Toward a Definition of Glare: Can Qualitative Issues Be Quantified?

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Abstract

This paper describes a method for quantifying and predicting the factors that create discomfort glare in the visual environment. The method involves scanning and digitizing an image which contains a known luminance and analyzing the histogram of the pixel luminances for patterns which create, and thus could predict, glare. It is an example of the discussion about whether or to what extent qualitative architectural experiences can be quantified.

Introduction

Architecture is filled with issues which are qualitative. For example, there are issues of culture, historical context, meaning and aesthetics. These are generally beyond the realm of quantification. There are issues which relate to physical phenomena, such as thermal comfort, visual comfort, acoustics and many others. These are both qualitative and quantitative. The issue of glare (or visual discomfort) is one example of the crossover. Aspects of the phenomenon can be measured; but what is perceived from one situation to the next is more elusive.

It has always been known that visual discomfort in a space is related to high contrasts and/or high luminance within the field of view of an occupant. But contrast alone is not a good predictor. Indeed, it is an issue which everyone believes they understand, but no one can truly explain or reliably predict in all but the most extreme cases. Unless there is a quantitative theory, the discussion becomes a question of personal opinion, with no way of evaluating different options in advance. It also becomes more difficult to predict in advance whether a particular situation causes glare, or if so, how much.

Glare has been usefully subdivided into two categoreis: discomfort glare and vieling reflections. Discomfort glare is a phenomenon in which the eye attempts to protect itself from light which might cause damage to the retina. Veiling reflection is a condition similar to a very low signal to noise ratio, where extraneous light obscures the desired information. Because veiling reflection is almost always a solved by the user, discomfort glare is the primary consideration of this research. Eliminating discomfort glare will ameliorate the likelihood of veilng relfection. But one of the issues considered in this paper is whether other forms of visual experience are eliminated by accident, as a byproduct of these calculations.

Past Work

It was originally suggested that contrast ratios of 10 to 1 were problematic within the field of view and that good designs would have ratios of 3 to 1 or less. This is clearly not true. A normal piece of bleached paper with reasonably dark print on it has contrast ratios in excess of 20 to 1. Thus, the phenomenon of glare has defied any simplistic numerical definition.

The current state of the art revolves around the concept of **Visual Comfort Probability** (or **VCP**). [DiLaura, Guth, IES] This is an estimate of how many people out of 100 would feel comfortable in the given visual environment. There are calculations of all of the sources of light within an environment, their subtended or viewed angles, their surface brightness, and the likelihood that a large sample of occupants would be comfortable. Tests were done using fluorescent fixtures with various diffuser types, etc. and tables were established for the resulting VCP.

Perhaps the clearest argument from a first principles approach is what is called the **Glare Index** [Hopkinson]. Hopkinson began with subjective testing to determine what factors were significant. It became clear that there was a relationship between the background level, based on adaptation levels and the object or "target" being examined and the possible glare source. The field of view and the glare source were defined in terms of steradians. Further studies established the luminance levels which caused discomfort glare, based on the background luminance, the luminance of a possible glare source, its portion of the field of view in steradians and the range of luminance, in general. This quantitative approach most closely follows the qualitative factors normally considered in evaluating glare.

There are other studies of the human eye which measure how much information is obscured by internal factors, such as longitudinal chromatic aberration or simply stray light from inaccurate focus. These are specific to the individual and not a significant factor in the design of a space.

A similar measure of the relative performance of individuals in completing tasks of differing contrast is **Relative Visual Performance** [Kambich]. The comfort within a space is assessed based on the speed and accuracy of performing a task. Visual performance is studied as contrast changes between the paper and the ink, or within the field of view of the task alone. The change of the background and other factors appear only as a change in the time taken to perform the task or in the increase in the number of errors. This method is suitable for determining productivity for specified contrasts on a surface, but is not useful in evaluating the luminous quality of an entire space.

None of these methods had available the technology to capture the entire field of view experimentally, which results in the benefit of being able to numerically compare all of the luminances within a field of view, as well as what percentage of the field of view they occupy. One of the early uses of the video scanning and digitizing was to continue the analysis of sky luminance under trees by scanning in hundreds of trees and analyzing them for typical densities and resultant obscuring of light. [Schiler].

There have been more recent attempts to apply video photometry to the determination of luminance levels and possible glare by Rea and others. [Rea, Orfield] These have relied on calibrating the camera to account for nonlinearity in response sensitivity. The iris opening is tracked throughout taping so that the resultant levels can be correlated with the image. This requires expensive equipment. It also introduces the possibility of compounding margin of error or of drift in the sensitivity over the life of the camera or even the temperature of the specific sampling environment.

Known Luminance Method

The method discussed in this paper uses a cheaper, non-calibrated video camera, the insertion of a known luminance within the field of view and common but more sophisticated image processing tools, such as Adobe Photoshop and MS-Excel to sort and analyze luminances and to look for possible situations which produce glare. To that end a fluorescent ballast and long life tube were placed inside a reflective box, with a high density opal glass diffuser (see Figure 1). The resultant luminance is fairly constant across the surface of the panel. There was an absorptive cavity created, as well. It was lined with black felt. Two such boxes were constructed.

The lit panel of the known luminance box provides a known luminance of approximately 200 fL (lumens/ft^2). The absorptive cavity provides a surface of approximately 0 fL resulting in 2 surfaces within the image, one at ~0 fL and the other at ~200 fL to provide the range of the pickup by the camera. Since two portions of the image now have an absolute value, other portions of the image can be determined in relation to or calibrated from this known absolute value. The boxes were located against the window wall below the desk level in the first extended test, so that there is a minimum effect of the other light sources on them and they do not disturb the adaptation of the occupant. A camera was mounted facing the outside wall. The luminance of the window, position of blinds, solar position, sunspots and shadows within the room were recorded. Occupants were also asked to fill out questionnaires regarding the visual comfort of the space. There was not, however, a statistically significant number of questionnaires. The results were used only as a guide to interpreting individual behaviors.

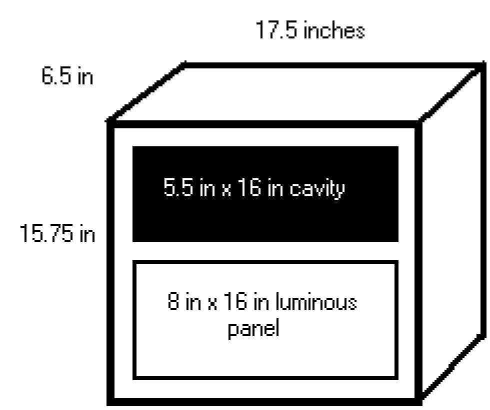

Fig. 1 – Construction of known luminance box

The luminance distribution of the known luminance surfaces was measured under several illuminance conditions. Subsequent to the experiment (one year later) the surfaces were measured again, both for lamp lumen depreciation and possible dirt depreciation. These measurements were taken with a Minolta luminance meter at a distance of 6 ft (2m) from the surfaces. The resulting luminance distributions are shown in Figures 2 - 3.

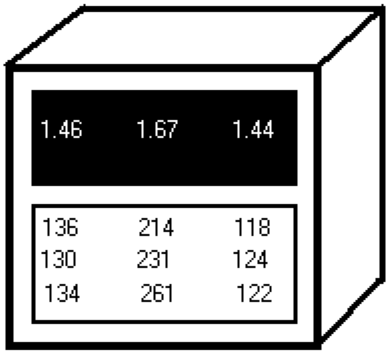

Fig. 2 - Box A, Starting luminances

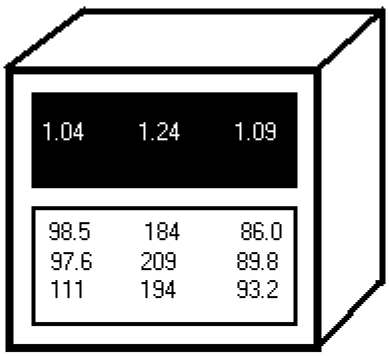

Fig. 3 - Box A, Ending luminances

Analysis of Histograms

Assorted images associated with glare were digitized. The distribution of the frequency of occurrence of different intensities within the image was plotted onto a histogram. The histograms were analyzed to look for distributions which could be consistently associated with discomfort glare.

The following digitized photographs show examples and their histograms.

Shape and distribution of a bell curve: There is a rough bell curve observed in the histograms of images of almost all days tested. This bell curve appears to be representative of the background level. The shape of the bell curve is sensitive to the luminance distributions within the space. A wider bell curve implies a more uniform distribution of light intensities. A narrow bell curve implies that portions of the image lie outside the curve and at higher intensities. This forces the camera to reduce the iris in order to include the brighter pixels in the image, which compresses the bell curve. This is analagous to what happens to the eye which is trying to cope with discomfort glare.

Figure 4 - Digitized image, showing glare

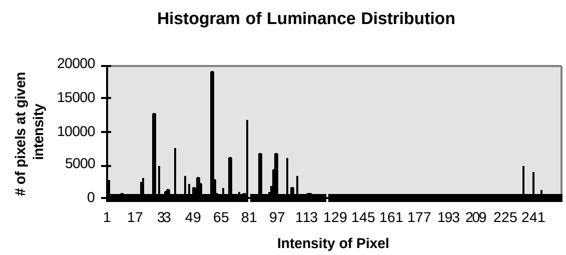

Figure 5- Histogram of luminance distribution in the image in Fig. 4. Note spike to the right.

Field of view: From the histograms it is possible to evaluate all of the pixels within that field of view. Within any fixed field of view there is a linear relationship between the number of pixels in the image and the actual steradians in the field of view.

Relative range of intensities: Just the relative range of intensities provides us with useful information on the contrast ratios present within the space. For example, there are ratios of 1:200 to 1:250 present within the space, but not all of them produce discomfort. The ratio of intensities of the glare source and the background can be established from the histograms and used to predict glare situations.

The spike: A separate spike in the histogram indicates a grouping of pixels outside the bell curve (background intensities. The position of the spike on the histogram and its relation to the bell curve determines the visual comfort within the space. A spike at a low intensity represents a portion of the view which is below the adaptation level (not likely a source of glare). A spike outside the bell curve and at a higher intensity (to the right of the bell curve) could be a potential glare source. The relationship between the spike and the bell curve is what determines glare or no glare situations.

Numerical analysis: The histograms were numerically analyzed in terms of the mean pixel intensity, number of background pixels, maximum intensity and ratio between the maximum intensity and background level (See Fig. 5).

Intentions

It has become clear that histograms which fall completely within a bell curve, or histograms that show outliers to the left of (intensities below) the bell curve do not cause glare. Many situations with a spike to the right of (intensities above) the bell curve cause glare, *but not all do*. There are some situations in which the spike above the adaptation curve is consdiered acceptable or even desirable. These conditions are variously described as containing sparkle, twinkle or delight. Corbusier's Ronchamp or La Tourette churches have very low adaptation levels, but the high intensity shafts of light provide the (desirable) drama. Even digitized images of stars or candles have histograms similar to that of a glare situation, but are often considered desirable by observers.

This means that the absence of glare *can* be predicted. The presence of glare cannot, yet, reliably be predicted.

The position of the camera is another critical factor in the method. These observations have been made with the entire space in the field of view. However there are other locations which are more interesting. The camera can be placed to mimic an occupant at his/her task location, either reading on a desk, looking at a computer screen etc. If the view out the window from the chair includes a high luminance from outdoors, the histogram would contain a large spike.

The critical factor determined from the histograms is the ratio of the extreme intensity to the mean of the background intensity. There are contrast ratios exceeding 1:250 within the space, but the ratio of highest intensity to that of the mean background intensity is more crucial in determining glare conditions. From the histograms it is found that a ratio of 2:1 or greater between the peak and the mean begins to feel uncomfortable. Ratios of 3:1 or greater produce a sensation of discomfort and should be avoided.

This quantitative method could be used by a computer program analyzing the histogram of isolux plots generated in lighting simulation programs. Thus it could be usefully employed in situations such as offices, manufacturing or educational faciilities. It also represents a more clearly quantifiable measure of glare and Visual Comfort Probability than is currently standard practice. It is not yet applicable to siutations such as dining, religious ritual, entertainment or other functions in which some glare may be traded for sparkle, twinkle and delight.

Figure 6 - Digitized Image, little or no glare.

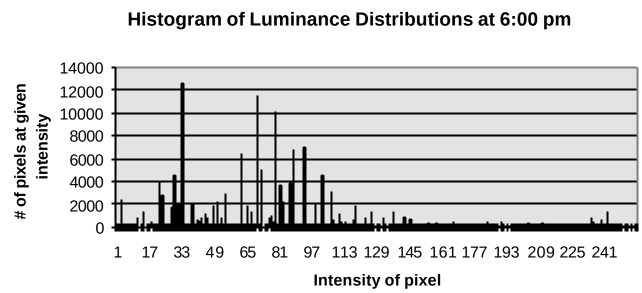

Figure 7- A Histogram of luminance distribution in Fig. 6. Small or no spike to the right.

Conclusions

It was, indeed, the great French philosopher/mathematician/scientist, who gave us two principles to employ in these pursuits. "If you would be a real seeker after truth, it is necessary that at least once in your life you doubt, as far as possible, all things." - René Descartes, *Principles of Philosophy*.   One has to question all assumptions. "It is not enough to have a good mind. The main thing is to use it well." - René Descartes, *Discourse on Method* (or *Discours de la methode*, 1637). One has to be careful about observing natural functions, but also about isolating variables and connecting their behavior.

The method seems to be applicable from a numerical standpoint, by analyzing the histograms. The histogram is capable of establishing the background level or the adaptation level within the space, the percentage of field of view that the glare source and the background occupy, as well as the absolute values of intensities within the space and contrast of highest luminance with that of the background level.

Thus, the qualitative phenomenon of discomfort glare can be quantified, at least to the extent that there is consistency in what observers consider to be glare. Carefully stated, it is quite possible to assure that certain situations *do not* cause glare. It is more difficult to say for certain that a situation with a spike outside the bell curve definitely *does* cause glare.

But the real conclusion of the paper deals with the overlying question: Can qualitative architectural issues be analyzed in a quantitative manner? Architectural issues are commonly known as “wicked” problems in that they have far too many variables which interact at any given moment. It makes it impossible to isolate those variables and test them independently. It makes it impossible to have a control case. Even when comparing against a base case, there may be unknown variables in play. Overly simplistic conclusions often are the result. By misunderstanding the implications of the numbers, bad decisions are made and justified. All of these things are true. Does this mean that quantification is worthless?

There are two reasons this is not true. The first reason is that it is much better to understand the relationships between any two of the variables in a quantitative sense, even if the problem is complex. It is far better than having decisions based on the force of personality of the proposer. Argument by image or asserted authority is rarely the best solution. Fortunately, we do not design structures in that fashion; buildings would collapse. We might want to limit that approach in other architectural areas, as well. Understanding the interaction of even a few of the variables will inform even an excellnt intuitive solution. An architectural theory should explain how things work. In general, it should correctly make predictions and evaluate the success of a design in specified areas. It should be testable and repeatable. This need not be numberical, but if it is possible to do so numerically and correctly, then this represents a very useful tool.

Furthermore, as new tools become available to us, we are able to track more variables at the same time. If we combine creativity with the tools, we can often use the computer to do much of the tedious sorting and calculating work for us. If we shed our fear of measurement and recognize the limitation of what we learn from the measurement, then it is clear that quantitative methods should be applied to qualitative issues.

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