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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

DISCOMFORT GLARE IN INTERIOR LIGHTING

CIE 117-1995

UDC: 628.931
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Descriptor: Electrical lighting design
Luminaires
Interior Lighting
Lighting of working environment
Evaluation of lighting installations

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2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
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2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
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This Technical Report has been prepared by CIE Technical Committee 3-13 of Division 3 'Interior Environment and Lighting Design' and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 3-13 de la Division 3 'Environnement intérieur et étude de l'éclairage' et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique décrit de la lumière et de l'éclairage; il est destiné à être utilisé par les membres de la CIE et tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Les derniers comptes rendus de la CIE ou du CIE NEWS devront être consultés pour connaître d'éventuels amendements.

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Foreword

The past decade has seen many changes affecting lighting design. These changes include the introduction of new types of lamps and luminaires, radical changes in work practices and an increasing community awareness of the need for energy conservation and the wise management of resources. These changes have resulted in the need to revise the CIE's recommendations on discomfort glare prediction due, particularly, to changes in technology and workplace design and use.

Two significant technological changes affecting discomfort glare have been:

- *New lamps.* The now commonly used 26mm diameter tubular fluorescent lamp has a lamp luminance of approximately $11 \text{ kcd} \cdot \text{m}^{-2}$. The 55 W compact fluorescent lamp's luminance is around $35 \text{ kcd} \cdot \text{m}^{-2}$. Both have significantly higher luminances than the lamps that they have replaced — 38mm tubular fluorescent lamps with luminances of about $7 \text{ kcd} \cdot \text{m}^{-2}$. The new lamps and others that are used in interiors might be considered as "retrofit" replacements but the higher lamp luminances may require luminaire optical redesign to meet comfort criteria.
- *New luminaire designs.* The replacement of prismatic lens panels with "batwing" reflectors has produced luminaires with disymmetrical intensity distributions where the C_0 (crosswise) distribution is significantly different from the C_{90} (lengthwise) distribution. This can allow greater spacings to be used in the C_0 direction, resulting in the need for fewer luminaires and energy and capital savings. However, intensity values at high γ angles in the C_{45} can be higher than in either the C_0 or C_{90} planes.

Two major workplace changes affecting discomfort glare have been:

- *Office design.* Large open areas with random arrangements of furniture are now common. In the 1940s and 1950s office furniture was arranged in a regular layout with the workers facing in the same direction: either in the C_0 or C_{90} directions. This meant that the "worst case" discomfort situations were locations either in the middle of the end or side walls. In present day offices the furniture arrangement may be irregular with many and varied viewing directions.
- *Screen based tasks and workstations.* The introduction of screen based tasks has led to ergonomic change in the workplace. The change with regard to discomfort glare is that the operator's line of sight is much closer to the horizontal than for reading, writing or typing tasks. This means that more of the ceiling and more luminaires will be within the peripheral field of view — more luminaires will be in the personal "glare zone".

This technical report presents a unified glare rating formula developed from existing glare index systems. It also provides, in appendices, guidance on the production of the tables and curves needed to apply the system manually. Advice is given to designers on the use of the data.

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DISCOMFORT GLARE IN INTERIOR LIGHTING

Summary

The task of the CIE Technical Committee TC 3-13 was to produce a practical discomfort glare evaluation system.

The *Unified Glare Rating (UGR) formula* described in this technical report, combines features of the Einhorn and the Hopkins formulae and incorporates the Guth position index. It may be regarded as being composed of the best parts of the major formulae in terms of practicability and of familiarity with the results of glare prediction. The formula recognises the effects on the glare index of observer position and direction of view.

The report also describes, in the appendices, a tabular method, which uses reference values and standard conditions, allowing the production of simple tables, similar to those for utilisation factors, for use in luminaire data sheets.

A rough estimate of discomfort glare is given by the luminance limiting curve (UGR curve) method. The appendices also show how the curves can be constructed and used.

The report recommends a practical CIE discomfort glare evaluation system for use in the next edition of the CIE Guide on Interior Lighting.

EBLOUISSEMENT INCONFORTABLE EN ECLAIRAGE INTERIEUR

Résumé

La tâche du comité technique TC 3-13 de la CIE était de déterminer un système pratique d'évaluation de l'éblouissement inconfortable.

La formule unifiée de l'éblouissement (formule UGR) qui est décrite dans ce rapport réunit des caractéristiques des formules d'Einhorn et de Hopkins et inclut l'indice de position de Guth. Elle peut être considérée comme la synthèse des meilleures parties des formules les plus importantes en ce qui concerne la praticabilité et la familiarité avec les résultats de la prévision de l'éblouissement. La formule tient compte des effets de la position de l'observateur et de la direction de vue sur l'indice d'éblouissement.

Le rapport décrit également, dans les appendices, une méthode tabulaire utilisant des valeurs de référence et des conditions normalisées, et permet la production de tables simplifiées, similaires à celles établies pour les facteurs d'utilisation, pour l'usage dans les feuilles de données pour luminaires.

Une estimation approximative de l'éblouissement inconfortable est donnée par la méthode de courbe de limitation de la luminance (courbe UGR). Les appendices montrent également la manière dont les courbes peuvent être construites et utilisées.

Le rapport recommande un système pratique d'évaluation de l'éblouissement inconfortable pour l'usage dans la prochaine édition du Guide CIE de l'éclairage intérieur.

PSYCHOLOGISCHE BLENDUNG IN DER INNENBELEUCHTUNG

Zusammenfassung

Die Aufgabe des Technischen Komitees CIE TC 3-13 bestand darin, ein praktisches System für die Bewertung der psychologischen Blendung zu entwickeln.

Die in diesem technischen Bericht beschriebene vereinheitlichte Blendungsbemessungsformel (UGR) kombiniert Einhorn- und Hopkins-Formeln und enthält den Guth-Positionsindex. Sie kann als aus den besten Teilen der wichtigsten Formeln bestehend angesehen werden, im Hinblick auf

Durchführbarkeit und Vertrautheit mit den Resultaten der Blendungsvoraussage. Die Formel berücksichtigt die Wirkung von Beobachterposition und Blickrichtung auf den Blendungsindex.

Der Bericht beschreibt im Anhang auch eine Tabellenmethode, die Bezugswerte und Normbedingungen verwendet, und ermöglicht die Erstellung einfacher Tabellen, ähnlich jenen für Wirkungsgrade, zur Verwendung in Datenblättern für Leuchten.

Die Leuchtdichte-Grenzkurven-Methode ermöglicht eine ungefähre Schätzung der psychologischen Blendung. Im Anhang wird auch gezeigt, wie die Kurven konstruiert und verwendet werden können.

Der Bericht empfiehlt ein praktisches CIE-System für die Bewertung der psychologischen Blendung zur Verwendung in der nächsten Ausgabe der CIE Richtlinien für Innenbeleuchtung.

1. Introduction and scope of the report

CIE Publication No 29.2-1986 "Guide on Interior Lighting" [1] contains both a CIE Glare Index formula and a CIE luminance limiting system, called the "CIE Safeguard System", for the prediction of discomfort glare in the working environment.

The formula can be applied in computer calculations to predict discomfort glare within a space for a particular set of conditions. The luminance limiting system is used for the simple assessment of the suitability of a luminaire for general use within a limited number of conditions.

TC 3-13 Committee was asked to produce a "practical glare evaluation system". This report contains the result of that task.

Three methods of glare evaluation have been developed:

- the basic *Unified Glare Rating (UGR) formula*
- the derived *tabular method* which enables the easy comparison of different lighting situations and
- the derived *luminance limiting curve method* to assist in the design of luminaires and to give designers rough guidance on the suitability of luminaire choices.

The Unified Glare Rating (UGR) formula is the method recommended for use by the CIE. Its practical application requires the use of computer software. The two derived methods, contained in the appendices, are provided for information with the purpose of assisting luminaire manufacturers in the construction of design aids, published as part of luminaire data sheets. (The derived methods are also in use in some countries' standards.)

2. Discomfort Glare

CIE Publication 17.4-1987 "International Lighting Vocabulary" [4] defines discomfort glare as:

glare which causes discomfort without necessarily impairing the vision of objects.

3. Derivation of the formula

Following a review of discomfort glare research and practice, the following CIE Glare Index Formula, CGI, was proposed in CIE Publication No. 55 [2] :

$$CGI = 8 \log \left[2 \cdot \frac{1 + E_d / 500}{E_d + E_i} \cdot \sum \frac{L^2 \omega}{p^2} \right] \quad (3.1)$$

where E_d is the direct vertical illuminance at the eye due to all sources (lux),

E_i is the indirect illuminance at the eye (lux),

L is the luminance of the luminous parts of each luminaire in the direction of the observer's eye ($\text{cd} \cdot \text{m}^{-2}$),

ω is the solid angle of the luminous parts of each luminaire at the observer's eye (sr),

and p is the Guth position index for each luminaire (displacement from the line of sight).

Throughout this document $\log$ is used to indicate the logarithm to the base 10.

At the time, the formula was considered to be the best mathematical compromise between the different national systems. Difficulties have been found in developing a practical discomfort glare evaluation system from this formula, so simplifications have been made.

All discomfort glare formulae have the form :

$$\text{Glare Rating} = C_1 \log (C_2 f_{\text{room}} \sum f_{\text{luminaire}}) \quad (3.2)$$

where C_1 and C_2 are constants,

f_{room} is a factor related to the room and the background luminance,

and $f_{\text{luminaire}}$ is a factor related to the luminaires and their positions.

The factor f_{room} proposed in CIE publication 55 [2] contained terms describing the indirect and the direct illuminance at the eye. The indirect illuminance at the eye is used as a measure of the background luminance produced by the room surfaces, against which the glare sources are seen. The direct illuminance at the eye allowed for adaptation and for co-variance (the change in glare sensation with change in size or number of luminaires). For the simplified glare calculation procedures (the Glare Rating Tables and the Glare Rating Curves) it has not been possible to find a way to include the direct illuminance.

Therefore, the direct illuminance has been omitted from the Unified Glare Rating formula. For practical purposes this has little effect when the formula is applied to rooms having illuminances within the usual range recommended for working interiors [1].

The factor $f_{\text{luminaire}}$ proposed in CIE Publication 55 has been adopted unchanged in the Unified Glare Rating formula.

The constants C_1 and C_2 have been chosen to give the best agreement with the formula originally proposed by Hopkins and used to form the British Glare Index scale.

4. The Unified Glare Rating (UGR) formula

4.1 The formula

The CIE Unified Glare Rating (UGR) is given by the formula (see Figure 4.1):

$$\text{UGR} = 8 \log \left[\frac{0,25}{L_b} \cdot \sum \frac{L^2 \omega}{p^2} \right] \quad (4.1)$$

where L_b is the background luminance ($\text{cd} \cdot \text{m}^{-2}$),

L is the luminance of the luminous parts of each luminaire in the direction of the observer's eye ($\text{cd} \cdot \text{m}^{-2}$),

ω is the solid angle of the luminous parts of each luminaire at the observer's eye (sr),

and p is the Guth position index for each luminaire (displacement from the line of sight).

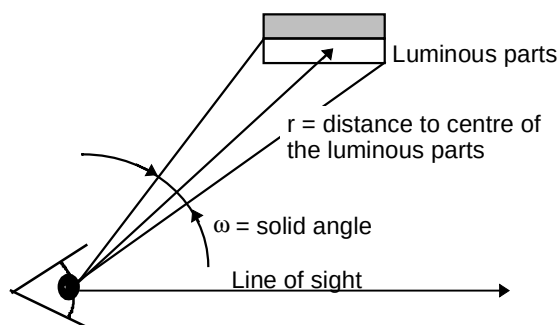


Figure 4.1 The luminaire luminance, L , and solid angle, ω , seen by the observer. The distance, r , is to the centre of the luminous parts of the luminaire.

4.2 The background luminance

The background luminance, L_b , is defined as that uniform 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 sources. It may be obtained from the formula :

$$L_b = \frac{E_i}{\pi} \quad (4.2)$$

where E_i is the indirect illuminance at the eye of the observer (lux).

The background luminance, L_b , is usually calculated from E_i which may be found either from computer calculations of the light distribution in space or calculated by means of the indirect utilization factor for walls (see TM10 of the British CIBSE [5]). Such a calculation is based on the assumption that the average indirect illuminance on the walls more or less equals the indirect illuminance at the eye of the observer. This assumption works well for general lighting systems, with luminaires in a uniform array.

A slightly different approach is to compute the luminances of the surfaces of the room. The indirect illuminance at the eye of the observer is obtained by calculating the illuminance due to the walls as illuminants. This approach is slightly better than the first but still relies on the assumption that the room surfaces are uniformly illuminated [7].

In the most general method, the surfaces of the room are divided into subsurfaces. The luminance of each of the subsurfaces is determined from the direct illuminance from the luminaires and from interreflection between the subsurfaces. Finally, the illumination of the eye of the observer produced by the subsurfaces is determined.

The UGR is relatively insensitive to errors in L_b ; for example, an error of +33% in L_b will result in an error of the UGR of 1 unit.

4.3 The luminaire luminance

The luminaire luminance, L , is generally derived from the luminous intensity of the luminaire in the direction of the observer, I , and the projected area of the luminaire, A_p .

$$L = \frac{I}{A_p} \quad (4.3)$$

4.4 The solid angle at the observer's eye

The solid angular size may be derived from the projected area of the luminous parts of the luminaire, and the distance of the centre to the luminaire from the observer's eye.

The solid angle ω is to be determined by the following expression:

$$\omega = \frac{A_p}{r^2} \quad (4.4)$$

where A_p is the projected area of the luminous parts of the luminaire (m^2),

and r is the distance from the observer to the centre of the luminous parts of the luminaire (m).

4.5 The position index

The position index p is found by interpolating the data of Table 4.1. The parameters of the table are defined in Figure 4.2. These parameters are T/R and H/R where (R, T, H) form a coordinate system based on the observer. Assuming that the line of sight is horizontal, R is the distance as projected onto the line of sight, T is the horizontal offset from the line of sight, and H is the height above the eye of the observer. All coordinates are to the centre of the luminaire.

Table 4.1 Table of position indices

HR																				
T/R	0,00	0,10	0,20	0,30	0,40	0,50	0,60	0,70	0,80	0,90	1,00	1,10	1,20	1,30	1,40	1,50	1,60	1,70	1,80	1,90
0,00	1,00	1,26	1,53	1,90	2,35	2,86	3,50	4,20	5,00	6,00	7,00	8,10	9,25	10,35	11,70	13,15	14,70	16,20	-	-
0,10	1,05	1,22	1,46	1,80	2,20	2,75	3,40	4,10	4,80	5,80	6,80	8,00	9,10	10,30	11,60	13,00	14,60	16,10	-	-
0,20	1,12	1,30	1,50	1,80	2,20	2,66	3,18	3,88	4,60	5,50	6,50	7,60	8,75	9,85	11,20	12,70	14,00	15,70	-	-
0,30	1,22	1,38	1,60	1,97	2,25	2,70	3,25	3,90	4,60	5,45	6,45	7,40	8,40	9,50	10,85	12,10	13,70	15,00	-	-
0,40	1,32	1,47	1,70	1,96	2,35	2,80	3,30	3,90	4,60	5,40	6,40	7,30	8,30	9,40	10,60	11,90	13,20	14,60	16,00	-
0,50	1,43	1,60	1,82	2,10	2,48	2,91	3,40	3,98	4,70	5,50	6,40	7,30	8,30	9,40	10,50	11,75	13,00	14,40	15,70	-
0,60	1,55	1,72	1,98	2,30	2,65	3,10	3,60	4,10	4,80	5,50	6,40	7,35	8,40	9,40	10,50	11,70	13,00	14,10	15,40	-
0,70	1,70	1,88	2,12	2,48	2,87	3,30	3,78	4,30	4,88	5,60	6,50	7,40	8,50	9,50	10,50	11,70	12,85	14,00	15,20	-
0,80	1,82	2,00	2,32	2,70	3,08	3,50	3,92	4,50	5,10	5,75	6,60	7,50	8,60	9,50	10,60	11,75	12,80	14,00	15,10	-
0,90	1,96	2,20	2,54	2,90	3,30	3,70	4,20	4,75	5,30	6,00	6,75	7,70	8,70	9,65	10,75	11,80	12,90	14,00	15,00	16,00
1,00	2,11	2,40	2,75	3,10	3,50	3,91	4,40	5,00	5,60	6,20	7,00	7,90	8,80	9,75	10,80	11,90	12,95	14,00	15,00	16,00
1,10	2,30	2,55	2,92	3,30	3,72	4,20	4,70	5,25	5,80	6,55	7,20	8,15	9,00	9,90	10,95	12,00	13,00	14,00	15,00	16,00
1,20	2,40	2,75	3,12	3,50	3,90	4,35	4,85	5,50	6,05	6,70	7,50	8,30	9,20	10,00	11,02	12,10	13,10	14,00	15,00	16,00
1,30	2,55	2,90	3,30	3,70	4,20	4,65	5,20	5,70	6,30	7,00	7,70	8,55	9,35	10,20	11,20	12,25	13,20	14,00	15,00	16,00
1,40	2,70	3,10	3,50	3,90	4,35	4,85	5,35	5,85	6,50	7,25	8,00	8,70	9,50	10,40	11,40	12,40	13,25	14,05	15,00	16,00
1,50	2,85	3,15	3,65	4,10	4,55	5,00	5,50	6,20	6,80	7,50	8,20	8,85	9,70	10,55	11,50	12,50	13,30	14,05	15,02	16,00
1,60	2,95	3,40	3,80	4,25	4,75	5,20	5,75	6,30	7,00	7,65	8,40	9,00	9,80	10,80	11,75	12,60	13,40	14,20	15,10	16,00
1,70	3,10	3,55	4,00	4,50	4,90	5,40	5,95	6,50	7,20	7,80	8,50	9,20	10,00	10,85	11,85	12,75	13,45	14,20	15,10	16,00
1,80	3,25	3,70	4,20	4,65	5,10	5,60	6,10	6,75	7,40	8,00	8,65	9,35	10,10	11,00	11,90	12,80	13,50	14,20	15,10	16,00
1,90	3,43	3,86	4,30	4,75	5,20	5,70	6,30	6,90	7,50	8,17	8,80	9,50	10,20	11,00	12,00	12,82	13,55	14,20	15,10	16,00
2,00	3,50	4,00	4,50	4,90	5,35	5,80	6,40	7,10	7,70	8,30	8,90	9,60	10,40	11,10	12,00	12,85	13,60	14,30	15,10	16,00
2,10	3,60	4,17	4,65	5,05	5,50	6,00	6,60	7,20	7,82	8,45	9,00	9,75	10,50	11,20	12,10	12,90	13,70	14,35	15,10	16,00
2,20	3,75	4,25	4,72	5,20	5,60	6,10	6,70	7,35	8,00	8,55	9,15	9,85	10,60	11,30	12,10	12,90	13,70	14,40	15,15	16,00
2,30	3,85	4,35	4,80	5,25	5,70	6,22	6,80	7,40	8,10	8,65	9,30	9,90	10,70	11,40	12,20	12,95	13,70	14,40	15,20	16,00
2,40	3,95	4,40	4,90	5,35	5,80	6,30	6,90	7,50	8,20	8,80	9,40	10,00	10,80	11,50	12,25	13,00	13,75	14,45	15,20	16,00
2,50	4,00	4,50	4,96	5,40	5,85	6,40	6,95	7,55	8,25	8,85	9,50	10,05	10,85	11,55	12,30	13,00	13,80	14,50	15,25	16,00
2,60	4,07	4,55	5,05	5,47	5,95	6,46	7,00	7,65	8,35	8,95	9,55	10,10	10,90	11,60	12,32	13,00	13,80	14,50	15,25	16,00
2,70	4,10	4,60	5,10	5,53	6,00	6,50	7,00	7,70	8,40	9,00	9,60	10,16	10,92	11,63	12,35	13,00	13,80	14,50	15,25	16,00
2,80	4,15	4,62	5,15	5,56	6,05	6,55	7,08	7,73	8,45	9,05	9,65	10,20	10,95	11,65	12,35	13,00	13,80	14,50	15,25	16,00
2,90	4,20	4,65	5,17	5,60	6,07	6,57	7,12	7,75	8,50	9,10	9,70	10,23	10,95	11,65	12,35	13,00	13,80	14,50	15,25	16,00
3,00	4,22	4,67	5,20	5,65	6,12	6,60	7,15	7,80	8,55	9,12	9,70	10,23	10,95	11,65	12,35	13,00	13,80	14,50	15,25	16,00

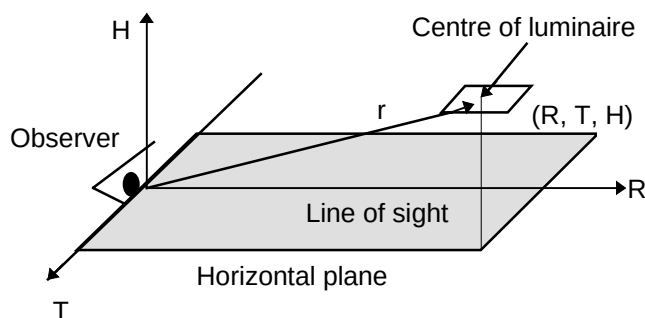


Figure 4.2 The position index coordinate system (R, T, H) based on the observer. The ratios H/R and T/R are based on the centre of the luminaire.

The (R, T, H) coordinate system shown in Figure 4.2 is also useful for calculations of the term $f_{\text{luminaire}}$. The coordinates of the luminaire must be derived in this coordinate system, and some supplementary information concerning the orientation of the luminaires must be given.

For the special case of disymmetric luminaires (see Figure 4.3), mounted either crosswise or endwise to the line of sight, the (C, γ) coordinates are derived by:

$$C = \arctan(T/R) \text{ for crosswise mounting} \quad (4.5)$$

$$C = 90^\circ - \arctan(T/R) \text{ for endwise mounting} \quad (4.6)$$

$$\gamma = \arctan\left(\frac{\sqrt{R^2 + T^2}}{H}\right) \quad (4.7)$$

The square distance, r^2 , is obtained by:

$$r^2 = R^2 + T^2 + H^2 \quad (4.8)$$

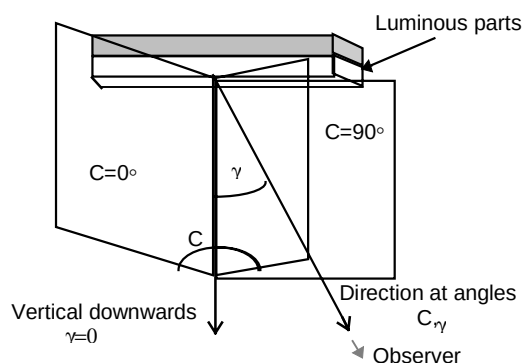


Figure 4.3 Any direction relative to a luminaire can be specified by the angular coordinates (C, γ). The UGR calculation uses L, the luminance of the luminous parts, and A_p , the projected luminous area. A disymmetric luminaire is symmetrical about the planes $C = 0/180$ and $C = 90/270$. The symmetry applies both for the luminous intensity distribution and for the luminous shape.

It is noted that the position index is symmetrical in the parameter T/R, and so the table only contains non-negative values of this parameter. Entries in the table are made with the absolute value of T/R.

It is recommended that luminaires with T/R values outside the range of the table (0 to 3) be ignored. It is further noted that some positions in the table at large H/R values are void. These correspond to