort glare, gender and the use of spectacles, were distributed unevenly across treatments. These factors were checked and the results are shown in Section 5.3.4.

Two periods, the pretest period and the real experiment, were carried out in this experiment. All the testing procedures for the pretest period and the real experiment as well as and methods for evaluating discomfort glare in this experiment were similar to that described in the previous experiment in this Chapter.

b. The Observers

Ninety-six subjects were recruited and took part in this experiment. All of them were university students of varying nationality, aged 18-30. Forty-four were men and fifty two were women. Twenty-six men and twenty-four women wore spectacles; all were self-certified as having no other eye problems and having no colour-vision deficiency.

5.3.3.5 Statistical Analysis

To test the hypothesis that the naturalness and the stratification of the view affect discomfort glare from windows and to see whether there is an interaction effect between these two factors, comparisons of the regression lines of the relationship between DGI and GRV were made. The data was fitted for natural views and urban views and for one-layer views and three-layer views using a Linear Regression analysis. Then, a two-way between subjects analysis of covariance (ANCOVA) was used to see whether there is an interaction effect and whether these lines are significantly different. The two-way ANCOVA was used instead of one-way ANCOVA. This is because in this experiment two factors, the view naturalness and stratification were investigated at the same time. Then, the data was fitted again for each treatment using a Linear Regression analysis and a Sidak t-test for multiple-group comparisons was used to see whether these lines are significantly different.. Similarly to the previous experiment, to test the effect of the Relative Maximum luminance of a window on discomfort glare, a Pearson's correlation coefficient (r) was used.

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5.3.4 Results and Conclusions

Figure 5.11 shows the relationships between DGI and GRV for natural and urban views. Figure 5.12 shows the relationships between DGI and GRV for one-layer and three-layer views. Figure 5.13 illustrates the relationships between DGI and GRV for four views. The two-way ANCOVA revealed no interaction effect between these two factors. But the main effects of these two factors were highly significant *(p<0.01)*. Natural views are significantly less glaring than urban views *(p<0.01)*. Three-layer views are significantly less glaring than one-layer views *(p<0.01)*. The Sidak *t*-test was used to compare the assessments between each treatment. The test indicated that a natural three-layer view was significantly less glaring than natural one-layer view *(p<0.01)* and an urban three-layer view is significantly less glaring than an urban one-layer view (p<0.01). It also illustrated that a natural three-layer view was significantly less glaring than an urban three-layer view *(p<0.01)* and that a natural one-layer view was significantly less glaring than an urban one-layer view *(p<0.01)*. As can be expected, the natural three-layer view was also significantly less glaring than the urban one-layer view *(p<0.01)*. But no significant difference was found between an urban three-layer view and a natural one-layer view.

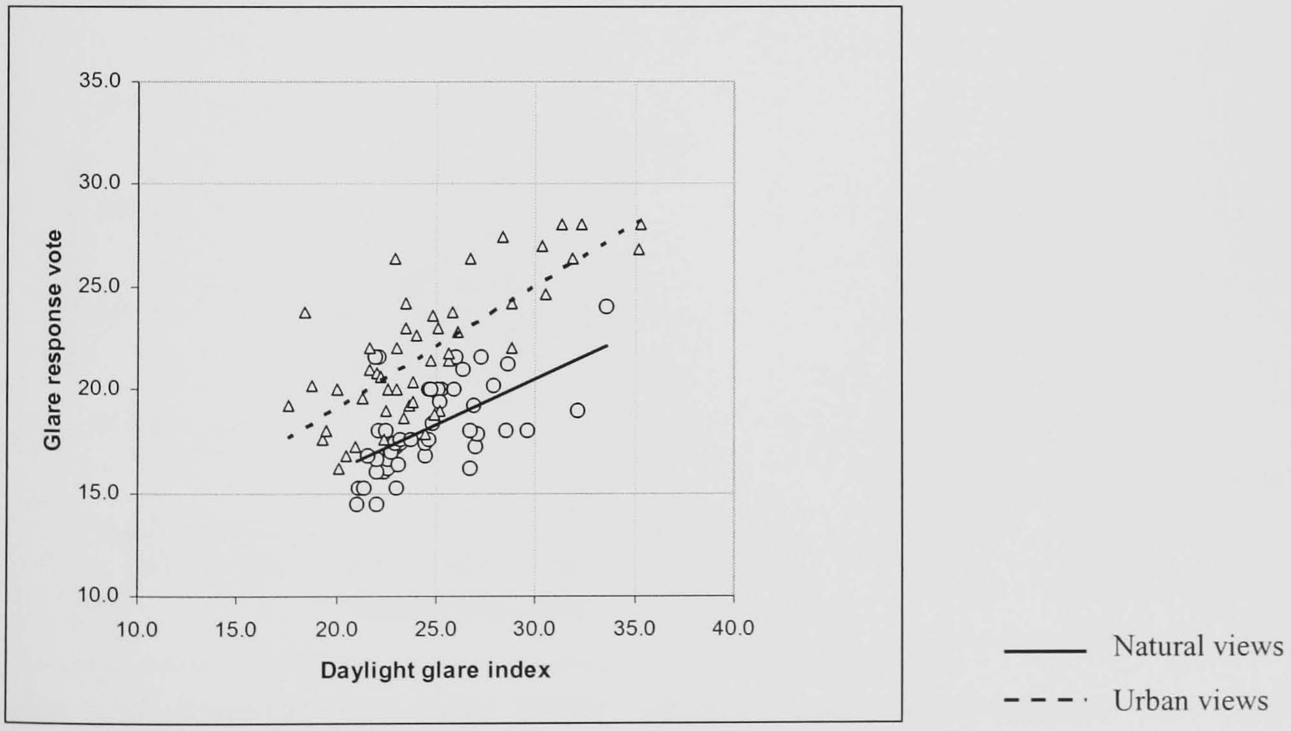

Figure 5.11 Daylight glare index calculated versus glare response (GRV) vote judged by subjects for natural views and urban views. The horizontal axis represents the calculated daylight glare index, the vertical axis represents the glare response vote reported by subjects or GRV. ○ natural views, × urban views. The lines are trend lines of the fitted function.

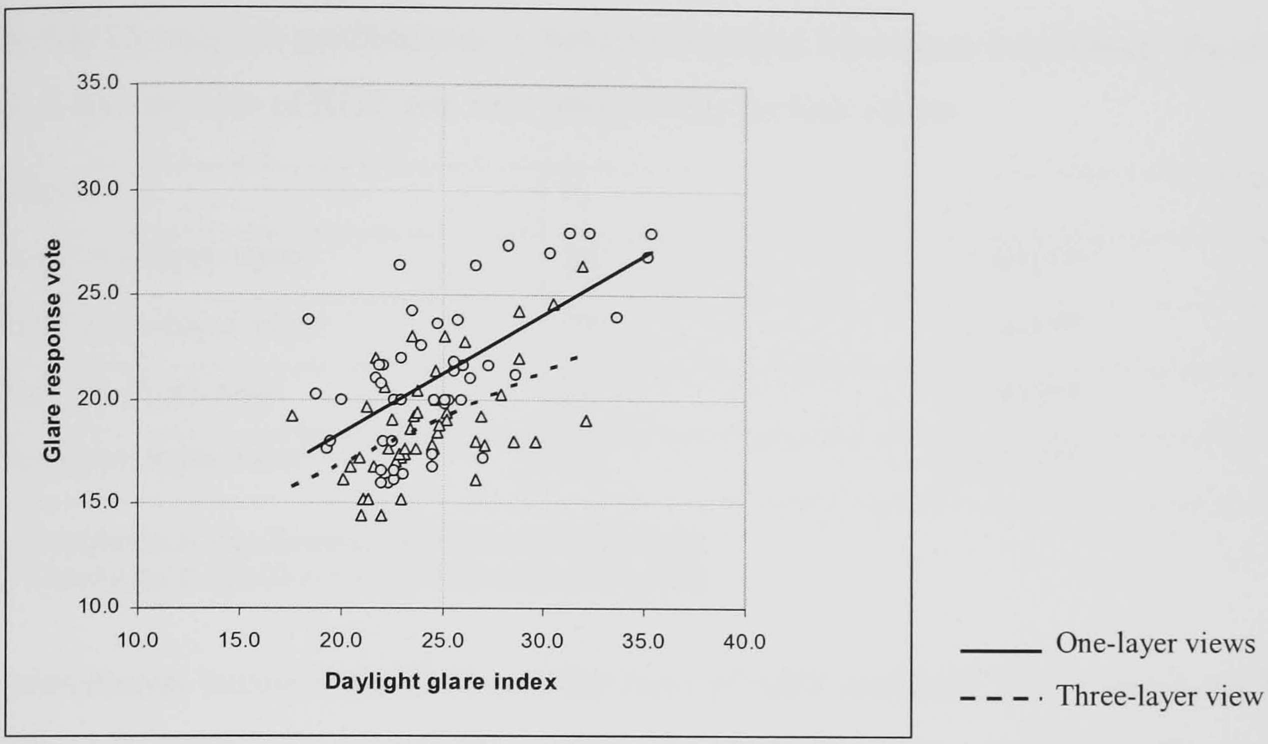

Figure 5.12: Daylight glare Index (DGI) calculated versus glare response vote (GRV) judged by subjects for views with one layer and those with three layers. ○ represent one-layer views. Δ refer to three-layer views. The lines are trend lines of the fitted function.

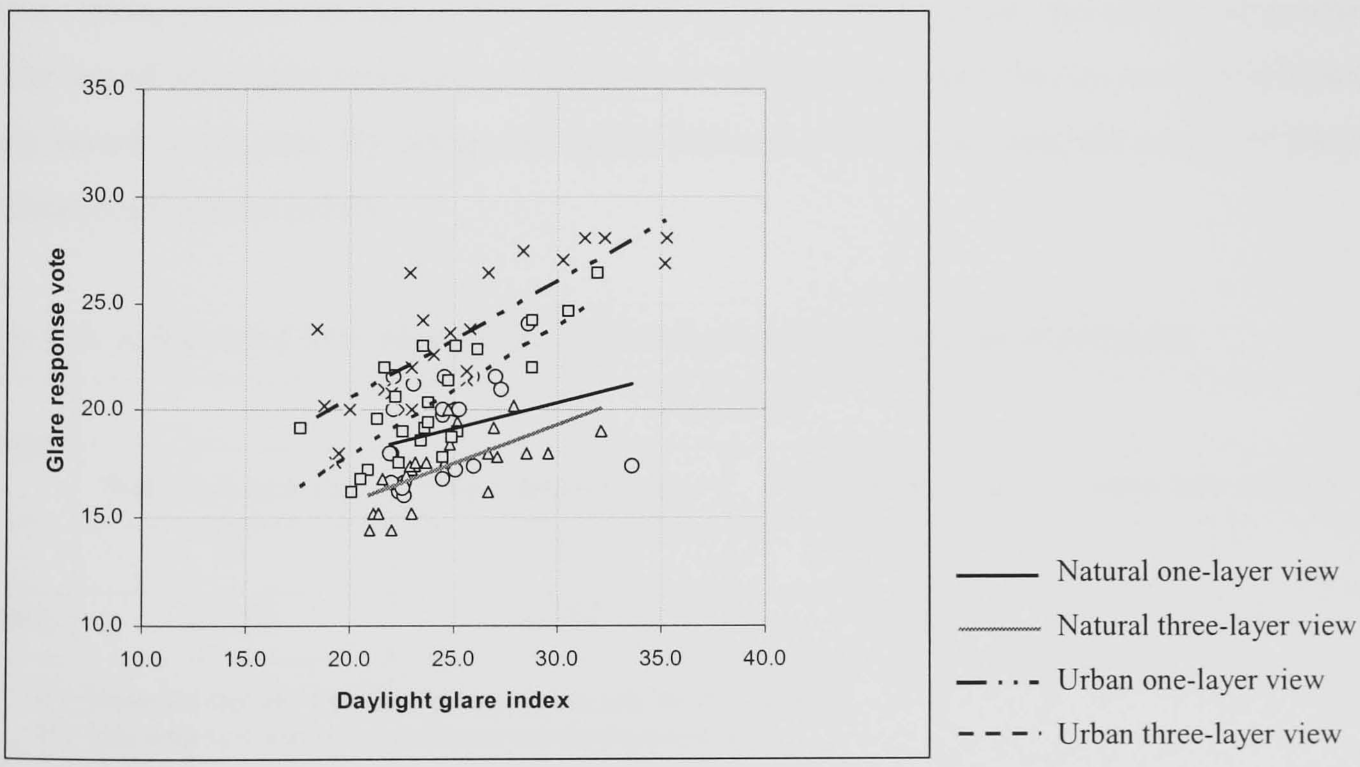

Figure 5.13: Daylight glare index (DGI) calculated versus glare response vote (GRV) judged by subjects for four views. ○ refers to natural one-layer view, Δ represents natural three-layer view. □ refers to urban one-layer view. X represents urban three-layer view. The lines are trend lines of the fitted function.

Table 5.8: Correlation coeffeicients, r, between Relative Maximum Luminance of a window (RML_w) and the ratio of RGV and DGI (RGV/DGI) for four views.

Treatment	N	r
Natural one-layer view	24	0.831**
Natural three-layer view	24	0.841**
Urban one-layer view	24	0.904**
Urban three-layer view	24	0.914**

** Correlation is significant at the 0.01 level (one-tailed)
* Correlation is significant at the 0.05 level (one-tailed)

The correlations between the RML and the ratio of GRV and DGI for all views are highly significant ($p<0.01$), as could have been expected from the results in the previous experiment. It can be concluded that discomfort glare increases with the Relative Maximum luminance within a window (RML_w).

With a similar purpose to that of the first experiment in this Chapter, the effects of gender and the use of spectacles were also checked, as to whether these two factors were distributed evenly across treatments. By using a Binomial test and a Chi-square test, the results of these two factors are shown below.

Table 5.9: A Binomial Statistics for the effect of gender in the second experiment

Gender	Treatment			
	Natural one-layer view	Natural three-layer view	Urban one-layer view	Urban three-layer view
x	11	12	10	11
p-value	0.838	1.162	0.542	0.838

** The binomial test showed highly significant results (two-tailed)
* The binomial test showed significant results (two-tailed)

Table 5.10: A Chi-square Statistics for the effect of gender in the second experiment

Treatment	E	O	$(O-E)^2$	$(O-E)^2/E$
Natural one-layer view	12	11	1.00	0.08
Natural three-layer view	12	12	0.00	0.00
Urban one-layer view	12	10	4.00	0.33
Urban three-layer view	12	11	1.00	0.08
χ^2				0.50
p-value				NS

** The Chi-square test proved a highly significant difference
* The Chi-square test proved a significant difference
NS The Chi-square test proved no significant difference

Table 5.11: Binomial Statistics for the effect of the use of spectacles in the second experiment

	Treatment			
	Natural one-layer view	Natural three-layer view	Urban one-layer view	Urban three-layer view
x	9	13	14	14
p-value	0.308	1.458	1.692	1.692

** The binomial test showed highly significant results (two-tailed)
* The binomial test showed significant results (two-tailed)

Table 5.12: A Chi-square Statistics for the effect of the use of spectacles in the second experiment

Treatment	E	O	$(O-E)^2$	$(O-E)^2/E$
Natural one-layer view	12	11	1.00	0.08
Natural three-layer view	12	12	0.00	0.00
Urban one-layer view	12	10	4.00	0.33
Urban three-layer view	12	11	1.00	0.08
χ^2				0.50
p-value				NS

** The Chi-square test proved a highly significant difference
* The Chi-square test proved a significant difference
NS The Chi-square test proved no significant difference

From a Binomial distribution table (Seigal, 1956) at a value of x in each treatment and N=24, the critical values for each treatment were obtained. It was found that all of these values were not less than 0.05. For the Chi-square test, consulting the Table of the Chi-square distribution (Cohen and Holladay, 1982), the critical value for χ^2= 7.82 when df= 2 and α= 0.05, and the critical value for χ^2= 11.34 when df= 2 and α= 0.01. The obtained values for χ^2 does not exceed the critical value of χ^2 where α= 0.05. By using the two statistics, no significant difference was also found between male and female subjects and subjects with and without glasses or contact lenses in each treatment. It can be concluded that these two factors were distributed evenly across treatments.

It should be noted that a specific point can affect the interpretation of the results of this Chapter and should be addressed here. If a blank screen is replaced by another screen that varies in luminance in any way but has the same mean luminance as the blank screen, there are three effects: 1) RML_m increases; 2) discomfort glare, as calculated with the small source formula, increases; 3) interest in image may increase. If, as found in the laboratory experiments, the level of subject glare decreases when images of real places are viewed, the reduction of glare due to interest in a view must be greater than the effect of increasing RML_w: interest in a view reduces glare, the luminance variation (RML_w) increases glare, and the effect of interest is stronger. That this was the case also in the real daylight experiments is evident from the parameters of the empirical equation fitted to the data (Appendix A). It is, however, necessary to check that there a negative correlation between interest and RML_w did not exist in the actual scenes used. If this were the case, any reduction in subjective glare could not be attributed to either factor alone. This association was examined statistically by calculating Pearson correlation coefficients and was found to be not significant.

In summary, a difference should be made between natural views and urban views. Natural views are less glaring than urban views and three-layer views gives less glaring than one middle-layer views. This experiment is also consistent with the previous experiment. It was found that discomfort glare from windows increases with Relative Maximum luminance of window (RML_w).

5.4 Tests of Experimental Procedure Effect

5.4.1 Introduction

The variances from both experiments are smaller than those in other discomfort glare from windows studies (Hopkinson, 1971, 1972; Osterhaus and Bailey, 1992; Osterhaus and Werner, 1998), as it can be seen from Figure 5.9, 5.11, 5.12, 5.13. As described earlier in the Section 5.2.3.4, the experimenter demonstrated what constitutes glare and its criteria by doing one-example trial in the pretest period. It has been tested in the first experiment in the laboratory that the demonstration using a one-example trial made by the experimenter does not have an effect on the experimental outcomes (see Section 4.3.4). However, since the scatters of the results in this part are relatively low, it might be that there is a possibility that this method influences the results in these two experiments. An experimenter demonstrated to subjects her assessments of the level of discomfort glare using a test window in the pretest period. The subjects seemed to then choose an assessed level of discomfort glare for the test window during the real experiment that was close to those demonstrated by the experimenter rather than what they actually perceived possibly. The data of discomfort glare obtained from the subjects' choices in the real experiment would not represent the level of discomfort glare they actually perceived. The variance of the real results having been observed as smaller than expected means it is necessary to find out whether the above is true.

The data from the pretest period was taken only where a relatively constant light level (a source luminance deviation of only ± 100 cdm^{-2} between when the experimenter demonstrated and when the subject made the pretest period assessment) was investigated for this purpose. We investigated the subject's data from the pretest periods instead of using the subjects' data from periods of real experiments. This is because in the pretest period the light level was fairly static from when the experimenter demonstrated the level of glare and the subject made the assessment, whereas there was more significant lag between the demonstration and the real experiment periods. As mentioned in Section 5.2.3.4a and 5.3.3.4a, in this pretest period, an experimenter made one evaluation of discomfort glare with a test window (an example trial) using the GSV scale. Then, each subject made his/her evaluation of discomfort glare of the test window on the same GSV scales five times, still as part of the pretest period. Where the light is constant and subjects make five judgments of discomfort glare following the judgment of the experimenter, if there is an influential effect of using this method on the experimental results (results in the real experiment), two indicators from the pretest period data would be presently observed:

Firstly, in terms of variation in the discomfort glare data assessed by each subject five times, the subjects would tend to have chosen the same discomfort glare level as those shown by the experimenter in the first assessment. Then, there would be a succession in the data towards the subject's in that the assessments would move away from those with the same values as the experimenter towards those in line with own sensations. Secondly, even though there will be no succession in the data (the subjects' data will be either randomly scattered or constant), there would still be a correlation between the data of discomfort glare assessed by experimenter and that data of discomfort glare evaluated by the subject. This is because, after the assessment by the experimenter, subjects would tend to choose levels of discomfort glare close to the level chosen previously by the experimenter.

Based on these two indicators, after all of the GSV data was converted on to the DGI scale, called GRV in this study, two steps were carried out. Firstly, variations within the five pieces of data given by each subject were explored. Secondly, the relationship between the GRV of an experimenter and the GRV of subjects was investigated.

5.4.2 The variations within the data of discomfort glare for each subject

Table 5.13: DGI and GRV of experimenter and those of subject of the first experiment

Subject	DGI	Experimenter	Subject tries					Mean
			1	2	3	4	5	
1	29.2	29.7	26.2	28.7	26	26.7	26.2	26.76
2	25.3	25.9	24.9	24.7	25.3	24.5	24.9	24.86
3	30.5	30.8	28.3	28	27.6	28.3	28.3	28.1
4	24.2	25	22	21.4	21.8	22	22	21.84
5	17.9	18.5	18.3	18.2	18.2	18.2	18.3	18.24
6	22.4	21.5	20.9	20.4	20.4	20.4	20.4	20.5
7	23.2	23	22	22.2	22.2	22.2	22.2	22.16
8	15.7	18.7	17.2	17.4	17.3	17.4	17.1	17.28

Table 5.14: DGI and GRV of experimenter and those of subject of the second experiment

Subject	DGI	Experimenter	Subject tries					Mean
			1	2	3	4	5	
1	18	18.6	18.2	18.3	18.2	18.3	18.3	18.26
2	20.6	20.3	17.6	18.2	17.4	18.9	17.6	17.94
3	20.3	22.7	18.9	18.2	17.8	19.2	18.9	18.6
4	20.4	22.9	17.6	18.4	18.1	18.2	18.6	18.18
5	16.4	15.9	17.4	17.5	17.1	17.4	17.4	17.36
6	17.3	20.2	17.1	17.0	17.0	17.1	17.0	17.0
7	18	18.9	18.2	18.3	18.5	18.3	18.2	18.3
8	25.2	27.2	23.3	23.7	23.2	24.2	23.6	23.6
9	22.2	22.7	19.2	19.4	20.1	19.2	20.2	19.62

It can be seen from Table 5.13 and Table 5.14 that there is no systematic change of subject readings. The scatters of these results are randomly about the mean of GRV of each subject and some subjects were constant in their evaluations. The results suggested that there was no effect of this experimental procedure on the outcome of these two experiments regarding the variations of the data for each subject.

5.4.3 Relationship between GRV of experimenter and subject

In order to investigate a correlation between the data of discomfort glare assessed by the experimenter and the data of discomfort glare evaluated by the subject, two statistical tests were carried out in this part, a Chi-square test and a Pearson correlation coefficient (r). The aim was to see whether there is a relationship between GRV of experimenter and those of the subject.

The Chi-square test is based on the assumption that if there is a relationship between GRV of experimenter and subject, when GRV of experimenter is higher/lower than the predicted values (DGI), this direction would be similar for the GRV of subjects. The direction of GRV from the experimenter relative to DGI and that of averaged GRV[13] of subject in relation to DGI were drawn. A value of -1 means GRV of experimenter or subject was lower than the DGI and a value of +1 means GRV of experimenter or subject was higher than the DGI. Then, a Chi-square test was used to see whether the direction of subject would be similar to those of the experimenter. An expected frequency is a direction of the experimenter and observed frequency is a direction of the subject. The results of Chi-square statistics for both experiments are shown below.

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[13] An averaged GRV refers to a value of averaged GRV value over five discomfort glare evaluations for each subject

Table 5.15: A Chi-square Statistics for directions of GRV relative to DGI in the first experiment

Subjects	E	O	$(O-E)^2$	$(O-E)^2/E$
1	1	-1	4.0	4.0
2	1	-1	4.0	4.0
3	1	-1	4.0	4.0
4	1	-1	4.0	4.0
5	1	1	0.0	0.0
6	-1	-1	0.0	0.0
7	-1	-1	0.0	0.0
8	1	1	0.0	0.0
χ^2				16.0*

* The Chi-square test showed a significant difference.
** The Chi-square test showed a highly significant difference.

According to the table of the Chi-square distribution (Cohen and Holladay, 1982), the critical value for χ^2= 14.06 when df= 7 and α= 0.05, and the critical for χ^2= 18.47 when df= 7 and α= 0.01. It can be seen that the obtained values for χ^2 exceed the critical value of χ^2 where α= 0.05 in both cases. The direction of discomfort glare assessed by the subject relative to the predicted values (DGI) is significantly different from those of the experimenter.

Table 5.16: A Chi-square Statistics for directions of GRV relative to DGI in the second experiment

Subject	E	O	$(O-E)^2$	$(O-E)^2/E$
1	1	1	0.0	0.0
2	-1	-1	0.0	0.0
3	1	-1	4.0	4.0
4	1	-1	4.0	4.0
5	-1	1	4.0	-4.0
6	1	-1	4.0	4.0
7	1	1	0.0	0.0
8	1	-1	4.0	4.0
9	1	-1	4.0	4.0
χ^2				16.0*

* The Chi-square test showed a significant difference.
** The Chi-square test showed a highly significant difference.

Consulting the table of the Chi-square distribution (Cohen and Holladay, 1982), the critical value for χ^2= 15.51 when df= 8 and α= 0.05, and the critical value for χ^2= 20.09 when df= 8 and α= 0.01. The obtained values for χ^2 exceeds the critical value of χ^2 where α= 0.05. The direction of discomfort glare assessed by the subject relative to the predicted values (DGI) is significantly different from and those of the experimenter.

It should be noted that, in these Chi-square statistics results, the effect of interest in a view was not controlled. However, it seems in the results that there is no correlation between the GRV of experimenter and those of the subjects. In the second statistics, the effect of interest in a view was eliminated and a Pearson Correlation Coefficient (r) was carried out. It is based on an assumption that if there is a relationship between GRV of experimenter and those of the subject, the relationship would exist as a difference between the GRV of experimenter and the DGI and between the GRV of subject and the DGI. The DGI was subtracted from the averaged GRV over five trial runs for each subject and a real difference was drawn. Also, the value of DGI for an experimenter corresponding to each subject was subtracted from the GRV and a real difference was drawn. To eliminate the effects of interest in a view, three steps were necessary, 1) finding the best-fit equation to the data of the relationship between interest in a view and a difference between the GRV (of experimenter) and DGI; 2) finding the effects from interest in a view using the best-fit equation and eliminating these effects from both the difference between the GRV of an experimenter and the DGI and the difference between the GRV of the subject and the DGI; 3) the relationship between these two differences after already eliminating the effects from interest in a view was taken and a Pearson Correlation Coefficient (r) was calculated and tested for significance. The results for both experiments are shown below.

Table 5.17: Correlation Coeffeicients, r, between a difference between GRV of an experimenter and DGI and a difference between GRV of subjects and DGI

Experiment	N	r
The first experiment	8	0.46
The second experiment	9	0.29

** Correlation is significant at the 0.01 level (2 tailed)
* Correlation is significant at the 0.05 level (2 tailed)

The correlation coefficient (r) for the first experiment is 0.46 and that for the second experiment is 0.29. After testing the significance of the correlations, it was found that they are not significant. This means that there is no relationship between GRV of experimenter and GRV of subject for both experiments.

In summary, based on the data in the pretest period, all investigations indicated no effect of the demonstration of one-example trial made by experimenter during the pretest period on the outcome in both experiments. Instead, this procedure seems to show great benefit in controlling some extraneous variables in these experiments. It was mentioned earlier that this thesis tried to control as many extraneous variables as possible, and many methods employed in these experiments for this purpose could explain the reasons for there being less scatter in the data than other glare from windows studies as follows:

Firstly, in the pretest period, the procedures begun from the time of obtaining the explanation of the study, completing informed consent form and completing pre-study questionnaire. This was followed by getting an instruction, obtaining examples of levels of the four glare thresholds shown by the experimenter, doing an example trial five times with a similar procedure as the real experiment; and finally relaxing for two minutes. By using these methods, many of the subject's variables could be controlled every time the subject did the experiment, for example the meaning of glare and its criteria, and subject anxiety level/mood. Secondly, in other discomfort glare from window studies, subjects evaluated the glare in real rooms performing some typical tasks (Hopkinson, 1971, 1972; Osterhaus and Bailey, 1992; Osterhaus and Werner, 1998). In our study, subjects evaluated the glare in test rooms with no furniture arrangements in the rooms and no task was carried out by the subjects. Hence, more effects could be controlled in our study. It could be said that the methods employed in these experiments are more careful and can bring a more sensitive evaluation.

5.5 Conclusions and Discussions

The main focus of the thesis was tested in this Chapter. Just as the laboratory results showed that interest in a small projected screen image significantly reduce discomfort glare, it was found that interest in a view has a significant effect in the reduction of discomfort glare from windows. Although, there are many more uncontrollable variables in the real daylight condition, the effect is still strong.

The most striking finding from the first experiment in this Chapter is that the effect of interest in a view was significant, even though the view stimulus was a concrete wall. This scene apparently contains very little information and was rated in the preliminary test as lowest interesting view. This result may be taken as supporting the findings of several researchers that, in most building environments, the desire to see outside seems to be overwhelming even the view is restricted or contains very small information content such as brick wall (Cooper *el al.*, 1973; Jackson and Holmes, 1973b)

In terms of view content, it was found that natural views are less glaring than urban views and views with three horizontal stratifications evokes less glare discomfort than those with just a middle layer of cityscape/landscape. The results from the two experiments also suggest that discomfort glare increase with the Relative Maximum luminance within a window (RML_w). Two important issues were discussed in this section based on all the findings in this part. They consist of 1) View preference and interest; 2) View content and discomfort glare.

5.5.1 View Preference and Interest

The results in the preliminary test of the first experiment seem to suggest that, in a window-view, there is a strong relationship between *interest* and *preference*. This assumption is consistent with the findings from small screen images that interest could be related to preference. The selection of views for the preliminary test of the first experiment was based on factors that seem to have an effect on view preference, as reviewed in Section 3.4.3. The results support this: highly interesting views are views that seem to be highly preferred. On the other hand, views of low preference were also ranked of low interest.

In Table 5.1, the most interesting view is a view containing all of the factors that could make a view highly preferred. It is a distant view with three horizontal stratifications and a balanced presentation of natural and urban qualities. This finding strengthens what other researchers found in their studies relating to views through windows particularly a strong effect of three horizontal strata—ground, city or landscape, and sky— on preference in a view (Markus, 1967a and b; Keighley, 1973a and b, Tregenza and Loe, 1998). In addition, as the view is considered more complex than the second and third most interesting views identified, the result also gives a strong support to the most resembled findings on an influence of complexity in a view on view preference. Indeed, combining with the other factors, in particular, with a three horizontal stratification, a high degree of complexity in the scene due to many aspects such as high irregularity in shape, variety of colours, and contains heterogeneity of elements makes the view becomes the most interesting view, as identified by subjects.

The views ranked on second and third on interest emphasize other important factors that could affect view preference found in this study: naturalness and the presence of water. Again, this finding is congruent with studies reported by previous researchers in environmental aesthetics and perception as well as window-view. It emphasises that views with dominant nature content tend to be more preferred than views dominated by the built environment (Markus, 1967a; Markus and Gray, 1973; Kaplan, 1978; Ulrich, 1979, 1981, 1983; Heerwagen and Heerwagen, 1984, Heerwageen and Orians 1986). Similar to the results found in the preliminary test of second experiment in the previous Chapter using small screen images in laboratory, in the context of natural scenes, it was found that views containing some forms of water get higher ranked in interest than those without. Accordingly, the effect of naturalness seems to be strengthened when there is the presence of water in a view.

On the contrary, the view of lowest interest was one of a monotone concrete wall. This supports the factors mentioned above: it is a one-layer view showing a man-made construction with the lowest degree of complexity— homogeneity of elements, texture, colour, material, and form. The view ranked second lowest on interest contains features that tend to make a view low preferred, but it seems to come with higher degree of complexity than the least interesting one.

In addition, the results in the first experiment found in this Chapter show that an increase in interest in a view is associated with a decrease in discomfort glare. As previously discussed, interest in a view seems to relate to the preference. The result found here also implies that an increase in view preference seems to be associated with a decrease in discomfort glare. . In other words, there is a strong tendency that discomfort glare from windows could be reduced by preferred views.

5.5.2 View Content and Discomfort Glare

The results in the second experiment are, thus, consistent with the conclusions from small projected screen images in the laboratory: 1) the effects of naturalness and stratification in a view, 2) the effect of the Relative Maximum luminance in a window (RML_w). The results seem to suggest the best solution for optimising discomfort glare that is a natural view with three layers—the sky, middle layer of cityscape/landscape, and a foreground.

With regards to the effect of RML_w in real daylighting situations, one could argue that using view with three layers could bring more discomfort glare perceived than we expected since the view normally contains the sky which is predominantly bright and hence produces the very high RML_w. This could lead to the point that whether a view of natural scene with the three strata should be actually provided to optimise discomfort glare from windows in real situations, where the effect of RML_w is not eliminated.

However, what we found in the second experiment seems to refute this line of argument. In Figure 5.12, the trends of the two graphs seem to show that views with three layers, containing higher RML_w values, are still less glaring than those with one middle layer. Specifically, in Figure 5.13, it appears that a natural three-layer view gives lower glare than other views[14]. In this way, the present findings implied two pertinent points. Firstly, the best solution to optimise discomfort glare from window suggested by our results is a natural three-layer view with a means to maintain the sky brightness for obtaining the low RML_w. However, the findings implied that without this means, a natural three-layer view should still be a good solution. Secondly, the finding supports the conclusion that the RML_w seems to be a less important factor in determining discomfort glare from window than view stratification is. In other word, as view stratification seems to be a factor affecting interest in a view, the results provide evidence that the effect of interest in a view on discomfort glare seems to be far greater than the effect of RML_w.

5.5.3 Conclusions

The findings in this Chapter supported the two general hypotheses of the effect of interest and Relative Maximum luminance (RML) on discomfort glare in another case—a view-window as a glare source. The results not only lead to some pertinent points discussed above, but also suggest that there is a need to modify the existing daylight glare formula to include the two more factors—the view interest and the Relative Maximum luminance of the window (RML_w). These two factors seem to have different magnitude of their effects on discomfort glare. This concern is considered beyond the scope of this thesis, but a further investigation was carried out. In accordance with the results found in this study, a modified daylight glare equation was proposed as a supplement section. It is presented in Appendix A.

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[14] It should be noted that all of the graphs in both the first and the second experiments in this Chapter, Figure 5.9, 5.11, 5.12, 5.13, were plotted without eliminating effect of RML_w.

In all, the findings in this Chapter emphasise the psychological benefits of views out. Indeed, the provision of view out could become one of the main functions of window in terms of a reduction in discomfort glare, especially when there is an appropriate control of luminance variation within a window. Although, in this thesis, the investigation of an effect of interest was limited to the two cases of glare sources, the findings tended to give a profound knowledge that could be applied to real life situations. In Chapter 6, implications of the results in this Chapter in terms of both theory and practice are broadly discussed. The Chapter also includes the limitation of this study as well as suggestions for further study regarding the thesis's findings.

Chapter 6
Conclusions

6.1 Introduction

It has been suggested many times in literature that interest in a glare source seems to have an effect on discomfort glare—for example, Hopkinson (1970, 1972) in a case of a view-window and Markus (1974 quoted in Boyce, 1981) in a case of a glaring television. Based on these, the general hypothesis of this thesis is that "*an increase in the interest in a glaring source is associated with a decrease in discomfort glare*" The findings of this thesis supported this. The laboratory studies showed that, in the case of a small projected screen image, an increase in interest in an image is associated with a decrease in discomfort glare. Similarly, studies under real daylighting condition showed that, in the case of a real window, an increase in the interest in a view is associated with a decrease in discomfort glare. In addition to the effect of interest, another general hypothesis, proposed later during the thesis, that discomfort glare is increased with an increase in the Relative Maximum Luminance of the glare source (RML). This was also supported by the results found from both sources of glare.

While the patterns of the results from two main studies in this thesis are consistent, it is necessary to note limitations of the thesis and suggestions for further study regarding the first general hypothesis. Firstly, this effect of interest in a glare source on discomfort glare was supported in this thesis only two cases of glare sources. In order to verify this general hypothesis of the study, the effect of interest from other sources should be examined—for example, television, film, and decorative sources, such as a crystal chandelier. Secondly, both the laboratory studies and those of real daylighting condition, the glare was evaluated within a short-time period. The results from this study do not, therefore, indicate whether the increased tolerance due to the effects of interest is a short-term effect, which may fade after prolonged viewing, or one that persists; and this unknown point affects the immediate practical implications of the findings. Moreover, it is unknown for the reason of why this effect of interest on discomfort glare was existed. This phenomenon might be related to some specific mechanisms of the visual systems. For better understanding on these issues, additional research is required.

Finally, as a main focus of this thesis, it is important to recognise that the results found in studies in real daylighting condition not only support the general hypothesis, but also supports Hopkinson's conjecture that a view with a great deal of interesting information may reduce discomfort from a glare source or light, in particular a window (Hopkinson, 1970, 1972). Hence, the effect of interest in a view on discomfort glare from windows is further discussed through this Chapter, concentrating on its implications both in theory and practice. The discussion also extends to other pertinent findings from studies in real daylighting condition that could contribute to window design guidelines for reducing discomfort glare from windows. The chapter also includes limitations of this study and ultimately the suggestions for further study regarding these findings of the thesis.

6.2 Implications

6.2.1 Theoretical Implication

The identification of the effect of interest in a view and the RML_w on glare discomfort in this study makes it possible to conclude that there are more factors than the four normally presented in the daylight glare model[15]: source luminance, source size, surround luminance and a position index. In fact, the results provide not only the evidence asserting other researchers' assumption in particular Hopkinson (1970, 1972) and Markus (1974) in that the glare discomfort could be affected by interest in a glare source, but also some pertinent explanation to the low correlation between discomfort glare and the predicted DGI values. This should include the finding of the effect of the RML_w on glare discomfort which undoubtedly makes the results more profound. On the basis of the results, it becomes evident that this existing daylight glare formula is conservative in its

[15] The Hopkinson-Cornell large-source formula

estimate for discomfort glare from windows. In other words, including these two additional factors, the interest in a view and the RML_w, in the glare calculation should make the prediction of discomfort glare from windows more accurate.

Earlier studies relating to window and view out have led to the identification some important characteristics that could make views interesting. Nonetheless, interest in a view is basically a subjective judgement. This, in most situations, becomes a prominent limitation when dealing with the issue concerning view-related factors such as window design, in particular when how much interest in the concerned view has to be known. However, adopting the modified discomfort glare formula proposed later in this study could alleviate this problem because it includes the two additional factors, the interest in a view and the RML_w (see Appendix A). Indeed, the modified formula provides an objective way of measuring interest in a view. This could be done by making the view concerned bright and measuring the glare and other factors, then, using the modified formula. Through this process, the interest in a view could be quantitatively quantified.

The results revealed the relationship between glare discomfort and interest in a view as well as features regarding view content. As noted by a number of researchers, a provision of a view seems to be a main cause making people's desire for windows (Markus, 1967a and b; Collins, 1975; Ludlow, 1975) and characteristics of view out could profoundly affect subjective sensations. However, most previous researches relating to this field have focused mainly on the psychological benefits of windows and view out such as relaxation and recovery and concentrated on the physical effects of view out on window dimensions. This study provides insightful evidence supporting the more physiological benefit of views in particular the potential to reduce glare discomfort.

6.2.2 Practical Implication

The findings in this study suggest that the glare discomfort may be manipulated by the designer with some knowledge of how the perception of glare is affected by interest in a view and view content as well as the RML_w. Specifically, apart from factors that embodied in daylight glare calculations, a reduction in discomfort glare from windows can be made by increasing interest in a view, while decreasing RML_w.

Several studies have shown that window views have beneficial outcomes, however, no hard evidence exists on their effects on glare discomfort. The results from this study emphasised the benefits of windows and view out. It has been shown that not only views could alleviate glare discomfort from windows, but also discomfort glare is dependent on view interest and some specific features of view content. Apparently, view out becomes an excitation factor in the perceived external environment and, it is possible that windows and view out could be designed in such a way that help to reduce glare discomfort. Indeed, the findings in this study allow designers to better design a window to meet daylighting objectives, which are essential in establishing the maximum benefit to be derived from natural light in and around buildings. In order to achieve this, it is important to consider all aspects of daylighting including the site layout, building orientation, as well as interior layout especially window location, window position and also windows size. In the issue of glare discomfort, the best result could be achieved either by modifying existing external view settings to be more interesting or designing the window to get the good view. For example, it has been found in this study that views with some certain characteristics such as natural views with three layers of foreground, city or landscape, and sky, strongly affects on discomfort glare. To reduce the discomfort glare effect, the design of the window can, therefore, make use of such natural features and three horizontal stratifications. However, as earlier discussed in Section 5.5.2, this requirement could create conflict with the effect of RML_w. This is because the sky is always very bright and, hence, an inclusion of the view of sky in a view that seen through window can yield to a very high RML_w. It could be assumed that a solution for this problem might be the use of daylighting techniques to maintain a low RML_w. In this way, not only could occupants be attracted by the interesting view outside, but the RML_w could be less due to the lower brightness of the view of sky.

It is also important to realise the relationship between daylighting systems and glare sensation. Designers should not underestimate discomfort glare from windows with daylighting systems. The main functions of daylighting systems on windows are to protect against sunlight, while increasing the utilization of daylight. With respect to the visual performance demands, the normal window plane performs better if it is installed with daylighting systems. Many daylighting systems— whether automatic or fixed solutions, cover the window plane with their slates, for example, Venetian blinds, fixed or adjustable louvers and vertical or horizontal fins. Nonetheless, based on the results of this study, daylighting systems do not necessarily increase the lighting quality in terms of visual comfort in a room. Discomfort glare can be more critical due to the sky and other bright elements seen through their slats, when the slate angle is controlled on the sun position. This is because, with the same view outside, due to relative dark bars of these elements against the bright view outside, the non-uniform luminance distribution within the window pane normally can yield to a higher RML_w, than the window fully open to outside and therefore this can lead to a higher glaring effect.

6.3 Limitations of the Study

The findings presented here are contingent on the experimental characteristics and conditions considered in the study. These may have influenced the outcomes and as such it should be stressed here until the following points are verified, the results should be taken with these considerations in mind.

1) It is acknowledged that the results in this thesis obtained related to one internal experimental set up only and this particular set up is not a representative of any typical room arrangements. Furthermore, it should also be noted the results are only applicable within the levels of the variables used in this study.

2) The subjects participating for all experiments in this thesis were university students, thus, the appraised glare discomfort in this study was limited to only one particular group of subjects, especially in terms of age.

3) The nature of views may have had an influence beyond the classification on which these studies are based. The results relating to views in this study remain contingent on the views investigated in this study.

4) The results in this study were discussed within the constraints mentioned above. Nothing, however, was found to suggest that the results would not work beyond these limitations. But, these need to be tested, and therefore further works are required.

6.4 Further Works

The investigation of the effect of interest in a view on discomfort glare from windows in this study provided not only evidence that help gain a better understanding of discomfort glare, but also allows elicitation regarding design guidelines for windows for optimizing the sensation of glare discomfort. However, there are some issues which would be worth mentioning for further studies that could be summarized as follows:

1) The experiments were done in test rooms and the setting was neither representative of any typical settings nor did the subjects do any typical tasks. It would be worth seeing how the results could be applied in real rooms with typical furniture arrangements and typical tasks, for example, an office or a school classroom, where the rooms are located with typical arrangements of furniture and subjects perform typical tasks.

2) On the basis that the result may not be entirely applicable to different groups of subjects, it would be interesting to know how interest in a view varies with population, and what causes any differences.

3) In order to form a completed practical design guideline for window design regarding the degree of discomfort glare, other additional research should examine factors regarding view content. The thesis emphasizes importance of view content, but could be considered as only a first step. Literature and the results found in this thesis suggest that there are other view content-related factors which may affect on the interest in a view and should be explored. These, for example, include simple descriptors in the scenes like water, trees or people, and some collative characteristics like the complexity, colour, and movement in a view (Kaplan,

1987; Kaplan, 1988; Ulrich, 1981; Platt, 1961). Moreover, due to limitations of time and access to buildings, only views that can be seen through the Arts Tower and some other buildings in the University of Sheffield could be investigated. More comprehensive classifications of views could be studied in order to confirm the results of this study.

4) Some limitations of experimental techniques need to be addressed. For the studies in real daylighting condition, the readings from a pyramid shield sensor were taken by two experimenters. As two values have to be recorded at the same time, the shielded and unshielded illuminances, it is possible that these two luminance values might not be recorded at precisely the same time. Although, there was not a significant fluctuation of the daylight during the experiment, it would be better if these two illuminance sensors were directly connected to a computer to get these simultaneous results. Also, due to time and cost constraints, the digital camera that has been used in the daylighting study to record the luminance values could not be sent for calibration with ENTPE as recommended. Hence, there were some small errors occurring in the experiments. These errors were acknowledged in section 5.2.3.3 and were certainly much smaller than experimental effects for each experiment. However, to get more accurate data, a calibration is required when the time and cost is adequately available.

6.5 Conclusion

In conclusion, the findings of this research supported the general hypothesis— interest in a glare source is associated with a decrease in discomfort glare. This hypothesis was supported in two cases of glare sources— a small projected screen image and a window. Not only the findings of the thesis emphasized the significance of meaning in the glare source, but the limitations existing also identified a gap of knowledge in terms of understanding this phenomenon and indicated the need for additional research. In terms of the main focus of the thesis, an investigation of the effect of interest in a view on discomfort glare, the findings showed that an increase in interest in a view is associated with a decrease in glare discomfort. The results from real daylighting studies also showed the effects on discomfort glare of view content and the Relative Maximum luminance of a window (RML_w). These findings provide useful information for both theoretical and practical implications that contribute to the fields of not only discomfort glare study, but also environmental aesthetics and perception, in particular the preference and interest in views through windows.

Overall, this thesis helps to fill a gap in research and professional practices, by providing a better understanding in the problem of discomfort glare and suggesting some issues regarding window design guidelines for optimizing reduction of discomfort glare. Specifically, the work has brought together two largely independent streams of research: discomfort glare and window-views.

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List of Appendices

Appendix A

Modifying the Daylight Glare Equation

A.1 Introduction

This section was to show the magnitude of the effects of interest in a view and the Relative Maximum luminance in a window (RML_w) in the original daylight glare equation, the Hopkinson— Cornell large-source glare formula. The way this was done was by fitting an equation modifying the original daylight glare index to the best fit of the data. This equation was derived by Prof Peter Tregenza[16] and from a single window. However, it may well also apply to a set of windows with a single view. This needs to be tested, however. By using the results from the two experiments from real daylighting studies, it was possible to write a supplementary equation that takes into account the interest in a view and the RML_w, and thus reduce the variation caused by these factors.

A.2 A modified daylight glare equation

After testing several alternative functions, the equation chosen was of the form:

$$DGI' = a\,DGI + b\,RML_w^{\,c} + d\,IV + e \qquad (1)$$

where DGI' is the daylight glare index modified for the effects of interest in a view and luminance variation, DGI is the daylight glare calculated from the Hopkinson equation (Hopkinson, 1957), RML_w is the ratio of maximum luminance to the mean luminance of the

[16] Prof. Peter Tregenza, School of Architecture, the University of Sheffield

window and IV is the mean interest score assigned to the view by subjects, using a eleven-point scale with the values 0 to 10, where 0 implies a view of no interest at all, and 10 indicates a view of extraordinary high interest.

The parameters *a* to *e* were chosen. This was done by finding the combination that gave values of DGI' with the minimum least-screens error from the GRV values obtained in experiment 1 in the real daylighting condition. Two real views (most interest and least interest) and a uniform neutral window representing a window containing a view with zero of interest were observed by the subjects in this experiment. To give flexibility in testing alternative functions, the numerical procedure adopted was to calculate arrays of DGI with varying parameters and search within this for the combination giving the best fit to the subjective results.

It was found that the result was more sensitive to variation in the interest parameter, *d*, than to the changes in *b* and *c* which modify the luminance ratio (RML_w). This implies that the effect of a subject's interest in the view has a greater effect on the glare discomfort than the Relative Maximum luminance in a window (RMLw). The best-fitting values of the parameters gave the equation

$$DGI' = 0.86\ DGI + 2.1\ RML_w^{0.345} - 1.03\ IV \quad (2)$$

Figure 1 plots the results from experiment 1 in the real daylighting condition. The 45° line is the null hypothesis: the subjective response being predicted perfectly by the calculated daylight glare index. The small circles represent the values for a blank window; the triangles are the values of least interesting view; and the crosses stand for the values of most interesting view. It can be seen that there is a systematic reduction of glare with increasing interest in a view. The values of DGI' given by equation 2 are indicated by the broken lines. Because the equation has two other independent variables, interest in a view and RML_w, the points have some scatter if plotted on the DGI'/DGI axis; the broken lines are linear trend lines fitted to them. It can be seen that these are also a good fit to the subjective data.

The parameters were then applied to the results from experiment 2. In this experiment, the subjects evaluated the glare from four views. These are a natural view with one layer and those with three layers; an urban view with one layer and those with three layers. The overall root-mean-screen error between DGI' and GRV values is even slightly smaller with these results than with the data to which the parameters were fitted. Figure 2 shows the results of a natural one-layer view and an urban one-layer view with their corresponding DGI' trend lines. The results suggest a very convenient rule of thumb:

Let I be a score of the interest of a scene on a scale where 0 signifies no view, 1 a view of very little interest and 6 a very interesting view; the discomfort glare from the window is then

DGI' = DGI - IV

This is equation 1 with the parameters, a=1, b=0, c=0, d=-1, e=0.

Table 1 gives the *rms* error for all the results from the two experiments for this rule of thumb, equation 2 and the null hypothesis. It reveals that the simple rule gives a significant increase of accuracy over the daylight glare equation alone, and that equation 2, which includes a luminance ratio term (RML_w), gives a further improvement. The highest interest score used in the experiments was 5.6 so the equations do not necessarily apply to very interesting scenes ranked above this value.

Table A.1: *rms* error in fitting equations for corrected daylight glare index, DGI', to discomfort glare sensation, GRV (Glare response vote)

[a b c d e]	Null hypothesis [1 0 0 0 0]	'Rule of thumb' [1 0 0 -1 0]	Equation 2 [0.86 2.10 0.345 -1.03 0]
blank screen	2.026	2.026	2.022
least interest view	3.121	1.987	1.277
most interest view	6.153	1.777	1.775
overall expt. 1	**4.151**	**1.933**	**1.720**
natural view / 1 layer	6.081	2.157	1.880
natural view / 3 layers	7.665	2.864	2.211
urban view / 1 layer	3.368	3.044	2.115
urban view / 3 layers	4.275	2.319	1.402
overall expt. 2	**5.598**	**2.622**	**1.927**
overall both expts.	**5.029**	**2.351**	**1.841**

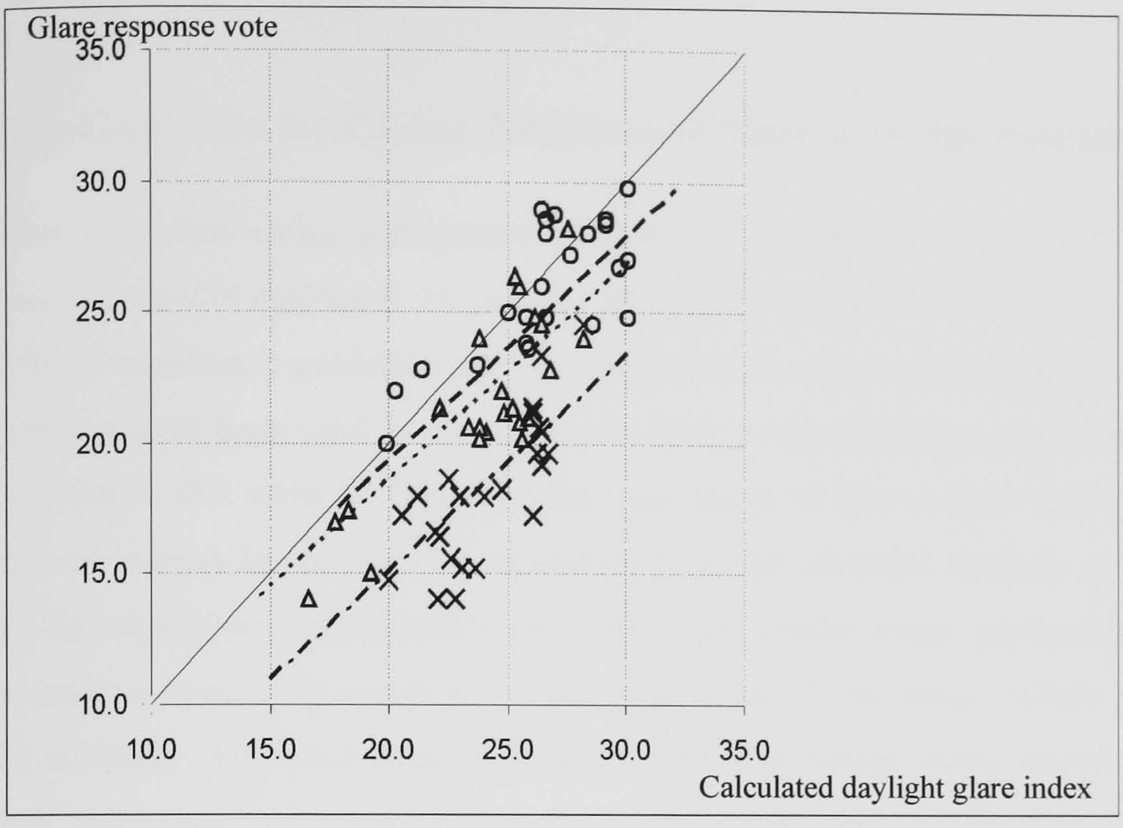


Figure A.1: Results from the first experiment in the real daylighting condition. The horizontal axis represents the calculated daylight glare index, the vertical axis represents the discomfort glare reported by subjects or GRV. ○ represents the results of a uniform blank window. Δ are the results of the least interesting view, × are the results of the most interesting view. The broken lines are trend lines of the fitted equation.

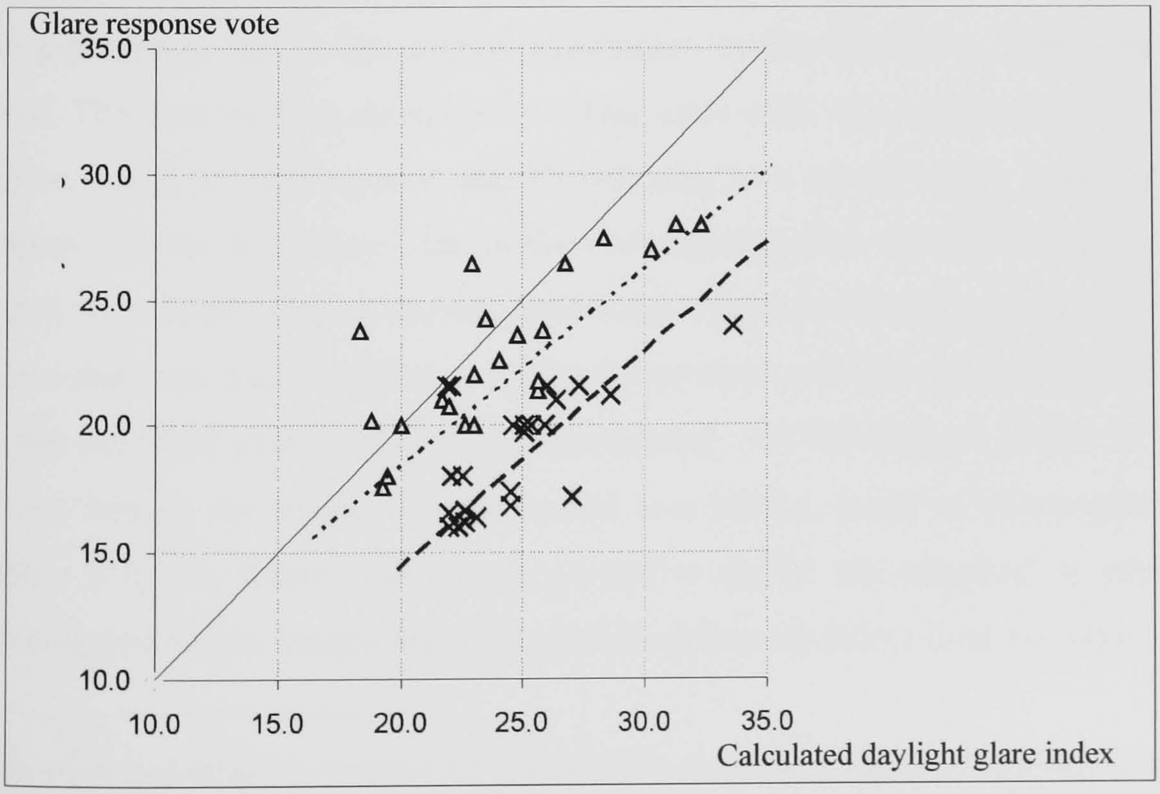


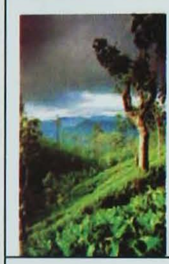
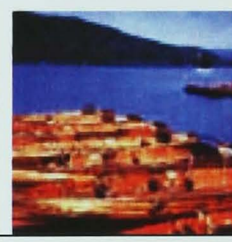
Figure A.2: Results of a natural one-layer view and a urban one-layer view from the second experiment in the real daylighting conditions. Δ represents the results of a natural view with one layer. × stand for the results of an urban view with one layer. The broken lines are trend lines of the fitted equation.

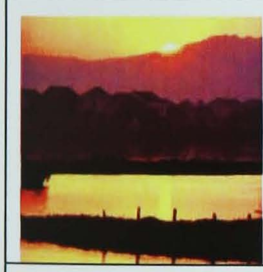
A.3 A Guideline for Giving Numbers of Interest in the Equation

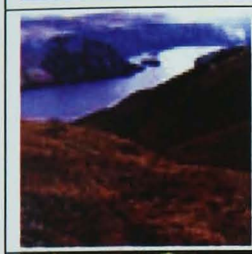
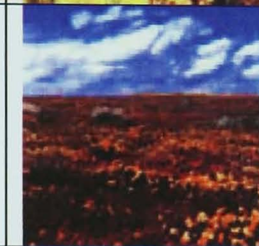
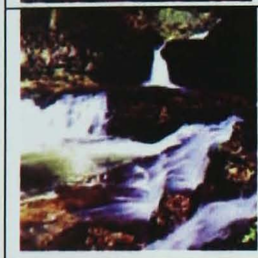
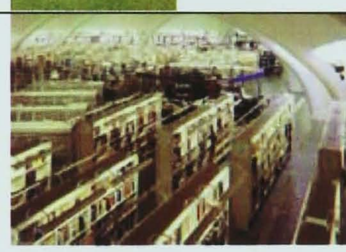
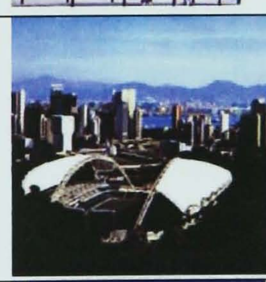
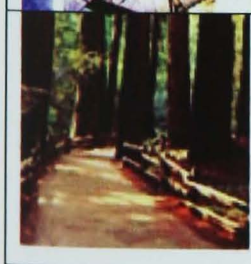
Interest in a view varies with people who assess the view, the view itself, and the situation where the view is evaluated. In order to determine a value of interest in a view (IV) in this modified equation, a guideline summarizing all interesting screen images and all interesting views that have been used in this study and their mean, minimum, maximum interest scores was given in this section. This guidance was aimed to give a basic idea of how much the scores of interest in an investigated view (IV) in the modified formula would be. This was done by relating an investigated view to the most similar image tabulated in this guideline. The interest score (IV) would be obtained by using of the mean interest score assigned to such an image. There are three preliminary tests that contain rating scores of the interest of image and interest of view. These are a preliminary test for the first experiment in the laboratory, that for the second experiment in the laboratory, and that for the first experiment in the real environment. Each test used different scales to rate the degree of interest[17]. For the preliminary test for the first experiment in the laboratory, thirty-one images were rated. This test used a five-point rating scale with the values from 1 to 5, where 0 implies a screen image of no interest at all, and 5 indicates a screen image of extraordinary high interest. For the preliminary test in the second experiment in the laboratory, fifty screen images were rated. This test used an eleven-point rating scale with values from 0 to 10, 0 representing a screen image of zero interest and 10 referring to a screen image with extraordinary high interest. For the preliminary test of the first experiment in the real daylighting condition, ten views were rated using an eleven-point scale. Apart from the three preliminary tests, all the views that were used in the second experiment were rated for interest before an investigation of the modified glare formula were performed. All the interest scores of the investigated screen images and views were converted to a similar scale, an eleven-point scale with the values 0 to 10, which was that employed to derive the equation. A table of images of investigated screen images and views and their interest scores is shown below.

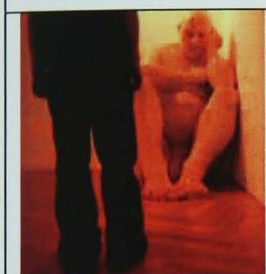
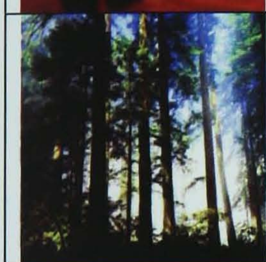
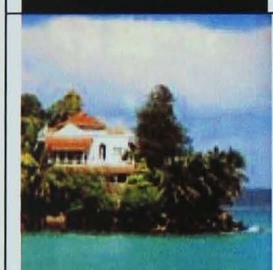
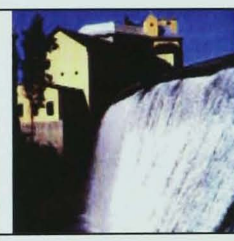
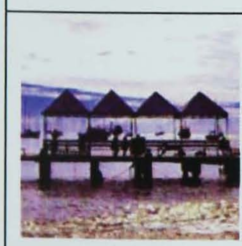
[17] As mentioned already in section 4.4.2.1, it should be emphasized again that the five-point rating scale was only used in the preliminary test for the first experiment in the laboratory, while the eleven-point scale was employed in subsequent experiments. The reason for this is that we used a simple method for the first test but we employed the different scale later because there was complaints from subjects in the first test for more comprehensive scaling.

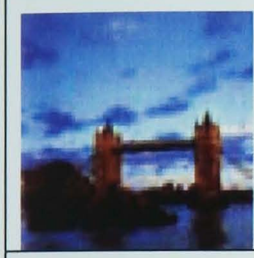
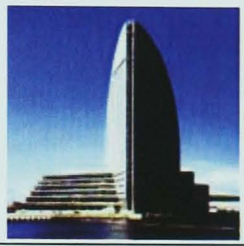
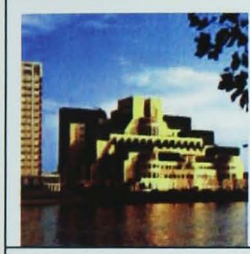
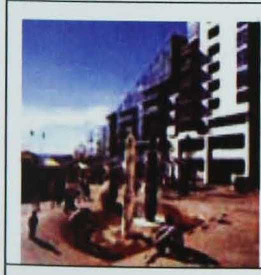
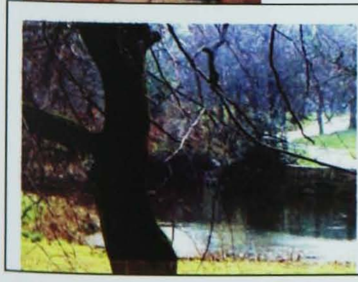
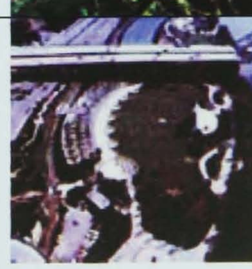
Table A.2: A guideline for giving numbers of interest in a view in the equation

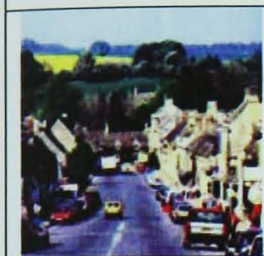
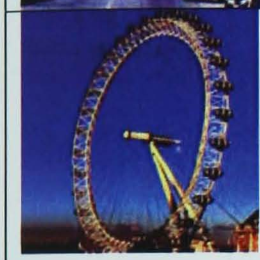
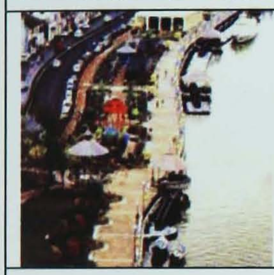
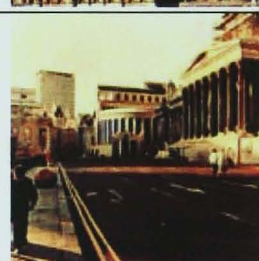
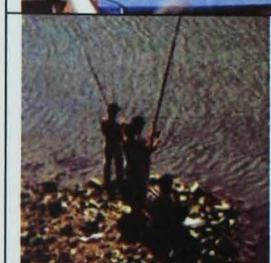
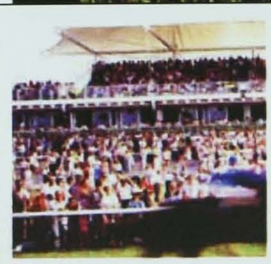
Pictures	Interest scores			Pictures	Interest scores		
	Ave	Min	Max		Ave	Min	Max
	9.50	8	10		9.26	8	10
	9.00	8	10		8.88	6	9
	8.76	8	10		8.70	6	10
	8.63	8	10		8.58	8	10
	8.58	7	10		8.50	8	10
	8.50	8	10		8.26	6	10
	8.00	7	9		7.76	6	10

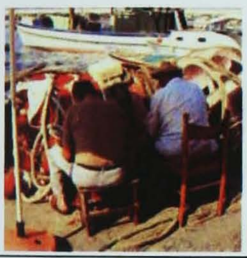
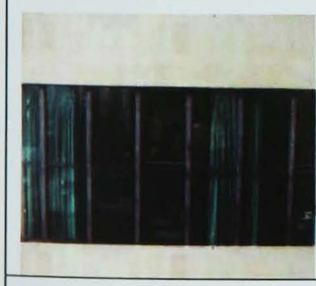
Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Max	Min
	7.76	6	10		7.76	5	10
	7.60	6	10		7.60	5	8
	7.50	5	8		7.50	6	8
	.750	8	10		7.50	8	10
	7.50	6	10		7.36	6	10
	7.36	5	10		7.24	6	8

Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Min	Max
	7.24	6	8		7.20	5	10
	7.20	5	8		7.20	5	8
	7.21	6	8		7.20	5	10
	7.00	6	8		7.00	5	8
	7.00	3	8		6.96	4	8
	6.96	4	8		6. 96	4	8
	6.94	4	8		6.94	5	8

Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Min	Max
	6.92	5	9		6.92	5	8
	6.90	4	9		6.90	6	8
	6.67	4	9		6.67	5	8
	6.60	5	7		6.50	4	8
	6.50	4	9		6.39	3	8
	6.39	3	8		6.38	3	8
	6.38	3	8		6.24	5	7

Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Min	Max
	6.20	5	8		6.13	2	8
	6.13	3	8		6.13	2	8
	5.83	3	8		5.56	4	7
	5.50	5	10		5.49	4	6
	5.36	4	6		5.29	4	7
	5.21	4	9		5.20	3	7
	5.22	3	6		5.00	3	7

Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Min	Max
	5.00	3	8		5.00	3	7
	5.00	3	7		5.00	3	7
	4.79	3	5		4.79	3	6
	4.79	3	7		4.70	3	8
	4.70	3	8		4.46	3	8
	4.46	2	6		4.31	3	6
	4.17	2	7		4.21	3	7

Pictures	Interest scores			Pictures	Interest scores		
	Mean	Min	Max		Mean	Min	Max
	4.07	3	7		3.90	3	8
	3.86	3	7		3.83	3	6
	3.76	3	7		3.63	2	5
	3.63	2	4		3.63	1	5
	3.63	2	5		2.79	2	4
	2.64	1	4		2.54	1	5
	1.83	1	3				

Appendix B

A Questionnaire for an Investigation of Effect of Image Interest on Discomfort Glare

B.1 EXPLANATION OF STUDY

Study: The effect of interest in an image on discomfort glare

Investigator: Nuanwan Tuaycharoen

Explanation:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. This research will investigate the effect of interest in a small projected screen image on the sensation of discomfort glare.

Overall procedure to be followed:

There are two sessions in this experiment. The first session is pretest period and the second is the real experiment. In the first period, you will be required to complete six steps. Firstly, you will obtain the explanation of this study and complete your informed consent. Secondly, you will complete your general information. Thirdly, you will listen to all instructions for you to do in the example test and all instructions in the real experiment which will be described by the experimenter. Then, the experimenter will show you an example of one experiment trial. Then, you will be required to do one trial of the example test. Finally, in this pretest period, after you have done the example test, I would like you to relax as much as possible. It is essential for the results of the experiment. The second period is the real experiment period, which you will participate in for the main results. This session will require you to sit in front of a series of bright screens and you will be asked to judge three criteria of discomfort glare from just noticeable level, just uncomfortable level, and just intolerable level.

Risks:

There are no significant risks associated with this experiment. You will be exposed to glare sources that may cause temporary discomfort.

Period of time required:

The study will require last about 10-15 minutes.

B.2 INFORMED CONSENT FORM

This is to certify that I,................................., hereby concur to participate as a volunteer in this investigation as an authorized part of the education of The University of Sheffield. The investigation and my part in the investigation have been defined and explained to me by Nuanwan Tuaycharoen, and I understand this explanation.

I have been given a chance to ask whatever questions and I am free to deny any answers to specific questions in questionnaires. I also understand that any answers to questions will remain confidential regarding my identity.

I certify that I have no physical or mental illness that would increase the risk to me of participation in this investigation. I also understand that if there is an injury occurring from this investigation, neither medical treatment nor financial support is provided for such an injury.

I understand that I am free to terminate my participation at any time.

....

Date Subject's Signature

I have had the investigation fully defined and explained to me on the above subject.

....

Date Investigator's Signature

B.3 PRE STUDY SUBJECT QUESTIONNAIRES

Subject number……

Please give information about yourself. This will help us in classifying your responses.

1. Are you male or female (circle one)? Female/ Male
2. What is your age? Under 18 18-45 Over 45
3. Do you have architecture or lighting background? y/n
4. Do you wear glasses or contact lens? y/n
5. Have you got normal colour vision? y/n
6. Have you got any other eye problems? y/n
7. Are you a University Student? y/n
8. Are there any concerns or other information that you feel the experimenter should know about? If so please indicate the concerns or information?

____

____

____

____

B.4 SUBJECT INSTRUCTIONS

Discomfort glare:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted.

Instructions:

In this real experiment, you will be asked to judge a series of bright screens with three discomfort glare criteria beginning form just noticeable level, just uncomfortable level, until just intolerable level. You are required to fix your eyes at the centre of the right screen. The screen will be bright and its brightness will be increased from the lowest luminance. You are required to judge the screen by saying, for example, “just noticeable” when you reach that level of discomfort glare. The light of the screen would be increased until you say you have reached just intolerable discomfort. If at anytime after observing a screen you have an afterimage, square in your field of view where the bright screens were positioned, indicate this to me. I will not present more stimuli until the afterimage is gone. This will allow your eyes to readapt if necessary. This is done in order to minimize the afterimage effect. Then, we will continue the rest of treatment. For each treatment, you required to judge three thresholds of discomfort glare. After you finish the judgement of each treatment, you are required to readapt your eyes for about 2 minutes or until you feel that you don’t have an afterimage effect. Then, the next treatment will begin until eight treatments have been completed. Please use the same evaluation method throughout this experiment. To give you better understanding of each level of discomfort sensation that you are required to judge, the three threshold criteria are described below:

Just noticeable glare: The point where you could tolerate the discomfort sensation for approximately 1 day, when working in someone else's room. But, you would require a change in lighting condition if you were to work there for longer periods of time.

Just uncomfortable glare: The point where you find the source could create the discomfort or annoyance sensation, which you could tolerate for approximately 15-30 minutes if the work has to be carried out. But it would require a change in lighting condition for any longer period.

Just intolerable glare: The most intense sensation of glare at which you feel that the glare source creates the discomfort sensation which you can't stand anymore. You would immediately need to change the lighting condition.

It is noted that, while you make judgements of these criteria, you should think from the perspective that you have to pursue some visual tasks in the working environment. Moreover, if you feel that you have difficulty in making judgements or there are some specific factors that you feel that affect your choice, please make these known by comments in a blank space in the questionnaire. If there are no questions, we will begin.

B.5 SUBJECT QUESTIONNAIRES

COMMENT:

THANK YOU FOR YOUR COOPERATION

Please do not write below

Date..Subject number...........................

Appendix C

A Questionnaire for an Investigation of Effects in Images of Natural Scenes on Discomfort Glare

C.1 EXPLANATION OF STUDY

Study: The effects in images of natural scenes on discomfort glare

Factors to be investigated:

1 An image of a natural scene instead of an urban or man-made environment
2 The presence of water in an image
3 The presence of visible sky in an image
4 The presence of nearby ground surface in an image

Investigator: Nuanwan Tuaycharoen

Explanation:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. This study will investigate the effects of contents in a small screen image on the sensation of discomfort glare.

Overall procedure to be followed:

There are two parts required for you to take part. The first part is a pretest period and the second is the real experiment. There are four main sessions in the real experiment periods and each session contains a specific aim. In the pretest period, after you get the explanation of this study, you will be required to complete your informed consent. Then, you will have to complete your general information. After that, all instructions for what you need to do in the example test in the pretest period and the real experiment will be described to you by the experimenter. Then, an example experiment trial will be illustrated to you by a experimenter. You will then do one trial of the example test and relax as much as possible. The real experiment period, will then begin. You are then required to sit in front of a series of two bright screens and you will be asked to determine which of the screens causes more discomfort.

Risks:

There are no significant risks associated with this experiment. You will be exposed to glare sources that may cause temporary discomfort.

Period of time required:

The study will last about 20-25 minutes.

C.2 SUBJECT INSTRUCTIONS

Discomfort glare:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted.

Instructions:

In the real experiment, you are about to participate in a study in which you will be asked to determine which of two bright screens cause more discomfort by indicating "left" or "right". Please make an evaluation for each pair within 3 seconds. You will be asked to look at a specific mark directly between two screens. It is important that you continually look at that mark and not at screens. If at anytime after observing a pair of screens you have afterimage in your visual field, indicate this to me. Otherwise you will have to re-adapt your eyes after completing 10 comparisons. I will not present more screens until the afterimage is gone. After you complete the first session (10 comparisons), you will relax for 2 minutes or until the after image has gone. Then, you will continue the next session until you complete four main sessions. Be sure to use the same evaluation procedure throughout this study. A bright light source in your field of view can cause discomfort. By **discomfort** we mean a sensation that a light is too glaring to comfortably work with it in your field of view. If there are no questions, we will begin.

Appendix D

A Questionnaire for an Investigation of Effect of Image stratification on Discomfort Glare

D. 1 EXPLANATION OF STUDY[18]

Study: The effect of image stratification on discomfort glare

Investigator: Nuanwan Tuaycharoen

Explanation:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. This experiment will investigate the effect of image stratification on discomfort glare.

Overall procedure to be followed:

There are two main periods, a pretest period and the real experiment. In the first period, you will obtain the explanation of this study containing an aim and overall procedure of this experiment and will be required to complete your informed consent. Then, you have to complete your general information. After that, you will listen to instructions for the example test and those for the real experiment. Then, the experimenter will show you an example experiment trial and also let you do one trial as an example test. Then, relax for about 5

[18] There are five forms for subjects to complete for this experiment. The informed consent form and the pre-study subject questionnaire are the same forms as those used in an investigation of the effects of image interest on discomfort glare, so they don't be reviewed here (refer to Appendix B). The same set of questionnaires was also used for the experiment for investigating the effect of luminance variation in an image (RMLm) on discomfort glare, but with different aim described in.

minutes. In the second period, you will be required to sit in front of a right bright screen and you will be asked to determine discomfort sensation on a questionnaire.

Risks:

There are no significant risks associated with this experiment. You will be exposed to glare sources that may cause temporary discomfort.

Period of time required:

The study will require last about 15-20 minutes.

D.2 SUBJECT INSTRUCTIONS

Discomfort glare:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted.

Instructions:

In this real experiment, you will be asked to sit at a seat and adapt your eyes to the environment. Then, you will be required to look at the centre of the right screen. You are required to evaluate discomfort glare form this screen by marking on GSV scale provided and at the same time sending a signal to the experimenter within 3 seconds. Then, please continually look at the centre of the screen again and continue the same evaluation for other treatments. If at anytime after observing a screen you have an "afterimage"— a square in your field of view where the bright screens were positioned, indicate this to me. I will not present more stimuli until the afterimage is gone. Otherwise you will have to re-adapt your eyes after completing all treatments. The same evaluation procedure should be made throughout this experiment. Four threshold criteria and a guideline are described below to help you make a decision of where on the scale you should mark.

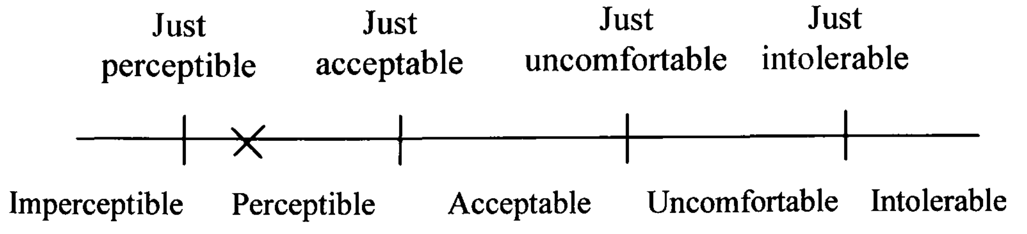
Just perceptible glare: The point where glare discomfort is first noticed by the subjects. This level was defined by the point at which you feels that the glare source is just irritating or noticeable, but causing no great annoyance. Below this level, you are aware of the glare source as a patch of light, without suffering any annoyance from it.

Just acceptable glare: The point where you could tolerate the discomfort sensation approximately 1 day, when working in someone else's room. But, you would require a change in lighting condition if they were to work there for longer periods of time.

Just uncomfortable glare: The point where you find the source creates a discomfort or annoyance sensation, which you could tolerate for approximately 15-30 minutes if the work has to be carried out. But it would require a change in lighting condition for any longer period.

Just intolerable glare: The most intense sensation of glare at which you feel that the glare source creates the discomfort sensation that you can't stand anymore. You would immediately change the lighting condition.

It is noted that, while you make judgements of these criteria, you have to think that you would have to pursue some visual tasks in the working environment. If you feel the glare source is perceptible but does not approach to acceptable glare, the mark would probably placed as shown below. If there are no questions, we will begin.



D.3 SUBJECT QUESTIONNAIRES[19]

Subject Number...........

INSTRUCTION:

How do you feel about discomfort glare from this screen image? Please mark on the line at the point that best describes how much discomfort you are having right now.

1
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

2
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

3
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

4
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

5
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

6
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

7
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

8
Just perceptible — Just acceptable — Just uncomfortable — Just intolerable
Imperceptible | Perceptible | Acceptable | Uncomfortable | Intolerable

COMMENT:

____

____

THANK YOU FOR YOUR COORPERATION

[19] Another typical questionnaire is used for image 9-16.

Appendix E

An Investigation of Effect of View Interest on Discomfort Glare from Windows

E.1 EXPLANATION OF STUDY[20]

Study: The effect of interest in a view on discomfort glare from windows

Investigator: Nuanwan Tuaycharoen

Explanation:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. The existing daylight glare model is based on traditional sources where there is no view-related effect. However, normally windows, as sources of glare, have views that can be seen through. This research will investigate the effect of interest in a view on the sensation of discomfort glare providing insight into modeling discomfort glare from windows with the effect of interest in a view.

Overall procedure to be followed:

Two main periods will be carried out in this experiment, which are a pretest period and a real experiment. In the first period, you will obtain the explanation of this study and will be required to complete your informed consent. After that, you will have to complete your

[20] There are five forms for subjects to complete for this experiment. The informed consent form and the pre-study subject questionnaire are the same forms as those used in an investigation of the effects of image contents on discomfort glare, so they don't be reviewed here (refer to Appendix B). The same questionnaire was also used for the second experiment in the field studies, but with different aims. The aims for the second experiment are to see the effects of naturalness of view and the view stratification on discomfort glare.

general information. Then, you will listen to all the instructions described by the experimenter. An example of experiment trial will be then described and shown by an experimenter to you and you will be required to do one trial of an example test. Finally you will relax for 5 minutes. The second period is the real experiment period, which you will be sat in front of a window and asked to determine discomfort sensation for each window by marking on a questionnaire provided.

Risks:

There are no significant risks associated with this experiment. You will be exposed to glare sources that may cause temporary discomfort.

Period of time required:

The study will require last about 5 minutes for each view.

E.2 SUBJECT INSTRUCTIONS

Discomfort glare:

Discomfort glare is the annoyance, or temporary discomfort produced by luminance (brightness) within the visual field that is sufficiently greater than the luminance to which the eyes are adapted.

Instructions:

You are about to participate in a study in which you will be asked to rate discomfort glare by marking on the continuous scale provided. Firstly, after the pretest period, you will be asked to sit at a seat and adapt your eyes to brightness of an environment. Then, you will be asked to look at the centre of the window for about 30 seconds to evaluate discomfort glare by marking on GSV scale provided and at the same time send a signal to the experimenter to record the light level. It is important that you continually look at that mark after you mark on the scale. If at anytime after observing a window you have afterimage, bright squares were positioned in your field of view, indicate this to me. You will have to re-adapt your eyes until the afterimage is gone. Otherwise you will have to re-adapt your eyes after completing each treatment evaluation. The same evaluation procedure should be used throughout this study. To help you to rate discomfort glare from a window, four thresholds of discomfort glare are defined as follows:

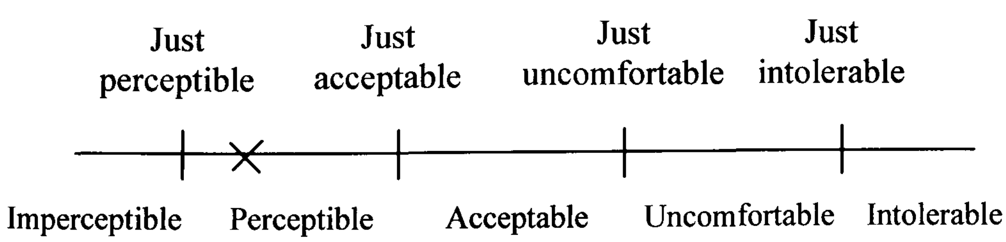
Just perceptible glare: The point where glare discomfort would be firstly noticed by the subjects. This level was defined by the point at which you feel that the glare source is just irritating or noticeable, but causing no great annoyance. Below this level, you are aware of the glare source as a patch of light, without suffering any annoyance from it.

Just acceptable glare: The point where you could tolerate discomfort sensation for approximately 1 day, when working in someone else's room. But, you would require a change in lighting condition if you were to work there for longer periods of time.

Just uncomfortable glare: The point where you find the source could create the discomfort or annoyance sensation which you could tolerate for approximately 15-30 minutes if the work had to be carried out. But it would require a change in lighting condition for any longer period.

Just intolerable glare: The most intense sensation of glare at which you feel that the glare source creates the discomfort sensation until you can't stand it anymore. You would immediately change the lighting condition.

It is noted that, while you make judgements of these criteria, you should think that you have to pursue some visual tasks in the working environment. If you feel discomfort glare from the window is perceptible but does not approach to acceptable glare, the mark would be placed approximately as shown below. If there are no questions, we will begin.



E.3 SUBJECT QUESTIONNAIRES[21]

INSTRUCTION:

When you raise your head and look at the window, how do you feel about the glare from the window? Please mark on the line at the point that best describes **HOW MUCH DISCOMFORT YOU ARE HAVING RIGHT NOW**. Notice that what is being measured is the perception **right now**, not a comparison such as, what is your discomfort sensation compared to what you had before.

Just perceptible	Just acceptable	Just uncomfortable	Just intolerable

Imperceptible	Perceptible	Acceptable	Uncomfortable	Intolerable

COMMENT:

____

____

____

THANK YOU FOR YOUR COOPERATION

Please do not write below

View...Date...

Subject number.......................................Time recorded.......................................

Weather condition: ....

[21] A typical questionnaire was used for each investigated view and a blank window.

Appendix F

Publications

F.1 DISCOMFORT GLARE FROM INTERESTING IMAGES

Lighting Res. Technol. 37,4 (2005) pp. 329–341

Discomfort glare from interesting images

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Received 14 August 2004; revised 18 February 2005; accepted 21 February 2005

In laboratory experiments, subjects viewed bright images projected on to small screens. The projected images ranged from neutral patterns to complex scenes. There was a greater tolerance of discomfort glare from images previously judged 'interesting' by an independent subject group than from other screen images giving the same calculated glare rating or from a reference source. When presented with matched pairs, images of natural scenes were reported as less glaring than pictures of urban scenes; specific elements of a view, such as the presence of water, also had an effect.

1. Introduction

Calculated daylight glare indices are often poor predictors of the subjective assessment of discomfort glare from real windows.[1,2] This suggests that window glare depends on more factors than the four normally embodied in glare calculations: source luminance, source size, surround luminance, and a position index. Hopkinson[2] says that the outside view is undoubtedly a mediating or an enhancing factor. He notes, from comments by observers, that a view with a great deal of interesting information extends subjects' tolerance level of discomfort glare. Boyce,[3] discussing glare in general, points out that the circumstances in which a high luminance occurs, and the meaning of the source of glare, can have an important effect on whether the condition is assessed as uncomfortable.

Most research on glare from windows has been devoted to developing prediction formulae using only the four parameters given earlier.[2,4–8] Some other factors have been investigated,[9] but there is no record of a systematic study on the effect on glare of the view through a window.

There have, though, been studies of subjective responses to different types of view, in particular of the characteristics that make the view through a window interesting. Ulrich[10,11] and also Tennessen and Cimprich[12] suggested that natural views are more interesting than urban or man-made views. Orland[13] pointed out that the presence of human influences is generally perceived as relatively less attractive than a purely natural landscape. Markus[14,15] examined the stratification of views; he argued that views containing all three horizontal layers—sky, landscape or cityscape, and nearby ground—are preferred to views that include only one or two layers.

It would be useful in both research and application to know whether an interesting view does reduce the sensation of glare from a window. It would, for instance, be evidence that even when examining physical comfort a purely psychophysical approach is insufficient; and the usefulness in practice of window glare formulae would be greatly enhanced if inclusion of view-related factors improved their predictive power.

This paper considers the fundamental question of whether there is a measurable effect of the information content of a bright source on

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discomfort glare. If so—if a window-view can have meaning and this can modify glare discomfort—the information content of a bright image might affect the degree of discomfort whatever the size of the glare source; and if the effect is small it might be measurable in the laboratory but masked by the continual variation of other factors with a real window.

The research strategy was therefore first, to see whether a relationship between image content and discomfort glare was measurable in a controlled laboratory experiment; second, if the first test gave a significant result, to use the laboratory procedure to look for systematic relationships between discomfort glare and the content of images—that is, whether different types of view might affect window glare differently; third, to test whether similar results could be found with large glaring images and real windows. This paper describes the first two experiments, each preceded by a preliminary test.

The general hypothesis was that *bright images that subjects find interesting are associated with a lower degree of discomfort glare than other sources with the same glare index*. The first experiment was a direct test of the question, 'Is there any measurable effect of image content on glare?' A small tightly controlled group of subjects viewed random sequences in which bright neutral screens were interspersed with images ranked on 'interest' by an independent subject group. The second experiment was designed to test whether discomfort glare varied with the type of image content. For this, a larger subject group viewed matched pairs of bright images.

2. Method

2.1 Setting

The experiments were conducted in the laboratories of the University of Sheffield School of Architecture between October 2003 and April 2004. The apparatus is shown in Figure 1.

Subjects sat in an open cubicle facing three potential glare sources: a small diffuse source seen through an aperture, which acted as a reference, and two diffusing screens onto which images were back-projected. The cubicle was half-hexagonal in plan; the interior surfaces were painted matt white internally and illuminated from outside the

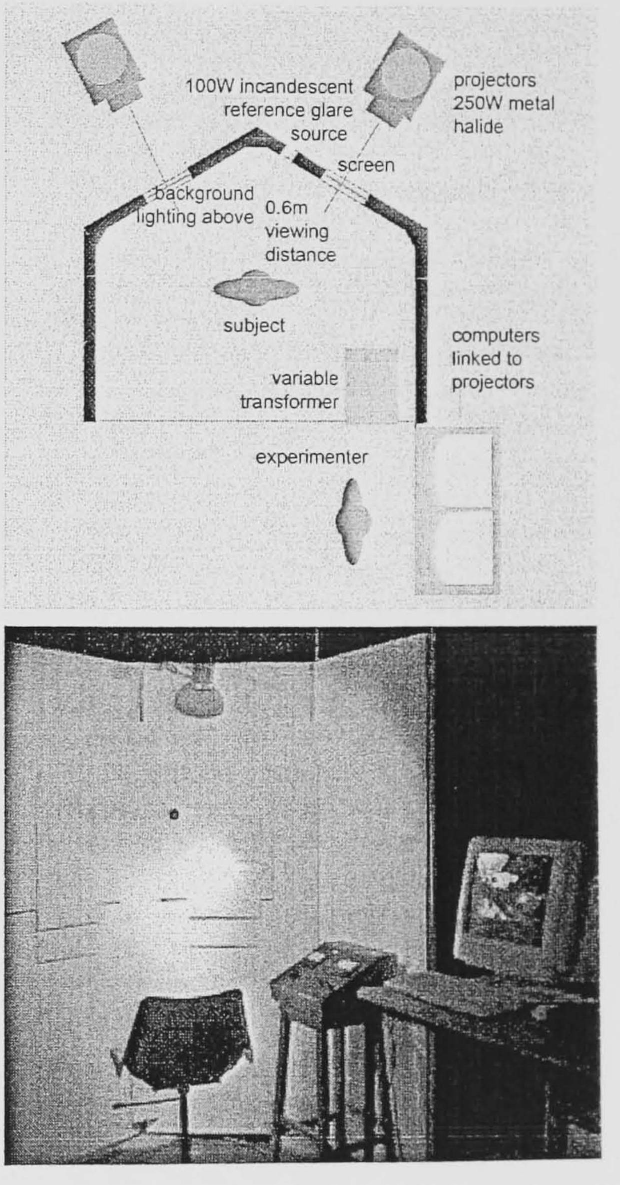

Figure 1 Drawing and photograph of experimental layout

cubicle to maintain an unchanging luminance distribution. Stray light outside was masked.

Subjects were positioned with their eyes at the centre of the hexagon in plan, 600 mm from both test screens and at the same height. The projected image size was either 40 mm × 80 mm or 40 m × 55 mm, subtending angles at the eye of 0.009 steradians and 0.006 steradians. Two fixation points were used: one at the subjects' eye-level in the centre of the panel between the screens (30° from the lines of sight to the test screen centres), the other in the centre of the right-hand screen.

For the test glare sources, two modified digital projectors located behind the partition projected images on diffusing screens, achieving a luminance range from 1000 cd/m^2 to 150 000 cd/m^2. The projectors used 250W metal halide lamps and the beams were condensed onto small areas with additional convex lenses. The projectors were connected to two computers which generated the images. An additional glare source, the 'reference' source was a 100W opal incandescent lamp, on dimmer control, seen through an opening in the central partition, 16° above and 12° to the right of the line of sight. Incandescent lamps provided the general illumination of the cubicle surfaces.

2.2 Photometric measurements

Luminance was measured from the subjects' eye position with Minolta LS-110 and Pritchard photometers. The mean background luminance was calculated from 17 measurements of the surrounding white surfaces taken on a regular grid symmetrical about the central fixation point and extending across the width of the cubicle. The mean luminances of non-uniform screen images were first calculated from point values on a grid across the screen and then validated by comparison with measured illuminances on a cell perpendicularly facing the screen.

2.3 Experiment I: image interest and glare tolerance

2.3.1 Aim

Is there an association between subjects' interest in the content of projected images and tolerance of discomfort glare? To be consistent with previous work we took 'glare' to be quantified by the glare indices at which the subjects' said the sensation they experienced was 'just noticeable', 'just uncomfortable' and 'just intolerable'. There is not, however, an appropriate conventional definition of 'interest', which is highly subjective and depends not only on the stimuli but on people and the circumstances they are in.

2.3.2 Defining interest

For this experiment the degree of interest of an image was quantified by the scores given by independent subjects (a different group from those used in the experiment itself). Thirty-one pictures were presented in random order on a 1.5 m × 2.0 m screen to eight subjects—university students in architecture but differing in nationality and social background. They were asked to assess the 'interest' of each using questionnaires with five-point rating scales. The pictures were ranked by mean score; the top eight are illustrated in Figure 2. The most highly ranked was a picture showing a man with a baby in an exotic interior.

2.3.3 Comparison with neutral screens

The four highest-scoring pictures were used in the experiment. The final set of eight images (four pictures and four blank slides matching each picture in mean luminance, shape and size) were shown in random order to subjects, initially at a low luminance, then, under the control of the experimenter, at increasing brightness in steps of about 2 kcd/m^2. The subjects were asked to fix their gaze on a point at the centre of the screen and were asked to say when the screen was just noticeably glaring, then when it became just

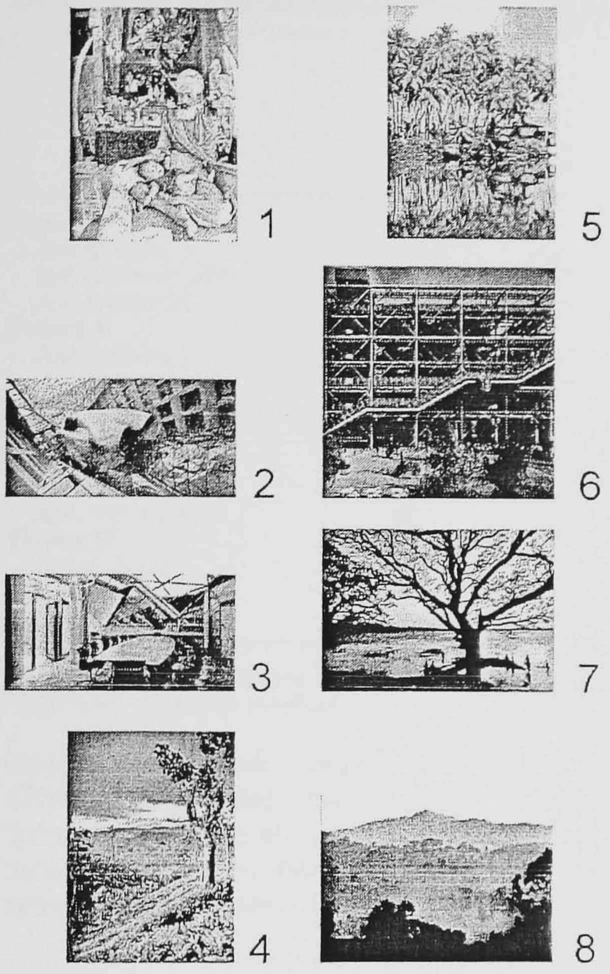

Figure 2 The eight images ranked most highly on 'interest' in the preliminary experiment

uncomfortable, then just intolerable; the settings at which these occurred were recorded. Subjects relaxed after each sequence and the next new image was not projected until any after-images had completely vanished.

Before testing, this was the procedure. On arrival, each subject was asked to complete a short questionnaire on general background, sight and medical condition. He or she then sat in the chair, which was adjusted in height so the subject's back was straight and the head located at the viewing position. The instructions were read to the subject; these included a definition of glare, the meaning of the three criteria, and a description of how the experiment would run. The subject was then asked to look at the central fixation point and to adjust the brightness of the reference source so that the glare sensation it produced was first 'just noticeable', then 'just uncomfortable' and 'just intolerable'. The first purpose of this was to affirm the subject's understanding: in this experiment, 'glare' and the three threshold criteria were in effect defined by this immediate experience with the reference source, and this was common to all subjects. The procedure also provided an initial calibration of the individual's glare response which might be used in later analysis. The procedure ended with a relaxation period of 10 min before the main experiment began.

To minimize cultural differences in 'interest' the first experiment used a subject group tightly controlled in educational and cultural background. A minimum possible sample size of seven subjects was calculated from operating characteristic curves[16] basing estimates of error variance of the population and minimum detectable luminance difference on results in Waters,[17] and adopting 0.05 for Type I and Type II error probability. A Balanced Latin Square randomized allocation of treatments required eight subjects and this number was adopted.

The subjects were university students of Thai nationality, four men and four women, aged 18–30. Two men and two women wore spectacles; all were self-certified as having no other eye problems and having no colour-vision deficiency.

2.3.4 Results

The outcome is summarized in Table 1 and Figure 3. There were significant differences between glare sensations from the two images ranked most interesting and the sensations from neutral screens of the same mean luminance.

The numerical results were a set of luminance values reported by subjects to be the three glare thresholds—noticeable, uncomfortable, intolerable—as they viewed screen

Table 1 Mean and standard deviation glare indices associated with levels of glare discomfort from images and neutral screen

	IES				UGR			
	Neutral screen		Image		Neutral screen		Image	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Picture A								
Just noticeable	20.2[b]	7.26	29.1[b]	3.97	22.2[b]	7.23	31.1[b]	3.97
Just uncomfortable	26.3[a]	7.79	34.2[a]	3.28	28.3[a]	7.80	36.2[a]	3.30
Just intolerable	32.6[a]	5.68	38.0[a]	4.30	34.6[a]	5.69	40.0[a]	4.30
Picture B								
Just noticeable	26.5[b]	6.49	33.0[b]	3.50	28.5[b]	6.49	35.0[b]	3.50
Just uncomfortable	34.1[b]	5.58	38.5[b]	3.30	36.2[b]	5.56	40.5[b]	3.32
Just intolerable	41.3[a]	3.29	42.5[a]	2.88	43.3[a]	3.31	44.5[a]	2.88
Picture C								
Just noticeable	27.1[a]	5.32	29.5[a]	4.54	29.1[a]	5.33	31.5[a]	4.54
Just uncomfortable	34.8	3.08	34.6	4.29	36.8	3.08	36.6	4.29
Just intolerable	40.0	2.45	39.7	3.78	42.0	2.45	41.7	3.76
Picture D								
Just noticeable	23.7[a]	7.22	25.9[a]	5.26	25.7[a]	7.22	27.9[a]	5.26
Just uncomfortable	31.4	5.23	31.7	5.13	33.4	5.23	33.7	5.13
Just intolerable	37.1	3.89	36.9	4.06	39.1	3.89	38.9	4.06

[a]Highly significant difference between pair of mean values ($P<0.01$) in *t*-test;
[b]Significant difference ($P<0.05$).

images becoming incrementally brighter. Glare ratings and indices were computed from these luminances, the angular dimensions and the measured background luminance using the equations:

$$\mathrm{UGR} = 8 \log\left[\frac{0.25}{L_b}\sum\frac{L_s^2\omega}{P^2}\right]$$

$$\mathrm{GI} = 10 \log 0.478 \sum\frac{L_s^{1.6}\omega^{0.8}}{L_b p^{1.6}}$$

I_s is source luminance (cd/m^2), L_b is background luminance (cd/m^2), ω is subtended size of sources (steradians), p and P are dimensionless position factors.

Table 1 shows the mean and standard deviation of the two glare quantities for all four images and their equivalent neutral screens. The glare rating or index at which a threshold was reported tended to be higher when the source was an image than when a matching neutral screen. A matched-pair t-test finds this difference to be significant across all degrees of glare threshold in the two images ranked highest in interest; in three of the six cases the result was highly significant ($P<0.01$). With the other two images there was a significant difference only at the 'just noticeable' level.

The effect of interest on glare sensation may diminish as glare becomes more intense. Figure 3 plots the image luminance at which each subject reached a threshold (y-axis) against the neutral screen luminance (x-axis) at which the subject reported the same degree of glare. All four images are included. The diagonal line is the null hypothesis: no difference between the mean image luminance at which a given degree of glare was reported and that of the neutral screen which caused the same response. The shorter lines are linear least-square interpolations of the separate data from the three levels of discomfort. The trend lines become almost horizontal at low image luminance, indicating that the UGR would be a poor predictor of glare discomfort there.

We conclude that, under some conditions at least, the sensation of discomfort glare is very

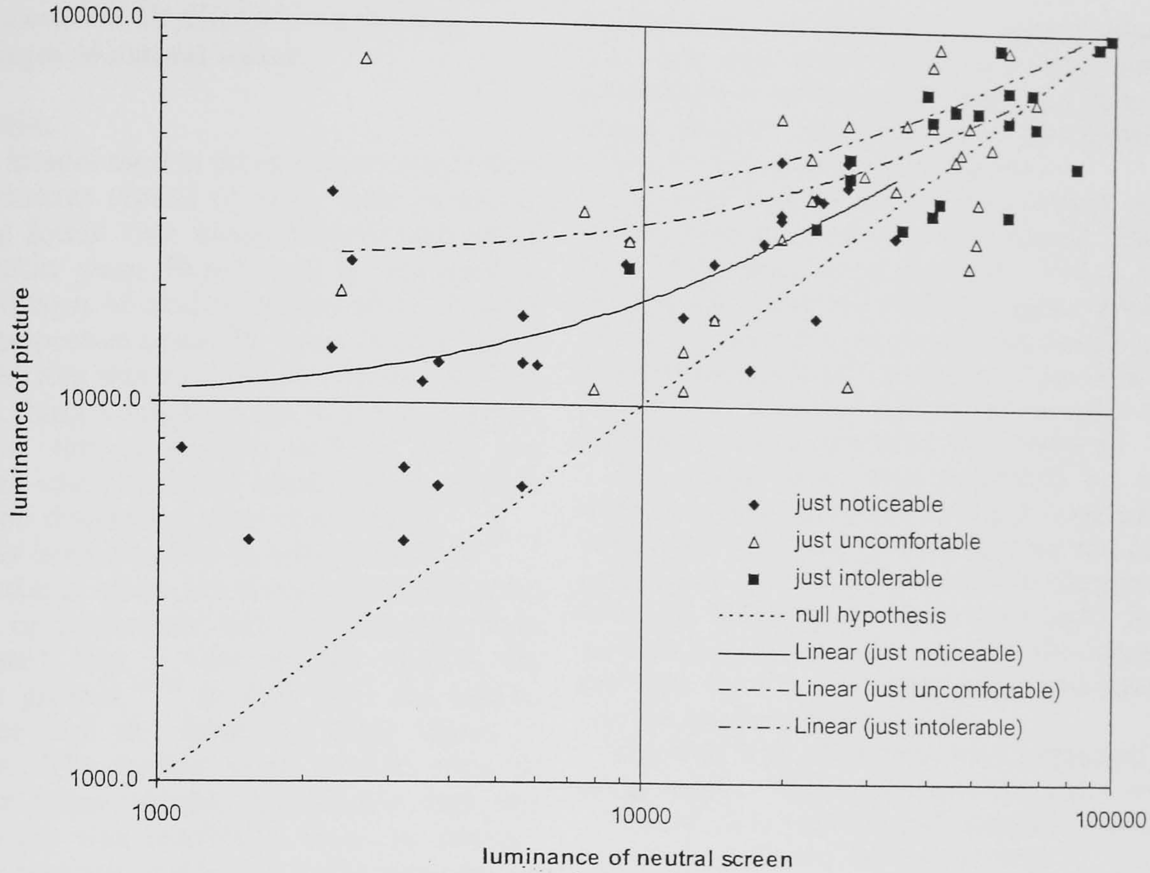

Figure 3 Comparison between luminance of blank screen causing glare and luminance of image causing the same level of glare. The higher the *y*-axis (image) value above the diagonal line the greater the glare tolerance of the image

likely to be affected by image content of a glare source. We note some factors specific to this experiment that affect interpretation of the results:

First, a uniform source was compared with one that varied in luminance and colour. If a small uniform screen is compared with an image of the same size and same mean luminance that varies in brightness across the surface, both glare formulae predict that the non-uniform image would produce a higher glare index because L_s has a higher exponent than ω. Waters *et al.*,[18] confirmed this experimentally for sources on which the subject's eyes were fixated (as in this case) but found the opposite effect with peripheral sources. The differences in Table 1 between image and blank screen glare GI and UGR values are likely therefore to be conservative.

Second, although the eight stimuli (four images, four neutrals) were presented in random order, the thresholds were determined with each source increasing incrementally in luminance. This was done to control adaptation and to avoid error occurring from very bright sources and low luminance sources being seen in succession; it was also the procedure used by Hopkinson.[19,20] The UGR and GI thresholds found are not necessarily those that would be found in other presentation sequences but this does affect the conclusions.

We note also that the use of a larger number of subjects in this experiment might have yielded more significant cases.

2.4 Experiment II: discomfort glare and images of natural scenes

2.4.1 Aim

The images used in the first experiment were by no means typical of views from windows. Having found that image content can affect discomfort glare, Experiment II was used to assess images of outdoor scenes which by scale and perspective could be views from a building. The aim was twofold: to confirm the first results using a larger group of subjects and a different test procedure; and to find out whether some types of scene have a greater effect on discomfort glare than others.

It has been reported by several authors[10–12] that natural views are more interesting than urban or man-made views. It has also been advocated that a view should include the nearby ground,[14,15] so that with the middle distance and sky there are three strata of interest. The earlier work seemed thus to provide some testable hypotheses and this conclusion was reinforced when, in another preliminary test, conducted in the same way as that preceding Experiment I, subjects ranked some pictures of outdoor views more highly than others. The most highly scored were natural scenes containing some form of water and the sky.

2.4.2 Matched pairs

To minimize variance between subjects, the experimental design used matched pairs of images. After the preliminary test, 10 pairs of slides were prepared for four cases:

1) a natural view instead of an urban or man-made environment;
2) the presence of water in a natural view;
3) the presence of visible sky in a natural view;
4) the presence of nearby ground surface in a natural view.

The images of each pair were chosen and digitally edited to be similar in subject, composition, hue distribution, colour saturation, size and mean luminance; one image contained the test item, the other, the 'control image', did not. The 20 images of the natural–urban set are illustrated in Figure 4.

The experimental setting and pre-test procedure were as in the first experiment. There were 24 subjects, equal numbers of men and women, all university students aged between 18 and 31 years but varying in nationality and cultural background. Spectacles were worn by 50% of both men and women but no other eye defects or colour-blindness were reported.

The image pairs were presented on two screens, both maintained at mean luminance, 8650 cd/m^2; the background lighting was held constant to give a spatial mean luminance of 65 cd/m^2. Subjects were instructed to fix their view on a point midway between the screens, and were asked to say which of the two images was the more uncomfortable.

The four sets of images were presented in each session. Within the sets the pairs were presented in a randomized sequence, randomized also between the two screens.

2.4.3 Results

There were significant differences in glare response between test image and control image in three of the four sets. These are shown in Table 2, which gives the number of subjects who chose each image.

On a χ^2 test, the results from all four sets indicate a highly significant difference from the null hypothesis of equal probability. With independent binary choices, as used in the experiment, the cumulative binomial distribution provides a more direct and discriminating one-tailed test. Applying this to the totals of each set of pairs in Table 2, it is found that for three of the sets there is a highly significant probability that choice of images with the specific feature differed from the null hypothesis of equal preference. The three sets were [natural view: urban view], [natural view with water: natural view without water], [natural view with foreground; natural view

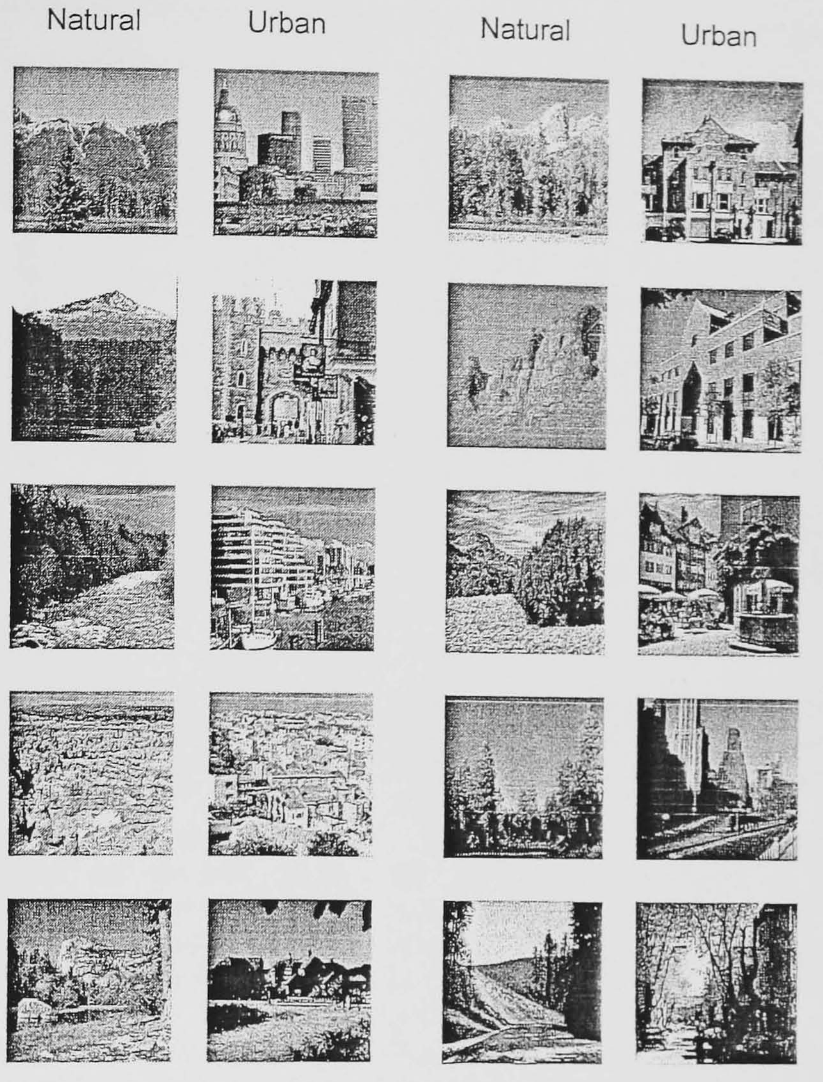

Figure 4 The 10 pairs of images of the natural–urban view set

without foreground]. The result was just below significance for the fourth set of pairs (with and without sky).

We conclude that elements of natural scenes in an image may alleviate the sensation of discomfort glare and that descriptive terms such as 'water' and 'ground' may represent significant factors. The images were complex views and each set included different ways in which the item occurred (such as, for water: sea, lake, waterfall, river); and, because there were some pairs of images not consistent with the overall result for each set, there is clearly scope for larger experiments with a multi-factorial design. We note also that the screens lay outside the subjects' central visual field and peripheral effects of non-uniform illuminance may have occurred; but because the number of subject-choices in each set was large (240) and the views were presented randomly in pairs, this is unlikely to have systematically affected the outcome.

3. Discussion

The results show that interest in the image content of a bright source can be associated

Table 2 Number of subjects (out of 24) choosing image as less glaring in paired comparison test of images with and without a given feature

Image pairs	1		2		3		4	
	Natural	Urban	Natural with water	Natural without water	Natural with sky	Natural without sky	Natural with foreground	Natural without foreground
	23	1	16	8	15	9	17	7
	11	13	21	3	3	21	16	8
	5	19	16	8	17	7	12	12
	22	2	12	12	12	12	14	10
	7	17	19	5	11	13	24	0
	6	18	9	15	4	20	21	3
	22	2	22	2	21	3	11	13
	20	4	14	10	15	9	11	13
	18	6	7	17	13	11	8	16
	20	4	20	4	19	9	19	5
Totals	154[a]	86	156[a]	84	131	109	153[a]	87

[a]Highly significant difference between pair of total values ($P<0.01$) in the cumulative binomial distribution with number of trials 10×24, $P=0.5$.

with an increased tolerance of discomfort glare. They support Hopkinson's conjecture[2] and, with particular reference to screens, add to the observation by Markus[21] quoted in Boyce[3] that 'people frequently sit for hours in front of a television set by free choice even though it should, according to the formula, be producing intolerable glare'.

It follows that, if a glare source contains some information regarded as interesting, the degree of discomfort predicted by standard glare index formulae is likely to be an overestimate. The results do not, however, indicate whether the increased tolerance is a short-term effect, which may fade after prolonged viewing, or one that persists; and this unknown affects the immediate practical implications of the findings.

Current knowledge of the mechanisms of discomfort glare is incomplete;[22] this inhibits any generalization of the results but we found no indication that the effect is peculiar to small sources. If an association between image content and glare could not have been found in a highly controlled laboratory test it would be unlikely that real windows would show a measurable effect. This, however, was not the case so the results strengthen the hypothesis that the nature of a window view is a factor affecting the sensation of discomfort from the window.

The work has brought together two largely independent streams of research: discomfort glare and preferences for window views. The finding that images of natural scenes invoke less glare discomfort than urban images supports the work of Ulrich,[10,11] Tennessen and Cimprich,[12] and Orland.[13] Knowing that simple descriptors like 'water', 'sky', 'ground', and 'view stratification' are related to decreased glare sensitivity may be useful in eventually giving practical guidance on window design. Conversely, the finding that a decrease in glare discomfort is an indicator of interest in a view may provide a useful objective tool in research on view content.

While the patterns of the results are consistent and their implications important, it is necessary to note two particular limitations of the experiments. First, the subjects participating were university students, a group of subjects distinctive in age-range and educational backgrounds. Second, the stimuli in this study were not actual luminaires or windows, and the setting was artificial; extension of the results into a real situation remains conjectural. These provide a clear programme for the next stage of research.

Acknowledgements

The authors thank the Thai Royal Government for the scholarship which funds this project. They are also grateful to the referees for their constructive comments.

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Discussion

Comment 1 on 'Discomfort glare from interesting images' by N Tuaycharoen and P Tregenza

AI Slater (Building Research Establishment, Garston, Watford, Herts, UK)

This study of glare has revealed new properties that could be particularly significant in real world circumstances. It has demonstrated that the sensation of discomfort glare caused by 'interesting' images containing a wide range of luminances is different from that caused by neutral uniform images of the same average luminance. But is this really a result of the 'interest' content of the image or could this difference in sensation be a result of the wider range of luminances contained in the complex images? A future study that compared an 'interesting' image with an 'uninteresting' image of, say, random dots but covering a similar range of luminances would address this issue.

The subjective glare responses shown in Figure 3 demonstrate the wide range of scatter usually associated with subjective studies. The fitted lines appear to show a deviation from the null hypothesis, but statistical analysis of the data to provide some measure of the scatter would be helpful in showing how important the difference is likely to be under practical situations in real buildings.

The second experiment presented matched pairs of images to the viewer. Although these were matched for many parameters, including average luminance, it is not stated in the paper whether the range of luminance contained in each image of the pair was also matched. If not, it could be that the image with the highest maximum luminance was found to be the most glaring.

As mentioned in the paper, within each set of pairs, for some pairs the image containing the test item was more often found to be more glaring, and for some pairs the image without the test item was found to be more glaring. For example, in the 'natural view: urban view' set, for six of the pairs more subjects found the natural view to be less glaring than the urban view, but for the other four pairs more subjects found the urban view to be less glaring. It may be that aspects of the content of the images other than their interest are important here. There is clearly much here for further study.

This paper has given a useful insight into the sensation of glare in a laboratory setting and some pointers to effects in the real world. The images used were similar in size to computer screens. It would be interesting to speculate whether the results could also explain why users of screens often seem relatively unconcerned about reflected images or large luminance variations when they are trying to view images with significant 'interesting' content.

Comment 2 on 'Discomfort glare from interesting images' by N Tuaycharoen and P Tregenza

MP Wilson (Director of Low Energy Architecture Research Unit, School of Architecture and Interior Design, University of North London, London, UK)

This paper deals in particular with the impact of images and the content of those images on glare. Its real impact, acknowledged by the authors, however will be in the contribution to the understanding of glare from windows. If interesting images are less glaring than others then a window with a view would be likely to be less glaring than an equivalent window of diffusing glazing. And that might be viewed as less glaring than an equivalent bank of fluorescents behind diffusing glass because the light level will be constantly changing where the diffusing glass is lit by daylight.

There is interest and information. A 'view' may be traditionally interesting in terms of the images used in this research but any view to the outside will contain information as to the weather outside and thus has some interest.

The impact of this changing view on window glare may be that glare is not the main consideration in the daylighting design of windows (apart of course from the actual level of daylight). As long as opportunity is given to orientate one's work station there is no reason to believe that one would not make adjustments to find the visually most comfortable position. This has severely limited previous work where the glare was evaluated from a position determined by the experimental set up. There is other evidence, from the PhD thesis of Y Sutter[1] that a very high level of daylight glare can be tolerated, as long as the veiling reflections on VDU screens, diffuse and specular, are controlled (more disability glare than discomfort). One explanation is that the occupants are 'adapting' their environment to minimize the glare through simple orientation. The reflection of TFT and plasma screens is much lower than those of CRT screens and as the brightness of screens increases it may be that the next controlling factor may be the potential glare of the screens themselves balanced by the veiling reflection from the window. The authors themselves mention the very high glare values of TV screens.

Reference

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Authors' response to Al Slater and MP Wilson

N Tuaycharoen and PR Tregenza

We are grateful for these valuable comments, unerringly aimed at the difficult topics.

Mr Slater raises the possibility of comparing meaningful images with random patterns. In a pilot for the first experiment we tested images not only against blank screens of the same mean luminance, but also against two other series of slides in which the information in the image was successively degraded—first to grey-scale images, and second to 'meaningless' patterns where the grey-scale elements of the images were randomly dispersed. Although we obtained consistent results comparing images with uniform screens, we did not do so with subjects' responses to the intermediate slides. From discussion it was clear that subjects were finding interest in random patterns.

In the second experiment we did match image pairs on their overall pattern of light and dark as well as their mean luminance, so the maximum brightness was approximately the same across each pair of slides. This is crucial to interpretation of the results; so on receiving Mr Slater's perceptive comment we re-examined the data and, taking slides where there was a measurable difference, we tested the association between maximum luminances and choice. There was not a significant relationship so we conclude that our pairing of images was adequate.

The point is important, though. In a later experiment we have compared subjective assessments of glare from larger sources, screens of the same mean luminance but with geometric patterns of different degrees of contrast. The screens with the brightest elements, the highest contrast within the figure, were chosen as the most glaring; this emphasises that mean luminance alone is not an adequate parameter in assessments of glare from large area sources.

We concur with Professor Wilson that glare from a window is in practice less likely to be troublesome than unsatisfactory brightness relationships within the working area but note that in tropical climates very bright sunlit surfaces can occur. We would be reluctant to squeeze more out of the results shown in Figure 3 without a larger number of subjects.

It is clear that much more testing is necessary. Having shown that the sensation of glare is modified by a subjective response to the content of a scene, the central questions are:

1) What is the mechanism—it is merely distraction? Is it more than a short-term effect?
2) What view content is effective? What is meant, for example, by 'natural'?

It would have been surprising if the experiments had given different results. There is a very large literature about analogous situations: we know, for example, that whether a noise source is even noticed depends on a person's relationship with the source; that distraction can mask pain; that the provision in a surgical ward of a natural view is associated with measurable benefits such as higher recovery rates and lower rates of analgesic use.

The study gives evidence in a new context that photometric values alone are inadequate criteria of lighting quality: quite apart from matters of satisfaction or preference, the experience of discomfort cannot be predicted accurately with solely physical parameters.