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DISCOMFORT GLARE IN THE INTERIOR WORKING ENVIRONMENT

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FOREWORD

The existence of discomfort glare in interior lighting cannot be ignored, nor the problem under-estimated in terms of loss of visual efficiency. For as the 1976 Australian Code says so succinctly :

“Experience has shown that when inefficiency, eye-fatigue, spoilt work or accidents are blamed on the lighting installation, failure to meet one or more of the quality recommendations is usually the true cause of the trouble.”

The limitation of discomfort glare is one of the major quality aspects of any lighting installation.

Following the 12th Session of the CIE, held in Stockholm in 1951, Committee E3.1.1.2. Estimation of Comfort in Lighting was formed and the secretariat allocated to Australia. Here, a small committee chaired by Mr. W.I. Stewart, prepared a long and detailed report for the CIE 13th Session at Zurich in 1955. Amongst other things, this report referred to a pioneer luminance limit system (evolved by Lowson and Dresler from the Harrison-Meaker Glare Index system) then in preparation for the Australian 1957 Lighting Code and a formula, proposed by the National Illumination Committee of Great Britain, for a “glare constant” developed at the Building Research Station in England. The Report concluded with a formal proposal, “that the CIE should undertake preparation of International Tables for the evaluation of direct discomfort glare from lighting fittings”.

The Committee also tried to establish some definition of “comfort in lighting” and found this a very difficult task. There was considerable division of opinion amongst the Committee as to whether “comfort” can be defined in terms of “absence of comfort”, or whether the positive aspects of comfort should also be considered. Because of the difficulty in resolving this dilemma, the Committee suggested a twofold approach to the problem :

- (a) to pursue a study of the fundamentals of the aesthetic, psychological and physiological aspects of glare and
- (b) at the same time develop a method of evaluation and control which would be internationally acceptable.

These proposals were well received at Zurich, and it was agreed they should be followed up. This task was undertaken by Dr S.K. Guth, and the Secretariat was re-allocated to the USA, where it remained for the next four quadrennia.

During this period, not much progress was made with objective *a*). To quote from the Secretariat report for Vienna (1963), “The physiological basis of discomfort glare has not been given as much attention as it deserves. What has been done by several investigators appears to be rather conflicting.” Again, the Washington (1967) report stated, “In comparison with the period before 1963, there were perhaps fewer truly fundamental investigations... many papers dealt with analyses and computational procedures and thus were aimed towards developing discomfort glare evaluation systems.” On the other hand, Dr Guth was able to make much progress with objective *b*), and by 1971 had fully developed his Visual Comfort Probability (VCP) method, now officially adopted in North America.

In the meantime, however, other countries had been studying the same problem and other new national systems had emerged independently, notably the British Glare Index system (1961) based on research by Dr R.G. Hopkinson, the German luminance limiting system (1965) of Dr H. Bodmann and Dr G. Söllner, the Russian system of Yepaneshnikov and in Czechoslovakia of Netusil. For this reason, when the Discomfort Glare Secretariat returned to Australia after the 1971 Session in Barcelona, the first objective was to study the existing systems and try to combine the best points of each into a single universally acceptable system. Much work was done on this project, but whilst a universally accepted, self-contained, CIE method is a desirable objective, it seems difficult to realize.

Those countries which have incorporated a glare limiting system into their quality of lighting recommendations have, in general, either adopted a method developed in that country or adopted from a country for which there is some national or cultural sympathy. Once the method has been formally adopted, it is invariably embodied into a national lighting code or even legislation. Thus the multiplicity of methods combined with national preference have made it difficult to obtain agreement on a universal self contained CIE method.

At the CIE 18th Session, in London (1975), it was therefore decided that the committee should turn its attention to the production of a computerisable glare formula incorporating the known facts, and leave each country free to produce its own system of rules for its national code and other purposes. Dr H.D. Einhorn of South Africa undertook to draft such a formula.

During the 1975-1979 quadrennium the major task of the Committee was towards the continuing study of the various national glare evaluation systems and the development of a comprehensive computer based glare formula and the production of this Technical Report. At the Intersessional Meeting, held in London in April 1978, Dr Einhorn unveiled his proposed CIE Glare Index formula. It was considered that the glare index formula has a marked advantage over other systems, in that it can be applied to a wider range of installations than any simplified system because it specifically includes all the major parameters of the installation.

The purpose of this Technical Report is to affirm what is the "state of the art" regarding the control of discomfort glare from ceiling mounted artificial lighting luminaires. Although the Report does suggest that the Einhorn formula can be used for large area sources, it should not be interpreted as being suitable for assessing glare from windows. It includes a discussion of accepted basic principles; a description of the currently recognized systems and Dr Einhorn's proposed computer based mathematical model. In addition there are several appendices which cover such matters as existing national systems; comparison of research work; determination of relevant parameters; methods of transforming glare numbers and a comprehensive bibliography.

Appendix C deals in some detail with determination of average luminance of a luminaire. This matter was discussed at considerable length at both the Intersessional Meeting in London in March 1974 and again at the Presessional Meeting to the CIE 18th Session, 1975. There was general agreement that division of intensity by projected area seems satisfactory in principle, even when the luminaire has a non-uniform luminance in a specific direction. The major problem has been to establish what parts to include in the projected area of the luminaire, when large sections of the latter have a very low luminance. Nevertheless, this method does appear to give reasonable representation of the "effective" source luminance for the installation.

It is generally acknowledged that in a modern industrial society there is a need to limit discomfort glare. This requires quantitative rules. However as glare is essentially a psychological phenomena, the question arises, which set of rules? Obviously any system must conform to the fundamental requirements of giving results which are in accordance with actual observation; sufficient precision to distinguish between different installations and be easy to apply in every day practice. Likewise it is generally accepted that the major "simple" systems do conform to these criteria. However each system does have its critics and their arguments are well documented in the various national technical journals. It is the opinion of the Committee that it is not the function of this report to criticize the various systems, but rather to make known the salient features of each system in such a manner that any country wishing to incorporate a glare limitation system into a national code, may adopt the system which is most appropriate to current practice in that country.

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SUMMARY

This report is firstly a state of the art review of discomfort glare in the interior working environment. Secondly, it proposes a CIE mathematical model, or system, for the prediction of discomfort glare from lighting installations. The first part of the report contains a review of basic principles, of methods of glare control and of glare prediction systems used in various countries. The second part contains a critical review of research and of major current prediction systems. This leads to the proposed CIE system, into which current knowledge has been assimilated as far as possible.

Whilst the report is not intended to be the final statement on the subject, there has been considerable research in recent times such that it is considered desirable by the CIE that this report be published. It will assist countries in revising their established systems and assist countries which have not yet adopted a particular system. The report should also assist lighting students and others associated with lighting, such as architects and consultants, in understanding the phenomenon of discomfort glare and its control.

RÉSUMÉ

En premier lieu, ce rapport fait le point sur la question de l'éblouissement inconfortable considéré comme facteur de l'environnement des personnes travaillant à l'intérieur. De plus, ce rapport propose un modèle ou système mathématique CIE pour la prévision de l'éblouissement inconfortable provoqué par les installations d'éclairage. La première partie du rapport comporte une revue : des principes de base, des méthodes de limitation de l'éblouissement et des systèmes de prévision de l'éblouissement, mis en œuvre dans différents pays. La seconde partie constitue un examen critique des recherches et des principaux systèmes de prévision couramment utilisés. Ceci conduit au système CIE proposé, dans lequel les connaissances classiques ont été, autant que possible, prises en compte.

Quoique ce rapport ne constitue pas un état final de la question, il a été jugé souhaitable par la CIE de le publier en raison du travail de recherche considérable effectué récemment. Il aidera les divers pays soit à réviser les systèmes qu'ils utilisent, soit à en établir un s'ils n'en possèdent pas. Ce rapport pourra aussi servir aux étudiants et autres personnes s'intéressant à l'éclairage, telles que architectes et ingénieurs conseil, en leur permettant de comprendre le phénomène de l'éblouissement inconfortable et la manière de le limiter.

ZUSAMMENFASSUNG

Dieser Bericht ist in erster Linie ein Überblick über den derzeitigen Wissensstand auf dem Gebiet der Psychologischen Blendung im Bereich der Beleuchtung von Arbeitsräumen. Darüber hinaus schlägt er ein mathematisches CIE-Model, oder - System, zu Vorhersage der psychologischen Blendung von Lichanlagen vor.

Der erste Teil des Berichtes enthält einen Überblick über Grundlagen, Methoden zur Blendungsbegrenzung und Blendungsvorhersagen, die in verschiedenen Ländern angewendet werden. Der zweite Teil enthält einen kritischen Überblick über Forschung und bedeutendere benutzte Vorhersagemethoden. Dies führt zu dem vorgeschlagenen CIE-System, in dem das vorhandene Wissen so weit wie möglich verwertet wurde.

Wenn auch der Bericht nicht dafür vorgesehen ist, die letzte Aussage auf diesem Gebiet zu machen, so ist doch beachtenswerte Forschung in den letzten Jahren betrieben worden, so daß es von der CIE als wünschenswert betrachtet wurde, diesen Bericht zu veröffentlichen.

Er wird den Ländern helfen, ihre eingebürgerten Systeme zu überdenken, und er wird auch den Ländern helfen, die noch kein spezielles System angenommen haben. Der Bericht sollte auch Studenten und anderen Personen, die mit der Lichttechnik verbunden sind, wie Architekten und Beratern, helfen die Erscheinungen der psychologischen Blendung und ihrer Kontrolle zu verstehen.

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PART A

BASIC PRINCIPLES, RESEARCH AND APPLICATION OF GLARE CONTROL

1. BASIC PRINCIPLES OF GLARE CONTROL

1.1. NATURE OF GLARE

According to definition 45-25-295 in the International Lighting Vocabulary (CIE Publication 17, 1970) glare is that condition of vision in which there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminances or to extreme contrasts in space or time. Two separate forms are identified :

- (a) discomfort glare, which causes discomfort without necessarily impairing the vision of objects (definition 45-25-315),
- (b) disability glare, which impairs the vision of objects without necessarily causing discomfort (definition 45-25-320).

Although they can occur in combination, these two forms of glare are quite different phenomena. Disability glare depends mainly on the quantity of light falling on the eye and is largely independent of the luminance of the source, whereas in the case of discomfort glare, source luminance is a major factor. Also, disability glare is little affected by time, whereas the discomfort glare can build up considerably in a factory or office interior where people are exposed to high luminance sources for long periods.

When considering measures to control glare produced by lamps and luminaires in ordinary interior lighting installations, control of discomfort glare is likely to be much more important than disability glare and it will normally be found that if discomfort glare is adequately controlled, disability glare will be kept within bounds as well.

Reference to glare in the sections that follow should be taken to mean discomfort glare unless otherwise specified.

1.2. FACTORS CONTROLLING DISCOMFORT GLARE

It is generally agreed that the discomfort glare produced by an individual source basically depends on four main parameters, illustrated diagrammatically in Figure 1 :

- L_s — source luminance in the direction of the observers eye.
- W — the solid angle subtended by the source at the observers eye.
- θ — the angular displacement of the source from the observers line of sight.
- L_f — the general field luminance controlling the adaptation level of the observers eye.

It is generally agreed that L_s must be greater than 500 to 700 cd.m^{-2} for discomfort glare to exist.

The subjective sensation of discomfort glare experienced by the observer can be related to the four parameters by a general expression of the following type :

$$G = \frac{L_s^a \cdot W^b}{L_f^c \cdot f(\theta)} \quad (1)$$

Where G is a quantity called here the Glare Constant expressing the subjective sensation on a semantic/numerical scale and a , b and c are suitable weighting exponents and $f(\theta)$ is a complex function of the displacement angle, which takes separate account of its vertical and azimuthal components.

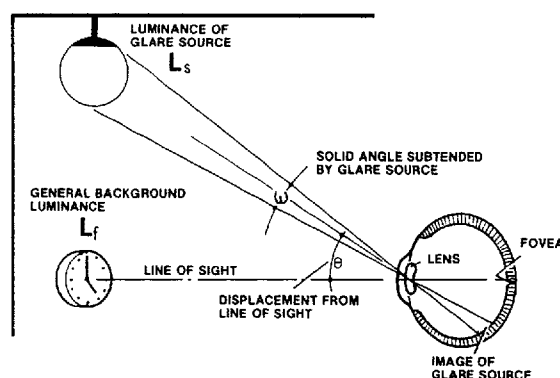


Figure 1. — Parameters of Discomfort Glare

In this very simplified diagram of the eye, the lens is shown forming an image on the fovea of the object upon which the gaze is fixed, and at the same time forming an image of the glaring luminaire at another point on the retina.

Discomfort produced by the glaring luminaire will be greatest

- (a) when its image on the retina approaches close to the fovea (i.e. when θ the angular displacement of the glare source from the line of sight is small);
- (b) when the image is large (i.e. when the solid angle ω subtended by the luminaire at the eye is large, or when there are numerous luminaires in the field of view);
- (c) when the flux per unit area over the image is large compared with the flux per unit area over the rest of the retina (i.e. when L_s is large compared with L_f).

For example, Hopkins found, from the studies referred to below, that the right hand side of equation (1) (with the exponents derived by him and with the quantities expressed in the relevant units) had the following numerical values for stated criteria of subjective sensation of discomfort glare.

Criterion of Discomfort Glare	Glare Constant
Just intolerable	600
Just uncomfortable	150
Just acceptable	35
Just perceptible	8

It is seen that the semantic glare scale is transformed into a numerical scale. In this case each step on the semantic scale gives rise to an interval on the numerical scale, with a common ratio of approximately four. When applied to a complete installation, G represents the aggregate effect of all the sources on an observer stationed at one end of the room and looking horizontally along it, as shown in Figure 2.

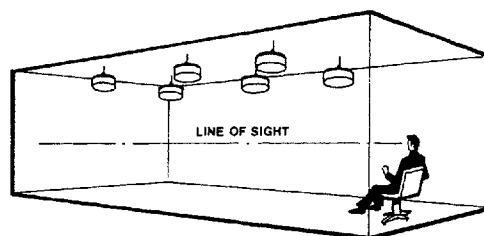


Figure 2. — Observation point normally assumed.

This introduces the problem of additivity, which has been a stumbling block in the past : Einhorn has shown that the problem can be simplified if the exponents in a formula are adjusted to make the exponent of W unity (see Part B).

In the past, a great deal of research has been done to establish suitable values for the exponents in equation (1), but direct comparison of results is difficult because of differences in research methods. Holladay, for example, confined his studies to the shock effect on an observer adapted to one luminance and then suddenly confronted with a glare source of a higher luminance. Guth derived his more complex formula using a

brief exposure method. Hopkinson, on the other hand, based his studies on a condition of continuous exposure to the glare source, thus allowing his observers more time to adapt.

The results of Holladay's experiments, which utilized a high luminance (L_s) and small area (W) source, can be stated as :

$$\text{Glare Constant} = \frac{L_s^{1.3} W^{1.0}}{L_f^{1.0}}$$

Hopkinson's studies employed a low luminance source (L_s) and large area source (W), and resulted in the formula :

$$\text{Glare Constant} = \frac{L_s^{1.6} W^{0.8}}{L_f^{1.0}}$$

Hopkinson suggested that the experimental results of both studies support a higher value of exponent of L_s for larger values of W and a lower value of the exponent of W for low values of L_s .

Hopkinson considered either formula, with suitable adjustment of the Glare Constant, could be applied to the results of either study, under comparable conditions of source luminance (L_s) and area (W). Thus, whilst earlier studies of Hopkinson did not lead to the same values of the exponents as in the Holladay formula, later observations of Hopkinson did agree.

Thus Einhorn's suggestion that the exponent of source luminance (L_s) should equal 2 and the exponent of source area (W) should equal 1 seems reasonable, considering the present state of knowledge of the mechanism governing glare and the present empirical approach to its formulation.

1.3. GLARE CONTROL METHODS

When the luminance of the bare lamp exceeds an appropriate limit, it can be controlled with three types of device. These are translucent diffusers, prismatic panels and shades or louvres. Ignoring for the moment special cases such as that of louvres made of translucent rather than opaque material, it is convenient to classify the luminance distributions of luminaires employing each of these three types of device as constant, non-constant, and cut-off.

1.3.1. Constant Distributions

Luminaires employing diffusing plastic or glass panels and enclosures normally have a moderate luminance not exceeding about 15 kcd.m^{-2} , and the luminance (L_s) usually remains reasonably constant throughout the critical angular range. This is 0° to 45° in θ or 45° to 90° in γ , when referring to the luminance distribution of the luminaire. It therefore becomes possible to determine a suitable luminaire limit L_s by rearranging formula (1) in the form

$$L_s = \sqrt[a]{\frac{G \cdot L_f^c \cdot f(\theta)}{W^b}} \quad (2)$$

Since direct application of either formula (1) or formula (2) is tedious, it is of course preferable to convert the data into the form of pre-calculated tables, as first utilized in the 1957 edition of the Australian Standard, Code for the Artificial Lighting of Buildings, based on the formula suggested by Harrison and Meaker. With tables of this type, the user need no longer calculate the parameters for the individual luminaires, but merely has to be concerned with the room dimensions, and orientation of luminaires.

1.3.2. Non-constant Distributions

Luminaires employing prismatic panels and enclosures have a varying luminance throughout the critical angular range, referred to in 1.3.1.

Well designed devices of this type reduce the luminance (L_s) progressively, making it much less near the horizontal (90°) than at $\gamma = 45^\circ$. They are extensively used in recessed luminaires mounted flush with the ceiling and in large rooms. This is because, as in the case of cut-off luminaires, the effective region causing glare is determined by the shape of the flux distribution of the luminaire rather than by the actual room size. This

concept was included in the system first developed by Harrison and Meaker; their tables were computed from the aggregate effect of many luminaires, from a fixed station point at the end of the room, as shown in Figure 2.

The surface mounted luminaire with a prismatic base panel and refractor side panels also has a non-constant distribution, since these luminaires can also effectively limit the luminance at the larger γ angles.

1.3.3. Cut-off Distributions

This is often referred to as control by shielding. The lamp is completely concealed whenever θ becomes less than a pre-determined shielding angle S which is controlled by the mechanical construction of the luminaire. The principle is illustrated in Figure 3. This method depends on two assumptions :

- (a) the workers normal line of sight is not above the horizontal,
- (b) extremely powerful lamps will not be mounted too low and close to the workers head.

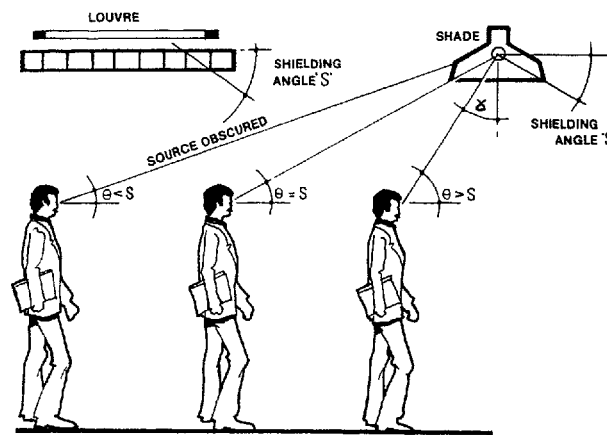


Figure 3. — Cut-off (shielding angle) principle, source hidden when θ is less than S .

This method has great practical advantages. For one thing the shielding angle is a simple concept readily defined and measured, as shown in Figure 4. Moreover, once cut-off has occurred, the luminance of the visible parts of the luminaire is usually low (about 1 kcd.m^{-2} in the case of luminaires using ordinary tubular fluorescent lamps). Hence the degree of glare becomes virtually independent of room size. In addition, by employing suitably shaped, specular finished louvres, the luminance after cut-off can be made extremely low and well below the threshold value referred to in section 1.2.

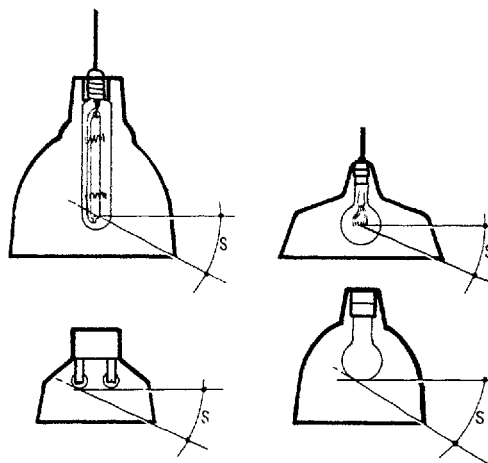


Figure 4. — Measurement of shielding angle S .

1.4. GLARE CONTROL SYSTEMS

When planning a lighting installation, there are various methods of ensuring that G does not exceed an appropriate value. One is to calculate a numerical Glare Index (conveniently, $10 \log G$) using a glare formula, or from tables based on that formula. Another is to specify suitable values for luminaire luminance L_s at a particular γ angle (or range of γ angles), and yet another is to specify an empirically determined shielding angle, coupled with rules governing minimum mounting heights and maximum lamp lumen outputs. Each of these methods has its advantages in particular cases. The effect of the parameters is illustrated in Figure 5 and the merits of each type of system is shown in Figure 6.

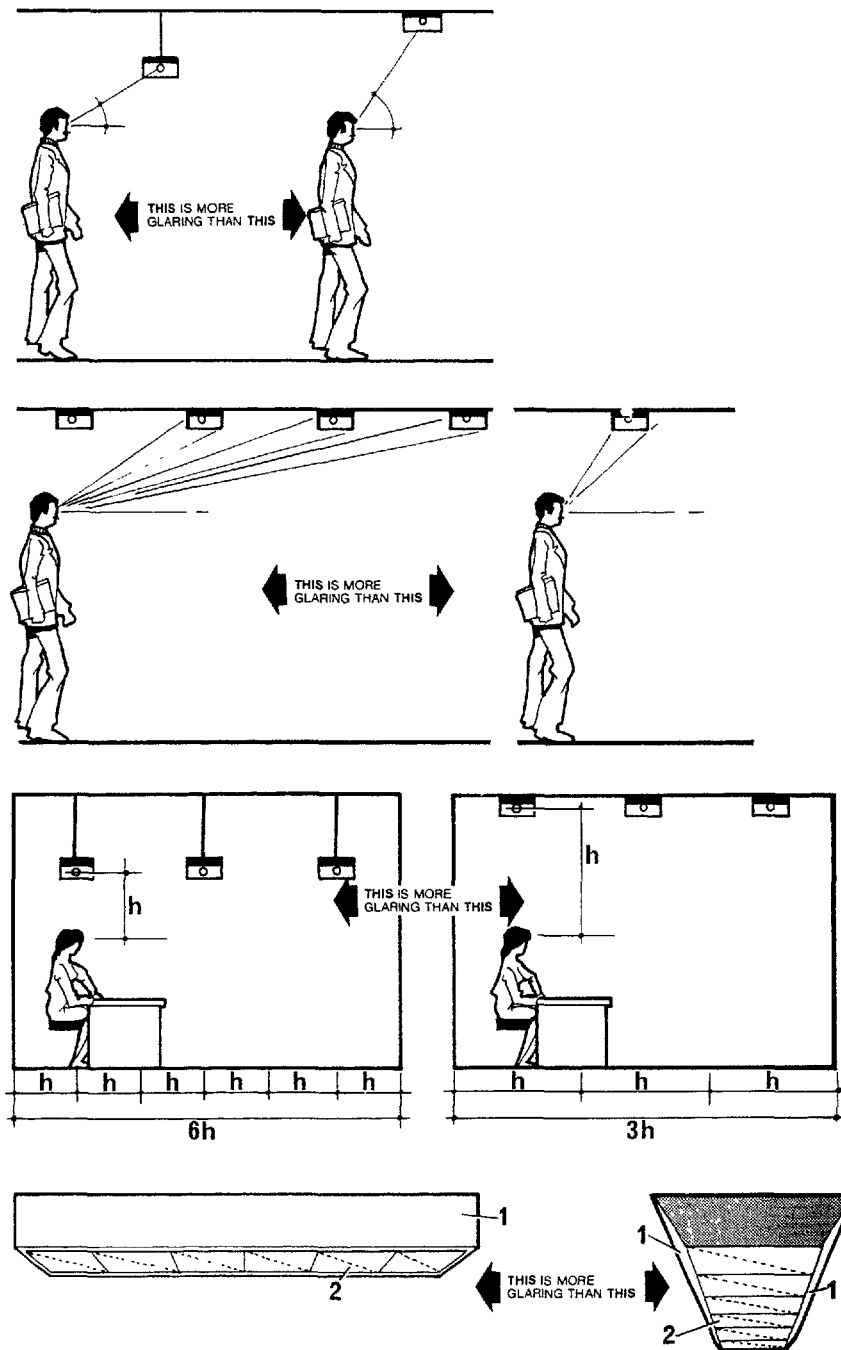


Figure 5. — The effect of some parameters on discomfort glare.

Glare is increased by reducing the mounting height and/or increasing number of non cut-off luminaires visible (i.e., lengthening room). These two separate effects can be allowed for simultaneously by expressing room dimensions in multiples of mounting height ' h ' above eye-level.

Bright-sided luminaires are more glaring when viewed crosswise rather than endwise; because in the latter case the apparent area W of the side panels (1) will be greatly diminished. On the other hand, the apparent area of the horizontal base panel (2) remains unchanged. Hence glare produced by units without bright sides is little affected by orientation.

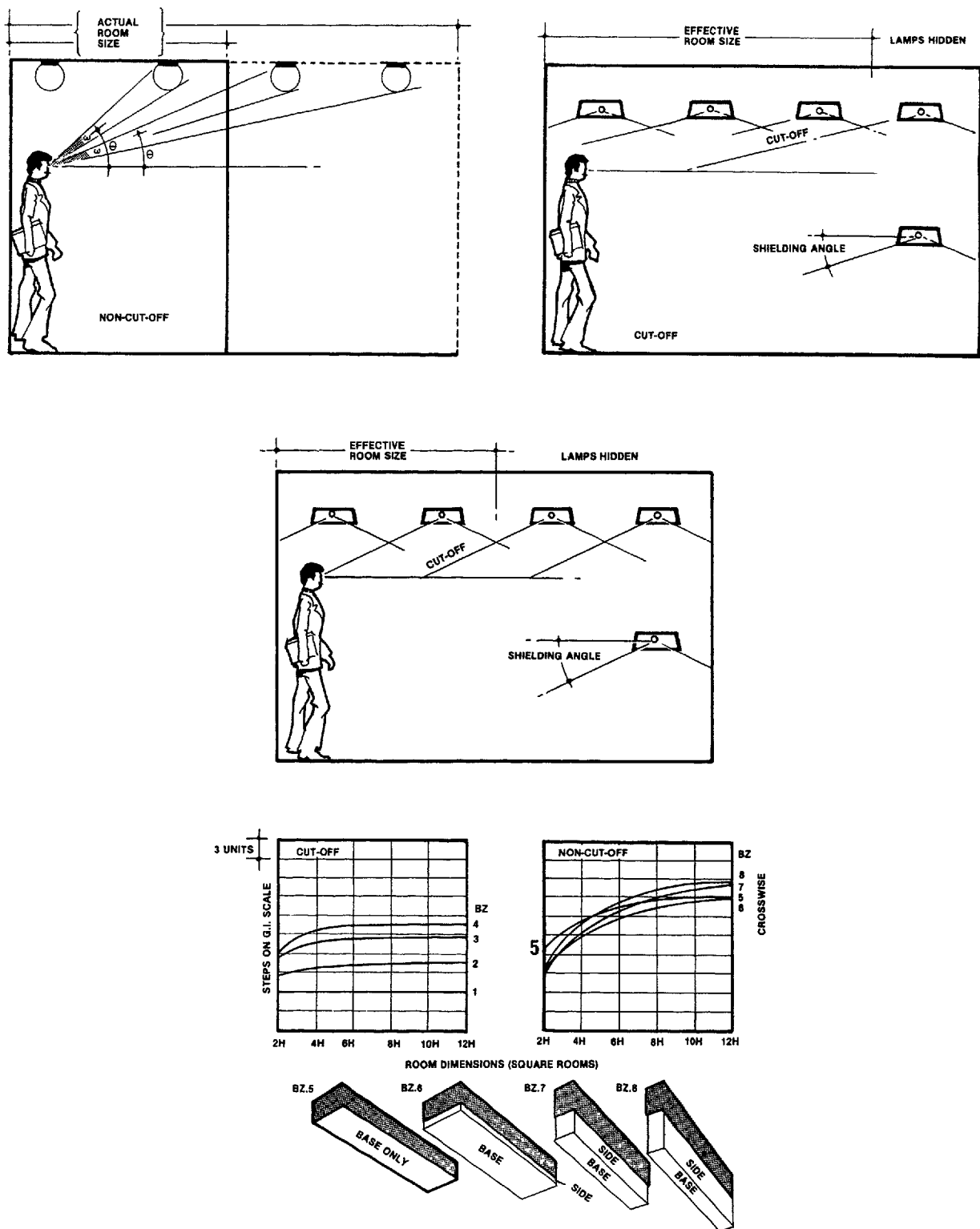


Figure 6. — Glare Control with cut-off and non-cut-off luminaires.

In the case of non-cut-off units, room size is important because this affects both θ and total value of w .

With cut-off units, *actual* size of room is unimportant. Instead, glare depends on *effective* room size, controlled by the shielding angle of the luminaires.

Increasing the shielding angle reduces both the effective size of room and the degree of glare.

The charts below, derived from the British Glare Index Tables, illustrate this point. These show the relation between room size and relative glare index for luminaires in the BZ 1-4 (cut-off) range, and those in the BZ 5-8 (non-cut-off) range, viewed crosswise.

Square rooms ($70/50/14$ q_c q_w q_r) are assumed, and the glare index figures are initial glare index plus an appropriate allowance for flux fraction ratio. The latter ratios are based on idealised versions of the BZ 6 - BZ 8 units shown in the lower sketch, and are assumed to be 0.33, 0.5 and 0.66 respectively. For the BZ 1-5 units the ratio is zero.

The trend of these curves supports the use of a luminance limit system for non-cut-off units, but suggests that shielding angles provide a better approach in the case of cut-off luminaires.

1.4.1. Glare Index Systems

Glare index calculated with the aid of an appropriate glare formula is the most flexible method in that it can be tailored exactly to meet the situation prevailing in a given installation. Similarly, the formula can indicate which of the components need to be manipulated in order that glare, in certain installations, can be controlled. The increasing availability of computer facilities, including the relatively cheap pocket-type instruments, has made direct application of basic glare formulae much easier than it used to be. Nevertheless, there is still scope for glare index systems in which the basic glare formula calculation has been converted into tables or graphs. This naturally requires some simplification and restriction of the problem, but lends itself more readily to use in lighting codes, design handbooks, and the like.

1.4.2. Luminance Limiting Systems

These are particularly applicable in the case of luminaires with an approximately constant luminance distribution. As shown in section 1.3.1, it is possible to calculate L_s values which will restrict glare to any desired value of G , which can then be tabulated in terms of other parameters such as room size, mounting height, etc. If desired, these luminance limits can be adjusted by a suitable factor to alter the value of G . For this particular type of luminaire, the luminance limit system is potentially as flexible and precise as the Glare Index method. For luminaires with a non-constant luminance distribution limiting luminances over a range of γ angles must be prescribed, in order to restrict glare to the desired value of G . The system becomes in effect an acceptability gauge, by comparing luminaires luminance distribution with that of the prescribed limiting one.

In either case, the luminance limiting system has practical benefits for both the manufacturer and installation designer. The manufacturer can, with simple photometry, publish in a conventional catalogue precise luminance data at the prescribed γ angle, or angles, for each of his luminaires. The designer can select the luminaire appropriate to the particular installation parameters. Furthermore, a designer can develop a luminaire with pre-determined requirements for limiting glare.

1.4.3. Shielding Angle System

This is the most practical and effective basis for rules designed to limit glare from cut-off type luminaires, especially those incorporating high-wattage discharge lamps or incandescent filament lamps. The conventional glare formula approach does not lend itself particularly well to the latter task, one reason being that with such sources, lumen output may become more important than luminance itself.

Consequently, whilst the framework for such rules can be worked out on theoretical principles, the actual details are best decided empirically, based on the observations and opinion of a panel of experienced lighting engineers. This method has been used successfully for many years in the various editions of the Australian Lighting Code.

1.5. SUBJECTIVE ASSESSMENT OF DISCOMFORT GLARE

In addition to calculating G in equation (1) it is necessary to relate this to the subjective degree of discomfort experienced by the average observer. This involves appraisal of a range of installations (full-scale, or model) by a group of observers.

As sensitivity to discomfort glare varies from person to person, the number of observers must be large enough to provide adequate statistical data. In Guth's well known VCP method, the observers may be merely asked to state individually whether they consider the installation acceptable, i.e., at or above the boundary between comfort and discomfort (BCD). The percentage of the group that say yes is then taken as the Visual Comfort Probability (VCP) rating of the installation under appraisal.

As an auxiliary, Guth also developed the Glare Evaluator technique in which observers are not asked to make absolute judgements, but merely determine equality of discomfort with an adjustable standard glare source — a somewhat easier task.

The simple yes/no type question referred to above is comparatively straightforward; it is also free from the translation and other difficulties which handicap international use of Multiple Criteria techniques used in the past by various workers. On the other hand, it demands the use of very large numbers of observers to obtain a statistically reliable result; Guth, for example, had to use 100 in his fundamental investigation.

It is evident that the problem of making practical appraisals is not a simple one. In view of the fact that the subject is now undergoing detailed study by a Japanese committee under the leadership of Manabe, firm recommendations on an international appraisal technique would be premature at this stage.

2. RESEARCH AND APPLICATION OF GLARE CONTROL, THE QUEST FOR A SUITABLE FORMULA

2.1. FORMULA BASED SYSTEMS

Much research has been carried on over many years by many different countries in an effort to establish suitable values of the exponents in the generalised formula, as stated in section 1.2. Also a number of glare formulae have been proposed and although their formulation appears to be different, their end result is generally the same. This can be illustrated by a brief review of some of these formulations.

In the following, the symbols M, G, and S all represent the subjective sensation of discomfort glare experienced by the observer from a single source. For example :

(i) Guth (USA) proposed a formula of the form :

$$M = \frac{0.5 L_s Q}{P F^{0.44}} \quad (3)$$

where $Q = 20.4 W + 1.52 W^{0.2} - 0.075$

L_s = Luminance of source

F = Luminance of field

P = Position index

W = Solid angle of the source

For a multiple source installation the Discomfort Glare Rating

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

where a is a function of a number of sources.

The Discomfort Glare Rating is then converted into Visual Comfort Probability, that is, the percentage of observers who would be expected to judge a lighting condition to be at or more comfortable than the border line between comfort and discomfort.

(ii) The British system was developed from a formula by Hopkinson and Petherbridge and later summated by Hopkinson :

$$G = \frac{L_s^{1.6} W^{0.8}}{L_B} \cdot \frac{1}{P^{1.6}} \quad (4)$$

Where L_B = luminance of the background.

For the multiple source installation a Glare Index (GI) is used where $GI = 10 \log \Sigma G$.

(iii) In Czechoslovakia, Netusil developed the relationship :

$$S = \frac{L_s W^{0.4}}{P F^{0.5}} \quad (5)$$

and for the multiple source installation,

$$S_r = (\Sigma S^2)^{0.5} \quad (6)$$

(iv) The formula used by Yeganeshnikov of the USSR :

$$M = \left(\frac{L_s^2 W}{P^2 F} \right)^{0.5} \quad (7)$$

To convert the glare constant, determined by a formula, into a Glare Index is often a complex operation, requiring a computer to handle the raw data. In some cases simplification is achieved by omitting some of the less important variables or by confining the system to certain classes of luminaire, or by supplying tabulated data pre-calculated for generalised classes of luminaire.

The American VCP and British Glare Index systems are typical examples of this class of system.