ISBN 978 3 901906 87 9

CIE

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

TECHNICAL REPORT

CALCULATION AND PRESENTATION OF UNIFIED GLARE RATING TABLES FOR INDOOR LIGHTING LUMINAIRES

CIE 190:2010

UDC: 628.931
628.95
628.972
628.977
628.987

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

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

The objectives of the CIE are:

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE

La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant environ 40 pays.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in rund 40 Ländern.

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1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen überprüft, berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

Published by the

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This Technical Report has been prepared by CIE Technical Committee 3-43 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 élaboré par le Comité Technique CIE 3-43 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 emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Il faut consulter les plus récents comptes rendus de la CIE, ou le CIE NEWS, en ce qui concerne des amendements nouveaux éventuels.

Dieser Technische Bericht wurde vom Technischen Komitee CIE 3-43 der Division 3 "Innenraum und Beleuchtungsentwurf" ausgearbeitet und vom Vorstand der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist. Die neuesten CIE-Tagungsberichte oder die CIE NEWS sollten im Hinblick auf mögliche spätere Änderungen zu Rate gezogen werden.

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The following members of TC 3-43, “Determination of Discomfort Glare“, took part in the preparation of this Technical Report. The committee comes under Division 3 “Interior Environment and Lighting Design”.

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CONTENTS

CALCULATION AND PRESENTATION OF UNIFIED GLARE RATING TABLES FOR INDOOR LIGHTING LUMINAIRES

SUMMARY

This report has been prepared to assist luminaire suppliers and lighting designers in the production of UGR tables for luminaires in preset arrays at 1:1 spacing to height ratio. This data is needed for the verification of conformity to the limiting UGR by the UGR tabular method specified in clause 6.2 of the Standard ISO 8995-1:2002(E)/CIE S 008/E:2001 "Lighting of Workplaces – Part 1: Indoor". The limiting UGR values are recommended in clause 5 of this standard. The report makes use of the basic UGR equation, described in CIE 117-1995, gives tables of preset values for the standard conditions and in step by step describes the calculation process needed to generate the uncorrected UGR table. The process is further demonstrated by a worked example of UGR calculation for a disymmetric distribution luminaire in a room $2H \times 4H$. The report also gives the uncorrected UGR table for this luminaire which can be used to validate software designed for the production of the UGR table.

CALCUL ET PRESENTATION DES TABLEAUX DE L'UGR POUR LES LUMINAIRES D'ECLAIRAGE INTERIEUR

RESUME

Ce document a été préparé pour les distributeurs de luminaires et ingénieurs éclairagistes afin de leurs permettre d'établir les tableaux de l'UGR pour des luminaires disposés suivant un arrangement prédéfini et un rapport espacement-hauteur de feu de 1. Cettes données sont nécessaires pour la vérification de la conformité des prescriptions de la méthode unifiée d'évaluation de l'éblouissement (UGR) sous une forme tabulée suivant le paragraphe 6.2 de la norme ISO 8995-1:2002(E)/CIE S 008/E:2001 "Lighting of Workplaces – Part 1: Indoor". Les valeurs limites de l'UGR recommandées sont données dans le paragraphe 5 de cette norme. Ce document utilise l'équation de base de l'UGR décrite dans la publication CIE 117-1995, donne des tableaux de valeurs préétablies suivant des conditions normalisées, et décrit le processus de calcul pas à pas nécessaire d'établir un tableau de l'UGR non-corrigé. Un cas-type de calcul de l'UGR est ensuite donné pour un luminaire de distribution symétrique dans une pièce de dimensions $2H \times 4H$. Ce document donne aussi un tableau de l'UGR non-corrigé pour un luminaire qui peut être validé dans les logiciels de calcul d'éclairage sous une forme normalisée.

BERECHNUNG UND DARSTELLUNG VON UGR-TABELLEN FÜR INNENRAUM-LEUCHTEN

ZUSAMMENFASSUNG

Dieser Bericht wurde erstellt, um Leuchtenhersteller und Lichtplaner bei der Erzeugung von UGR-Tabellen für Leuchten in vorgegebenen Feldern bei einem Abstand-zu-Höhen-Verhältnis von 1:1 zu unterstützen. Diese Daten werden zur Überprüfung der Einhaltung des UGR-Grenzwertes nach der UGR-Tabellenmethode gemäß Absatz 6.2 des Standards ISO 8995-1:2002(E)/CIE S 008/E:2001 "Lighting of Workplaces – Part 1: Indoor" benötigt. In Absatz 5 dieses Standards werden UGR-Grenzwerte empfohlen. Der Bericht basiert auf der grundlegenden UGR-Formel, die in CIE 117-1995 beschrieben wird, stellt Tabellen vorgegebener Werte für Standardbedingungen zur Verfügung und beschreibt Schritt für Schritt den Berechnungsvorgang zur Erzeugung der unkorrigierten UGR-Tabelle. Die Vorgehensweise wird weiterhin durch ein ausgearbeitetes Beispiel einer UGR-Berechnung für eine Leuchte mit zweiachsig symmetrischer Lichtstärkeverteilung in einem Raum mit den Grundabmessungen $2H \times 4H$ gezeigt. Der Bericht liefert ebenso die unkorrigierte UGR-Tabelle für diese Leuchte, die zur Validierung von Software zur Erzeugung von UGR-Tabellen verwendet werden kann.

1 INTRODUCTION

The discomfort glare rating of the lighting installation is determined by the CIE Unified Glare Rating (UGR) tabular method based on the basic equation:

$$R_{\mathrm{UG}} = 8\log\left[\frac{0{,}25}{L_{\mathrm{b}}}\sum\frac{L^2\omega}{p^2}\right] \quad (1)$$

where

- R_{UG} is the UGR-value;
- L_{b} is the background luminance ($\mathrm{cd{\cdot}m^{-2}}$), calculated as $E_{\mathrm{ind}}\pi^{-1}$, in which E_{ind} is the vertical indirect illuminance at the observer eye;
- L is the luminance of the luminous parts of each luminaire in the direction of the observer's eye ($\mathrm{cd{\cdot}m^{-2}}$);
- ω is the solid angle of the luminous parts of each luminaire at the observer's eye (sr);
- p is the Guth position index for each individual luminaire which relates to its displacement from the line of sight.

The full details of the UGR method are given in CIE 117-1995 [1].

In the Standard ISO 8995-1:2002(E)/CIE S 008/E:2001 [2] the recommended limiting UGR values, in clause 5, are based on the standard observer's position which have been validated by the UGR tabular method at a 1:1 spacing to height ratio. As a consequence the verification of unified glare rating should follow the same rules. The verification clause 6.2 states that, *"Authenticated UGR data produced by the tabular method at 1:1 spacing to height ratio in accordance with Publication CIE 117-1995 shall be provided for the luminaire/scheme by the manufacturer of the luminaire."*

2 SCOPE

This document specifies the necessary information and the process required for the production of the standard-condition CIE UGR table for a luminaire at spacing to height ratio (R_{SH}) of 1:1. The procedure makes use of the CIE basic equation and defines the standard conditions for the calculation and presentation of the standard-condition CIE UGR table. The process is set out to assist luminaire manufacturers and lighting software providers to prepare and publish the standard-condition CIE UGR table for indoor lighting luminaires.

The UGR values produced by the methodology described in this report can be used for the verification of conformity to the limiting UGR values specified in the Standard ISO 8995-1:2002(E)/CIE S 008/E:2001 Lighting of Indoor Workplaces [2].

3 TERMS AND DEFINITIONS

The terms used in this report are as defined in the International Lighting Vocabulary (CIE DS 017.2/E:2009, ILV: International Lighting Vocabulary, 2009) [3], together with the following additional definitions:

CIE zonal flux (in the lower hemisphere) [Φ_{zL}]

calculated accumulated luminous fluxes of the luminaire in the lower hemisphere for the four zones from 0° to 41,4° (Φ_{zL1}), 0° to 60° (Φ_{zL2}), 0° to 75,5° (Φ_{zL3}), 0° to 90° (Φ_{zL4}) from the normalised luminous intensity values

Unit: lm

direct flux to horizontal reference plane (at observer eye level) [Φ_{DFL}] (lm)

proportion of the total emitted luminous flux that arrives directly onto the horizontal reference plane at the observers eye level

distribution factor [F_D]

factor indicating the proportion of the total emitted luminous flux reaching the reference surface

NOTE $F_{DF} = \Phi_{DFL} \Phi_0^{-1}$ is the distribution factor for horizontal reference plane at observer eye level, $F_{DW} = R_{DLO} - F_{DF}$ is the distribution factor for walls and $F_{DC} = R_{ULO}$ is the distribution factor for ceiling.

Unit: 1

disymmetric distribution

luminous intensity distribution of a luminaire symmetric about two C planes

geometric factor [F_G)

multiplying factor to calculate the proportion of the zonal flux directly reaching the reference plane

NOTE The geometric factor (F_G) is also known as geometric multiplier (GM) in CIE Technical Report CIE 52-1982 [4]

Unit: 1

normalisation flux [Φ_0]

total luminous flux of 1000 lm used to normalise luminous intensity distribution of the luminaire and uncorrected UGR values

Unit: lm

scale factor [F_S]

factor used to correct the relative luminous intensity values into normalised values of cd/1000 lm

Unit: 1

spacing to height ratio [R_{SH}]

ratio of the distance between the light centres of adjacent luminaires to the mounting height above the reference plane

Unit: 1

transfer factor [F_T]

ratio of the total luminous flux falling on a surface to the direct luminous flux on the other surface which caused it

Unit: 1

NOTE 1 $F_{T,FW}$ is the transfer factor horizontal reference plane at the observer eye level to wall, $F_{T,CW}$ is the transfer factor ceiling to wall and $F_{T,WW}$ is the transfer factor wall to wall.

NOTE 2 In this report the “ceiling” is taken to be a horizontal reference plane at the luminaire mounting centre.

uncorrected UGR table

set of UGR values, $R_{UG}(\Phi_o)$, of the luminaire in the defined room based on a luminous flux of 1000 lm in the luminaire

4 REFERENCE DATA

4.1 CIE UGR Table

To ensure consistency and give help for checking the data, this report provides the table of factors and angles that should be used in the preparation of the standard-condition CIE UGR table. The UGR values in the standard-condition CIE UGR table are normalised to 1000 lm total bare lamp flux in the luminaire and therefore the table should be labelled as “Uncorrected UGR table”. Table 1 shows as an example the standard-condition uncorrected UGR table for a disymmetric distribution luminaire. The pair of tables is produced for crosswise and endwise viewing. For symmetric distribution half of the table is sufficient but for asymmetric distribution additional tables will be required. The data are provided for 19 standard room shapes with 5 different combinations of room surface reflectance.

For application of the “Uncorrected UGR table” the values must be corrected to the actual lamp flux in the luminaire by using conversion terms defined by

$$R_{\mathrm{UG}}(\Phi) = R_{\mathrm{UG}}(\Phi_{\mathrm{o}}) + 8\ \log(\frac{\Phi}{\Phi_{\mathrm{o}}}) \tag{2}$$

where

$R_{\mathrm{UG}}(\Phi_{\mathrm{o}})$ is the UGR value from the uncorrected UGR table;

Φ is the actual total lamp flux (lm);

Φ_0 is 1000 lm.

Table 1. Example of presentation of an uncorrected UGR table for a disymmetric distribution luminaire (luminaire described in 5.1).

Reflectances:											
Ceiling (cavity)		0,7	0,7	0,5	0,5	0,3	0,7	0,7	0,5	0,5	0,3
Wall		0,5	0,3	0,5	0,3	0,3	0,5	0,3	0,5	0,3	0,3
Reference plane		0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Room dimensions		Viewed crosswise					Viewed endwise				
X=2H	Y=2H	8,9	10,5	9,3	10,8	11,1	10,7	12,2	11,0	12,5	12,9
	3H	10,5	11,9	10,8	12,2	12,6	12,4	13,8	12,8	14,2	14,5
	4H	11,0	12,3	11,4	12,6	13,0	13,1	14,5	13,5	14,8	15,2
	6H	11,5	12,7	11,9	13,1	13,5	13,6	14,8	14,0	15,2	15,6
	8H	11,7	12,9	12,2	13,3	13,7	13,8	14,9	14,2	15,3	15,7
	12H	12,0	13,2	12,5	13,5	14,0	13,8	15,0	14,3	15,3	15,8
4H	2H	9,6	11,0	10,0	11,3	11,7	11,0	12,4	11,4	12,7	13,1
	3H	11,4	12,5	11,8	12,9	13,3	13,0	14,1	13,4	14,5	14,9
	4H	12,0	13,0	12,4	13,4	13,9	13,9	14,9	14,3	15,3	15,7
	6H	12,7	13,5	13,1	14,0	14,4	14,5	15,4	15,0	15,8	16,3
	8H	13,0	13,8	13,5	14,2	14,7	14,7	15,5	15,2	16,0	16,4
	12H	13,4	14,1	13,8	14,6	15,0	14,8	15,6	15,3	16,0	16,5
8H	4H	12,4	13,2	12,8	13,6	14,1	14,0	14,8	14,5	15,3	15,8
	6H	13,2	13,8	13,7	14,3	14,8	14,8	15,4	15,3	15,9	16,4
	8H	13,6	14,2	14,1	14,7	15,2	15,0	15,6	15,5	16,1	16,6
	12H	14,1	14,7	14,6	15,1	15,7	15,2	15,7	15,7	16,2	16,8
12H	4H	12,4	13,1	12,9	13,6	14,1	14,0	14,8	14,5	15,2	15,7
	6H	13,2	13,8	13,8	14,3	14,8	14,8	15,4	15,3	15,9	16,4
	8H	13,7	14,3	14,3	14,8	15,3	15,1	15,6	15,6	16,1	16,7

4.2 Standard Conditions

The standard conditions are defined as follows:

- The position of the complete array of luminaires is shown in Figure 1.
- The observer is located at the mid-point marked **O** of a wall and has horizontal line of sight towards the centre of the opposite wall (see Figure 1).
- The height of the luminaires centre above the observer eye level (mounting height) is H = 2 m.
- The spacing of the luminaires is 2 m in both x_T and y_R directions where x_T is the horizontal distance between vertical planes through the luminaire centre and through the observer's eye position, both parallel to the direction of view, and y_R is the horizontal distance, parallel to the viewing direction, from observer's eye position to the vertical plane, perpendicular to the viewing direction, through the luminaire centre (see Figures 1 and 3).
- The spacing to height ratio (R_{SH}) is 1:1.
- The height of that part of the wall that is considered for calculation is 2 m.
- The horizontal reference plane is at the observer eye level at 1,2 m above floor.
- The room dimensions X and Y are expressed in terms of the mounting height H. The X dimension is perpendicular to the line of sight and the Y dimension is parallel to the line of sight.
- The luminous intensity distribution of the luminaire (I table) is provided in normalised form of cd/1000 lm.

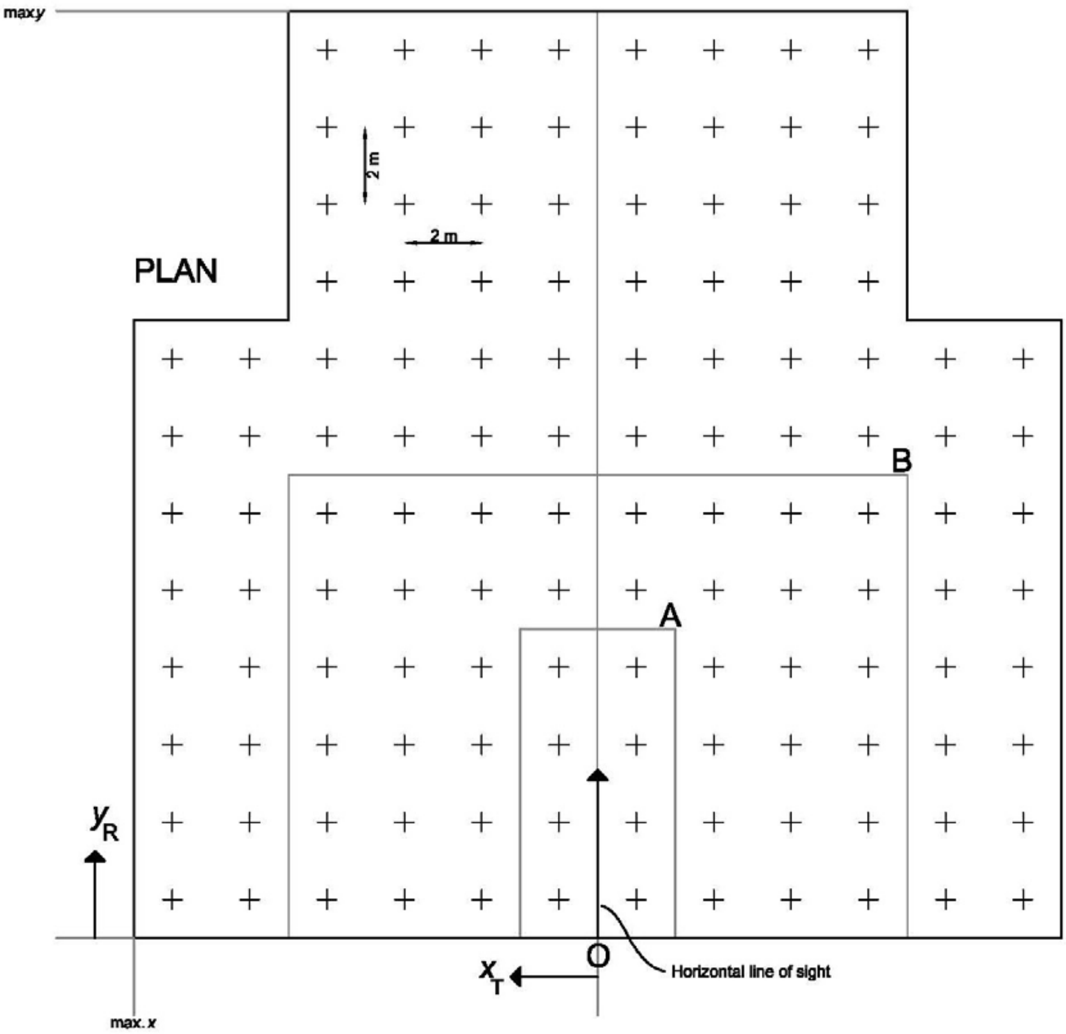

Figure 1. Position of luminaires (+) in the standard array area, with examples of area A size $2H \times 4H$ and area B size $8H \times 6H$.

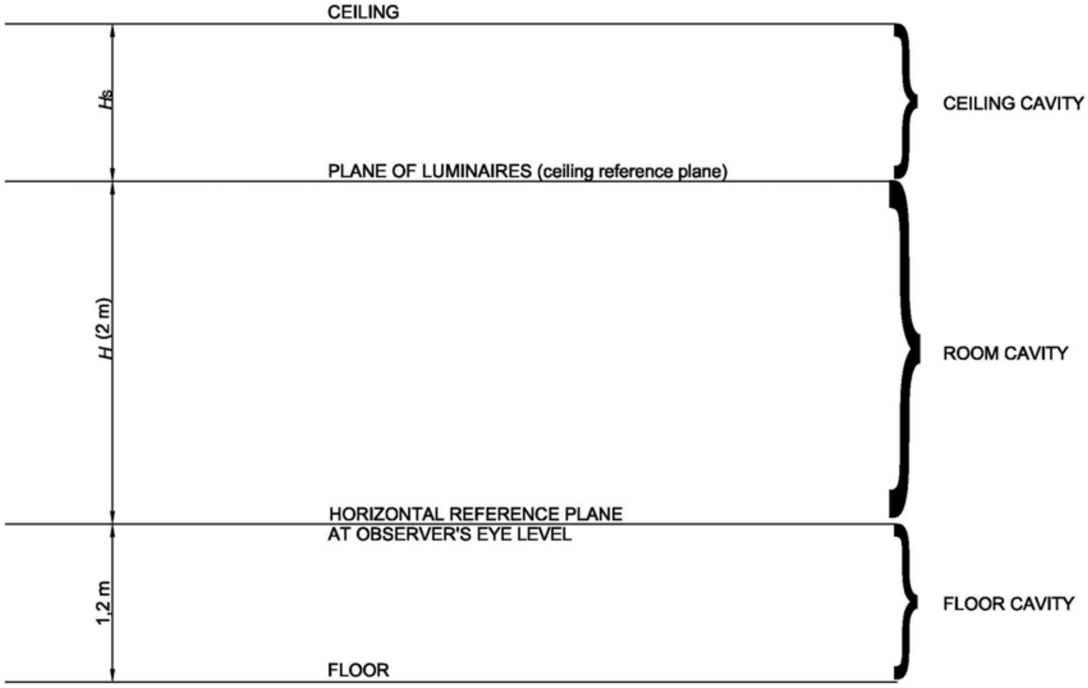

Figure 2. Dimensions of the standard room section.

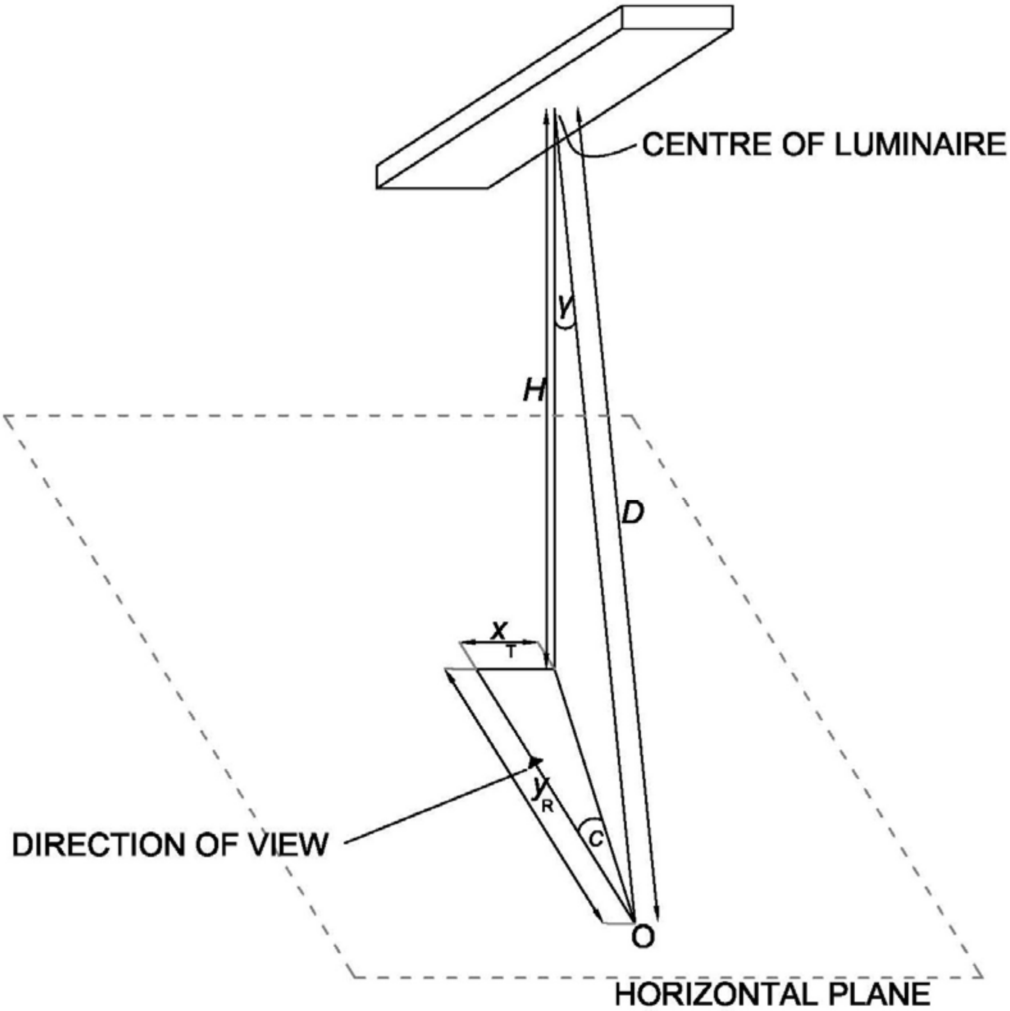

Figure 3a. Position of luminaire centre relative to observer O.

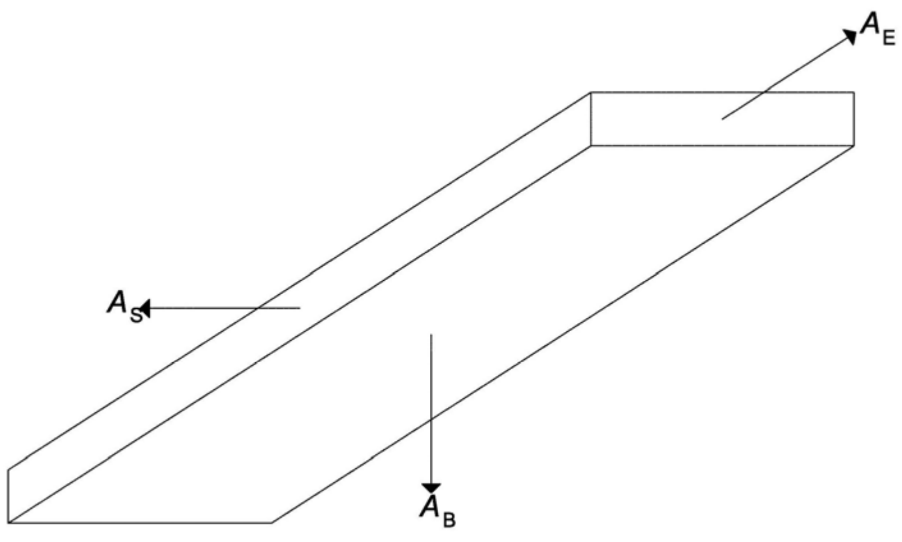

Figure 3b. Projected areas for linear luminaire.

4.3 Procedure for Determination of Standard-Condition CIE UGR Table

The table is generated with the basic equation but rearranged and simplified by the use of preset conditions and values.

The basic equation is

$$R_{UG} = 8\ \log\left[\frac{0,25}{L_b}\sum\frac{L^2\omega}{p^2}\right] \tag{3}$$

This may be expressed in term of apparent luminaire surface area, A, distance to luminaire, D, luminous intensity towards the observer, $I_{C\gamma}$, position index, p, and indirect illuminance on the wall produced by a luminaire, E_{WID}.

$$R_{UG} = 8\ \log\sum\left[\frac{\pi}{4E_{WID}}\frac{I_{C\gamma}^2 A}{A^2D^2p^2}\right] \tag{4}$$

This equation can be further simplified for the standard luminaire arrangements to:

$$R_{UG} = 8\ \log\sum\left[\frac{K}{E_{WID}}\frac{I_{C\gamma}^2}{A}\right] \tag{5}$$

$$R_{UG} = 8\ \log\sum\left[\frac{K\,I_{C\gamma}^2}{A}\right] - 8\ \log E_{WID} \tag{6}$$

where

$$K = \frac{\pi}{4p^2D^2}; \tag{6a}$$

$I_{c\gamma}$ is the luminous intensity of the source at the angles to the downward vertical γ and of azimuth C, appropriate to the eye position **O** of the observer and the viewing direction - see Figure 3a;

$$C = \arctan\frac{x_T}{y_R} \quad \text{is the azimuth;} \tag{6b}$$

$$\gamma = \arccos\frac{H}{D} \quad \text{is the elevation;} \tag{6c}$$

A is the projected luminous area of the source (m^2) from the observer position **O** – see Figures 3a and 3b:

$$A = A_B\frac{H}{D} + A_S\frac{x_T}{D} + A_E\frac{y_R}{D} \quad \text{(for linear luminaires viewed endwise);} \tag{6d}$$

$$A = A_B\frac{H}{D} + A_S\frac{y_R}{D} + A_E\frac{x_T}{D} \quad \text{(for linear luminaires viewed crosswise);} \tag{6e}$$

$$D = \sqrt{H^2 + x_T^2 + y_R^2}; \tag{6f}$$

E_{WID} is the indirect component of the illuminance on the walls.

NOTE The pre-calculated parameters of K, Azimuth (C), Elevation (γ), H/D, x_T/D, y_R/D are given in Table 2.

The indirect component of the illuminance on the walls can be calculated with the following equation:

$$E_{\text{WID}} = \frac{F_{\text{UWID}}\ N\ \Phi_0}{A_{\text{W}}} \tag{7}$$

where

F_{UWID} is the indirect utilisation factor for walls;

N is the number of luminaires;

A_{W} is the total area of walls (m^2) between reference plane and luminaire plane;

Φ_0 = 1000 lm.

This may be simplified to:

$$E_{\text{WID}} = B\ F_{\text{UWID}} \tag{8}$$

where

$$B = 1000\frac{N}{A_{\text{W}}}; \tag{8a}$$

$$F_{\text{UWID}} = F_{\text{DF}}\ F_{\text{T,FW}} + F_{\text{DW}}\ (F_{\text{T,WW}} - 1) + F_{\text{DC}}\ F_{\text{T,CW}}. \tag{8b}$$

NOTE Table 3 gives a column of 19 values of B and the Room index for the standard-condition CIE UGR table.

The calculation of E_{WID} can be made with the following steps:

- Have I table with C planes at 15º intervals around the luminaire (0º to 345º) and γ elevation angles at 5º intervals from 0º to 180º.

  NOTE In this report the azimuth angles are indicated by C and the elevation angles are indicated by γ for the luminous intensity table (I table) of the luminaire.

- Calculate R_{LO}, R_{DLO}, R_{ULO} using the worksheet Table 6.

- Calculate the cumulative CIE zonal fluxes Φ_{zL1}, Φ_{zL2}, Φ_{zL3} and Φ_{zL4} using zonal flux values calculated with the worksheet Table 6:

  Φ_{zL1} = zonal flux (0º to 40º) + 0,130 × zonal flux (40º to 50º)

  Φ_{zL2} = zonal flux (0º to 60º)

  Φ_{zL3} = zonal flux (0º to 70º) + 0,547 × zonal flux (70º to 80º)

  Φ_{zL4} = zonal flux (0º to 90º)

- Calculate Φ_{zL} using the geometric factors from Table 4 and the following equation:

$$\Phi_{\text{zL}} = \Phi_{\text{zL1}}\ F_{\text{GL1}} + \Phi_{\text{zL2}}\ F_{\text{GL2}} + \Phi_{\text{zL3}}\ F_{\text{GL3}} + \Phi_{\text{zL4}}\ F_{\text{GL4}} \tag{9}$$

- Calculate the distribution factors F_{DF}, F_{DW}, F_{DC} using Φ_{zL} and the R_{LO} and R_{DLO} values calculated with the worksheet Table 6:

$$F_{\text{DF}} = \frac{\Phi_{\text{zL}}}{\Phi_0} \tag{10}$$

$$F_{\text{DW}} = R_{\text{DLO}} - F_{\text{DF}} \tag{11}$$

$$F_{\text{DC}} = R_{\text{ULO}} \tag{12}$$

- Calculate the indirect utilisation factor for walls, F_{UWID}, for each room index of the standard-condition CIE UGR table:

$$F_{UWID} = F_{DF}\, F_{T,FW} + F_{DW}\, (F_{T,WW} - 1) + F_{DC}\, F_{T,CW} \qquad (13)$$

- Table 5 gives the transfer factor values for each of the 19 standard-condition CIE UGR table room index and reflectance combinations.
- Multiply F_{UWID} by the value B given in Table 3 to obtain E_{WID} for each room index of the standard-condition CIE UGR table.

Table 2. Pre-calculated parameters for luminaires in the standard array (part 1).

$x_T/H = 0{,}5$						
y_R/H	C (º)	γ (º)	K	H/D	y_R/D	x_T/D
0,5	45,00	35,26	n/a	0,816 5	0,408 2	0,408 2
1,5	18,43	57,69	0,004 12	0,534 5	0,801 8	0,267 3
2,5	11,31	68,58	0,005 41	0,365 1	0,912 9	0,182 6
3,5	8,13	74,21	0,004 73	0,272 2	0,952 6	0,136 1
4,5	6,34	77,55	0,003 86	0,215 7	0,970 5	0,107 8
5,5	5,19	79,74	0,003 08	0,178 2	0,980 0	0,089 1
6,5	4,40	81,28	0,002 43	0,151 6	0,985 5	0,075 8
7,5	3,81	82,42	0,001 97	0,131 9	0,989 1	0,065 9
8,5	3,37	83,30	0,001 63	0,116 6	0,991 5	0,058 3
9,5	3,01	84,00	0,001 37	0,104 5	0,993 1	0,052 3
10,5	2,73	84,57	0,001 16	0,094 7	0,994 4	0,047 4
11,5	2,49	85,03	0,001 00	0,086 5	0,995 3	0,043 3

$x_T/H = 1{,}5$						
y_R/H	C (º)	γ (º)	K	H/D	y_R/D	x_T/D
0,5	71,57	57,69	n/a	0,534 5	0,267 3	0,801 8
1,5	45,00	64,76	0,001 55	0,426 4	0,639 6	0,639 6
2,5	30,96	71,07	0,002 94	0,324 4	0,811 1	0,486 7
3,5	23,20	75,29	0,003 29	0,254 0	0,889 0	0,381 0
4,5	18,43	78,10	0,002 92	0,206 3	0,928 3	0,309 4
5,5	15,26	80,05	0,002 49	0,172 8	0,950 3	0,259 2
6,5	12,99	81,47	0,002 09	0,148 2	0,963 6	0,222 4
7,5	11,31	82,55	0,001 77	0,129 6	0,972 3	0,194 5
8,5	10,01	83,39	0,001 50	0,115 1	0,978 2	0,172 6
9,5	8,97	84,06	0,001 29	0,103 4	0,982 5	0,155 1
10,5	8,13	84,61	0,001 11	0,093 9	0,985 6	0,140 8
11,5	7,43	85,07	0,000 97	0,085 9	0,987 9	0,128 9

$x_T/H = 2{,}5$						
y_R/H	C (º)	γ (º)	K	H/D	y_R/D	x_T/D
0,5	78,69	68,58	n/a	0,365 1	0,182 6	0,912 9
1,5	59,04	71,07	0,000 53	0,324 4	0,486 7	0,811 1
2,5	45,00	74,21	0,001 19	0,272 2	0,680 4	0,680 4
3,5	35,54	76,91	0,001 66	0,226 5	0,792 6	0,566 1
4,5	29,05	79,01	0,001 83	0,190 7	0,858 1	0,476 7
5,5	24,44	80,60	0,001 76	0,163 3	0,898 1	0,408 2
6,5	21,04	81,83	0,001 59	0,142 1	0,923 9	0,355 3
7,5	18,43	82,79	0,001 40	0,125 5	0,941 2	0,313 7
8,5	16,39	83,56	0,001 24	0,112 2	0,953 3	0,280 4
9,5	14,74	84,19	0,001 09	0,101 3	0,962 1	0,253 2
10,5	13,39	84,71	0,000 96	0,092 3	0,968 7	0,230 6
11,5	12,26	85,14	0,000 84	0,084 7	0,973 7	0,211 7

Table 2. Pre-calculated parameters for luminaires in the standard array (part 2).

$x_T/H = 3,5$						
y_R/H	C (°)	γ (°)	K	H/D	y_R/D	x_T/D
0,5	81,87	74,21	n/a	0,272 2	0,136 1	0,952 6
1,5	66,80	75,29	0,000 24	0,254 0	0,381 0	0,889 0
2,5	54,46	76,91	0,000 53	0,226 5	0,566 1	0,792 6
3,5	45,00	78,58	0,000 83	0,198 0	0,693 1	0,693 1
4,5	37,87	80,05	0,001 05	0,172 8	0,777 5	0,604 7
5,5	32,47	81,28	0,001 15	0,151 6	0,833 9	0,530 7
6,5	28,30	82,29	0,001 13	0,134 2	0,872 5	0,469 8
7,5	25,02	83,11	0,001 06	0,120 0	0,899 6	0,419 8
8,5	22,38	83,79	0,000 99	0,108 1	0,919 3	0,378 5
9,5	20,22	84,36	0,000 90	0,098 3	0,933 8	0,344 0
10,5	18,43	84,84	0,000 81	0,090 0	0,944 8	0,314 9
11,5	16,93	85,24	0,000 73	0,082 9	0,953 4	0,290 2

$x_T/H = 4,5$						
y_R/H	C (°)	γ (°)	K	H/D	y_R/D	x_T/D
0,5	83,66	77,55	n/a	0,215 7	0,107 8	0,970 5
1,5	71,57	78,10	0,000 15	0,206 3	0,309 4	0,928 3
2,5	60,95	79,01	0,000 27	0,190 7	0,476 7	0,858 1
3,5	52,13	80,05	0,000 45	0,172 8	0,604 7	0,777 5
4,5	45,00	81,07	0,000 59	0,155 2	0,698 5	0,698 5
5,5	39,29	81,99	0,000 72	0,139 3	0,766 4	0,627 1
6,5	34,70	82,79	0,000 77	0,125 5	0,815 7	0,564 7
7,5	30,96	83,48	0,000 78	0,113 6	0,851 9	0,511 2
8,5						
9,5						
10,5						
11,5						

$x_T/H = 5,5$						
y_R/H	C (°)	γ (°)	K	H/D	y_R/D	x_T/D
0,5	84,81	79,74	n/a	0,178 2	0,089 1	0,980 0
1,5	74,74	80,05	n/a	0,172 8	0,259 2	0,950 3
2,5	65,56	80,60	0,000 17	0,163 3	0,408 2	0,898 1
3,5	57,53	81,28	0,000 26	0,151 6	0,530 7	0,833 9
4,5	50,71	81,99	0,000 36	0,139 3	0,627 1	0,766 4
5,5	45,00	82,67	0,000 44	0,127 5	0,701 3	0,701 3
6,5	40,24	83,30	0,000 52	0,116 6	0,758 2	0,641 5
7,5	36,25	83,86	0,000 56	0,106 9	0,801 8	0,588 0
8,5						
9,5						
10,5						
11,5						

Table 3. Data for calculation of indirect illuminance on walls for luminaires in the standard array.

X Dimension	Y Dimension	Room Index	Number of Luminaires	Wall Area (A_W) (m²)	B
$2H$	$2H$	1,00	4	32,00	125,00
	$3H$	1,20	6	40,00	150,00
	$4H$	1,33	8	48,00	166,67
	$6H$	1,50	12	64,00	187,50
	$8H$	1,60	16	80,00	200,00
	$12H$	1,71	24	112,00	214,29
$4H$	$2H$	1,33	8	48,00	166,67
	$3H$	1,71	12	56,00	214,29
	$4H$	2,00	16	64,00	250,00
	$6H$	2,40	24	80,00	300,00
	$8H$	2,67	32	96,00	333,33
	$12H$	3,00	48	128,00	375,00
$8H$	$4H$	2,67	32	96,00	333,33
	$6H$	3,43	48	112,00	428,57
	$8H$	4,00	64	128,00	500,00
	$12H$	4,80	96	160,00	600,00
$12H$	$4H$	3,00	48	128,00	375,00
	$6H$	4,00	72	144,00	500,00
	$8H$	4,80	96	160,00	600,00

Table 4. Geometric factor values for luminaires in the standard array.

X Dimension	Y Dimension	Room Index	F_{GL1}	F_{GL2}	F_{GL3}	F_{GL4}
$2H$	$2H$	1,00	0,690	0,109	0,085	-0,016
	$3H$	1,20	0,578	0,200	0,127	-0,018
	$4H$	1,33	0,528	0,218	0,170	-0,017
	$6H$	1,50	0,485	0,215	0,222	-0,012
	$8H$	1,60	0,466	0,207	0,249	-0,006
	$12H$	1,71	0,448	0,198	0,272	0,005
$4H$	$2H$	1,33	0,528	0,218	0,170	-0,017
	$3H$	1,71	0,394	0,275	0,268	-0,020
	$4H$	2,00	0,338	0,257	0,351	-0,018
	$6H$	2,40	0,296	0,203	0,449	-0,006
	$8H$	2,67	0,280	0,165	0,499	0,006
	$12H$	3,00	0,264	0,125	0,541	0,027
$8H$	$4H$	2,67	0,280	0,165	0,499	0,006
	$6H$	3,43	0,248	0,058	0,628	0,032
	$8H$	4,00	0,239	-0,012	0,690	0,058
	$12H$	4,80	0,232	-0,084	0,740	0,098
$12H$	$4H$	3,00	0,264	0,125	0,541	0,027
	$6H$	4,00	0,238	-0,003	0,677	0,063
	$8H$	4,80	0,232	-0,084	0,740	0,098

Table 5. Transfer factor values for the room index (k) and reflectance combinations Ceiling / Wall / Reference plane (C/W/R) for the standard-condition CIE UGR table.

Reflectance C/W/R											
	X	$2H$	$2H$	$2H$	$2H$	$2H$	$2H$	$4H$	$4H$	$4H$	$4H$
	Y	$2H$	$3H$	$4H$	$6H$	$8H$	$12H$	$2H$	$3H$	$4H$	$6H$
	k	1,00	1,20	1,33	1,50	1,60	1,71	1,33	1,71	2,00	2,40
70/50/20	$F_{T,FW}$	0,220	0,199	0,187	0,174	0,167	0,160	0,187	0,158	0,142	0,124
	$F_{T,WW}$-1	0,422	0,376	0,351	0,322	0,307	0,290	0,351	0,295	0,265	0,230
	$F_{T,CW}$	0,646	0,571	0,531	0,488	0,466	0,443	0,531	0,439	0,389	0,335
70/30/20	$F_{T,FW}$	0,188	0,173	0,164	0,154	0,149	0,143	0,164	0,142	0,129	0,114
	$F_{T,WW}$-1	0,217	0,196	0,184	0,171	0,164	0,156	0,184	0,159	0,144	0,127
	$F_{T,CW}$	0,553	0,497	0,465	0,432	0,415	0,397	0,465	0,393	0,351	0,307
50/50/20	$F_{T,FW}$	0,198	0,178	0,166	0,154	0,147	0,141	0,166	0,140	0,125	0,108
	$F_{T,WW}$-1	0,380	0,338	0,314	0,287	0,273	0,257	0,314	0,263	0,235	0,204
	$F_{T,CW}$	0,445	0,393	0,365	0,335	0,320	0,304	0,364	0,301	0,267	0,230
50/30/20	$F_{T,FW}$	0,172	0,157	0,148	0,138	0,133	0,128	0,148	0,126	0,114	0,100
	$F_{T,WW}$-1	0,198	0,179	0,167	0,155	0,147	0,140	0,167	0,143	0,129	0,113
	$F_{T,CW}$	0,386	0,346	0,324	0,301	0,288	0,276	0,324	0,272	0,244	0,212
30/30/20	$F_{T,FW}$	0,157	0,141	0,132	0,123	0,118	0,113	0,132	0,112	0,100	0,087
	$F_{T,WW}$-1	0,181	0,162	0,151	0,139	0,132	0,124	0,151	0,128	0,115	0,101
	$F_{T,CW}$	0,227	0,203	0,190	0,176	0,169	0,161	0,190	0,159	0,142	0,124

Reflectance C/W/R										
	X	$4H$	$4H$	$8H$	$8H$	$8H$	$8H$	$12H$	$12H$	$12H$
	Y	$8H$	$12H$	$4H$	$6H$	$8H$	$12H$	$4H$	$6H$	$8H$
	k	2,67	3,00	2,67	3,43	4,00	4,80	3,00	4,00	4,80
70/50/20	$F_{T,FW}$	0,115	0,105	0,115	0,094	0,083	0,071	0,105	0,083	0,071
	$F_{T,WW}$-1	0,211	0,190	0,211	0,175	0,155	0,133	0,190	0,153	0,133
	$F_{T,CW}$	0,307	0,279	0,307	0,247	0,215	0,183	0,279	0,216	0,183
70/30/20	$F_{T,FW}$	0,106	0,098	0,106	0,088	0,078	0,067	0,098	0,078	0,067
	$F_{T,WW}$-1	0,117	0,106	0,117	0,098	0,088	0,076	0,106	0,086	0,076
	$F_{T,CW}$	0,283	0,259	0,283	0,231	0,203	0,174	0,259	0,204	0,174
50/50/20	$F_{T,FW}$	0,100	0,091	0,100	0,081	0,071	0,061	0,091	0,071	0,061
	$F_{T,WW}$-1	0,187	0,167	0,187	0,154	0,137	0,117	0,167	0,134	0,117
	$F_{T,CW}$	0,211	0,191	0,211	0,169	0,147	0,125	0,191	0,148	0,125
50/30/20	$F_{T,FW}$	0,093	0,085	0,093	0,076	0,067	0,058	0,085	0,068	0,058
	$F_{T,WW}$-1	0,104	0,094	0,104	0,087	0,078	0,067	0,094	0,077	0,067
	$F_{T,CW}$	0,196	0,179	0,196	0,158	0,140	0,120	0,179	0,140	0,120
30/30/20	$F_{T,FW}$	0,081	0,074	0,081	0,066	0,058	0,049	0,074	0,058	0,049
	$F_{T,WW}$-1	0,092	0,083	0,092	0,077	0,069	0,059	0,083	0,067	0,059
	$F_{T,CW}$	0,114	0,104	0,114	0,092	0,081	0,069	0,104	0,081	0,069

Table 6. Worksheet for calculation of R_{LO}.

	C angles (C)																								E	F	G	H
Gamma angles (γ)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	Average Intensity	Zone Factor	Zonal Flux (ExF)	Zonal Flux (FxSF)
0																												
5																												
10																												
15																												
20																												
25																												
30																												
35																												
40																												
45																												
50																												
55																												
60																												
65																												
70																												
75																												
80																												
85																												
90	5																											
																							Total flux 0° to 90° in arbitrary units(L):					
95																												
100																												
105																												
110																												
115																												
120																												
125																												
130																												
135																												
140																												
145																												
150																												
155																												
160																												
165																												
170																												
175																												
180	0																											
																							Total flux in arbitrary units(M):					

$$R_{LO} = \frac{\text{Total flux in arbitrary units (M)}}{\text{Total bare lamp flux in arbitrary units}} = \underline{\qquad\qquad} =$$

$$\text{Scale Factor } (F_S) = \frac{R_{LO} \times 1000}{\text{Total flux in arbitrary units (M)}} = \underline{\qquad\qquad} =$$

$$R_{DLO} = \frac{\text{Total flux 0° to 90° in arbitrary units (L)} \times F_S}{1000} = \frac{\qquad\qquad}{1000} =$$

$$R_{ULO} = R_{LO} - R_{DLO} =$$

5 WORKED EXAMPLE

5.1 Luminaire Data

This example will calculate the UGR values for area A in Figure1 for the arrangement $2H \times 4H$ and reflectances of 70/50/20. The example uses the luminous intensity table for a disymmetric distribution luminaire as shown in Table 7. The polar distribution is shown below in Figure 4. (The complete uncorrected UGR table for this luminaire is shown in Table 1.)

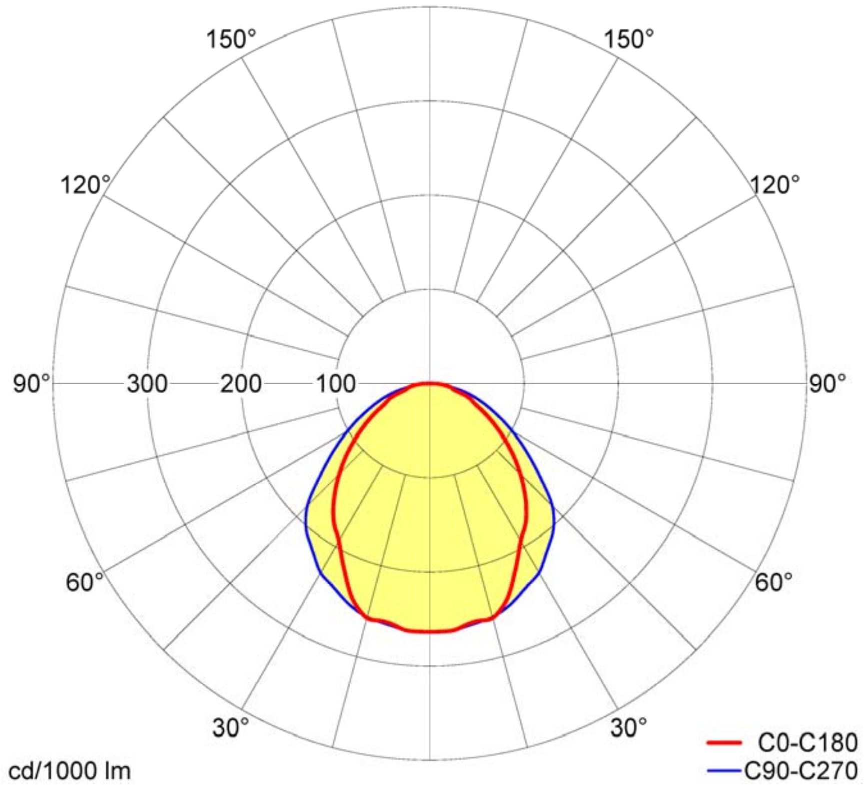

Figure 4. Luminous intensity distribution diagram for the example luminaire.

The luminaire has the following luminous areas:

- area of luminous base A_B = 0,316 m^2;
- area of luminous side A_S = 0,0 m^2;
- area of luminous end A_E = 0,0 m^2.

Table 7. Luminous intensity table for the example luminaire (values in cd/klm) (Part 1).

	C angles / °											
γ angles / °	0	15	30	45	60	75	90	105	120	135	150	165
0	264	264	264	264	264	264	264	264	264	264	264	264
5	264	265	264	265	264	263	264	263	264	265	264	265
10	258	257	258	260	262	261	260	261	262	260	258	257
15	258	257	255	255	256	258	257	258	256	255	255	257
20	242	244	246	249	249	251	250	251	249	249	246	244
25	216	218	223	232	238	240	240	240	238	232	223	218
30	193	194	197	208	222	231	232	231	222	208	197	194
35	178	179	181	182	194	214	217	214	194	182	181	179
40	158	160	162	167	171	189	204	189	171	167	162	160
45	136	135	140	145	153	163	184	163	153	145	140	135
50	114	115	118	123	130	143	152	143	130	123	118	115
55	92	94	99	105	111	119	125	119	111	105	99	94
60	72	73	77	86	92	99	101	99	92	86	77	73
65	54	55	59	65	75	79	79	79	75	65	59	55
70	44	44	43	47	55	61	60	61	55	47	43	44
75	27	29	34	33	36	44	43	44	36	33	34	29
80	22	21	20	18	21	25	25	25	21	18	20	21
85	14	14	13	12	8	8	9	8	8	12	13	14
90	5	5	4	3	1	0	0	0	1	3	4	5
95	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0

Table 7. Luminous intensity table for the example luminaire (values in cd/klm) (Part 2).

	C angles / °											
γ angles / °	180	195	210	225	240	255	270	285	300	315	330	345
0	264	264	264	264	264	264	264	264	264	264	264	264
5	264	265	264	265	264	263	264	263	264	265	264	265
10	258	257	258	260	262	261	260	261	262	260	258	257
15	258	257	255	255	256	258	257	258	256	255	255	257
20	242	244	246	249	249	251	250	251	249	249	246	244
25	216	218	223	232	238	240	240	240	238	232	223	218
30	193	194	197	208	222	231	232	231	222	208	197	194
35	178	179	181	182	194	214	217	214	194	182	181	179
40	158	160	162	167	171	189	204	189	171	167	162	160
45	136	135	140	145	153	163	184	163	153	145	140	135
50	114	115	118	123	130	143	152	143	130	123	118	115
55	92	94	99	105	111	119	125	119	111	105	99	94
60	72	73	77	86	92	99	101	99	92	86	77	73
65	54	55	59	65	75	79	79	79	75	65	59	55
70	44	44	43	47	55	61	60	61	55	47	43	44
75	27	29	34	33	36	44	43	44	36	33	34	29
80	22	21	20	18	21	25	25	25	21	18	20	21
85	14	14	13	12	8	8	9	8	8	12	13	14
90	5	5	4	3	1	0	0	0	1	3	4	5
95	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0

5.2 Calculation of E_{WID} Value

Calculate R_{LO}, R_{DLO}, R_{ULO} using the worksheet (Table 6).

Table 8. Example of flux calculations with worksheet (see Table 6).

	C angles (C)																								E	F	G	H
Gamma angles (γ)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	Average Intensity	Zone Factor	Zonal Flux (ExF)	Zonal Flux (FxSF)
0	264																											
5	264	265	264	265	264	263	264	263	264	265	264	265	264	265	264	265	264	263	264	263	264	265	264	265	264,17	0,095	25,10	25,00
10	258																											
15	258	257	255	255	256	258	257	258	256	255	255	257	258	257	255	255	256	258	257	258	256	255	255	257	256,35	0,283	72,55	72,26
20	242																											
25	216	218	223	232	238	240	240	240	238	232	223	218	216	218	223	232	238	240	240	240	238	232	223	218	230,43	0,463	106,69	106,26
30	193																											
35	178	179	181	182	194	214	217	214	194	182	181	179	178	179	181	182	194	214	217	214	194	182	181	179	191,83	0,628	120,47	119,98
40	158																											
45	136	135	140	145	153	163	184	163	153	145	140	135	136	135	140	145	153	163	184	163	153	145	140	135	149,91	0,774	116,03	115,57
50	114																											
55	92	94	99	105	111	119	125	119	111	105	99	94	92	94	99	105	111	119	125	119	111	105	99	94	106,70	0,897	95,71	95,32
60	72																											
65	54	55	59	65	75	79	79	79	75	65	59	55	54	55	59	65	75	79	79	79	75	65	59	55	67,13	0,993	66,66	66,39
70	44																											
75	27	29	34	33	36	44	43	44	36	33	34	29	27	29	34	33	36	44	43	44	36	33	34	29	35,52	1,058	37,58	37,43
80	22																											
85	14	14	13	12	8	8	9	8	8	12	13	14	14	14	13	12	8	8	9	8	8	12	13	14	10,96	1,091	11,95	11,91
90	5																											
																									Total flux 0° to 90° in arbitrary units(L):		652,74	650,12
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	1,091	0,00	0,00
100	0																											
105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	1,058	0,00	0,00
110	0																											
115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,993	0,00	0,00
120	0																											
125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,897	0,00	0,00
130	0																											
135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,774	0,00	0,00
140	0																											
145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,628	0,00	0,00
150	0																											
155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,463	0,00	0,00
160	0																											
165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,283	0,00	0,00
170	0																											
175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,095	0,00	0,00
180	0																											
																									Total flux in arbitrary units(M):		652,74	

$$R_{LO} = \frac{\text{Total flux in arbitrary units (M)}}{\text{Total bare lamp flux in arbitrary units}} = \frac{652{,}74}{1000} = 0{,}65$$

$$\text{Scale Factor } (F_S) = \frac{R_{LO} \times 1000}{\text{Total flux in arbitrary units (M)}} = \frac{0.65 \times 1000}{652{,}74} = 0{,}996$$

$$R_{DLO} = \frac{\text{Total flux 0° to 90° in arbitrary units (L)} \times F_S}{1000} = \frac{652{,}74 \times 0{,}996}{1000} = 0{,}65$$

$$R_{ULO} = R_{LO} - R_{DLO} \quad = 0{,}65 – 0{,}65 = 0$$

The room dimensions $2H \times 4H$ result in a room index of 1,33 (see Table 3).

Calculate the cumulative CIE zonal flux Φ_{zL1}, Φ_{zL2}, Φ_{zL3}, Φ_{zL4}, using zonal fluxes, R_{DLO} and R_{ULO} values calculated in the previous step:

Φ_{zL1} = zonal flux (0º to 40º) + 0,130 × zonal flux (40º to 50º)

Φ_{zL2} = zonal flux (0º to 60º)

Φ_{zL3} = zonal flux (0º to 70º) + 0,547 × zonal flux (70º to 80º)

Φ_{zL4} = zonal flux (0º to 90º)

Zone	Zonal Flux
0 - 10	25,00
10 - 20	72,26
20 - 30	106,26
30 - 40	119,98
40 - 50	115,57
50 - 60	95,32
60 - 70	66,39
70 - 80	37,43
80 - 90	11,91

Φ_{zL1} = 338,52
Φ_{zL2} = 534,39
Φ_{zL3} = 621,25
Φ_{zL4} = 650,12

Calculate Φ_{zL} using equation (9) and the geometric factor values from Table 4:

$$\Phi_{zL} = \Phi_{zL1}\, F_{GL1} + \Phi_{zL2}\, F_{GL2} + \Phi_{zL3}\, F_{GL3} + \Phi_{zL4}\, F_{GL4}$$

$$\Phi_{zL} = (338{,}52 \times F_{GL1}) + (534{,}39 \times F_{GL2}) + (621{,}25 \times F_{GL3}) + (650{,}12 \times F_{GL4})$$

$$\Phi_{zL} = (338{,}52 \times 0{,}528) + (534{,}39 \times 0{,}218) + (621{,}25 \times 0{,}170) + (650{,}12 \times (-0{,}017))$$

$$\Phi_{zL} = 389{,}80$$

Hence find the distribution factors:

$$F_{DF} = \Phi_{zL} / \Phi_0 = 389{,}80 / 1000 = 0{,}39$$

$$F_{DW} = R_{DLO} - F_{DF} = 0{,}65 - 0{,}39 = 0{,}26$$

$$F_{DC} = R_{ULO} = 0{,}0$$

NOTE Φ_0 = 1 000 lm.

Calculate the indirect utilisation factor for walls, F_{UWID}, for each room index of the standard-condition CIE UGR table:

$$F_{UWID} = F_{DF}\, F_{T,FW} + F_{DW}\, (F_{T,WW} - 1) + F_{DC}\, F_{T,CW}$$

Table 5 gives the transfer factor values ($F_{T,FW}$, $F_{T,WW}$ - 1, $F_{T,CW}$) for each of the 19 standard-condition CIE UGR table room index and reflectance combinations.

$$F_{UWID} = (0{,}39 \times 0{,}187) + (0{,}26 \times 0{,}351) + (0{,}0 \times 0{,}531)$$

$$F_{UWID} = 0{,}164\,2$$

Multiply F_{UWID} by the value B given in Table 3 to get E_{WID}:

$$E_{WID} = 0{,}164\,2 \times 166{,}67 = 27{,}37 \text{ lx}$$

5.3 Calculation of UGR Value

For an arrangement of $2H \times 4H$, 8 luminaires are placed as shown in Figure1 as area A (see also Table 3).

From Table 2 find the K values:

y_R/H	x_T/H	K	
0,5	0,5	n/a	Luminaires to the left of the observer
1,5	0,5	0,004 12	
2,5	0,5	0,005 41	
3,5	0,5	0,004 73	
0,5	0,5	n/a	Luminaires to the right of the observer
1,5	0,5	0,004 12	
2,5	0,5	0,005 41	
3,5	0,5	0,004 73	

From Table 2 find the values for azimuth and elevation, and then, using the luminous intensity table for the luminaire (Table 7), calculate $I_{C\gamma}$ by linear interpolation. Omit the lines for luminaires at y_R/H = 0,5, x_T/H = 0,5 as these have a K value of n/a.

y_R/H	x_T/H	C (°)	γ (°)	$I_{C\gamma}$ (cd/klm)
1,5	0,5	18,4	57,7	83,03
2,5	0,5	11,3	68,6	47,12
3,5	0,5	8,1	74,2	29,70
1,5	0,5	341,6	57,7	83,03
2,5	0,5	348,7	68,6	47,12
3,5	0,5	351,9	74,2	29,70

NOTE The second set of azimuth values (i.e. for the luminaires to the right of the observer) are 360° – 18,4° = 341,6°;
360° – 11,3° = 348,7°;
360° – 8,1° = 351,9°.

This gives the values of $I_{C\gamma}$ for the observer viewing the luminaires crosswise. $I_{C\gamma}$ values are also required for the observer viewing the luminaires endwise. For this the above table is repeated, but with azimuth angles increased by 90°.

y_R/H	x_T/H	C (°)	γ (°)	$I_{C\gamma}$ (cd/klm)
1,5	0,5	108,4	57,7	106,55
2,5	0,5	101,3	68,6	65,57
3,5	0,5	98,1	74,2	46,22
1,5	0,5	71,6	57,7	106,55
2,5	0,5	78,7	68,6	65,57
3,5	0,5	81,9	74,2	46,22

NOTE The second set of azimuth values (i.e. for the luminaires to the right of the observer) are 90° – 18,4° = 71,6°;
90° – 11,3° = 78,7°;
90° – 8,1° = 81,9°.

Using the values of H/D in Table 2, and equation (6d) and (6e) respectively:

$$A = A_B \frac{H}{D} + A_S \frac{x_T}{D} + A_E \frac{y_R}{D}$$ (for linear luminaires viewed endwise),

$$A = A_B \frac{H}{D} + A_S \frac{y_R}{D} + A_E \frac{x_T}{D}$$ (for linear luminaires viewed crosswise),

calculate the projected area. This uses the luminaire information

- area of luminous base A_B = 0,316 m^2;
- area of luminous side A_S = 0,0 m^2;
- area of luminous end A_E = 0,0 m^2.

Therefore

y_R/H	x_T/H	H/D	A (m²)
1,5	0,5	0,535	0,169
2,5	0,5	0,365	0,115
3,5	0,5	0,272	0,086
1,5	0,5	0,535	0,169
2,5	0,5	0,365	0,115
3,5	0,5	0,272	0,086

Finally calculate the UGR value using equation (6):

$$R_{UG} = 8\ \log \sum \left[\frac{K\, I_{C\gamma}^2}{A} \right] - 8\ \log E_{WID}$$

Viewed Crosswise

$$R_{UG} = 8\ \log \left\{ \begin{matrix} \left(\frac{0{,}004\ 1 \times 83{,}03^2}{0{,}169} \right) + \left(\frac{0{,}005\ 4 \times 47{,}12^2}{0{,}115} \right) + \left(\frac{0{,}004\ 7 \times 29{,}70^2}{0{,}086} \right) \\ + \left(\frac{0{,}004\ 1 \times 83{,}03^2}{0{,}169} \right) + \left(\frac{0{,}005\ 4 \times 47{,}12^2}{0{,}115} \right) + \left(\frac{0{,}004\ 7 \times 29{,}70^2}{0{,}086} \right) \end{matrix} \right\} - 8\ \log(27{,}37)$$

R_{UG} = 8 log (167,25 + 104,26 + 48,21 + 167,25 + 104,26 + 48,21) – 8 log (27,37)

R_{UG} = 22,45 – 11,50

R_{UG} = 10,95 ≈ 11,0

Viewed Endwise

$$R_{UG} = 8\ \log \left\{ \begin{matrix} \left(\frac{0{,}004\ 1 \times 106{,}55^2}{0{,}169} \right) + \left(\frac{0{,}005\ 4 \times 65{,}57^2}{0{,}115} \right) + \left(\frac{0{,}004\ 7 \times 46{,}22^2}{0{,}086} \right) \\ + \left(\frac{0{,}004\ 1 \times 106{,}55^2}{0{,}169} \right) + \left(\frac{0{,}005\ 4 \times 65{,}57^2}{0{,}115} \right) + \left(\frac{0{,}004\ 7 \times 46{,}22^2}{0{,}086} \right) \end{matrix} \right\} - 8\ \log(27{,}37)$$

R_{UG} = 8 log (275,43 + 201,89 + 116,75 + 275,43 + 201,89 + 116,75) – 8 log (27,37)

R_{UG} = 24,60 – 11,50

R_{UG} = 13,1

6 CORRECTION TERMS

6.1 Luminaire Length

The UGR table of a luminaire can be used for other lengths of the same type of luminaire by correcting the values with a correction term. The corrections terms are added to or subtracted from the uncorrected UGR value as appropriate. The correction term for other luminaire lengths can apply if two or more luminaires are of the same type and have the same light distribution, light output ratio and no vertical luminous area at the luminaire ends with the following equation:

$$8 \log \frac{l_o}{l_n}$$

where

l_o is the length of the original luminaire (m);

l_n is the length of the new luminaire (m).

6.2 Luminaire Area

The UGR table of a luminaire can be used for other dimensions of the same type of luminaire by correcting the values with a correction term. The correction terms are added to or subtracted from the uncorrected UGR value as appropriate. The correction term for other luminaire dimensions can apply if two or more luminaires are of the same type and have the same light distribution and light output ratio with the following equation:

$$8 \log \frac{A_o}{A_n}$$

where

A_o is the area of the original luminaire (m^2);

A_n is the area of the new luminaire (m^2).

7 REFERENCES

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