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Calculation and Presentation of the Standard CIE UGR Table for Indoor Lighting Luminaires

French Title

Berechnung und Darstellung der Standard CIE UGR Tabelle für Innenraumleuchten

This document is a draft circulated to CIE Div3 & Board for approval.
It shall not be referred to as a CIE Standard until accepted by CIE National Committees.

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FOREWORD

Standards produced by the Commission Internationale de l'Eclairage (CIE) are a concise documentation of data defining aspects of light and lighting, for which international harmony requires such unique definition. CIE Standards are therefore a primary source of internationally accepted and agreed data, which can be taken, essentially unaltered, into universal standard systems.

This Standard has been prepared by the Technical Committee TC 3-43* of CIE Division 3 "Interior Environment and Lighting Design". This Standard was approved by the National Committees of the CIE.

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* The chairperson of this TC was L. Bedocs (UK), secretary was P. Thorns (UK), members were: P. Dehoff (AT), B. Duval (FR), T. Goven (SE), K. Poulton (AU) and P. Raynham (UK).

CALCULATION AND PRESENTATION OF THE STANDARD CIE *UGR* TABLE FOR INDOOR LIGHTING LUMINAIRES

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:

$$UGR = 8\log\left[\frac{0{,}25}{L_b}\sum\frac{L^2\omega}{p^2}\right] \quad (1)$$

where

L_b is the background luminance (cd/m²);

L is the luminance of the luminous parts of each luminaire in the direction of the observer's eye (cd/m²);

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

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.

In the ISO 8995-1:2002(E)/CIE S 008/E:2001 standard 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 required for the production of the standard CIE *UGR* table for a luminaire at spacing to height ratio 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 CIE *UGR* table. The process is set out to assist luminaire manufacturers and lighting software providers to prepare and publish the standard CIE *UGR* table for indoor lighting luminaires.

3. NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE 40-1978. *Calculations for interior lighting: Basic method*.

CIE 117-1995. *Discomfort glare in indoor lighting*.

ISO 8995-1:2002(E)/CIE S 008/E:2001: Joint ISO/CIE Standard: *Lighting of Work Places - Part 1: Indoor* [incl. Technical Corrigendum ISO 8995:2002/Cor. 1:2005(E)].

EN 13032-2:2004. *Light and lighting. Measurement and presentation of photometric data of lamps and luminaires. Presentation of data for indoor and outdoor work places*.

4. TERMS AND DEFINITIONS

4.1 uncorrected *UGR* table

set of *UGR* values of the luminaire in the defined rooms based on 1000 total lumens in the luminaire

4.2 CIE zonal flux (*FCL*)

calculated, accumulated luminous fluxes of the luminaire in the lower hemisphere for the four zones from 0° to 41,4° (*FCL*1), to 60° (*FCL*2), to 75,5° (*FCL*3), to 90° (*FCL*4) from the normalised intensity

4.3 geometric multiplier (*GML*)

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

4.4 distribution factor (*DF*)

factor indicating the proportion of the total emitted flux reaching the reference surface where *DF*(F) = *DFL*/1000 for horizontal reference plane (observer plane), *DF*(W) = *DLOR* - *DF*(F) for walls and *DF*(C) = *ULOR* for ceiling

4.5 scale factor (*SF*)

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

4.6 disymmetric distribution

luminous intensity distribution of the luminaire symmetric in two *C* planes

4.7 spacing to height ratio (*SHR*)

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

4.8 utilization factor (*UF*)

ratio of the luminous flux received by the reference surface to the sum of the rated individual fluxes of the lamps of the installation

4.9 transfer factor (*TF*)

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

TF(F,W) is Transfer Factor working plane (F) to wall (W), *TF*(C,W) is Transfer Factor ceiling (C) to wall (W) and *TF*(W,W) is Transfer Factor wall (W) to wall (W)

4.10 light output ratio (of a luminaire) (*LOR*)

ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions

4.11 downward light output ratio (of a luminaire) (*DLOR*)

ratio of the downward flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions

4.12 upward light output ratio (of a luminaire) (*ULOR*)

proportion of the total flux of the lamp(s) of a luminaire that is emitted by the luminaire above the horizontal when the luminaire is mounted in its normal, designed position

4.13 direct flux to observer plane *DFL*

proportion of the total emitted flux arrives directly onto the horizontal reference plane (observer plane)

4.14 downward flux *L*

cumulative flux of the source for the solid angle 2π steradians, below the horizontal plane passing through the source

4.15 total flux *M*

cumulative flux of the source for the solid angle 4π steradians

5. STANDARD DATA

5.1 CIE *UGR* table

To ensure consistency and give help for checking the data, this standard provides the table of factors and angles that should be used in the preparation of the standard CIE *UGR* table. The *UGR* values in the standard 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 the standard 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

$$UGR(\Phi) = UGR(\Phi_o) + 8\log(\frac{\Phi}{\Phi_o}) \qquad (2)$$

where

$UGR(\Phi_o)$ is the *UGR* value from the uncorrected *UGR* table;

Φ is the actual total lamp flux;

Φ_o is 1000 lm.

Table 1. Example of presentation of an uncorrected UGR table for a dissymmetric distribution luminaire.

Spacing 1:1

Reflectances:											
Ceiling/cavity		0,70	0,70	0,50	0,50	0,30	0,70	0,70	0,50	0,50	0,30
Wall		0,50	0,30	0,50	0,30	0,30	0,50	0,30	0,50	0,30	0,30
Working plane		0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20
Room dimensions		Viewed crosswise					Viewed endwise				
X =2*H*	*Y*=2*H*	8,9	10,5	9,3	10,8	11,1	10,6	12,2	11,0	12,5	12,9
	3*H*	10,4	11,9	10,8	12,2	12,6	12,4	13,8	12,8	14,2	14,5
	4*H*	10,9	12,3	11,3	12,6	13,0	13,1	14,4	13,5	14,8	15,2
	6*H*	11,5	12,7	11,9	13,1	13,5	13,6	14,8	14,0	15,2	15,6
	8*H*	11,7	12,9	12,1	13,3	13,7	13,7	14,9	14,2	15,3	15,7
	12*H*	12,0	13,2	12,4	13,5	14,0	13,8	14,9	14,2	15,3	15,7
4*H*	2*H*	9,6	11,0	10,0	11,3	11,7	11,0	12,4	11,4	12,7	13,1
	3*H*	11,3	12,5	11,7	12,9	13,3	13,0	14,1	13,4	14,5	14,9
	4*H*	12,0	13,0	12,4	13,4	13,9	13,9	14,9	14,3	15,3	15,7
	6*H*	12,6	13,5	13,1	14,0	14,4	14,5	15,4	15,0	15,8	16,3
	8*H*	13,0	13,8	13,5	14,2	14,7	14,7	15,5	15,2	16,0	16,4
	12*H*	13,4	14,1	13,8	14,6	15,0	14,8	15,6	15,3	16,0	16,5
8*H*	4*H*	12,4	13,2	12,8	13,6	14,1	14,0	14,9	14,5	15,3	15,8
	6*H*	13,2	13,8	13,6	14,3	14,8	14,8	15,4	15,2	15,9	16,4
	8*H*	13,6	14,2	14,1	14,7	15,2	15,0	15,6	15,5	16,1	16,6
	12*H*	14,1	14,6	14,6	15,1	15,7	15,2	15,7	15,7	16,2	16,8
12*H*	4*H*	12,4	13,2	12,9	13,6	14,1	14,0	14,8	14,5	15,2	15,7
	6*H*	13,2	13,8	13,7	14,3	14,8	14,8	15,4	15,3	15,9	16,4
	8*H*	13,8	14,3	14,3	14,8	15,3	15,1	15,6	15,6	16,1	16,7

5.2 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 a horizontal line of sight towards the centre of the opposite wall.
- The height of the luminaires centre above the observer eye level is H = 2 m.
- The spacing of the luminaires is 2 m in both T and R directions where 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 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 (*SHR*) is 1:1.
- The height of the wall is 2 m.
- The eye level and horizontal reference planes are 1,2 m above floor.
- The room dimensions X and Y are expressed in terms of H the mounting height and where the X dimension is perpendicular to the line of sight and Y dimension is parallel to the line of sight.
- The luminous intensity distribution of the luminaire is provided in normalised form of cd/1000 lm.

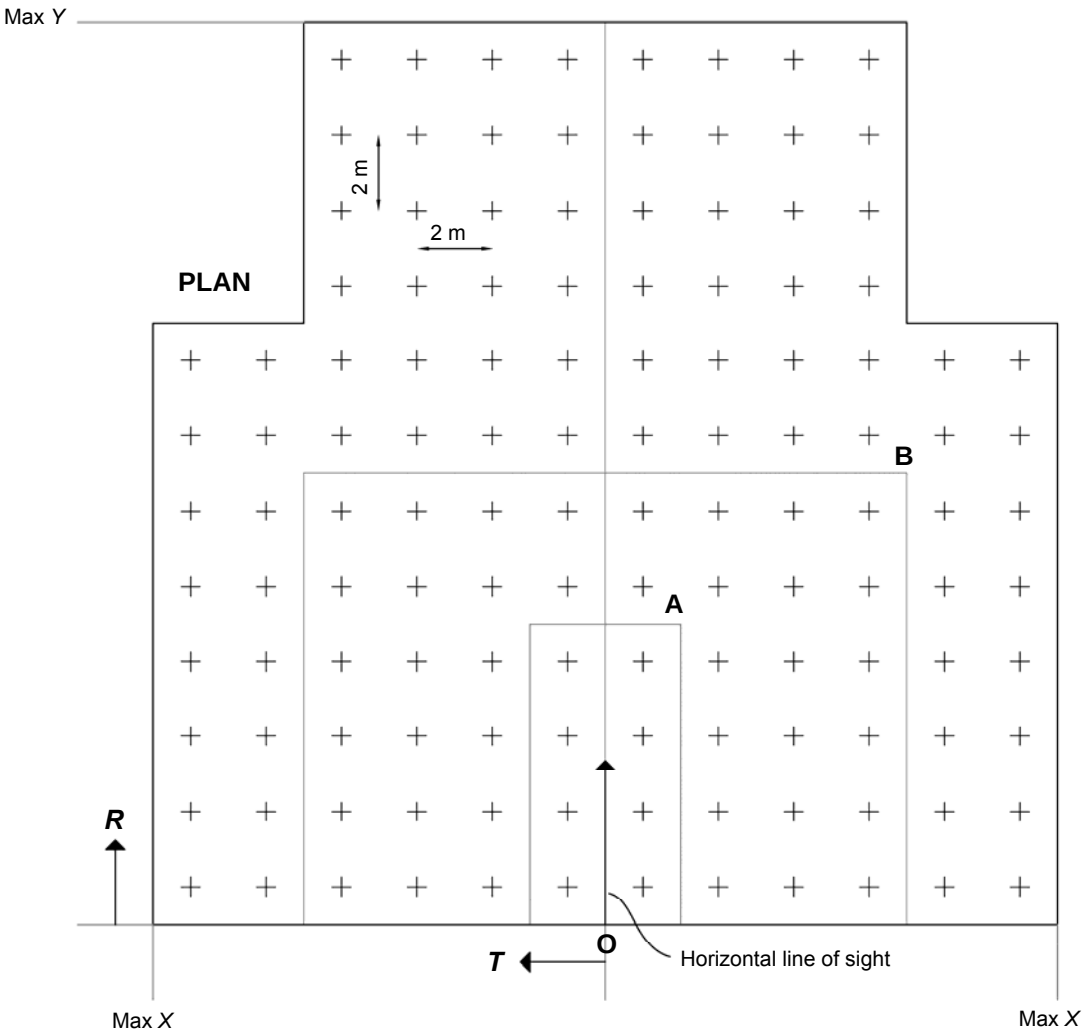


Fig. 1. Positions of the standard array of luminaires.

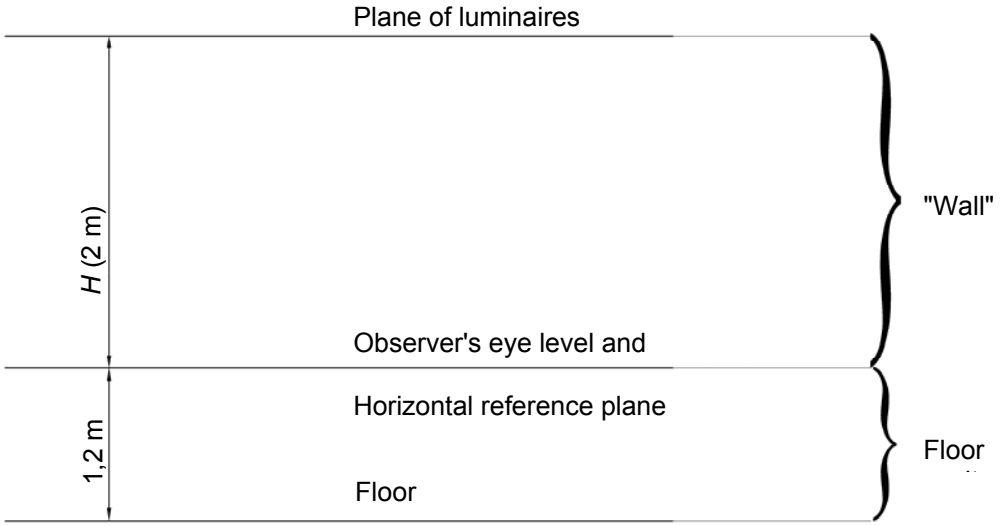


Fig. 2. Dimensions of the standard room section.

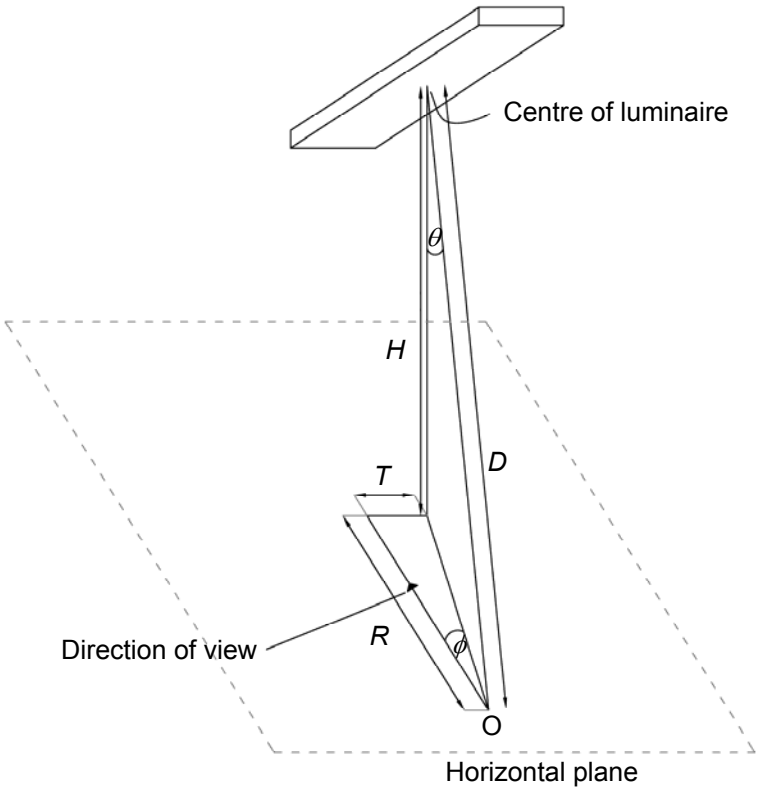


Fig.-3a. Position of luminaire centre relative to observer.

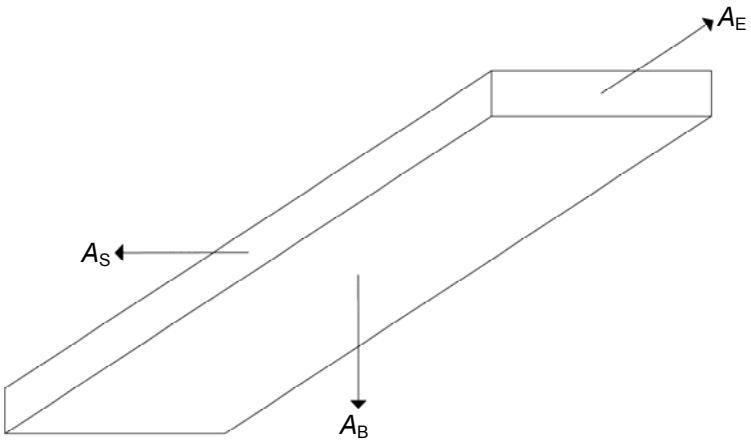


Fig. 3b. Projected areas for linear luminaire.

Figure 3. Luminaire luminous area configurations.

5.3 Procedure for determination of standard 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

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

This may be expressed in term of apparent luminaire surface area, distance to luminaire, intensity towards the observer, position index and indirect illuminance on the wall produced by a luminaire.

$$UGR = 8\log\sum\left[\frac{\pi}{4E(\mathrm{W,ID})}\frac{I_{\theta\phi}^2 A}{A^2D^2p^2}\right] \tag{4}$$

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

$$UGR = 8\log\sum\left[\frac{K}{E(\mathrm{W,ID})}\frac{I_{\theta\phi}^2}{A}\right] \tag{5}$$

$$UGR = 8\log\sum\left[\frac{KI_{\theta\phi}^2}{A}\right] - 8\log E\left(\mathrm{W,ID}\right) \tag{6}$$

where

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

$I_{\theta\phi}$ luminous intensity of the source at the angles to the downward vertical θ and of azimuth ϕ, appropriate to the eye position O of the observer and the viewing direction - see Figure 3;

$\phi = \tan^{-1} T/R$ azimuth;

$\theta = \cos^{-1} H/D$ elevation;

A is the projected luminous area of the source (in m^2) from the observer position O – see Figure 3;

$A = A_B \cdot H/D + A_S \cdot T/D + A_E \cdot R/D;$

$D = \sqrt{}(H^2 + T^2 + R^2)$;

E(W, ID) is the indirect component of the illuminance on the walls.

NOTE The pre-calculated parameters of K, Azimuth (Φ), Elevation (θ), H/D, T/D, R/D are given in Table 2.

The indirect component of the illuminance on the walls can be calculated by the method given below.

$$E\left(\mathrm{W,ID}\right) = \frac{UF\left(\mathrm{W,ID}\right)\cdot N\cdot 1000}{A\left(\mathrm{W}\right)} \tag{7}$$

where:

UF(W,ID) indirect utilisation factor for walls;

N number of luminaires;

A(W) total area of walls (m^2) between reference plane and luminaire plane.

This may be simplified to:

$$E(\mathrm{W,ID}) = C \times UF(\mathrm{W,ID}) \quad (8)$$

where:

$C = 1000 \cdot N/A(\mathrm{W})$;

$UF(\mathrm{W,ID}) = DF(\mathrm{F}) \cdot TF(\mathrm{F,W}) + DF(\mathrm{W}) \cdot [TF(\mathrm{W,W}) - 1] + DF(\mathrm{C}) \cdot TF(\mathrm{C,W})$

NOTE Table 3 gives a column of 19 values of *C* and the Room index for the CIE standard *UGR* table.

The calculation of *E*(W,ID) 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 5˚ intervals from 0˚ to 180˚.

  NOTE In this standard the azimuth angles are indicated by *C* or ϕ and the elevation angles are indicated by γ or θ.

- Calculate *LOR*, *DLOR*, *ULOR* using Table 6.

- Calculate the cumulative CIE zonal flux *FCL*1, *FCL*2, *FCL*3 and *FCL*4 using zonal flux values calculated in Table 6, where

  FC1 (*FCL*1) = Zone flux (0º to 40º) + 0,130 · Zone flux (40º to 50º)

  FC2 (*FCL*2) = Zone flux (0º to 60º)

  FC3 (*FCL*3) = Zone flux (0º to 70º) + 0,547 · Zone flux (70º to 80º)

  FC4 (*FCL*4) = Zone flux (0º to 90º)

- Calculate *DFL* using the geometric multipliers from Table 4 and the equation:

  $$DFL = FCL1 \cdot GML1 + FCL2 \cdot GML2 + FCL3 \cdot GML3 + FCL4 \cdot GML4 \quad (9)$$

- Calculate the Distribution Factors *DF*(F), *DF*(W), *DF*(C) using *DFL* and the *LOR* and *DLOR* values calculated in Table 6.

  $DF(\mathrm{F}) = DFL/1000$

  $DF(\mathrm{W}) = DLOR - DF(\mathrm{F})$

  $DF(\mathrm{C}) = ULOR$

- Calculate the *UF* (W,ID) for each room index of the CIE standard *UGR* table:

  $$UF(\mathrm{W,ID}) = DF(\mathrm{F}) \cdot TF(\mathrm{F,W}) + DF(\mathrm{W}) \cdot [TF(\mathrm{W,W}) - 1] + DF(\mathrm{C}) \cdot TF(\mathrm{C,W}) \quad (10)$$

  Table 5 gives the Transfer factor values for each of the 19 CIE standard *UGR* table room index and reflectance combinations.

- Multiply *UF*(W,ID) by the value *C* given in Table 3 to get *E*(W,ID) for each room index of the CIE standard *UGR* table.

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

T/H	0,5						1,5					
R/H	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*
0,5	45,00	35,26	n/a	0,8165	0,4082	0,4082	71,57	57,69	n/a	0,5345	0,2673	0,8018
1,5	18,43	57,69	0,00412	0,5345	0,8018	0,2673	45,00	64,76	0,00155	0,4264	0,6396	0,6396
2,5	11,31	68,58	0,00541	0,3651	0,9129	0,1826	30,96	71,07	0,00294	0,3244	0,8111	0,4867
3,5	8,13	74,21	0,00473	0,2722	0,9526	0,1361	23,20	75,29	0,00329	0,2540	0,8890	0,3810
4,5	6,34	77,55	0,00386	0,2157	0,9705	0,1078	18,43	78,10	0,00292	0,2063	0,9283	0,3094
5,5	5,19	79,74	0,00308	0,1782	0,9800	0,0891	15,26	80,05	0,00249	0,1728	0,9503	0,2592
6,5	4,40	81,28	0,00243	0,1516	0,9855	0,0758	12,99	81,47	0,00209	0,1482	0,9636	0,2224
7,5	3,81	82,42	0,00197	0,1319	0,9891	0,0659	11,31	82,55	0,00177	0,1296	0,9723	0,1945
8,5	3,37	83,30	0,00163	0,1166	0,9915	0,0583	10,01	83,39	0,00150	0,1151	0,9782	0,1726
9,5	3,01	84,00	0,00137	0,1045	0,9931	0,0523	8,97	84,06	0,00129	0,1034	0,9825	0,1551
10,5	2,73	84,57	0,00116	0,0947	0,9944	0,0474	8,13	84,61	0,00111	0,0939	0,9856	0,1408
11,5	2,49	85,03	0,00100	0,0865	0,9953	0,0433	7,43	85,07	0,00097	0,0859	0,9879	0,1289

T/H	2,5						3,5					
R/H	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*
0,5	78,69	68,58	n/a	0,3651	0,1826	0,9129	81,87	74,21	n/a	0,2722	0,1361	0,9526
1,5	59,04	71,07	0,00053	0,3244	0,4867	0,8111	66,80	75,29	0,00024	0,2540	0,3810	0,8890
2,5	45,00	74,21	0,00119	0,2722	0,6804	0,6804	54,46	76,91	0,00053	0,2265	0,5661	0,7926
3,5	35,54	76,91	0,00166	0,2265	0,7926	0,5661	45,00	78,58	0,00083	0,1980	0,6931	0,6931
4,5	29,05	79,01	0,00183	0,1907	0,8581	0,4767	37,87	80,05	0,00105	0,1728	0,7775	0,6047
5,5	24,44	80,60	0,00176	0,1633	0,8981	0,4082	32,47	81,28	0,00115	0,1516	0,8339	0,5307
6,5	21,04	81,83	0,00159	0,1421	0,9239	0,3553	28,30	82,29	0,00113	0,1342	0,8725	0,4698
7,5	18,43	82,79	0,00140	0,1255	0,9412	0,3137	25,02	83,11	0,00106	0,1200	0,8996	0,4198
8,5	16,39	83,56	0,00124	0,1122	0,9533	0,2804	22,38	83,79	0,00099	0,1081	0,9193	0,3785
9,5	14,74	84,19	0,00109	0,1013	0,9621	0,2532	20,22	84,36	0,00090	0,0983	0,9338	0,3440
10,5	13,39	84,71	0,00096	0,0923	0,9687	0,2306	18,43	84,84	0,00081	0,0900	0,9448	0,3149
11,5	12,26	85,14	0,00084	0,0847	0,9737	0,2117	16,93	85,24	0,00073	0,0829	0,9534	0,2902

T/H	4,5						5,5					
R/H	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*	Azimuth	Elevation	*K*	*H/D*	*R/D*	*T/D*
0,5	83,66	77,55	n/a	0,2157	0,1078	0,9705	84,81	79,74	n/a	0,1782	0,0891	0,9800
1,5	71,57	78,10	0,00015	0,2063	0,3094	0,9283	74,74	80,05	n/a	0,1728	0,2592	0,9503
2,5	60,95	79,01	0,00027	0,1907	0,4767	0,8581	65,56	80,60	0,00017	0,1633	0,4082	0,8981
3,5	52,13	80,05	0,00045	0,1728	0,6047	0,7775	57,53	81,28	0,00026	0,1516	0,5307	0,8339
4,5	45,00	81,07	0,00059	0,1552	0,6985	0,6985	50,71	81,99	0,00036	0,1393	0,6271	0,7664
5,5	39,29	81,99	0,00072	0,1393	0,7664	0,6271	45,00	82,67	0,00044	0,1275	0,7013	0,7013
6,5	34,70	82,79	0,00077	0,1255	0,8157	0,5647	40,24	83,30	0,00052	0,1166	0,7582	0,6415
7,5	30,96	83,48	0,00078	0,1136	0,8519	0,5112	36,25	83,86	0,00056	0,1069	0,8018	0,5880
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	*C*
2*H*	2*H*	1,00	4	32,00	125,00
	3*H*	1,20	6	40,00	150,00
	4*H*	1,33	8	48,00	166,67
	6*H*	1,50	12	64,00	187,50
	8*H*	1,60	16	80,00	200,00
	12*H*	1,71	24	112,00	214,29
4*H*	2*H*	1,33	8	48,00	166,67
	3*H*	1,71	12	56,00	214,29
	4*H*	2,00	16	64,00	250,00
	6*H*	2,40	24	80,00	300,00
	8*H*	2,67	32	96,00	333,33
	12*H*	3,00	48	128,00	375,00
8*H*	4*H*	2,67	32	96,00	333,33
	6H	3,43	48	112,00	428,57
	8*H*	4,00	64	128,00	500,00
	12*H*	4,80	96	160,00	600,00
12*H*	4*H*	3,00	48	128,00	375,00
	6*H*	4,00	72	144,00	500,00

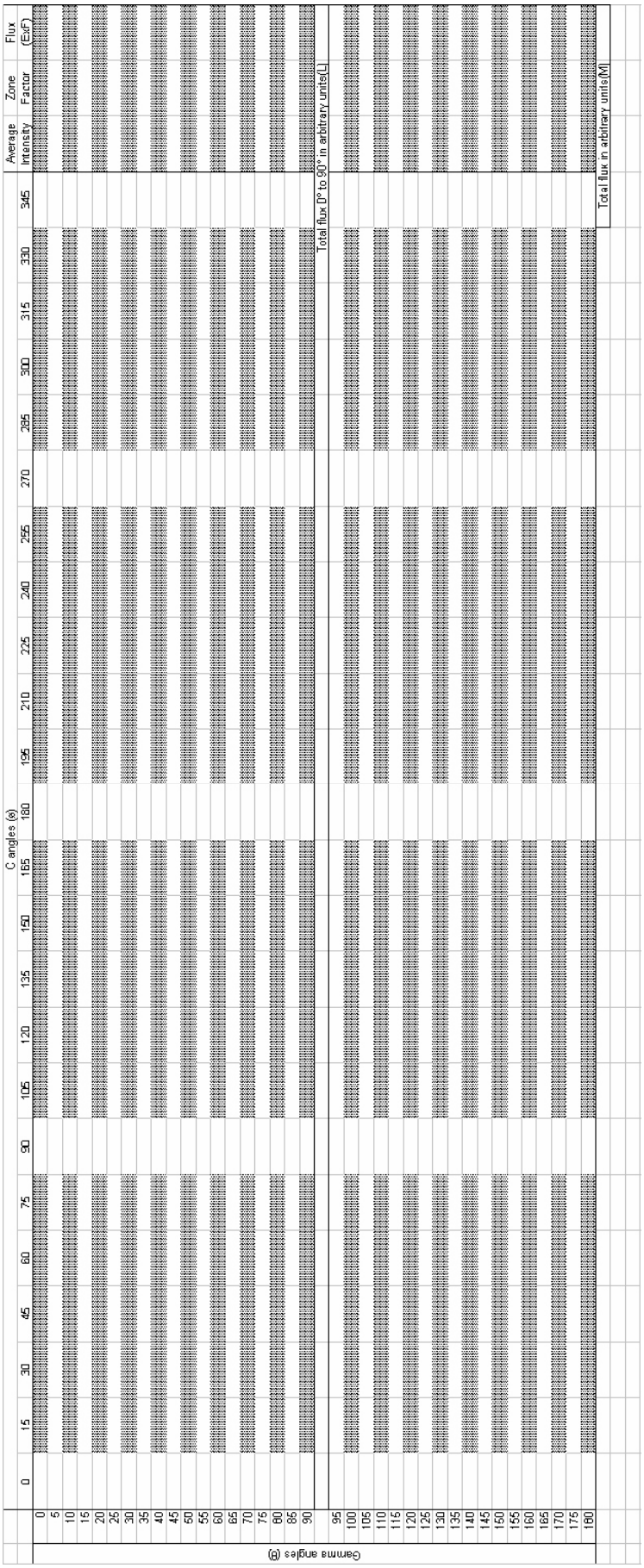
Table 4. Geometric multiplier values for luminaires in the standard array.

Geom	Room index												
Multipl	1,00	1,20	1,33	1,50	1,60	1,71	2,00	2,40	2,67	3,00	3,43	4,00	4,80
GML1	636	535	484	429	414	398	354	300	276	258	249	236	232
GML2	121	215	250	275	270	264	248	202	166	118	65	-6	-80
GML3	88	122	154	202	232	264	350	446	502	563	615	684	735
GML4	-15	-16	-17	-18	-17	-17	-15	-5	3	16	35	60	98

Table 5. Transfer factor values for the Room Index and reflectance combinations for the CIE standard *UGR* table.

Reflect-ance C/W/F	Transfer factor	Room Index												
		1,00	1,20	1,33	1,50	1,60	1,71	2,00	2,40	2,67	3,00	3,43	4,00	4,80
70/50/20	*TF*(F,W)	0,2199	0,1987	0,1868	0,1732	0,1661	0,1588	0,1423	0,1245	0,1147	0,1046	0,0939	0,0827	0,0708
	TF(W,W)-1	0,4218	0,3762	0,3516	0,324	0,3098	0,2956	0,2639	0,2302	0,2121	0,1937	0,1742	0,1538	0,1324
	TF(C,W)	0,6458	0,5714	0,5313	0,4864	0,4633	0,4403	0,3891	0,3353	0,3066	0,2776	0,2471	0,2157	0,1831
70/30/20	*TF*(F,W)	0,1882	0,1727	0,1638	0,1533	0,1477	0,142	0,1288	0,1140	0,1057	0,0971	0,0878	0,0779	0,0672
	TF(W,W)-1	0,2165	0,1962	0,1849	0,1721	0,1654	0,1586	0,1432	0,1265	0,1173	0,1079	0,0977	0,087	0,0755
	TF(C,W)	0,5526	0,4967	0,4658	0,4306	0,4122	0,3937	0,352	0,3070	0,2827	0,2577	0,231	0,2032	0,1739
50/50/20	*TF*(F,W)	0,1984	0,1777	0,1663	0,1534	0,1467	0,1399	0,1247	0,1084	0,0996	0,0906	0,0811	0,0711	0,0607
	TF(W,W)-1	0,3808	0,3377	0,3147	0,2892	0,2761	0,2631	0,2342	0,2038	0,1875	0,1711	0,1537	0,1356	0,1167
	TF(C,W)	0,4448	0,3931	0,3652	0,3341	0,3181	0,3022	0,2669	0,2298	0,2101	0,1901	0,1692	0,1476	0,1253
50/30/20	*TF*(F,W)	0,1722	0,1566	0,1477	0,1375	0,1321	0,1266	0,114	0,1003	0,0927	0,0848	0,0764	0,0675	0,058
	TF(W,W)-1	0,1983	0,1785	0,1677	0,1555	0,1492	0,1428	0,1285	0,1130	0,1047	0,0961	0,0869	0,0772	0,0669
	TF(C,W)	0,386	0,3463	0,3244	0,2995	0,2865	0,2735	0,2441	0,2125	0,1954	0,178	0,1594	0,14	0,1197
30/30/20	*TF*(F,W)	0,1569	0,1412	0,1324	0,1225	0,1173	0,112	0,1002	0,0874	0,0804	0,0733	0,0657	0,0578	0,0494
	TF(W,W)-1	0,1808	0,1616	0,1513	0,1398	0,1338	0,1279	0,1146	0,1004	0,0928	0,085	0,0767	0,0681	0,059
	TF(C,W)	0,2267	0,2029	0,1899	0,1751	0,1674	0,1597	0,1423	0,1237	0,1136	0,1034	0,0925	0,0812	0,0693

Table 6. Calculation of *LOR*.



$$LOR = \frac{\text{Total flux in arbitrary units } (M)}{\text{Total bare lamp flux in arbitrary units}} \quad (11)$$

$$\text{Scale Factor}(SF) = \frac{LOR \times 1000}{\text{Total flux in arbitrary units } (M)} \quad (12)$$

$$DLOR = \frac{\text{Total flux D° to 90° in arbitrary units } (L) \times SF}{1000} \quad (13)$$

$$ULOR = LOR - DLOR \quad (14)$$

6. ANNEX (INFORMATIVE)

6.1 Worked example

This example will calculate the *UGR* values for the arrangement 2*H* x 4*H* for reflectance's of 0,7/0,5/0,2.

This example uses the intensity table for a disymmetric distribution luminaire as shown in Table 7. The polar distribution is shown below in Figure 4.

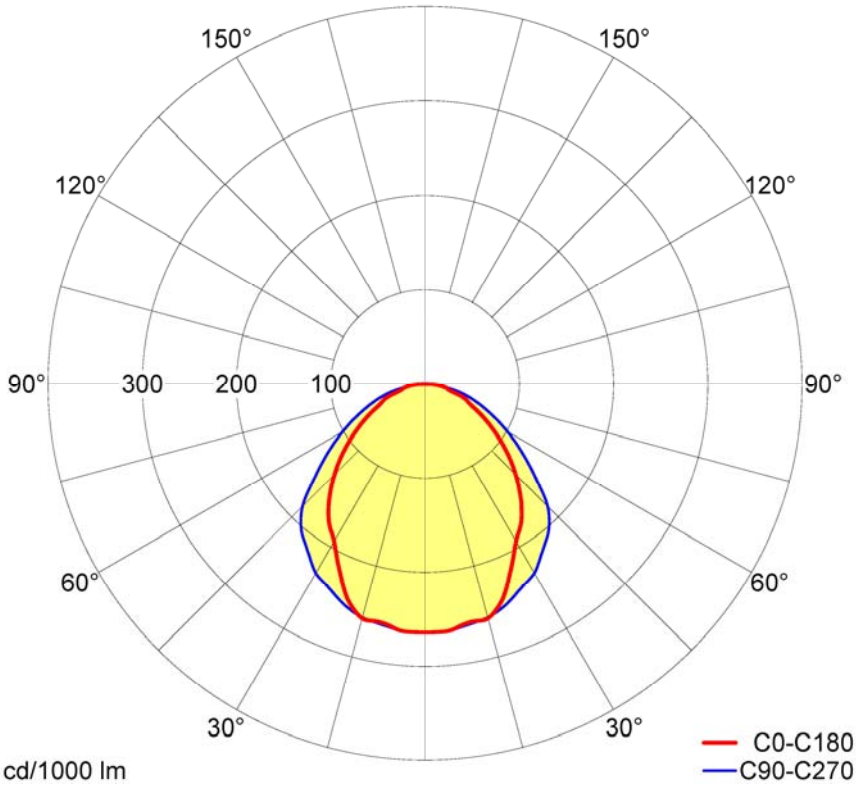


Fig. 4. Intensity distribution diagram for the disymmetric distribution luminaire.

It has luminous areas of

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

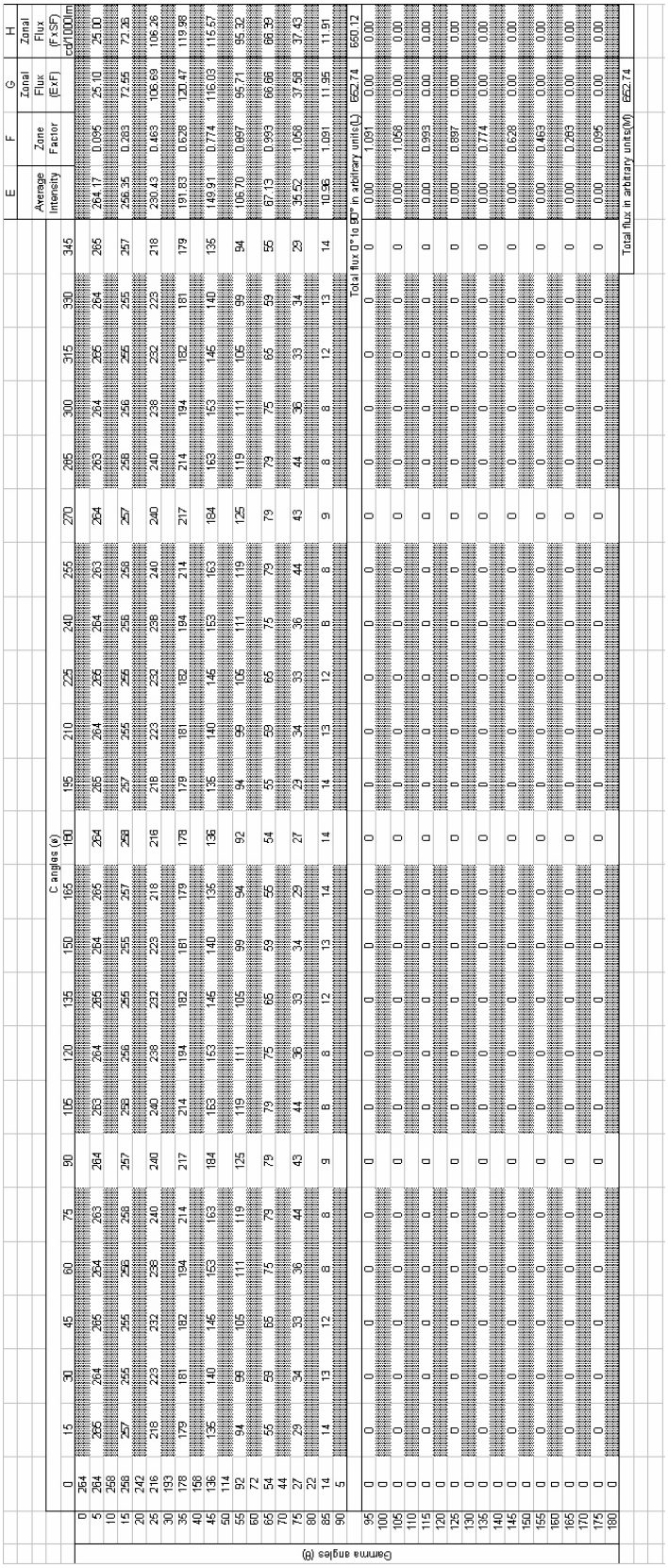
Table 7. Example intensity table.

		C angles (ϕ)																							
		0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345
Gamma angles (θ)	0	264	264	264	264	264	264	264	264	264	264	264	264	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	0	0	0	0	0	0	0	0	0	0	0	0

6.2 Calculate the *E*(W,ID) value

Calculate *LOR*, *DLOR*, *ULOR* using Table 6.

Table 8. Example of flux calculations.



Gamma angles (θ)	C angles (φ)																								E	F	G	H
	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 (E x F)	Zonal Flux (F x SF) cd/1000lm
0	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	25.10
5	264	265	264	265	264	263	264	263	264	265	264	265	264	265	264	265	264	263	264	263	264	265	264					
10	268	257	255	255	255	258	257	258	256	256	255	257	258	257	255	255	256	256	257	258	256	255	255	257	256.36	0.283	72.55	72.26
15	268																											
20	242	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
25	216																											
30	193	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
35	178																											
40	156	135	140	145	153	163	184	163	163	145	140	135	136	135	140	145	153	163	184	163	153	145	140	135	149.91	0.774	116.03	115.57
45	136																											
50	114	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
55	92																											
60	72	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
65	54																											
70	44	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	1.056	37.50	37.43
75	27																											
80	22	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
85	14																											
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	1.056	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	

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

$$Scale\ Factor\ (SF) = \frac{LOR \times 1000}{Total\ flux\ in\ arbitrary\ units\ (M)} = \frac{0{,}65 \times 1000}{652{,}74} = 0{,}996$$

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

From Table 3 2*H* x 4*H* gives a room index of 1,33.

Calculate the cumulative CIE zonal flux *FCL*1, *FCL*2, *FCL*3, *FCL*4 using zonal fluxes, *DLOR* and *ULOR* values calculated in the previous step.

FC1 (*FCL*1) = Zone flux (0º to 40º) + 0,130 · Zone flux (40º to50º)

FC2 (*FCL*2) = Zone flux (0º to 60º)

FC3 (*FCL*3) = Zone flux (0º to 70º) + 0,547 · Zone flux (70º to 80º)

FC4 (*FCL*4) = Zone 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

*FCL*1 = 338,52 /1000 = 0,33852

*FCL*2 = 534,39 /1000 = 0,53439

*FCL*3 = 621,25 /1000 = 0,62125

*FCL*4 = 650,12 /1000 = 0,65012

Calculate *DFL* using the formula and geometric multiplier values from Table 4:

$DFL = FCL1 \cdot GML1 + FCL2 \cdot GML2 + FCL3 \cdot GML3 + FCL4 \cdot GML4$

$DFL = (0{,}33852 \times 484) + (0{,}53439 \times 250) + (0{,}62125 \times 154) + [0{,}65012 \times (-17)]$

$DFL = 163{,}84 + 133{,}60 + 95{,}67 - 11{,}05$

$DFL = 382{,}06$

Hence find the distribution factors

$DF(F) = DFL / 1000 = 0{,}3821$

$DF(W) = DLOR - DF(F) = 0{,}650 - 0{,}3821 = 0{,}2679$

$DF(C) = ULOR$

Calculate the *UF* (W,ID) for each room index of the CIE standard *UGR* table:

$UF(W,ID) = DF(F) \cdot TF(F,W) + DF(W) \cdot [TF(W,W)-1] + DF(C) \cdot TF(C,W)$

Table 5 gives the Transfer factor values for each of the 19 CIE standard *UGR* table room index and reflectance combinations.

$UF(W,ID) = (0{,}3821 \times 0{,}1868) + (0{,}2679 \times 0{,}3516) + (0{,}00 \times 0{,}5313)$

$= 0{,}1656$

Multiply *UF*(W,ID) by the value *C* given in Table 3 to get *E*(W,ID):

$E(W,ID) = 0{,}1656 \times 166{,}67 = 27{,}60$ lx

6.3 Calculate the *UGR* value

From Table 3, for an arrangement of 2*H* x 4*H*, 8 luminaires are placed as shown in Figure 1, box A.

From Table 2 find the *K* values.

R/H	*T/H*	*K*	
0,5	0,5	n/a	
1,5	0,5	0,0041	Luminaires to the left of the observer
2,5	0,5	0,0054	
3,5	0,5	0,0047	
0,5	0,5	n/a	
1,5	0,5	0,0041	Luminaires to the right of the observer
2,5	0,5	0,0054	
3,5	0,5	0,0047	

From Table 2 find the values for azimuth and elevation, and then using the intensity table for the luminaire (Table 7) calculate $I_{\theta\varphi}$. Omit the lines for luminaires at *R/H* = 0,5; *T/H* = 0,5 as these have a *K* value of n/a.

R/H	*T/H*	Azimuth	Elevation	$I_{\theta\varphi}$
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 $I_{\theta\varphi}$ for the observer viewing the luminaires crosswise. $I_{\theta\varphi}$ 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°.

R/H	*T/H*	Azimuth	Elevation	$I_{\theta\varphi}$
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 the formula

Projected area (A) = $A_B \cdot H/D + A_S \cdot T/D + A_E \cdot R/D$

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

R/H	***T/H***	***H/D***	***A***
1,5	0,5	0,535	0,169
2,5	0,5	0,365	0,115
3,5	0,5	0,272	0,088
1,5	0,5	0,535	0,169
2,5	0,5	0,365	0,115
3,5	0,5	0,272	0,088

Finally calculate the *UGR* using the formula

$$UGR = 8\log\sum\left[\frac{KI_{\partial\phi}^2}{A}\right] - 8\log E(\mathrm{W},\mathrm{ID})$$

Viewed crosswise

$$UGR = 8\log\left[\left(\frac{0{,}0041\times 83{,}03^2}{0{,}169}\right)+\left(\frac{0{,}0054\times 47{,}12^2}{0{,}115}\right)+\left(\frac{0{,}0047\times 29{,}70^2}{0{,}088}\right)+\left(\frac{0{,}0041\times 83\text{`},03^2}{0{,}169}\right)+\left(\frac{0{,}0054\times 47{,}12^2}{0{,}115}\right)+\left(\frac{0{,}0047\times 29{,}70^2}{0{,}088}\right)\right] - 8\log(27{,}60)$$

UGR = 8 log(167,25 + 104,26 + 47,11 + 167,25 + 104,26 + 47,11) – 8 log(27,60)

UGR = 22,42 – 11,53

UGR = 10,89 (~10,9)

Viewed endwise

$$UGR = 8\log\left[\left(\frac{0{,}0041\times 106{,}55^2}{0{,}169}\right)+\left(\frac{0{,}0054\times 65.57^2}{0{,}115}\right)+\left(\frac{0{,}0047\times 46{,}22^2}{0{,}088}\right)+\left(\frac{0{,}0041\times 106{,}55^2}{0{,}169}\right)+\left(\frac{0{,}0054\times 65.57^2}{0{,}115}\right)+\left(\frac{0{,}0047\times 46{,}22^2}{0{,}088}\right)\right] - 8\log(27{,}60)$$

UGR = 8 log(275,43 + 201,89 + 114,10 + 275,43 + 201,89 + 114,10) – 8 log(27,60)

UGR = 24,58 – 11,53 = 13,05

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