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CALCULATIONS FOR INTERIOR LIGHTING APPLIED METHOD

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52, BOULEVARD MALESHERBES 75008 PARIS - FRANCE

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RESUMÉ

La méthode présentée dans ce rapport est limitée aux éclairagements moyens sur le plan utile, les murs et le plafond.

Il s'agit d'une méthode d'avant projet (choix de la répartition lumineuse et de l'implantation des luminaires capables de satisfaire les éclairagements exigés) aussi bien que d'une méthode de vérification (calcul des éclairagements d'un projet ou d'une installation réalisée).

La méthode se distingue de la plupart des méthodes courantes par sa possibilité de tenir compte de l'influence de l'implantation des luminaires.

La méthode s'appuie sur la Méthode de Base (Publication CIE No. 40 (TC-1.5) 1978)

KURZFASSUNG

Die vorliegende Methode beschränkt sich auf mittleren Beleuchtungsstärken der Raumbegrenzungsflächen. Es ist sowohl eine Planungsmethode (Bestimmung von benötigter Lichtverteilung und Anordnung der Leuchten erforderlich um spezifizierte Beleuchtungsstärken zu bekommen) wie eine Prüfungsmethode (Berechnung der Beleuchtungsstärken für einen Entwurf oder für eine realisierte Anlage).

Die Methode unterscheidet sich von den meisten Methoden dass sie die Möglichkeit bietet auch den Einfluss der Leuchtenanordnung Rechnung zu tragen.

Die Methode basiert auf der Basis Methode (Publikation CIE No. 40 (TC-1.5) 1978)

SUMMARY

The method presented in this report deals with average illuminances at the working plane, walls and ceiling.

It is a design method (determination of light distribution and arrangement of luminaires required for specified illuminances) as well as a verification method (calculation of illuminances of a design or of an existing installation).

The method is distinguished from most of the existing methods by its possibility to take into account the influence of the luminaire arrangement.

The method is based on the Basic Method (Publication CIE No. 40 (TC- 1.5) 1978).

Table of contents

<u>Part I</u>	<u>Page</u>
<u>1. _ _ Introduction</u>	4
1.1 the method	4
1.2 the presentation	6
<u>2. _ _ General Conventions</u>	7
2.1 maintenance factor	7
2.2 the use of suffixes	7
2.3 room surface reflectances	7
2.4 the shape of the interior	7
2.5 interpolation	8
<u>3. _ _ Parameters affecting the illuminances</u>	9
3.1 the installed luminous flux per square metre	9
3.2 the proportions of the interior	9
3.3 the zonal flux distribution of the luminaires	9
3.4 the geometry of the installation	9
3.5 the reflectances of the surfaces	10
<u>4. _ _ Principles of the Method</u>	11
4.1 the photometric data of a luminaire	11
4.2 the direct flux from a luminaire towards the working plane	12
4.3 the direct flux from an installation towards the working plane	13
4.4 the relations between direct fluxes and illuminances	14
4.5 utilances	15
4.6 classification of installations	16
4.6.1 classification procedure for one specific installation	
4.6.2 classification procedure for one specific luminaire type in reference arrangements; the luminaire reference class set	
4.7 classification of luminaires	18
4.7.1 classification procedures	
4.8 optional photometric data of a luminaire	19
<u>5. _ _ The Design Method</u>	20
5.1 determination of the required installation flux densities	20
5.2 selection of the installation	21
5.2.1 specified luminaire arrangement, specified suspension ratio	
5.2.2 luminaire arrangement not specified, specified suspension ratio	
5.2.3 luminaire arrangement not specified, suspension ratio not specified.	
<u>6. _ _ The Verification Method</u>	22
6.1 determination of the direct-ratio	22
6.1.1 calculation using the flux triplet	
6.1.2 calculation using published reference direct-ratio values	
6.1.3 calculation using published reference class set	
6.1.4 calculation using published luminaire class	
6.2 determination of the reduced utilances	23
6.2.1 calculation using interreflection coefficients	
6.2.2 calculation using utilisation tables	
6.3 calculation of illuminances	24

	<u>Page</u>
<u>7. _ _ Examples</u>	25
7.1 an installation with luminaires in reference arrangement	25
7.1.1 general	
7.1.2 design	
7.1.3 verification	
7.2 an installation with luminaires not in reference arrangement	27
7.2.1 general	
7.2.2 design	
7.2.3 verification	
7.3 an installation with no specification of luminaire arrangement	29
7.3.1 general	
7.3.2 design	
7.3.3 verification	
7.4 an installation with no specification for its geometry	31
7.4.1 general	
7.4.2 design	
7.4.3 verification	
7.5 classification of an installation	37
7.5.1 luminaires in reference arrangement	
7.5.2 luminaires not in reference arrangement	
7.6 classification of luminaires	38
7.6.1 the luminaire reference class set	
7.6.2 the luminaire class	
7.7 determination of the correction factor for the direct-ratio	40
7.7.1 calculation using tabulated values	
7.7.2 calculation using the basic method	
 <u>8. _ _ Existing Methods</u>	 43
8.1 utilization factor tables	43
8.2 tables of reduced utilization factors	43
8.3 the British method	44
8.4 the French method	45
8.5 the German method	45
8.6 the U.S.A. Method	46
8.7 comparison of results	47
 <u>9. _ _ Bibliography</u>	 50

<u>Part II</u>	<u>Page</u>
<u>10. -- Terminology and Symbols</u>	52
10.1 the interior	52
10.2 the luminaire	52
10.3 the installation	54
10.4 an installation of luminaires in an interior	55
10.5 list of symbols	58
 <u>11. -- Introduction to the tables</u>	 61
11.1 the flux code and the flux triplet	61
11.2 the basic geometric multipliers	61
11.3 the direct-ratio of an installation	63
11.4 relations between direct fluxes and total illuminances	63
11.5 utilances	64
11.6 tables of reduced utilances	64
11.7 classification tables	64
 <u>12. -- Tables</u>	 65
Table I geometric multipliers for single luminaires	
Tables II coefficients for the computation of reduced utilances	
Tables III coefficients for the computation of flux densities	
Table IV geometric multipliers for reference arrangements	
Table V direct-ratio correction factors for non-reference arrangements	
Table VI installation classification	
Table VII luminaire classes	
Table VIII reduced utilances	
 <u>Appendix A</u>	 157
Computation of the flux code of a luminaire	
A.1 from specified zonal flux values	157
A.2 from specified average luminous intensity values	158
A.3 from specified luminous intensity values in specified planes	159
 <u>Appendix B</u>	 161
Computation of optional photometric data of a luminaire	
E.1 computation of reference direct-ratio set	161
B.2 computation of a reference class set	161
B.3 determination of a luminaire class	162
B.4 calculation of reduced utilization factor tables	163
<u>Appendix C</u>	164
Presentation of Photometric data of a luminaire.	

Part I1. INTRODUCTION1.1 The Applied Method

The Applied Method as presented in this report is a further elaboration of the Basic Method. This elaboration concerns the calculation of the direct flux to the working plane and the determination of the combined effect of direct and reflected fluxes of an installation in an interior.

With the Applied Method the direct flux is calculated direct for a reference arrangement of the luminaires; for other arrangements of luminaires (on condition that they are regular and rectangular) a correction factor is applied to the direct flux of the reference arrangement. When using the Basic Method the direct flux of the installation must be calculated for each of its luminaires separately, which is a much more time consuming procedure. However, for irregular or non rectangular luminaire arrangements use of the Basic Method is the only approach open; for this reason, the geometric multipliers given in the Basic Method are reproduced in this report.

The combined effect of direct and reflected fluxes on the illuminances at the room surfaces i.e. ceiling, walls and working plane can, with the Applied Method, be rapidly calculated using utilances. These utilances are given in tables for ranges of values of the direct ratio. The procedure followed in the Basic Method for the calculation of these illuminances is necessarily protracted since it involves using a set of linear equations relating the direct fluxes per square meter to the total illuminance, and the applications of nine tabulated interreflection coefficients. However, the Basic Method, which unlike the Applied Method does not rely on approximated direct ratios, is the more accurate of the two methods. For this reason the interreflection coefficients from the Basic Method are reproduced in this report.

In practice, the illuminances required at the room surfaces are given and the design of the installation will involve calculating the lumen output per luminaire and the flux distribution of the luminaire as a function of the luminaire arrangement needed to produce these specified illuminances.

In general there will not be one unique solution, but different luminaires in different arrangements may lead to the same illuminances. Furthermore, since it is unlikely that a luminaire will be found that will give exactly the required lumen output and exactly the required flux distribution, a certain approximation to the specified illuminance values is to be expected. For this reason, an inverse or (verification) calculation method is required in order to see which of the alternative solutions best meets the illuminance requirements specified. Both methods, the design method and the verification method, are given in this report.

Most of the existing calculation methods deal only with the calculation of the illuminance at the working plane. With such methods the need to distinguish between a design method and a verification method is less apparent because only one relationship is involved, and this is used directly or inversely as the occasion demands.

For the calculation of the average illuminance at the working plane the use of utilization factor tables or of utilance tables is the most widely spread method. Similar procedures can be followed for the calculation of the illuminances at the walls and ceiling, although due to the definitions of utilization factor and utilance new concepts had to be introduced (reduced utilization factor and reduced utilance) to permit of rapid calculations. Whereas (reduced) utilization factor tables are valid for one specific luminaire in one arrangement only, (reduced) utilance tables can be applied for a group of installations having approximately the same direct ratio values.

For this reason (reduced) utilisation tables are given in this report. Grouping installations for which the same utilisation table is applicable is frequently referred to as classification.

Instead of classification of installations some methods use a classification of luminaires in which luminaires with similar luminous flux distributions are grouped.

In this report examples of both a system of classification of installations and a system of classification of luminaires have been introduced. These systems are mutually compatible. They are not dissimilar to some of the existing methods.

The only data required on a luminaire for application of the Applied Method are five values of its flux distribution - which are contained in its flux code - and the flux of its lamps.

The Applied Method is meant to retain and combine all the good features of the existing procedures and methods. As illustrated in Chapter 8, within their domain of validity the various existing methods do not differ from each other and from the Applied Method in the results obtained. The Applied Method as presented does not pretend to be more accurate than existing methods but is primarily intended to extend the domain of validity and to stimulate international standardization. Parts of the Applied Method can be used in combination with existing methods. As explained above, two steps can be distinguished in the calculation procedure: firstly the determination of the direct flux to the working plane and secondly the combined effect of direct and reflected fluxes. If, for example, the direct flux has been determined by means of an existing method that deals with the calculation of the illuminance at the working plane, the data provided in this report can be used for the calculation of the illuminances at the other room surfaces, thus supplementing the existing method.

The same principle can also be used to deal with installations having an obviously asymmetrical light distribution¹⁾, one of the various existing methods having been used to calculate the direct flux.

It is also possible to make the first step with an existing method, switch over to the Applied Method in order to calculate, for example, the effect of changing the luminaire arrangement, and then continue with the second step according to the existing method. This is possible because for the determination of the flux radiated towards the working plane use is made of the important feature of the Basic Method which is that the data required to account for the effects of the light distribution and the geometry are given separately. For each of the room index values a reference arrangement has been defined {(10.3.6)} for which the average geometric multipliers have been tabulated. The effect of the geometry of an arbitrary regular, rectangular arrangement is accounted for by means of tabulated correction factors.

The restrictions to the application of the Basic Method should be respected for the Applied Method as well: the room surfaces are assumed to be uniform and the luminaires are assumed to be symmetrical²⁾.

A restriction that is not mentioned explicitly in the Basic Method is that it cannot be applied to luminaires that emit more than 80% of their downward flux within a cone of $\pi/2$ steradians.

- 1) As stated in the Basic Method, the determination of the direct flux from asymmetrical luminaires will be dealt with in another Technical Report.
- 2) As explained in the Basic Method the essential characteristic of symmetry of fluorescent luminaires is that the direct flux does not vary significantly with the direction of the lamps. It should be noted that in the Applied Method continuous lines of luminaires with symmetrical light distribution are not excluded, although the direct flux on the working plane might be different for lines of luminaires mounted crosswise and lengthwise.

1.2 The Presentation

The Applied Method is based on the extensive use of tabulated photometric data. For ease of use and convenience of reference, therefore, this tabulated material together with the terminology and the description and instructions for use of the Method are presented in two volumes. Volume I contains all the relevant information needed for a full and proper understanding of the Method, as well as instruction for use and worked examples illustrating the various calculation techniques employed. Volume II is much shorter. It contains, besides the tables themselves, just sufficient information for the day-to-day use of the Method.

The photometric data of the luminaires used in the various examples are also given in Volume II: Appendix C.

2. GENERAL CONVENTIONS

2.1 Maintenance Factor

In this report the maintenance factor is not included in the expressions given for the calculation of illuminances or luminances. It should be noted that in practice the depreciation of the installation should be accounted for in an appropriate way.

2.2 The Use of Suffixes

In accordance with the implemented recommendations of the 1959 CIE Congress (9.2) the following suffixes are used to designate the various room surfaces:

- 1 for the ceiling
- 2 for the frieze
- 3 for the walls
- 4 for the working plane

If a suffix is not used it is tacitly assumed that the quantity refers to the working plane, in accordance with the use in existing methods dealing with the working plane only.

In conformity with the usual computer output, the suffixes in the text are printed on the line:

E.g.: R1 = the reflectance of the ceiling
 L2 = the luminance of the frieze
 E3 = the illuminance on the walls
 U4 = U = the utilance of the working plane.

2.3 Room Surface Reflectances

As is the case in the Basic Method, each of the reflecting surfaces is assumed to be a uniform diffuser with a constant reflectance over its entire surface. In practice the average reflectance of the surface should be used. In this report the room surface reflectance combinations are given, in accordance with the presentation in the Basic Method, as a four or three-digit code number. The three digit number is used where the interior has no frieze, and the four digit number in all other cases.

The last digit refers to the working plane reflectance, the last but one to the wall reflectance and the first to the ceiling reflectance. In a four digit number the second digit represents the reflectance of the frieze. For example:

7531 represents a reflectance combination of an interior with

R1 = 0,7; R2 = 0,5; R3 = 0,3; R4 = 0,1.

751 represents a reflectance combination of an interior without frieze in which

R1 = 0,7; R3 = 0,5; R4 = 0,1.

2.4 The Shape of The Interior

The shape of the interior for which the tables have been calculated is rectangular with sides A and B, where (in accordance with the Basic Method) A is the shorter side.

In accordance with the recommendations of the XIVth C.I.E. Congress (9.2) the tables are calculated for rooms with $B = A * \varphi$ in which φ is the positive root of the equation

$$\varphi - \frac{1}{\varphi} = 1, \text{ so that } \varphi \approx 1,6$$

2.5 Interpolation

In general the values of the parameters affecting the illuminances in a practical case will not appear exactly as entry-values of the tables.

It is recommended to interpolate for the geometric parameters but to take the nearest values for the reflectances.

An approximate linear interpolation will be sufficient. It is recommended to interpolate for the room index and for the suspension ratio by working from the end results, and not from the coefficients given in the tables direct. Correction factors are themselves end results and may therefore be interpolated direct from the tables.

Illustrations of the above are given in the examples (Chapter 7).

3. PARAMETERS AFFECTING THE ILLUMINANCES

The parameters that affect the average illuminances on the working plane, the walls and the ceiling of an interior are:

3.1 The Installed Luminous Flux Per Square Metre

All other parameters remaining constant, the illuminances are proportional to the installed luminous flux per square metre floor area, i.e. to the installed lamp flux density. The value of the installed lamp flux density is either given (as in the case of the verification method) or must be calculated (as in the case of the design method).

3.2 The Proportions Of The Interior

The room index K accounts for the proportions of the interior {(10.1.5)}. All other parameters remaining constant, the direct illuminance on the working plane and the contribution of interreflections to the illuminances on all the surfaces increase with increasing value of K . In this report, the value of the room index is always the main entry to the tables.

3.3 The Zonal Flux Distribution Of The Luminaires

The flux code $N1\ N2\ N3\ N4\ N5$ characterises the zonal flux distribution of the luminaire {(10.2.15)}. All other parameters remaining constant, the greater the value of $N1$ {(10.2.10)}, the higher the illuminance on the working plane and the lower the illuminances on the walls and the ceiling. All other parameters remaining constant, the greater the downward light output ratio, $.N4 * .N5$, {(10.2.10)} the greater the illuminances on all the surfaces of the interior. All other parameters remaining constant, the greater the light output ratio, $.N5$ (upward and downward fluxes taken together) the greater the illuminances on all the surfaces of the interior. The flux code is the basis of the luminaire data in this report.

3.4 The Geometry Of The Installation

The geometry of an installation having a regular, rectangular arrangement can be described by means of five variables:

1. the proximity lengthwise {(10.3.2)},
2. the proximity crosswise {(10.3.2)},
3. the suspension height {(10.3.3)},
4. the number of luminaires crosswise {(10.3.6)},
5. the number of luminaires lengthwise {(10.3.6)}.

All other parameters remaining constant, the smaller the proximity (i.e. the nearer the outer luminaires are to the walls), the lower will be the illuminance on the working plane and the higher the illuminance on the walls. When all other parameters remain constant (including the installed lamp flux density and the room index), the influence that the number of luminaires will have on the room-surface illuminances (either crosswise or lengthwise) will be small compared with the influences of suspension height and proximity. A change in the suspension height is reflected in the value of the room index (see 10.3.4 note) and also in the appropriate tables for suspension factors 0 and 1/3.

The Applied Method is based on a defined reference arrangement of the luminaires (TABLE IV). For the regular, rectangular arrangements differing from the reference arrangement correction factors for the value of the direct ratio must be applied (TABLE V. 1 et seq.)

3.5 The Reflectances of the Surfaces

The illuminances on the surfaces of the interior are the result of a flux direct from the luminaires of the installation and a flux reflected from the surfaces. All other parameters remaining constant, the greater the reflectances the greater the contribution by interreflection and the higher the illuminances. It should be emphasized that the working plane reflectance, R_4 , is the reflectance of a horizontal plane at tabletop height. Because of the cavities formed by floor, furniture, occupants and other objects, the value of R_4 is much less than that obtained by averaging the reflectances of the projected surfaces. In general $R_4 = 0,1$ represents a realistic value for normally clean interiors, only in the case of an extremely "clean" interior may $R_4 = 0,3$ be used. The values of the reflectances of the surfaces are entries to the tables in this report.

4. PRINCIPLES OF THE APPLIED METHOD

In this section the principles used in the Applied Method are explained. In general, in a calculation procedure, a sequence of applications of these principles will be used, as is illustrated in Sections 5 and 6. Some of these principles can be selected for use in supplementing other calculation methods.

4.1 The Photometric Data of a Luminaire

The luminous flux distribution of a luminaire can be represented in a zonal luminous flux diagram, as illustrated in fig. 4.1.

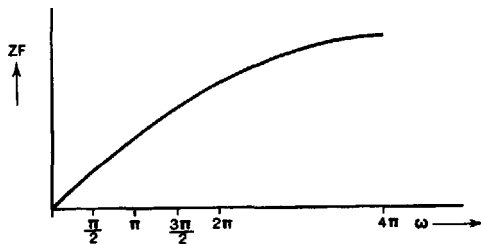


Fig. 4.1 An illustration of a zonal flux diagram

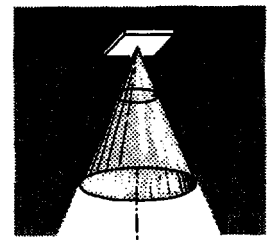


Fig. 4.2 Sketch of a right cone with a solid angle ω about the vertical axis

A zonal flux diagram is the graphical representation of the total flux emitted in a right cone of vertical axis as a function of the solid angle defined by that cone (figs. 4.1 and 4.2).

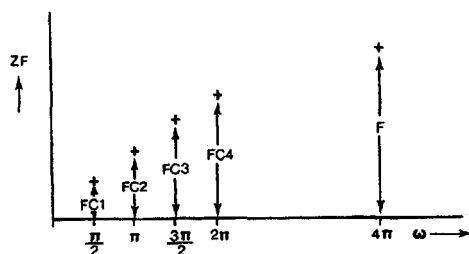


Fig. 4.3 Plots of the 5 characteristic zonal flux values

The luminous zonal flux ZF radiated by a luminaire is cumulative when plotted as a function of increasing solid angle ω , as can be seen in figure 4.1. The flux in fact increases smoothly with increase in solid angle and only four points, in addition to the point ($\omega = 0$, $ZF = 0$) are needed to adequately define the shape of the curve over the lower hemisphere (i.e. $\omega = 0$ to $\omega = 2\pi$). These points, given by the values of the luminous flux $FC1$, $FC2$, $FC3$ and $FC4$ at the four equidistant solid angles $\pi/2$, π , $3\pi/2$ and 2π are shown in figure 4.3

Since none of the flux radiated in the upper hemisphere can reach the working plane direct, the shape of the curve from $\omega = 2\pi$ to $\omega = 4\pi$ is of no consequence when calculating the direct flux reaching this plane.

The only additional point needed is that defining the total luminous flux output of the luminaire, i.e. the value of ZF at $\omega = 4\pi$, giving five points in total:
 $FC1 = ZF(\pi/2)$; $FC2 = ZF(\pi)$; $FC3 = ZF(3\pi/2)$; $FC4 = ZF(2\pi)$ and $F = ZF(4\pi)$.

It is recommended to use not absolute flux values, but rather the following relative values:

$$\frac{FC1}{FC4} = .N1; \frac{FC2}{FC4} = .N2; \frac{FC3}{FC4} = .N3; \frac{FC4}{F} = .N4 \text{ and } \frac{F}{PHIS} = .N5$$

where PHIS (PHI is computer language for Φ) is the sum of the fluxes of the individual lamps of the luminaire.

The flux code is the combination of these relative values, each to two decimal places: N1 N2 N3 N4 N5.

It represents all the characteristics of a luminaire needed in calculating the average illuminances at the room surfaces of an interior.

If the flux code of a luminaire has not been given by the manufacturer it can be calculated from other photometric data as explained in Appendix A.

4.2 The Direct Flux from a Luminaire to the Working Plane

As is explained in the Basic Method, the flux radiated by a luminaire towards the working plane can be calculated in four steps.

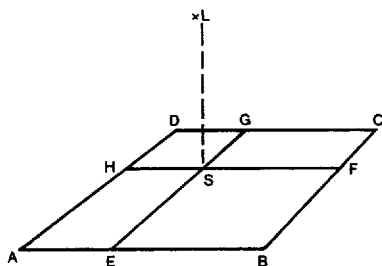


Fig. 4.4 Sketch of a luminaire situated at point L vertically above point S on the working plane ABCD

Consider a luminaire L at a distance LS above a working plane ABCD (fig. 4.4). The proportion of its downward flux that is radiated towards the rectangle AESH is calculated from a knowledge of the flux triplet N1 N2 N3 of the luminaire and the geometric multipliers $GM1_1$, $GM2_1$, $GM3_1$ and $GM4_1$ read from TABLE I for $A/H = ES/LS$ and $B/H = HS/LS$. The required proportion, P_1 , is given by

$$P_1 = GM1_1 \cdot N1 + GM2_1 \cdot N2 + GM3_1 \cdot N3 + GM4_1$$

The proportions P_2 , P_3 and P_4 radiated towards the rectangles EBPS, SFCG and HSGD are calculated in a similar way:

$$P_2 = GM1_2 \cdot N1 + GM2_2 \cdot N2 + GM3_2 \cdot N3 + GM4_2$$

$$P_3 = GM1_3 \cdot N1 + GM2_3 \cdot N2 + GM3_3 \cdot N3 + GM4_3$$

$$P_4 = GM1_4 \cdot N1 + GM2_4 \cdot N2 + GM3_4 \cdot N3 + GM4_4$$

The total downward flux proportion P , radiated towards the working plane is then
 $P = P_1 + P_2 + P_3 + P_4 = (\sum GM1) \cdot N1 + (\sum GM2) \cdot N2 + (\sum GM3) \cdot N3 + \sum GM4$
 The absolute value $F4$ of the flux radiated towards the working plane is given by:
 $F4 = P \cdot N4 \cdot N5 \cdot PHIS$, in which $PHIS$ is the sum of fluxes of the individual lamps of the luminaire.

4.3 The Direct Flux from an Installation to the Working Plane

The flux radiated by an installation towards the working plane is equal to the sum of the fluxes radiated in this direction by the individual luminaires of the installation.

It may be noted that, should the installation consist of luminaires of the same type, then the corresponding geometric multipliers for all the luminaires involved can be added before multiplying the first three with their corresponding identifiers $N1$, $N2$ and $N3$.

These sums of corresponding geometric multipliers can thus be interpreted as composite geometric multipliers for the particular luminaire arrangement concerned. The proportion of the downward flux of the installation radiated towards the working plane, i.e. the direct ratio DR , is then

$$DR = \frac{.N1 \cdot \sum GM1 + .N2 \cdot \sum GM2 + .N3 \cdot \sum GM3 + \sum GM4}{NM}$$

In which NM is the total number of luminaires in the installation (in the case of regular rectangular luminaire arrangements M represents the number of luminaires lengthwise and N the number of luminaires crosswise).

The relation above can be rewritten as:

$$DR = \frac{\sum GM1}{NM} \cdot .N1 + \frac{\sum GM2}{NM} \cdot .N2 + \frac{\sum GM3}{NM} \cdot .N3 + \frac{\sum GM4}{NM}$$

in which the average composite geometric multipliers can be interpreted as geometric multipliers for the installation:

$$DR = GM1 \cdot N1 + GM2 \cdot N2 + GM3 \cdot N3 + GM4.$$

For the usual series of room indices K , and for interiors in which the ratio of length to width conforms to the golden rule, and for reference arrangements as defined in TABLE IV, geometric multipliers are tabulated. This enables a rapid calculation of the direct ratio for reference arrangements.

For regular, rectangular arrangements that differ from the reference arrangements in the number of luminaires lengthwise and/or crosswise, and/or in the distances from the wall to the outer rows of luminaires, correction factors must be used. These (CORR) factors are tabulated in TABLE V. When applied to the direct ratio for the reference arrangement DRR they give the direct ratio DR for the arrangement considered:

$$DR = CORR \cdot DRR^1)$$

The proportion of the downward flux radiated towards the walls is equal to $1 - DR$.

¹⁾ Strictly speaking the correction factors (CORR) are only valid for luminaires with a reference flux distribution. The influence of the light distribution, however, is small compared to that of the geometry of the arrangement, so that in practice the correction factors (CORR) can still be used. Further details on the use of correction factors can be found in literature (9.8).

The absolute values of the direct flux radiated towards the working plane (F4) are calculated by means of the relation:

$$F4 = DR * .N4 * FD * A4$$

in which FD = the installation flux density

A4 = the area of the working plane.

The direct flux F3 radiated towards the walls is given by:

$$F3 = (1 - DR) * .N4 * FD * A4.$$

The direct flux F12 radiated towards the combination of frieze and ceiling is given by:

$$F12 = (1 - .N4) * FD * A4.$$

4.4 The Relation Between Direct Fluxes and Illuminances

Direct and interreflected fluxes result in illuminances at the room surfaces.

As is explained in the Basic Method, the direct fluxes and the room surface illuminances are related by means of the following expressions:

$$\left. \begin{aligned} E1 &= E2 = RM11 * FD + RM12 * DFD + RM13 * FD4 \\ E3 &= RM31 * FD + RM32 * DFD + RM33 * FD4 \\ E4 &= RM41 * FD + RM42 * DFD + RM43 * FD4 \end{aligned} \right\} (4.4.1)$$

and their inverse equivalents:

$$\left. \begin{aligned} FD &= MR11 * E1 + MR13 * E3 + MR14 * E4 \\ DFD &= MR21 * E1 + MR23 * E3 + MR24 * E4 \\ FD4 &= MR31 * E1 + MR33 * E3 + MR34 * E4 \end{aligned} \right\} (4.4.2)$$

in which E1 = the ceiling illuminance

E3 = the wall illuminance

E4 = the illuminance at the working plane

FD = the installation flux density

DFD = the downward flux density

FD4 = the flux density at the working plane

The coefficients RM and MR are given in TABLES II and III respectively for the usual series of room indices K and reflectance combinations for ceiling, (frieze), walls and working plane.

These expressions can be used to calculate either the required fluxes that must be installed per square metre to obtain specified illuminances, or the illuminances obtained for given installed flux densities.

The direct ratio, DR, equals FD4/DFD, where DFD, the downward installation flux density, equals .N4 * FD. The expressions 4.4.1 above can therefore also be written

$$\left. \begin{aligned} E1 &= (RM11 + (RM12 + RM13 * DR) * .N4) * FD \\ E3 &= (RM31 + (RM32 + RM33 * DR) * .N4) * FD \\ E4 &= (RM41 + (RM42 + RM43 * DR) * .N4) * FD \end{aligned} \right\} (4.4.3)$$

4.5 Utilance

It is common, for existing methods, to calculate the illuminance at the working plane as the product of a single factor and one or other of two photometric quantities, viz. the installed nominal lamp flux per square metre or the installed luminaire flux per square metre. In the former case the factor used is referred to as a utilization factor ((10.4.4)) while in the latter case it is termed as a utilance ((10.4.5)).

Utilization factors are tabulated for one specific luminaire in one specific arrangement; utilances are tabulated in general for groups of luminaires with similar luminous flux distributions in one specific arrangement.

Utilization factor tables are best supplied by the manufacturer of the luminaire concerned. Utilance tables require a procedure to be followed in order to determine which table should be used for a specific luminaire. This procedure is frequently referred to as classification, and is part of a general method of calculation. From the expressions ((4.4.3)) above it follows that the utilance U is given by $U = RM41 + (RM42 + RM43 * DR) * .N4$.

For the calculation of the ceiling illuminance $E1$ and the wall illuminance $E3$ similar factors can be defined, neither of which, according to the definition of utilance ((10.4.5)) may be termed a utilance. This is because the area of the reference plane is not involved.

They will be referred to here as reduced utilances:

$RU1$ = the reduced ceiling utilance, $RU3$ = the reduced wall utilance. The term reduced utilance may also be applied in connection with the working plane. Thus $RU4 = U$ = the (reduced) utilance for the working plane.

The illuminances then are calculated by means of the relations:

$$\left. \begin{aligned} E1 &= RU1 * FD \\ E3 &= RU3 * FD \\ E4 &= RU4 * FD \end{aligned} \right\} \quad (4.5.1)$$

in which:

$$\left. \begin{aligned} RU1 &= RM11 + (RM12 + RM13*DR) * .N4 \\ RU3 &= RM31 + (RM32 + RM33*DR) * .N4 \\ RU4 &= RM41 + (RM42 + RM43*DR) * .N4 \end{aligned} \right\} \quad (4.5.2)$$

For luminaires with downward flux only, $.N4 = 1$ and the only characteristic of the installation appearing in the expressions is the direct ratio DR . The resulting reduced utilances will be referred to as reduced downward utilances $RDU1$, $RDU3$ and $RDU4$:

$$\left. \begin{aligned} RDU1 &= RM11 + RM12 + RM13*DR \\ RDU3 &= RM31 + RM32 + RM23*DR \\ RDU4 &= RM41 + RM42 + RM43*DR \end{aligned} \right\} \quad (4.5.3)$$

These can be tabulated for installations having similar DR-values. In this report, by way of illustration, a classification of installations with similar values of DR is given in TABLE VI. and described in 4.6. The corresponding tables of reduced utilances are given in TABLE VIII. 1. et seq.

Installations employing luminaires giving both downward and upward flux can be considered to consist of two installations, one with downward flux only and an installed luminaire flux density equal to $.N4 * FD$, and one with upward flux only and an installed luminaire flux density equal to $(1 - .N4) * FD$.

The reduced utilances of the downward flux installation are

$$\left. \begin{aligned} RU1 &= RDU1 * .N4 \\ RU3 &= RDU3 * .N4 \\ RU4 &= RDU4 * .N4 \end{aligned} \right\} \quad (4.5.4)$$

Similarly, by introducing reduced upward utilances RUU1, RUU3 and RUU4 the reduced utilances of the upward flux installation may be written as

$$\left. \begin{aligned} RU1 &= RUU1 * (1 - .N4) \\ RU3 &= RUU3 * (1 - .N4) \\ RU4 &= RUU4 * (1 - .N4) \end{aligned} \right\} \quad (4.5.5)$$

Since for the sum of both installations the reduced utilances are given by the relations (4.5.2) it follows, by adding the corresponding expressions from (4.5.4) and (4.5.5) and substituting those from (4.5.3) in (4.5.4), that the reduced upward utilances are:

$$\left. \begin{aligned} RUU1 &= RM11 \\ RUU3 &= RM31 \\ RUU4 &= RM41 \end{aligned} \right\} \quad (4.5.6)$$

The reduced upward utilances are thus independent of the types of luminaires used and are given as the last line of each table in the TABLE VIII. 1 et seq.

4.6 Classification of Installations

As can be seen from the relations (4.5.3) the reduced utilances of an installation are linear functions of its direct-ratio. For this reason the direct-ratio has been chosen as the criterion for the classification of installations. Installations with direct-ratio values within a defined range are grouped in a class. For each class, values of the downward utilances can be tabulated. The smaller the range of direct-ratio values per class, the smaller will be the differences between the exact values of the utilances of an installation and the tabulated values, but this means that more classes will be required and so a greater number of values will have to be tabulated.

The parameters determining the direct ratio of an installation are the room index, the relative downward zonal flux distribution of the luminaires and the luminaire arrangement. In practice, the useful range of direct-ratio values proves to be different for different values of the room index. In order to economize on the number of classes, only the useful range of direct-ratio values per room index has been considered for the classification instead of the theoretically possible values ranging from 0 to 1 inclusive for each.

These useful ranges for each room index are divided into 10 parts. Each part represents the range of direct-ratio values of one class for that room index. The classes are numbered from 1 to 10. The limits of the ranges as well as the central values are given in TABLE VI for the usual series of K-values.

As part of the photometric luminaire data, the classes of installations with the luminaire in reference arrangement may be given for the standard series of room indices as a series of ten class numbers. These classes will be referred to as luminaire reference classes.

4.6.1 Classification Procedure For a Specific Installation

The class of a specific installation employing a given type of luminaire can be determined as follows:

1. determine the room index,

$$K = \frac{A * B}{H3 * (A + B)}$$

in which A and B are the sides of the room and H3 the mounting height;

2. knowing the room index K, select the geometric multipliers GM1, GM3 and GM4 for the reference arrangement from TABLE IV;
3. read the identifying numbers N1, N2 and N3 from the flux code number of the luminaire ¹⁾
4. calculate the direct ratio DRR for the reference arrangement:
 $DRR = GM1 * N1 + GM2 * N2 + GM3 * N3 + GM4$;
5. determine the correction factor CORR for the given arrangement from TABLE V. as described in 4.2.1;
6. calculate the direct ratio DR for the given arrangement: $DR = DRR * CORR$;
7. compare the value of DR with those tabulated for the limits of the various classes in the column for room index K of TABLE VI and read the class of the installation from the first column of the table.

4.6.2 Classification Procedure for a Specific Luminaire Type in Installations with Reference Arrangements

The classes of the reference installations with one specific luminaire throughout the range of room index values can be determined as follows:

1. read the identifying numbers, N1, N2 and N3 from the flux code number of the luminaire ¹⁾;
2. read the geometric multipliers GM1, GM2, GM3 and GM4 from TABLE IV for each room index sequentially;
3. calculate the direct-ratios DRR for the room indices:
 $DRR = GM1 * N1 + GM2 * N2 + GM3 * N3 + GM4$;
4. compare the value of each DRR with those tabulated for the limits of the various classes in the column for the corresponding room index from TABLE VI and read the class for each room index.

The classification of the luminaire in reference installations (the luminaire reference class set) may be presented as part of the photometric luminaire data by this series of 12 class numbers separated by strokes:

.../.../.../.../.../.../.../.../.../.../.../.../.../ (see fig. C.3, Appendix C)

¹⁾ where the flux code number is not given, consult Appendix A.

4.7 Luminaire Classification

When the luminaire reference classes for a given luminaire are the same throughout the series of room index values this should preferably be specified by one single class number instead of by a series of twelve identical numbers separated by strokes. This single number will be referred to as the luminaire class.

The flux triplets as given in TABLE VII give the required relative downward zonal flux distributions for the luminaires that, when used in reference arrangement, will result in direct-ratio values the same as those tabulated in TABLE VI throughout the range of room index values. Luminaires with flux triplets similar to those from TABLE VII will have a constant luminaire reference class throughout the range of room index values and hence can be classified in a luminaire class. The advantage of this luminaire classification is that it is not necessary to first calculate the direct-ratio values for the reference arrangements: in general, a comparison of flux triplets will show directly whether or not the luminaire can be classified and if so, what its class is. However, it is not always true that if each of the identifying numbers of a triplet lies between the corresponding identifying numbers of the limiting triplets of a given luminaire class, that the luminaire concerned will be of that same class. Deviations may occur especially for low and high values of the room index in this case where the identifying numbers of the luminaire are near to the identifying numbers of both limiting triplets. (see fig. C.3, luminaire type G 200).

It should be noted that luminaire classification can never be exhaustive unless a large number of classes is employed. (see fig. C.3, luminaire type F 175).

For installations of luminaires of a given class in reference arrangement, the downward utilances are read directly from the TABLE VIII. 1 et seq. at the lines labelled with the class number of the luminaire. The direct-ratio values of these installations are read from TABLE VI at the lines labelled with the class number of the luminaire.

4.7.1 Classification Procedure

The classification procedure for a luminaire is as follows:

1. read the identifying numbers N_1 , N_2 , N_3 from the flux code of the luminaire ¹⁾;
2. check in TABLE VII whether N_1 , N_2 , and N_3 each lie between the corresponding identifying numbers of the triplets of the limits of one and the same CIE luminaire class:
 - a) If this is not the case proceed with step 5,
 - b) If this is the case proceed with step 3;
3. check whether N_1 , N_2 and N_3 are very close to one or more of the abovementioned corresponding identifying numbers:
 - a) If this is not the case proceed with step 6,
 - b) If this is the case proceed with step 4;
4. calculate the luminaire reference classes for the room index values $K = 0,6; 1,5$ and $5,0$. Check whether the numbers of the luminaire reference classes are equal to that of the CIE luminaire class mentioned above:
 - a) If this is not the case proceed with step 5,
 - b) If this is the case proceed with step 6;
5. the luminaire cannot be classified into a CIE luminaire class and its luminaire reference class set should be determined as described in 4.6.2.;
6. the luminaire can be classified into a CIE luminaire class and its class number is that of the abovementioned CIE luminaire class.

¹⁾ In case the flux code is not given, consult Appendix A.

4.8 Optional Photometric Luminaire Data

In principle the only photometric luminaire data required for the calculation of average illuminances at the room surfaces of an interior is its flux code
N1 N2 N3 N4 N5.

From the flux code the direct ratio for an installation can be calculated by means of the geometric multipliers for reference installations and a correction factor. To assist the user it would be useful to precalculate the direct-ratio values (DRR) for reference installations (viz. installation employing a reference luminaire arrangement). The manufacturer could supply these optional values, either as a series of the values (to two decimal places) or as a sequence of the class numbers for the reference installations for the usual series of room indices: the luminaire reference class set. (figs. C.2 and C.3).

The user would be helped further were the manufacturer to supply additional tables giving reduced utilization factors for specified luminaire arrangements (fig. C.6)

Examples of ways in which the data may be presented are given in Appendix C.

5. THE DESIGN METHOD

In the international C.I.E. Guide on Interior Lighting (9.3) and in many other national recommendations or codes of practice for interior lighting, values of luminances or of illuminance and reflectance are recommended for the room surfaces, either as ratios or as absolute values. Assuming diffuse reflection at these surfaces, all these recommendations can be expressed in terms of the illuminance recommended for a given reflectance. The design method involves the selecting of luminaires, luminaire arrangements or both to give the illuminances recommended.

In general, there will be more than one design solution: but the more limiting the design requirements, the more limited also will be the number of solutions possible. For instance, if the arrangement of luminaires is specified, then the number of possible solutions will be reduced considerably. Needless to say, there will be no solution possible at all if the design specifications are contradictory in themselves. This will be the case, for instance, if the illuminance specified for the ceiling is less than the ceiling illuminance resulting from interreflection from the walls and working plane.

5.1 Determination of the Required Installation Flux Densities

For a given interior with given room surface reflectances and a given height of the plane of the luminaires the total, downward and utile installation flux densities (FD, DFD and FD4), which are required to obtain specified illuminances E_1 , E_3 and E_4 at the ceiling the walls and the working plane, can be calculated by means of the relations (see 4.4.2):

$$\begin{aligned} FD &= MR_{11} * E_1 + MR_{13} * E_3 + MR_{14} * E_4 \\ DFD &= MR_{21} * E_1 + MR_{23} * E_3 + MR_{24} * E_4 \\ FD4 &= MR_{31} * E_1 + MR_{33} * E_3 + MR_{34} * E_4 \end{aligned}$$

The MR coefficients are read from TABLE III according to the room index (K), the room suspension ratio (J) and the room surface reflectances concerned.

The room index, K, is given by

$$K = \frac{A * B}{H_3 * (A + B)},$$

and the suspension ratio, J, by

$$J = \frac{H_2}{H_2 + H_3},$$

in which A and B are the sides of the interior, H_3 is the distance between the working plane and the plane of the luminaires, and H_2 is the distance between the plane of the luminaires and the ceiling.

Where the suspension ratio differs from $J = 0$ or $J = 1/3$, the installation flux densities should be calculated at both these values, followed by an interpolation of the flux densities for the actual value of the suspension ratio.

5.2 Selection of the Installation

Once the required flux densities have been determined, the process of selecting an installation that gives illuminances E_1 , E_2 and E_3 is reduced to the selection of an installation having flux densities FD , DFD and FD_4 .

The direct ratio DR of the installation must be equal to

$$DR = FD_4/DFD,$$

the downward flux fraction of the installation DFF must be equal to

$$DFF = DFD/FD,$$

which will be the case when using luminaires with

$$.N_4 = DFD/FD,$$

the flux F emitted by each luminaire must be equal to

$$F = FD * A_4/NM,$$

in which A_4 is the area of the working plane and NM is the number of luminaires.

Installations that have a direct ratio DR for luminaires in a given arrangement must make use of the luminaire types that have a direct-ratio DRR when used in reference arrangement with $DRR = DR/CORR$, in which $CORR$ is the correction factor, read from TABLE V, for the arrangement given.

In this way the problem of selecting installations is reduced to one of selecting luminaires having:

- a direct ratio in reference arrangement DRR ,
- a downward flux fraction $.N_4$, and
- a total flux F .

5.2.1 Specified Luminaire Arrangement, Specified Suspension Ratio

Where both the luminaire arrangement and the suspension ratio are specified, the procedure described above can again be followed exactly, as is illustrated by means of the example in Section 7.1 and 7.2.

5.2.2 Specified Suspension Ratio, Luminaire Arrangement Not Specified

Where the luminaire arrangement can be chosen, there will be more solutions possible than in the former case. This follows, because if a solution is found in which a certain luminaire type is placed in a certain arrangement, another solution employing luminaires having a more concentrated luminous flux distribution is always possible by altering the arrangement such that the luminaires are positioned closer to the walls. Similarly, where luminaires having a broader distribution are employed, mounting these nearer the middle will again give an acceptable solution. This is illustrated by means of the example in Section 7.3.

5.2.3 Suspension Ratio Not Specified, Arrangement Not Specified

Where the suspension ratio is not specified an even greater number of solutions are possible. This is because now the room index can be changed, and the value of this index has a great influence on the direct ratio for a given luminaire type. The influence of the suspension ratio upon the room index can be determined from the relation:

$$K = \frac{A * B}{(H_2 + H_3)(A + B)} \cdot \frac{1}{(1 - J)}$$

The above comments are illustrated by means of the example in Section 7.4.

6. THE VERIFICATION METHOD

As is explained in the Introduction, it should not be assumed that installations designed to provide illuminances E1, E3 and E4 at the room surfaces will give these illuminances exactly; this is because, in general, the required luminaire flux and the required flux distribution will not be exactly available. An inverse calculation method is therefore needed to calculate the actual illuminances prevailing with the proposed installation. This inverse method can thus be used to compare various alternative solutions. Of course, the same method is needed to calculate the room surface illuminances in an existing installation. Two steps can be distinguished: first the determination of the direct flux to the working plane (or the direct ratio), and secondly the determination of the combined effect of direct and reflected fluxes, or the utilisation.

For the determination of the direct ratio the flux triplet of the luminaire, its direct-ratio in reference arrangement, or its reference class, may be used each in combination with the correction factor CORR for the arrangement concerned.

For the determination of the combined effect of direct and reflected fluxes the coefficients from TABLE II 1. et seq. can be used, as can the reduced utilisation TABLE VIII. 1 et seq.

6.1 Determination Of The Direct Ratio

The room index K of the interior is calculated by means of the relation

$$K = \frac{A * B}{H3 * (A + B)},$$

in which A and B are the sides of the interior and H3 is the mounting height (viz. the distance between the working plane and the plane of the luminaires). Where the K value does not appear in the series of values used as entries to the table, the direct-ratio should be calculated for the two nearest values of the entries. The value obtained by interpolation between these two is the direct-ratio to be used.

6.1.1 Calculation Using The Flux Triplet N1 N2 N3

The geometric multipliers GM1, GM2, GM3 and GM4, corresponding to the room index K, are read from TABLE IV.1 et seq.

The direct-ratio for the luminaires in reference arrangement

$$DRR = .N1*GM1 + N2*GM2 + .N3*GM3 + GM4$$

The actual arrangement employed in the installation the correction factor CORR is read from TABLE V. 1. et seq. The direct-ratio DR = CORR * DRR.

6.1.2 Calculation Using Published DRR Values

Sometimes the values of the direct-ratio for a reference arrangement are tabulated according to room index as part of the information published by the manufacturer of the luminaire. Where this is the case, the published value of the direct-ratio (DRR) for the room index concerned, multiplied by the correction factor (CORR) for the particular luminaire arrangement employed as read from TABLE V will yield the direct-ratio (DR) needed for calculation purposes; thus
 $DR = DRR * CORR.$

6.1.3 Calculation Using Published Reference Class Set

Where the reference class set for different room indices is provided by the manufacturer of the luminaire, the reference class number corresponding to a particular value of room index can be determined. The correction factor (CORR) for the particular luminaire arrangement employed is read from TABLE V.

If $|CORR - 1| < 0,05$ this class number can be maintained. If

$|CORR - 1| \geq 0,05$ the value of the centre of the class for the value of

K concerned (DRR) is read from TABLE VI. The value $DR = CORR * DRR$ is compared with the values in TABLE VI for the room index concerned and the class of the corresponding installation is read.

6.1.4 Calculation Using a Published Luminaire Class

The procedure followed when the luminaire class is published is similar to that described above in 6.1.3. It is only if $|CORR - 1| \geq 0,05$ that the installation class has to be determined.

6.2 Determination of the Reduced Utilances

The reduced utilance of an installation for one of the room surfaces is built up from a reduced downward and a reduced upward utilance weighted according to the downward and upward flux fraction:

$$RU = RUU * (1 - .N4) + RDU * .N4$$

In the case of installations with emission in the lower hemisphere only, $RU = RDU$. The reduced upward utilances $RUU1 = RM11$, $RUU3 = RM31$ and $RUU4 = RM41$ are given in TABLE II, 1. et seq. but for convenience, are repeated at the foot of the columns of TABLE VIII. The reduced downward utilances are calculated using the RM coefficients from TABLE II, 1. et seq., or are read directly for installation classes from TABLE VIII.

6.2.1 Calculation of Utilances Using the RM Coefficients

If the direct ratio DR has been determined, the reduced downward utilances are calculated by means of the following relations:

$$RDU1 = RM11 + RM12 + RM13 * DR$$

$$RDU3 = RM31 + RM32 + RM33 * DR$$

$$RDU4 = RM41 + RM42 + RM43 * DR$$

the RM coefficients being read from the TABLE II, 1 et seq. for the room surface reflectances and the room index concerned.

In the case where the installation has emission in the lower hemisphere only, the reduced downward utilance and the reduced utilances are equal:

$$RU1 = RDU1$$

$$RU3 = RDU3$$

$$RU4 = RDU4.$$

In the case where the installation has an emission in the upper hemisphere as well as in the lower hemisphere, and where the downward flux fraction of the luminaires $DFD = .N4$, the reduced utilances are:

$$RU1 = RM11 * (1 - .N4) + (RM11 + RM12 + RM13 * DR) * .N4$$

$$RU3 = RM31 * (1 - .N4) + (RM31 + RM32 + RM33 * DR) * .N4$$

$$RU4 = RM41 * (1 - .N4) + (RM41 + RM42 + RM43 * DR) * .N4.$$

6.2.2 Calculation of Utilances Using TABLE VIII

If the direct-ratio (DR) of the installation has been determined, its value can be compared with those of the installation classes from TABLE VI, having the same room index and the installation class determined.

The appropriate table of TABLE VIII. 1 et seq., as determined by the suspension ratio (for interpolation see 2.5) and the room index concerned, is then selected. The reduced downward utilances RDU1, RDU3 and RDU4 are then read from the table according to the room surface reflectances (column) and installation class (row) concerned, while the reduced upward utilances RUU1, RUU3 and RUU4 are simply read from the foot of the appropriate column.

For the installation having emission in the lower hemisphere only, the reduced utilances are:

$$\begin{aligned}RU1 &= RDU1 \\RU3 &= RDU3 \\RU4 &= RDU4\end{aligned}$$

For an installation having an emission in both the upper and lower hemisphere the downward flux fraction of the luminaires: DFF = .N4, is used. The reduced utilances are then:

$$\begin{aligned}RU1 &= RUU1 * (1 - .N4) + RDU1 * .N4 \\RU3 &= RUU3 * (1 - .N4) + RDU3 * .N4 \\RU4 &= RUU4 * (1 - .N4) + RDU4 * .N4.\end{aligned}$$

6.3 Calculation of Illuminances

The room surface illuminances are calculated from the reduced utilances and the luminaire flux density FD using the relations:

$$\begin{aligned}E1 &= RU1 * FD \\E3 &= RU3 * FD \\E4 &= RU4 * FD.\end{aligned}$$

The luminaire flux density is calculated from the number of luminaires NM, the number of lamps per luminaire n, the nominal flux per lamp PHI, the light output ratio of the luminaire .N5 and the area of the working plane A4:

$$FD = NM * n * PHI * .N5 / A4.$$

7. EXAMPLES

In this section some examples are worked out in order to illustrate the use of the Applied Method.

7.1 An Installation with luminaires in Reference Arrangement

Assume that it is required to select ceiling mounted luminaires ($J = 0$) which when used in an interior of $5,4 \times 9$ m having a ceiling height of 3 m will give illuminances at the ceiling, walls and working plane:

$E_1 = 100$ lux

$E_3 = 300$ lux

$E_4 = 600$ lux

The working plane is taken to be at 0,75 m above the floor.

The reflectances of ceiling, walls and working plane are:

$R_1 = 0,7, R_3 = 0,5$ and $R_4 = 0,1$ resp.

For reasons of construction, the arrangement of the luminaires is fixed at 3 rows of luminaires lengthwise each consisting of 4 luminaires, and the proximities (def.10.3.2) are half the corresponding spacings (def.10.3.1).

7.1.1 General

The situation is illustrated in the sketch of fig. 7.1.

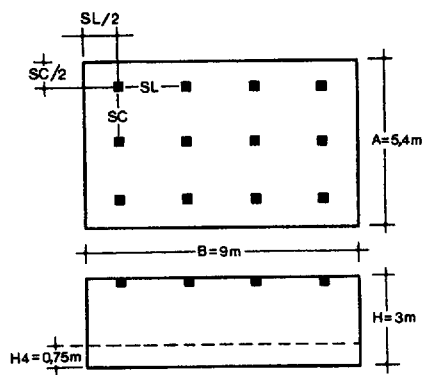


Fig.7.1 Projected ceiling and cross section of the interior

The mounting height of the installation

$$H_3 = 3 - 0,75 = 2,25 \text{ m}$$

The width $A = 5,4$ m, the length $B = 9$ m.

The room index

$$K = \frac{A * B}{H_3 * (A + B)} = \frac{5,4 * 9}{2,25 * (5,4 + 9)} = 1,50$$

The reflectances are: $R_1 = 0,7$; $R_3 = 0,5$ and $R_4 = 0,1$. This reflectance combination is coded as 751

$E_1 = 100$; $E_3 = 300$; $E_4 = 600$ lux;

$M = 4$; $N = 3$;

$$A_4 = 5,4 * 9 = 48,6 \text{ m}^2.$$

7.1.2 Design

The MR coefficients from TABLE III-5 at the line 751 in thousandths are:

300; 667; 900/-700; 893; 955/-383; -227; 1000.

According to the expressions given in the heading of the table:

$$FD = (300 * 100 + 667 * 300 + 900 * 600) / 1000 = 770,1$$

$$DFD = (-700 * 100 + 893 * 300 + 955 * 600) / 1000 = 770,9$$

$$FD4 = (-383 * 100 + -227 * 300 + 1000 * 600) / 1000 = 493,6$$

FD = flux to be installed per m^2 ;

$$F = FD * A4/NM = 770,1 * 48,6/3 * 4 = 3119 \text{ lm} = \text{the flux per luminaire.}$$

The lower flux fraction of the luminaire $.N4 = DFD/FD = 1,00^{1)}$

The direct ratio of the installation must be: $DR = FD4/DFD = 0,64$.

From the reference arrangement given in TABLE IV for $K = 1,50$ it will be noted that this is equal to the arrangement used in this case so that $DRR = DR$ which means that the luminaire chosen should have a direct-ratio in reference arrangement for $K = 1,5$ of $DRR = 0,64$.

Conclusion: the luminaire data are: $F = 3119 \text{ lm}$

$$.N4 = 1,00$$

$$\text{for } K = 1,5: DRR = 0,64$$

From TABLE VI it follows, by comparing the value of $DRR = 0,64$ with those in the column of $K = 1,50$, that the reference class of the luminaire should be: class 4.

Assume that of the available luminaires having only downward light output ($N4 = 100$), three are suitable for instance in view of customers preference. Each houses 2 lamps of 2500 lm each: $n = 2$; $PHI = 2500$ so $PHIS = 5000 \text{ lm}$. According to the manufacturer's photometric data, the first luminaire has a reference class 4 for $K = 1,50$ and a light output ratio $.N5 = 0,63$; the second luminaire has a reference direct ratio $DRR = 0,65$ for $K = 1,50$ and a light output ratio $.N5 = 0,60$; and the third luminaire a reference direct-ratio $DRR = 0,63$ for $K = 1,5$ and a light output ratio of $.N5 = 0,62$.

7.1.3 Verification

It is now necessary to verify to what extent the selected luminaires are able to satisfy the specified illuminance requirements, i.e. $E1 = 100$, $E3 = 300$ and $E4 = 600 \text{ lux}$.

The total flux of each luminaire: $F = .N5 * 5000 \text{ lm}$.

The installation flux density $FD = NM * F/A4 = 12 * .N5 * 5000/48,6 = 1235 * .N5 \text{ lm/m}^2$.

For the first luminaire: $FD = 1235 * 0,63 = 778 \text{ lm/m}^2$.

Because $N4 = 100$ the reduced downward utilances are also the reduced utilances and these can be read direct from TABLE VIII.5 at column 751 and at the line of class 4:

$RU1 = 0,132$; $RU3 = 0,396$ and $RU4 = 0,774$. The illuminances are:

$$E1 = RU1 * FD = 0,132 * 778 = 103 \text{ lux}$$

$$E3 = RU3 * FD = 0,396 * 778 = 308 \text{ lux}$$

$$E4 = RU4 * FD = 0,774 * 778 = 602 \text{ lux.}$$

For the second luminaire: $FD = 1235 * .N5 = 1235 * 0,60 = 741 \text{ lm/m}^2$ and for the third luminaire: $FD = 1235 * 0,62 = 766 \text{ lm/m}^2$.

From TABLE VI, at column $K = 1,50$, the range of direct-ratio for class 4 extends from 0,611 to 0,656. The second and third luminaires are therefore both of reference class 4 and the utilances used to calculate the illuminances are the same as for the first luminaire.

1)

DFD is slightly greater than FD: $DFD/FD = 1,001$. This means that more light should be emitted downward than in total, which can be explained by the fact that the light reflected by the walls and the working plane to the ceiling exceeds the required 100 lm/m^2 .

Thus for the second luminaire, the illuminances will be:

$$E1 = 0,132 * 741 = 98; E3 = 0,396 * 741 = 293; E4 = 0,774 * 741 = 574 \text{ lux}$$

and for the third luminaire:

$$E1 = 0,132 * 766 = 101; E3 = 0,396 * 766 = 303 \text{ and } E4 = 0,774 * 766 = 593 \text{ lux.}$$

For the second and third luminaires a more accurate calculation could be made by using not the utilisation tables, but the expressions 4.4.3, the coefficients for which are given in TABLE II.5 at the line 751:

$$1,103; -0,865; -0,166/0,333; 0,640; -0,910/0,497; 0,186; 0,730.$$

According to these headings in the table:

$$RU1 = 1,103 - 0,865 - 0,166 * DR$$

$$RU3 = 0,333 + 0,640 - 0,910 * DR$$

$$RU4 = 0,497 - 0,186 + 0,730 * DR$$

For the second luminaire $DR = 0,65$ so that:

$$RU1 = 0,130; RU3 = 0,382; RU4 = 0,786. \text{ Since } FD = 741, \text{ it follows:}$$

$$E1 = 96; E3 = 283; E4 = 582 \text{ lux.}$$

For the third luminaire: $DR = 0,63; FD = 766 \text{ lm/m}^2$ and: $E1 = 103; E3 = 306$ and

$E4 = 591 \text{ lux}$. It should be noted that the latter results for the second and third luminaires cannot be compared with those for the first luminaire. This is because the exact DRR of the first luminaire is not known, only that $0,611 < DRR \leq 0,656$ the range of DRR corresponding to its reference class, which is 4. The differences that could result are:

$$E1 = 106 \rightarrow 100 \text{ lux}$$

$$E3 = 324 \rightarrow 293 \text{ lux}$$

$$E4 = 589 \rightarrow 615 \text{ lux.}$$

7.2 An Installation with Luminaires Not in Reference Arrangement

Assume that it is required to select ceiling mounted luminaires which in an interior of $5,4 \times 9 \text{ m}$ having a ceiling height of 3 m will give illuminances at the ceiling, walls and working plane:

$$E1 = 100 \text{ lux}$$

$$E3 = 300 \text{ lux}$$

$$E4 = 600 \text{ lux}$$

The working plane is taken to be at $0,75 \text{ m}$ above the floor. In view of the location of the work positions, the installation should have three continuous rows of luminaires running in the length of the interior, two of these to be as close as possible to the walls and the third in the middle.

The reflectances of ceiling, walls and working plane are:

$$R1 = 0,7, R3 = 0,5 \text{ and } R4 = 0,1 \text{ respectively.}$$

7.2.1 General

The situation is illustrated in the sketch of fig. 7.2. The mounting height of the installation $H3 = 3 - 0,75 = 2,25 \text{ m}$.

The width $A = 5,4 \text{ m}$, the length $B = 9 \text{ m}$;

$$\text{The room index } K = \frac{A * B}{H3 * (A + B)} = \frac{5,4 * 9}{2,25 * (5,4 + 9)} = 1,50; J = 0$$

The reflectances $R1 = 0,7; R3 = 0,5$ and $R4 = 0,1$. This reflectance combination is coded as 751.

$$E1 = 100; E3 = 300 \text{ and } E4 = 600 \text{ lux.}$$

$$A4 = 5,4 \times 9 = 48,6 \text{ m}^2.$$

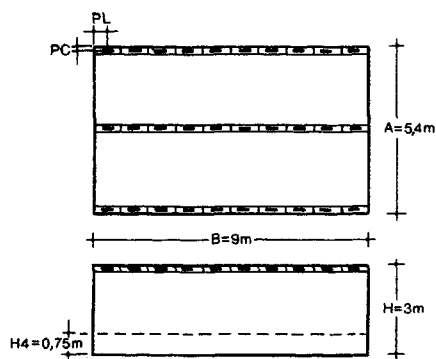


Fig. 7.2 Projected ceiling and cross section of interior

For $M = 40$; $N = 3$:

PM = 0,10	PN = 0,10	:	CORR = 0,87	}	+	PM = 0,05; PN = 0,10	CORR = 0,86
PM = 0,60	PN = 0,10	:	CORR = 0,93				
PM = 0,10	PN = 0,45	:	CORR = 1,01	}	+	PM = 0,05; PN = 0,45	CORR = 1,00
PM = 0,60	PN = 0,45	:	CORR = 1,09				
							↓
							PM = 0,05; PN = 0,05 CORR = 0,84.

The correction factor to be used for the direct ratio is thus: CORR = 0,84.

This correction factor is based on the use of 40 luminaires per row, but the results will in fact not be affected if a luminaire is chosen that consists of a number of these luminaires together.

7.2.2 Design

The same MR coefficients (TABLE III.5, line 751) as were used in the previous example are used again here to give (as in 7.1.2):

$$FD = 770 \text{ lm/m}^2; \quad DFD = 771 \text{ lm/m}^2; \quad FD4 = 494 \text{ lm/m}^2.$$

Now, instead of calculating the flux per luminaire, the length of the continuous rows of luminaires ($3 \times 9 = 27 \text{ m}$) is used to calculate the flux per metre length of luminaire $F^1 = FD \cdot A4/27 = 1386 \text{ lm/m}^1$. The lower flux fraction of the installation:

$$N4 = DFD/FD = 1,00^{1)}. \quad \text{The direct ratio of the installation must be: } DR = FD4/DFD = 0,64.$$

In reference arrangement, the direct ratio of the luminaire to be selected should be:

$$DRR = DR/CORR = 0,64/0,84 = 0,76.$$

From TABLE VI it follows that for $K = 1,50$ an installation with $DR = 0,76$ is a class 1 installation, so that the luminaire reference class should be class 1.

Assume that two luminaires are available with reference class 1 for $K = 1,50$ having no emission in the upper hemisphere: the first luminaire houses 1 lamp of 2500 lm, and has a light output ratio, $N5 = 0,60$ and a length $\ell = 1,25 \text{ m}$: the second luminaire houses 1 lamp of 4000 lm, has a light output ratio $N5 = 0,58$ and a length $\ell = 1,50 \text{ m}$.

The flux per metre length for the first luminaire (type A 140 from fig. C.1)

$$F^1 = 2500 \cdot 0,6/1,25 = 1200 \text{ lm/m}^1 \text{ and for the second (type A 165 from fig. C.1)}$$

$$F^1 = 4000 \cdot 0,58/1,50 = 1547 \text{ lm/m}^1.$$

1) see note 7.1.2.

7.2.3 Verification

Illuminances specified: $E1 = 100$, $E3 = 300$ and $E4 = 600$ lux.

- a) First luminaire: 7 can be installed per row giving $NM = 3 * 7 = 21$ in total for the installation. The installation flux density $FD = NM * F/A4 = NM * N5 * PHIS/A4 = 21 * 0,6 * 2500 / 48,6 = 648 \text{ lm/m}^2$.
The direct ratio $DR = DRR * CORR$. For class 1 and $K = 1,5$: $DRR = 0,769$ (TABLE VI); as explained in 7.2.1: $CORR = 0,84$, so that $DR = 0,769 * 0,84 = 0,65$. From TABLE VI it follows that the installation is class 4 (because $0,611 < 0,65 \leq 0,656$). The utilisation values needed for the calculation of the illuminances should therefore be read from TABLE VIII.5 at column 751 and line class 4: $RU1 = 0,132$; $RU3 = 0,396$; $RU4 = 0,774$.

Giving the illuminances:

$$E1 = RU1 * FD = 0,132 * 648 = 86 \text{ lux}$$

$$E2 = RU3 * FD = 0,396 * 648 = 257 \text{ lux}$$

$$E4 = RU4 * FD = 0,774 * 648 = 502 \text{ lux}$$

- b) Second luminaire: 6 can be installed per row giving $NM = 6 * 3 = 18$ in total. The installation flux density: $FD = NM * PHIS/A4 = 18 * 0,58 * 4000/48,6 = 859 \text{ lm/m}^2$, resulting in illuminances:

$$E1 = 0,132 * 859 = 113 \text{ lux}$$

$$E3 = 0,396 * 859 = 340 \text{ lux}$$

$$E4 = 0,774 * 859 = 665 \text{ lux}.$$

Comparing illuminance values it may be noted that the illuminances obtainable with the first luminaire are lower than those specified and with the second higher. This is to be expected from the values F^1 at the end of the previous section. If neither solution is acceptable, a search for more suitable luminaires is called for.

7.3 An Installation with No Specification of Luminaire Arrangement

Assume that it is required to select ceiling mounted luminaires which in an interior of $5,4 * 9 \text{ m}$ having a ceiling height of 3 m will give illuminances at the ceiling, walls and working plane:

$$E1 = 100 \text{ lux}$$

$$E3 = 300 \text{ lux}$$

$$E4 = 600 \text{ lux}.$$

The working plane is taken to be $0,75 \text{ m}$ above the floor. The reflectances of ceiling, walls and working plane are: $R1 = 0,7$; $R3 = 0,5$ and $R4 = 0,1$ respectively.

General

The situation is illustrated in the sketch of fig. 7.3

The mounting height of the installation $H3 = 3 - 0,75 = 2,25 \text{ m}$.

The width $A = 5,4 \text{ m}$, the length $B = 9 \text{ m}$;

$$\text{The room index } K = \frac{A * B}{H3 * (A + B)} =$$

$$\frac{5,4 * 9}{2,25 * (5,4 + 9)} = 1,50$$

The reflectances $R1 = 0,7$; $R3 = 0,5$ and $R4 = 0,1$.

This combination is coded as 751.

7.3.1

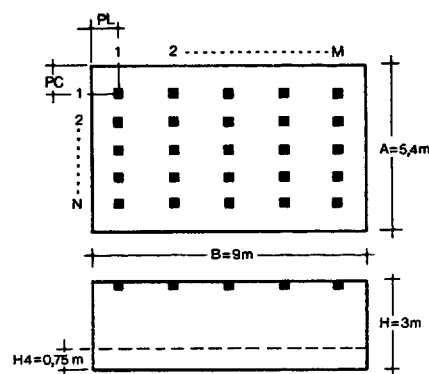


Fig. 7.3 Projected ceiling and cross section of the interior

The number of the luminaires is NM.

The area of the working plane $A_4 = 5,4 * 9 = 48,6 \text{ m}^2$.

$E_1 = 100$; $E_3 = 300$ and $E_4 = 600 \text{ lux}$.

7.3.2 Design

The MR coefficients and the resultant flux densities remain the same as in the previous examples:

$FD = 770 \text{ lm/m}^2$; $DFD = 771 \text{ lm/m}^2$; $FD_4 = 494 \text{ lm/m}^2$.

Lower flux fraction required of the luminaires: $N_4 = 1,00$ ¹⁾

Direct ratio: $DR = FD_4/DFD = 0,64$.

From TABLE VI it follows that the installation should be of class 4, i.e.

$0,611 < DRR \leq 0,656$.

One approach would be to use reference class 4 luminaires in reference arrangement, which means that (according to TABLE VI) $M = 4$ and $N = 3$. The flux emitted by these luminaires should then be $F = FD * A_4/NM = 770 * 48,6/3 * 4 = 3119 \text{ lm}$.

Alternatively, these class 4 luminaires could be employed in a non-reference arrangement to which the appropriate correction factor has been applied. For the case in question ($0,611 < DRR \leq 0,656$) the correction factor would lie between 1,05 (i.e. $0,64/0,611$) and 0,98 (i.e. $0,64/0,656$). From TABLE V.5 it follows that for each value of N and M proximities can be chosen such that the correction factor lies between 0,98 and 1,05, which means that there is no restriction on the number of luminaires to be used.

But assume that for some reason or another it is preferred to use a luminaire, for $K = 1,50$, of reference class 3. From TABLE VI it follows that the upper limit of class 3 for $K = 1,50$ is 0,701, so that the arrangements that can be used with a luminaire of reference class 3 lie between $CORR = 0,64/0,701 = 0,91$ and $CORR = 0,98$. From the tabulated values of the correction factors in TABLE V.5 it follows that again most of the values of N and M can be used, on condition that the proper values of PL and PC are chosen. Compared to the luminaires with reference class 4, those with reference class 3 must be mounted closer to the walls. Similarly it follows that when for any reason it is preferred to use a luminaire with a class 5, the luminaire should then be moved towards the centre.

The above point can be illustrated by taking the following three luminaires given in fig. C.2:

B240 with $F = 2900 \text{ lm}$ and $DRR = 0,69$ for $K = 1,50$

C240 " $F = 3200 \text{ lm}$ " $DRR = 0,64$ for $K = 1,50$

D240 " $F = 3100 \text{ lm}$ " $DRR = 0,57$ for $K ; 1,50$

From TABLE VI it follows that the luminaire reference classes are 3,4 and 5 respectively.

Required $FD = 770 \text{ lm/m}^2$. Required number of luminaires $MN = FD * A_4/F$;

for B240 $MN = 770 * 48,6/2900 = 12,9 \approx 4 * 3$; $CORR = 0,64/0,69 = 0,93$

for C240 $MN = 770 * 48,6/3200 = 11,7 \approx 4 * 3$; $CORR = 0,64/0,64 = 1,00$

for D240 $MN = 770 * 48,6/3100 = 12,1 \approx 4 * 3$; $CORR = 0,64/0,57 = 1,12$

Thus for B240:

if $M = 4$ and $N = 3$; $CORR = 0,93$ then e.g. $PM = 0,35$; $PN = 0,35$

for C240: $M = 4$ and $N = 3$ then e.g. $PM = 0,60$; $PN = 0,35$

for D240: $M = 4$ and $N = 3$ " " $PM = 1,60$; $PN = 0,35$

or $PM = 0,75$; $PN = 0,70$

¹⁾ see note 7.1.2

7.3.3 Verification

Luminaire B240: $M = 4$, $N = 3$; $PM = 0,35$; $PN = 0,35$. From TABLE V.5, after interpolation: $CORR = 0,93$; $DRR = 0,69$ so $DR = CORR * DRR = 0,64$; $N4 = 1,00$; $F = 2900 \text{ lm}$; $A4 = 48,6 \text{ m}^2$.

According to TABLE II.5, with the coefficients from line 751:

$$RU1 = 1,103 - 0,865 - 0,166 * 0,64 = 0,132$$

$$RU3 = 0,333 + 0,910 - 0,910 * 0,64 = 0,391$$

$$RU4 = 0,497 - 0,186 + 0,730 * 0,64 = 0,778$$

$$FD = NM * F/A4 = 4 * 3 * 2900/48,6 = 716 \text{ lm/m}^2$$

The illuminances are:

$$E1 = RU1 * FD = 0,132 * 716 = 95 \text{ lux}$$

$$E3 = RU3 * FD = 0,391 * 716 = 280 \text{ lux}$$

$$E4 = RU4 * FD = 0,778 * 716 = 560 \text{ lux}$$

Luminaire C240: $M = 4$; $N = 3$; $PM = 0,60$; $PN = 0,30$;

After interpolation in TABLE V.5: $CORR = 1,00$; $DRR = 0,64$ so $DR = 0,64$; $N4 = 1,00$;

$F = 3200 \text{ lm}$; $A4 = 48,6 \text{ m}^2$.

Again, as for B240: $DR = 0,64$ and $RU1 = 0,132$; $RU3 = 0,391$ and $RU4 = 0,778$;

$$FD = NM * F/A4 = 4 * 3 * 3200/48,6 = 790 \text{ lm/m}^2$$

The illuminances are:

$$E1 = RU1 * FD = 0,132 * 790 = 105 \text{ lux}$$

$$E3 = RU3 * FD = 0,391 * 790 = 310 \text{ lux}$$

$$E4 = RU4 * FD = 0,778 * 790 = 615 \text{ lux}$$

Luminaire D240: $M = 4$; $N = 3$; $PM = 0,75$; $PN = 0,70$ → $CORR = 1,12$.

$FD = 4 * 3 * 3100/48,6 = 765 \text{ lm/m}^2$, and the illuminances:

$$E1 = RU1 * FD = 0,132 * 765 = 100 \text{ lux}$$

$$E3 = RU3 * FD = 0,391 * 765 = 300 \text{ lux}$$

$$E4 = RU4 * FD = 0,778 * 765 = 595 \text{ lux}$$

All illuminances are rounded off to multiples of 5 lux.

From the verification for these three cases it can be seen that all solutions lead to the required result, on condition that the correct proximities are respected: the smaller the class number, the nearer the outer rows of luminaires should be mounted to the walls. An extreme case has been considered in the example 7.2, where the luminaires were mounted against the walls resulting in the use of luminaires with reference class 1.

7.4 An Installation with Unspecified Geometry

Assume that it is required to select and arrange luminaires for an interior of $5,4 * 9 \text{ m}$ having a ceiling height of 3 m to give illuminances at the ceiling, walls and working plane:

$$E1 = 100 \text{ lux}$$

$$E3 = 300 \text{ lux}$$

$$E4 = 600 \text{ lux}$$

The working plane is taken to be at 0,75 m above the floor.

The reflectances of ceiling, walls and working plane are: $R1 = 0,7$; $R3 = 0,5$ and $R4 = 0,1$ respectively.

7.4.1 General

The situation is illustrated in the sketch of fig. 7.4

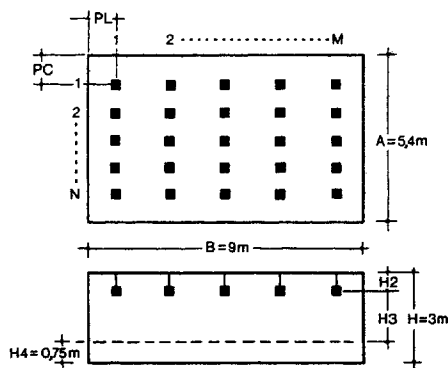


Fig. 7.4 Projected ceiling and cross section of the interior

The Luminaires are to be suspended at a distance H_2 from the ceiling; the mounting height H_3 is then equal to $H_3 = H - H_2 - 0,75 = 2,25 - H_2$. According to its definition the suspension ratio J is then equal to

$$J = H_2 / (H_2 + H_3) = H_2 / 2,25$$

Since the width of the room $A = 5,4$ m and the length of the room $B = 9$ m, the room index

$$K = \frac{A * B}{(H_2 + H_3) (A + B)} * \frac{1}{(1 - J)}$$

$$= \frac{5,4 * 9}{2,25 * (5,4 + 9)} * \frac{1}{(1 - J)} = \frac{1,5}{(1 - J)}$$

The number of luminaires lengthwise is N and crosswise M . The proximities lengthwise and crosswise are PL and PC respectively.

The reflectances are $R_1 = 0,7$; $R_2 = R_3 = 0,5$ and $R_4 = 0,1$. This reflectance combination is coded as 751 for $J = 0$ and as 7551 for $J \neq 0$. The illuminances required are:

$E_1 = 100$; $E_3 = 300$ and $E_4 = 600$ lux.

7.4.2 Design

Since the geometry of the installation is not specified, many solutions will be possible. The range of admissible suspension height ratios will be considered first.

In order that the suspended luminaires should not prove a hindrance at the work position they should be no lower than say 0,75 m above the working plane. However, because of the need to establish a certain uniformity of illuminance at the working plane the average spacing to mounting height ratio should be limited to say 1,6 giving an average spacing of $1,6 * 0,75 = 1,20$ m. But this will not leave sufficient space to move freely upright through the interior. In practice, therefore, it would seem more reasonable to make the height of the luminaires above the floor sufficient for this purpose, e.g. 2,10 m. If this figure is accepted, the mounting height becomes $H_3 = 2,10 - 0,75 = 1,35$ m resulting in a maximum admissible average spacing of $1,6 * 1,35 = 2,16$ m and a minimum admissible number of luminaires of $NM = A * B / (2,16)^2 = 10,4$, say $NM = 12$. The maximum suspension ratio to be considered will then be $J = (H - H_3 - H_4) / (H - H_4) = 0,9 / 2,25 = 0,40$ and the maximum room index $K = 1,5 / (1 - 0,40) = 2,5$.

The other extreme case is that of ceiling mounted luminaires which means $J = 0$ and $K = 1,5$. Since between $K = 1,5$ and $K = 2,5$, $K = 2,0$ is given as an entry to the table, the calculations of the required flux densities will be made for $K = 1,5$; 2,0 and 2,5.

For $K = 2,0$ follows $J = 1 - 1,5/K = 0,25$.

The required illuminances are $E_1 = 100$, $E_3 = 300$ and $E_4 = 600$ lux.

$K = 1,5$, $J = 0$, consult TABLE III.5 line 751

$$FD = (300 * 100 + 667 * 300 + 900 * 600) / 1000 = 770 \text{ lm/m}^2$$

$$DFD = (-700 * 100 + 893 * 300 + 955 * 600) / 1000 = 771 \text{ lm/m}^2$$

$$FD_4 = (-383 * 100 - 227 * 300 + 1000 * 600) / 1000 = 494 \text{ lm/m}^2$$

$$\text{so that } DR = FD_4 / DFD = 0,64$$

$$N_4 = DFD / FD = 1,00$$

$$FD = 770 \text{ lm/m}^2$$

K = 2, J = 0,25, consult TABLE III.6 line 751 for J = 0
and TABLE III.18 line 7551 for J = 0,333.

$$\begin{aligned} FD &= (300 * 100 + 500 * 300 + 900 * 600) / 1000 = 720 \text{ lm/m}^2 \\ DFD &= (-700 * 100 + 684 * 300 + 963 * 600) / 1000 = 713 \text{ lm/m}^2 \\ FD4 &= (-442 * 100 - 184 * 300 + 1000 * 600) / 1000 = 501 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} J = 0: \quad DR &= FD4 / DFD = 0,70 \\ .N4 &= DFD / FD = 0,99 \\ FD &= 720 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} FD &= (550 * 100 + 500 * 300 + 900 * 600) / 1000 = 745 \text{ lm/m}^2 \\ DFD &= (-658 * 100 + 684 * 300 + 963 * 600) / 1000 = 717 \text{ lm/m}^2 \\ FD4 &= (-418 * 100 - 184 * 300 + 1000 * 600) / 1000 = 503 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} J = 0,333: \quad DR &= FD4 / DFD = 0,70 \\ .N4 &= DFD / FD = 0,96 \\ FD &= 745 \text{ lm/m}^2 \end{aligned}$$

By interpolation follows for J = 0,25:

$$\begin{aligned} DR &= 0,70 \\ .N4 &= 0,97 \\ FD &= 739 \text{ lm/m}^2 \end{aligned}$$

K = 2,5, J = 0,40: consult TABLE III.7 line 751 for J = 0
and TABLE III.19 line 7551 for J = 0,333

$$\begin{aligned} FD &= (300 * 100 + 400 * 300 + 900 * 600) / 1000 = 690 \text{ lm/m}^2 \\ DFD &= (-700 * 100 + 555 * 300 + 969 * 600) / 1000 = 678 \text{ lm/m}^2 \\ FD4 &= (-483 * 100 - 155 * 300 + 1000 * 600) / 1000 = 505 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} J = 0: \quad DR &= FD4 / DFD = 0,75 \\ .N4 &= DFD / FD = 0,98 \\ FD &= 690 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} FD &= (500 * 100 + 400 * 300 + 900 * 600) / 1000 = 710 \text{ lm/m}^2 \\ DFD &= (-665 * 100 + 555 * 300 + 969 * 600) / 1000 = 681 \text{ lm/m}^2 \\ FD4 &= (-460 * 100 - 155 * 300 + 1000 * 600) / 1000 = 508 \text{ lm/m}^2 \end{aligned}$$

$$\begin{aligned} J = 0,333: \quad DR &= FD4 / DFD = 0,75 \\ .N4 &= DFD / FD = 0,96 \\ FD &= 710 \text{ lm/m}^2 \end{aligned}$$

By extrapolation follows for J = 0,4:

$$\begin{aligned} DR &= 0,75 \\ .N4 &= 0,96 \\ FD &= 714 \text{ lm/m}^2 \end{aligned}$$

Summary of the above:

to the suspension ratios
belong: room indices

mounting heights

direct ratios

lower flux fractions

flux densities

J = 0	0,25	0,40
K = 1,5	2,0	2,5
H3 = 2,25	1,69	1,35 m
DR = 0,64	0,70	0,75
.N4 = 1,00	0,97	0,96
FD = 770	739	714 lm/m ²

and according to TABLE VI.

installation classes: Class =	4	4	4
and minimal number of			
luminaires NM min	= 4	8	12
when taking 1,6 as maximum spacing			
to mounting height ratio, from which			
it follows that the maximum luminous			
flux per luminaire	$F_{\max} = 9400$	4500	2900 lm

Consider the luminaire listed in figure C.3.

The luminaires C 240, D 240, E 240 and F 175 have approximately the required direct-ratio values when used in reference arrangement.

For $J = 0$ and $0,25$ C 240 gives the best fit and for $J = 0,40$ F 175 fits best.

a. The solution with ceiling mounted luminaires C 240 has been given already in the preceding examples 7.1 i.e. 12 luminaires in reference arrangement.

b. Take luminaire F 175 with one lamp HID 75 W with an efficacy of 70 lm/W so that $\text{PHI} = 5250 \text{ lm}$ and $F = 0,62 * 5250 = 3255 \text{ lm}$.

The required number of luminaires $\text{NM} = \text{FD} * \text{A4}/F$ varies from $\text{NM} = 770 * 48,6/3255 = 12$ for $J = 0$ to $\text{NM} = 714 * 48,6/3255 = 11$ for $J = 0,4$ so $\text{NM} = 12$ will do throughout.

The direct ratios for reference arrangement read from fig. C.2. for $K = 1,5; 2$ and $2,5$ are $\text{DRR} = 0,58; 0,67$ and $0,73$ resp. whereas required are $\text{DR} = 0,64; 0,70$ and $0,74$ resp. so that the arrangements should be selected with the aid of TABLES V.1 et seq. which have correction factors CORR : $0,64/0,58 = 1,10$; $0,70/0,67 = 1,04$ and $0,74/0,73 = 1,01$ for $M = 4$ and $N = 3$.

For $K = 1,5$; $M = 4$; $N = 3$; $\text{CORR} = 1,10$ for $\text{PM} = \text{PN} = 0,65$ and since $H3 = 2,25$ the luminaires must be mounted at a distance $\text{PL} = \text{PC} = 2,25 * 0,65 = 1,46 \text{ m}$ from the walls. The resulting mean spacing then is 1,59.

For $K = 2,0$; $M = 4$; $N = 3$; $\text{CORR} = 1,04$ for $\text{PM} = \text{PN} = 0,70$ and since $H3 = 1,69$ the proximities are $\text{PL} = \text{PC} = 1,18 \text{ m}$ and the resulting mean spacing is 1,83 m.

In a similar way it follows that for $K = 2,5$ $\text{PL} = \text{PC} = 1,0 \text{ m}$ with a mean spacing of 1,99 m.

The mean proximity to spacing ratios for $K = 1,5; 2,0$ and $2,5$ are:

$1,46/1,59 = 0,92$; $1,18/1,83 = 0,64$ and $1,0/1,99 = 0,5$ resp. For an even distribution of the luminaires above the working plane the mean proximity to spacing ratio is taken to be not greater than 0,6. The solutions with $K = 1,5$ and $K = 2,0$ are thus not acceptable, because the luminaires then are too far from the walls. The only solution that remains is thus for $K = 2,5$ which implies a suspension ratio $J = 0,40$: $M = 4$; $N = 3$; $\text{PL} = \text{PC} = 1,0 \text{ m}$.

c. The luminaire type E 240 is a luminaire with emission in the upper hemisphere.

Take $\text{PHI} = 2500 \text{ lm}$ for the lamps so that $\text{PHIS} = 2 * 2500 = 5000 \text{ lm}$ and

$F = .N5 * \text{PHIS} = 0,66 * 5000 = 3300 \text{ lm}$. The required number of luminaires

$\text{NM} = \text{FD} * \text{A4}/F$ varies from 11,3 for $J = 0$ to 10,5 for $J = 0,4$ so that $\text{NM} = 12$ will do throughout. The direct ratios for the luminaire in reference arrangement for $K = 1,5; 2$ and $2,5$ are 0,58; 0,66 and 0,72. Thus, following a similar approach to that adopted for the type F 175 luminaire, the resulting solution is found to be: type E 240 to be used with $J = 0,4$, $M = 4$, $N = 3$, $\text{PL} = \text{PC} = 1,1 \text{ m}$.

d. Assume that the customer wishes to use the luminaire type B 240 with two lamps of 2500 lm each so that $\text{PHIS} = 5000 \text{ lm}$ and $F = .N5 * \text{PHIS} = 0,58 * 5000 = 2900 \text{ lm}$. The required number of luminaires $\text{NM} = \text{FD} * \text{A4}/F$ varies from 12,9 for $J = 0$ to 12 for $J = 0,4$ so that $\text{NM} = 12$ will do throughout.

The direct ratios for the luminaire in reference arrangement for $K = 1,5$; 2 and 2,5 are 0,69; 0,76 and 0,80 whereas what is required are values 0,64; 0,70 and 0,75 resp. The arrangements should, therefore, be selected from TABLES V.1 et seq. which give correction factors CORR of $0,64/0,69 = 0,93$; $0,70/0,76 = 0,92$ and $0,75/0,80 = 0,94$. From TABLE V mean proximity ratios are determined that correspond with the required values of CORR in a similar way to the previous solution: 0,35; 0,45 and 0,55. Consequently the mean proximities are then: $PL = PC = 0,35 * 2,25 = 0,79$; $PL = PC = 0,45 * 1,69 = 0,76$ and $PL = PC = 0,55 * 1,35 = 0,74$ m resp. for $J = 0$; 0,25 and 0,40.

These luminaires must thus be mounted much closer to the walls than the types F 175 and E 240. It should now be checked whether or not the spacings between the luminaires are too large. It can easily be calculated that the average spacing to mounting height ratios are 0,97; 1,30 and 1,64 for $J = 0$; 0,25 and 0,40 resp. From these values it follows indeed that it might be risky, in view of the need to obtain uniformity of illuminance on the working plane, to use a suspension ratio $J = 0,40$. A suspension ratio of $J = 0,25$ however, could be used. In order to illustrate the variety of solutions possible, consider the suspension ratio $J = 0,25$;
 $M = 4$; $N = 3$; $PL = PC = 0,75$ m.

7.4.3 Verification

- a. Solution a (i.e. 12 luminaires type C 240) has been verified previously in example 7.1:
 $E1 = 104$; $E3 = 309$ and $E4 = 615$ lux.
- b. For solution b (i.e. 12 luminaires type F 175) the installed flux density FD equals the downward flux density DFD: $FD = DFD = NM * .N5 * PHIS/A4 = 12 * 0,62 * 5250/9 * 5,4 = 804$ lm/m². The installed direct flux density $FD4 = DR * DFD = DRR * CORR * DFD$.
 $PL = PC = 1,0$ m; $H3 = 1,35$ m so that $PM = PN = 1,0/1,35 = 0,74$.
 From TABLE V.7 follows for $M = 4$; $N = 3$: $CORR = 1,02$ From the DRR-set follows for $K = 2,5$: $DRR = 0,73$ so that $DR = 0,74$.

The reduced utilances can be calculated by means of the coefficients given in TABLES II et seq. as was done in the previous examples. However, in order to illustrate that the use of TABLES VIII et seq. is not restricted to classifications but that they also can be used for arriving at accurate values, the reduced utilances will be calculated from the values given in these tables.

The direct-ratio values are read at the last column of the appropriate table labelled (reduced) working plane utilance. Using these values, the lines in the tables between which direct-ratio values should be interpolated can be selected. Since $K = 2,5$ the values for $J = 0$ are obtained from TABLE VIII.7 and for $J = 0,33$ from TABLE VIII.19; the direct ratio $DR = 0,74$ so the interpolation must be made between the lines of class 4 and class 5.

The results are:

$J = 0$ $RU1 = 0,129$; $RU3 = 0,443$; $RU4 = 0,872$

$J = 0,33$ $RU1 = 0,108$; $RU3 = 0,435$; $RU4 = 0,858$

from these, extrapolation for $J = 0,40$ gives:

$J = 0,40$ $RU1 = 0,10$; $RU3 = 0,43$ and $RU4 = 0,86$.

Another way of interpolating would be to go from the values for $J = 0$ at $K = 1,5$ and for $J = 0,33$ at $K = 2,25$ to the required values for $J = 0,4$ at $K = 2,5$. The intermediate values are:

from TABLE VIII.5 $J = 0$: $RU1 = 0,114$; $RU3 = 0,299$; $RU4 = 0,852$
 from TABLE VIII.18: $RU1 = 0,100$; $RU3 = 0,364$; $RU4 = 0,848$
 from TABLE VIII.19: $RU1 = 0,108$; $RU3 = 0,435$; $RU4 = 0,858$
 so that for $K = 2,25$ and $J = 0,33$: $RU1 = 0,104$; $RU3 = 0,400$; $RU4 = 0,853$,
 extrapolation for $J = 0,40$ from the values for $J = 0$ and $J = 0,33$ results in:
 $J = 0,40$: $RU1 = 0,10$; $RU3 = 0,42$; $RU4 = 0,85$

A comparison of the end results reveals that these are virtually the same which ever method of interpolation is employed.

The resulting illuminances are:

$E1 = RU1 * FD = 80 \text{ lux}$
 $E3 = RU3 * FD = 340 \text{ lux}$
 $E4 = RU4 * FD = 690 \text{ lux}$.

- c. For solution c (i.e. 12 luminaires type E 240) the installed flux density
 $FD = NM * F/A4 = 12 * 3300/9 * 5,4 = 815 \text{ lm/m}^2$.
 The geometry of the installation is the same as in the previous solution so that
 $CORR = 1,03$ and since $DRR = 0,72$, $DR = CORR * DRR = 0,74$.
 The reduced utilances for $J = 0$ and $K = 2,50$ are calculated using the coefficients
 from TABLES II.7 at the line 751:
 $J = 0$: $RU1 = 0,225$; $RU3 = 0,436$; $RU4 = 0,842$.
 For $J = 0,33$ the coefficients from TABLE II.19 at the line 7551 are used:
 $J = 0,33$: $RU1 = 0,190$; $RU3 = 0,419$; $RU4 = 0,818$
 Extrapolating for $J = 0,4$ gives:
 $J = 0,40$: $RU1 = 0,18$; $RU3 = 0,42$; $RU4 = 0,81$ so that the resulting illuminances
 are:

$E1 = RU1 * FD = 150 \text{ lux}$
 $E3 = RU3 * FD = 350 \text{ lux}$
 $E4 = RU4 * FD = 660 \text{ lux}$

- d. For solution d (i.e. 12 luminaires type B 240, each with a luminaire flux $F = 2900 \text{ lm}$)
 the installed flux density is $FD = NM * F/A4 = 12 * 2900/9 * 5,4 = 716 \text{ lm/m}^2$.
 $J = 0,25$ so that $K = 1,5/(1 - J) = 2,0$ and $H3 = (1 - J)(H2 + H3) = 0,75 * 2,25 = 1,69 \text{ m}$;
 $PL = PC = 0,75 \text{ m}$ so that $PM = PN = 0,75/1,69 = 0,44$. From TABLE V.6 for $M = 4$,
 $N = 3$ and $PM = PN = 0,44$ follows $CORR = 0,92$; from the photometric data the direct
 ratio in reference arrangement for $K = 2,0$ is read: $DRR = 0,76$ so that $DR =$
 $CORR * DRR = 0,70$. The reduced utilances for $K = 2,0$ and $J = 0$ are calculated by
 means of the coefficients from TABLE II.6 at the line 751 and those for $J = 0,33$
 using the coefficients from TABLE II.18 at the line 7551.
 $J = 0$: $RU1 = 0,130$; $RU3 = 0,420$; $RU4 = 0,835$
 $J = 0,33$: $RU1 = 0,105$; $RU3 = 0,410$; $RU4 = 0,819$
 Interpolation for $J = 0,25$ gives:
 $J = 0,25$: $RU1 = 0,11$; $RU3 = 0,41$; $RU4 = 0,82$.
 The illuminances are then:

$E1 = RU1 * FD = 80 \text{ lux}$
 $E3 = RU3 * FD = 290 \text{ lux}$
 $E4 = RU4 * FD = 590 \text{ lux}$

A comparison of the illuminances obtained for the various solutions shows:

- a: $E_1 = 100$; $E_3 = 310$ and $E_4 = 615$ lux $J = 0$
 b: $E_1 = E_2 = 80$; $E_3 = 340$ and $E_4 = 690$ lux $J = 0,4$
 c: $E_1 = E_2 = 150$; $E_3 = 340$ and $E_4 = 660$ lux $J = 0,4$
 d: $E_1 = E_2 = 80$; $E_3 = 290$ and $E_4 = 590$ lux $J = 0,25$

It will be noted that the required ceiling illuminance of 100 lux is in fact only obtained with solution a. This is because for $J = 0$ the required value of $N_4 = 100$ can be found in the selection of luminaires considered. For $J = 0,4$, however, the required value of $N_4 = 96$ and no luminaires with this value are available; a luminaire with $N_4 = 100$ will result in too low an illuminance value, and one with $N_4 = 90$ will give an illuminance E_1 that is too high. For all solutions the ratio obtained for E_4/E_3 is as specified, differences in absolute values being caused by the fact that the number of luminaires NM must be rounded off rather severely.

7.5 Classification of an Installation

The procedure for the classification of an installation is explained in section 4.6. As an illustration two examples will be worked out.

7.5.1 An Installation With Luminaires in Reference Arrangement

Consider an installation of luminaires type C 240 in reference arrangement in an interior of 9 m wide, 15 m long and 3 m high. The working plane is at 0,75 m above the floor. It is requested to determine the installation class.

- a. If the luminaire data are given as in fig. C.3. the class of the installation can be read direct from the luminaire reference class set because the luminaires are used in reference arrangement. Since in the luminaire reference class set the number 4 appears throughout the range of K-values it may be concluded that the installation is class 4.

- b. If the luminaire data are given as in fig. C.2. the first thing to be determined is

the room index $K = \frac{A * B}{H_3 * (A + B)}$ in which $A = 9$; $B = 15$; $H_3 = 3 - 0,75 = 2,25$ so that

$K = 2,5$. From fig. C.2. follows for $K = 2,5$ and luminaire C 240: $DRR = 0,77$.

Because the luminaires are used in reference arrangement $DR = DRR = 0,77$. From TABLE VI follows that the installation is class 4 because $0,746 < 0,77 \leq 0,781$ in which 0,746 and 0,781 are the direct-ratio limits of class 4 for $K = 2,5$.

- c. If the luminaire data are given as in fig. C.1., the flux triplet is read from the flux code 56 83 95. In order to determine the direct-ratio in reference arrangement, the geometric multipliers must be read from TABLE IV, which means that first the room index has to be determined:

$K = \frac{A * B}{H_3 * (A + B)}$ in which $A = 9$; $B = 15$; $H_3 = 3 - 0,75 = 2,25$ so that $K = 2,5$.

The geometric multipliers to be used are:

$GM_1 = 0,301$; $GM_2 = 0,190$; $GM_3 = 0,469$; and $GM_4 = -0,002$.

It follows that $DRR = GM_1 * N_1 + GM_2 * N_2 + GM_3 * N_3 + GM_4 =$
 $= 0,301 * 0,56 + 0,190 * 0,83 + 0,469 * 0,95 - 0,002 = 0,77$.

Because the luminaires are used in reference arrangement $DR = DRR = 0,77$. From TABLE VI follows that the installation is class 4 because $0,746 < 0,77 \leq 0,781$ in which 0,746 and 0,781 are the direct-ratio limits of class 4 for $K = 2,5$.

7.5.2 An Installation with Luminaires in a Given Arrangement

Consider an installation of luminaires type C 240 in an interior of 9 m wide, 15 m long and 3 m high. The working plane is at 0,75 m above the floor. The outer luminaire centres are mounted at 0,50 m from the short walls and at 1,00 m from the long walls. The number of luminaires lengthwise is 6, the number of luminaires crosswise is 4. It is requested to determine the class of the installation.

The class of the installation depends on the direct-ratio of the installation at the room index of the interior. The direct-ratio is the product of the direct-ratio in reference arrangement and the correction factor for non-reference arrangement:

$$DR = DRR * CORR.$$

The classification procedure is to determine the room index K and the correction factor CORR first:

$$K = \frac{A * B}{H3 * (A + B)} \quad \text{in which } A = 9; B = 15; H3 = 3 - 2,25 = 0,75 \text{ so that } K = 2,5.$$

The proximity lengthwise PL = 0,5 and the proximity crosswise PC = 1,0 m so that

$$PM = PL/H3 = 0,22 \text{ and } PN = PC/H3 = 0,44; M = 6 \text{ and } N = 4.$$

From TABLE V.7 for M = 6 and N = 4:

PM	0,10	0,60	0,22	
PN = 0,10	0,80	0,89	0,82	
PN = 0,60	0,93	1,02	0,95	→ PN = 0,44 CORR = 0,91.

- If the luminaire data are as given in fig. C.3. the class of the installation with the luminaires in reference arrangement is class 4. The reference direct-ratio for a class 4 installation for K = 2,5 is DRR = 0,764 so that DR = DRR * CORR = 0,764 * 0,91 = 0,70 which is a class 6 installation because 0,669 < 0,70 ≤ 0,712 in which 0,669 and 0,712 are the reference direct-ratio limits for class 6 at K = 2,5.
- If the luminaire data are as given in fig. C.2. the direct-ratio of the installation with the luminaires in reference arrangement is read: DRR = 0,77 for K = 2,5. DR = DRR * CORR = 0,70, which is a class 6 installation as follows from TABLE VI because 0,669 < 0,70 ≤ 0,712 in which 0,669 and 0,712 are the reference direct-ratio limits for class 6 at K = 2,5.
- If the luminaire data are given as fig. C.1., the flux triplet is read from the flux code: 56 83 95, which means .N1 = 0,56; .N2 = 0,83 and .N3 = 0,95. The direct-ratio of the installation with the luminaires in reference arrangement

$$DRR = GM1 * .N1 + GM2 * .N2 + GM3 * .N3 + GM4$$
in which the geometric multipliers GM1, GM2, GM3 and GM4 are taken from TABLE IV at K = 2,5.

$$DRR = 0,301 * 0,56 + 0,190 * 0,83 + 0,469 * 0,95 - 0,002 = 0,77;$$

$$DR = DRR * CORR = 0,77 * 0,91 = 0,70.$$
From TABLE VI follows that the installation is class 6 because 0,669 < 0,70 ≤ 0,712 in which 0,669 and 0,712 are the reference direct-ratio limits for class 6 at K = 2,5.

7.6 Classification of Luminaires

If the class numbers contained in the luminaire reference class set of a luminaire are constant the luminaire is said to be of the class as given by that number. In general it may be noted that the flux triplet of that luminaire then is similar to one of the flux triplets given in TABLE VII. In many cases classification can be done much faster by comparing the luminaire's flux triplet with those given in TABLE VII. However if the identifiers .N1, .N2 and .N3 are near opposite limits of a class the procedure described above has to be followed to see whether the luminaire reference class set contains one constant number indeed.

7.6.1 The Luminaire Reference Class Set

Consider luminaire type F 175 from fig. C.1. Its flux triplet is read as: 43 79 97. For each of the usual series of room index values the reference direct-ratio can be calculated by using the geometric multipliers as given in TABLE IV. The expression to be used is: $DRR = GM1 \cdot .N1 + GM2 \cdot .N2 + GM3 \cdot .N3 + GM4$. The values of DRR then are compared with the reference direct ratio values of the various class limits as given in TABLE VI. From this comparison follows the determination of the reference class. See the last three columns of the table below.

K	GM1	.N1	GM2	.N2	GM3	.N3	GM4	DRR	>	≤	→	RC
		0,43		0,79		0,97						
0,6	0,943		-0,318		0,145		-0,027	0,27	0,247	0,284		6
0,8	0,752		-0,033		0,082		-0,016	0,36	0,325	0,365		6
1,00	0,636		0,120		0,089		-0,015	0,44	0,437	0,489		5
1,25	0,510		0,238		0,131		-0,016	0,52	0,509	0,558		5
1,50	0,429		0,274		0,202		-0,018	0,58	0,566	0,611		5
2,00	0,338		0,263		0,343		-0,014	0,67	0,653	0,692		5
2,50	0,301		0,190		0,469		-0,002	0,73	0,712	0,746		5
3,00	0,282		0,118		0,562		0,016	0,78	0,756	0,786		5
4,00	0,256		-0,005		0,682		0,061	0,83	0,809	0,834		5
5,00	0,245		-0,095		0,745		0,108	0,86	0,844	0,864		5

The reference class set then follows to be:

6/6/5/5/5/5/5/5/5

See also fig. C.3.

7.6.2 The Luminaire Class

Consider the luminaires A 140 and E 240 given in fig. C.3.

- a. type A 140 with flux triplet 78 96 98.

The characteristic zonal flux values of the centre and its limits of class 1

(see TABLE VII) are: upper limit: 0,800; 0,973; 0,985

centre : 0,764; 0,951; 0,980

lower limit: 0,728; 0,928; 0,976

from comparing these values with those of the identifiers $.N1 = 0,78$; $.N2 = 0,96$ and $.N3 = 0,98$ follows that the identifiers each are in the range of the corresponding characteristic zonal flux values and not near opposite limits so that it may be concluded that the luminaire is class 1. Indeed when calculating the luminaire reference class set follows a set containing nothing but class numbers 1.

- b. type E 240 with flux triplet 44 77 95.

The characteristic zonal flux values of the limits of class 5 are (see TABLE VII):

upper limit: 0,510; 0,795; 0,947

lower limit: 0,438; 0,750; 0,938

The identifiers of the flux triplet: $.N1 = 0,44$; $.N2 = 0,77$ and $.N3 = 0,95$.

The values of $.N1$ and $.N2$ are within the range of the corresponding characteristic zonal flux values. Considering that the value 0,95 is a rounded off value for the range of values between 0,945 and 0,955 it could be that the value of $.N3$ should be counted to lie within the range of values between 0,938 and 0,947.

However then the identifier .N3 is near the upper limit, whereas the first identifier .N3 is near the lower limit so that it should be checked by calculating the luminaire reference class set.

The latter is given in figure C.3 from which follows that the class number is not constant so that the luminaire cannot be classified by a single luminaire class number.

7.7 Determination of the Correction Factor for the Direct Ratio

Correction factors for the calculation of the direct ratio of installations with an arbitrary regular, rectangular arrangement of the luminaires are given in TABLES V.1 et seq. The direct-ratio then is obtained by multiplying the correction factor with the direct ratio of an installation with the luminaires in reference arrangement:

$$DR = CORR * DRR.$$

However, the direct-ratio could have been calculated by following the procedure of the Basic Method. The disadvantage of the use of the Basic Method is that the procedure is rather lengthy. An advantage of the use of the Basic Method is that no approximation is made with regard to the flux distribution of the luminaires, whereas when using the tabulated values of the correction factors, the influence of the flux distribution is disregarded.

In this section the use of both ways will be illustrated by means of an example. The effect of the flux distribution of the luminaires will be illustrated by calculating the correction factors for the flux distribution of the 10 luminaire classes given in TABLE VII.

Consider an interior with a width $A = 5,4$ m, a length $B = 9$ m, a height $H = 3$ m and take the working plane at a height above the floor $H_4 = 0,75$ m. The installation is taken to consist of $M = 4$ luminaires lengthwise, $N = 3$ luminaires crosswise and proximity ratios $PM = PN = 0,2$.

$$\text{The room index } K = \frac{A * B}{H_3 * (A + B)} = 1,50.$$

7.7.1 Calculation by means of correction factor tables

$K = 1,50$ and therefore the correction factor must be obtained from TABLE V.5 by interpolation for $M = 4$, $N = 3$:

PM =	0,10	0,60	0,20	
PN = 0,10	0,77	0,89	→ 0,79	} → PN = 0,20: <u>CORR = 0,84</u>
PN = 0,45	0,90	1,04	→ 0,93	

7.7.2 Calculation by means of the Basic Method

$A = 5,4$ m, $B = 9$ m, so that $A/H_3 = 5,4/2,25 = 2,40$ and $B/H_3 = 9/2,25 = 4,0$

$M = 4$; $N = 3$; $PM = PN = 0,2$.

Of the rectangles for which the geometric multipliers must be read from TABLES I et seq. the sides will be expressed in ratios of the mounting height. It will be clear that only 12 different rectangles need to be considered, each of which must be counted four times. The average geometric multipliers are obtained by dividing the sum of the four folds of geometric multipliers by the number of the luminaires $NM = 12$.

The same result will be obtained when dividing the sums of the geometric multipliers for the 12 different rectangles by 3. For the luminaires in the corners the following side ratios of the rectangles must be considered: 0,2; 0,2; (2,4 - 0,2); (4,0 - 0,2). For other luminaires of the outer row along the long wall the side ratios to be

considered are: 0,2; $0,2 + \frac{4 - 2 * 0,2}{4 - 1}$; (2,4 - 0,2) and $0,2 + 2 * \frac{4 - 2 * 0,2}{4 - 1}$.

For the luminaires near the end walls at the centre line parallel to the long walls, the side ratios to be considered are: 2,4/2; 0,2; (4,0 - 0,2).

For the remaining luminaires the side ratios to be considered are:

$\frac{2,4}{2}$; $0,2 + \frac{4 - 2 * 0,2}{4 - 1}$; $0,2 + 2 * \frac{4 - 2 * 0,2}{4 - 1}$.

The geometric multipliers read from TABLES I.1 et seq. for the various side ratios are given in the table below which is concluded by the resulting average geometric multipliers:

Short side ratio	long side ratio	GM1	GM2	GM3	GM4
0,2	0,2	88	-62	27	-5
0,2	3,8	128	-53	41	-5
0,2	2,2	127	-44	33	-6
2,2	3,8	-18	89	180	-4
0,2	1,4	135	-45	25	-5
0,2	2,6	127	-47	36	-6
1,4	2,2	-2	217	37	-3
2,2	2,6	-33	146	142	-9
0,2	1,2	141	-50	25	-5
1,2	3,8	38	152	64	1
1,2	1,4	62	216	-27	4
1,2	2,6	29	186	38	-2
		— +	— +	— +	— +
	Totals:	822	705	621	-45
	/3:	274	235	207	-15

average geometric multipliers: 0,274 0,235 0,207 -0,015

By means of the characteristic zonal flux values as given in TABLE VII for the 10 luminaire classes, the direct-ratio for installations with these luminaires can be calculated by means of the expression:

$$DR = GM1 * .N1 + GM2 * .N2 + GM3 * .N3 + GM4.$$

The correction factor COR = DR/DRR for these flux distributions can easily be calculated because the DRR values can be read from table VI:

Luminaire class	DR	DRR	COR
1	0,621	0,769	0,81
2	0,588	0,724	0,81
3	0,556	0,679	0,82
4	0,524	0,634	0,83
5	0,491	0,588	0,84
6	0,461	0,546	0,84
7	0,417	0,492	0,85
8	0,368	0,431	0,85
9	0,326	0,378	0,86
10	0,281	0,319	0,88

Comparing the values of COR with the value of CORR = 0,84 it will be noted that indeed the influence of the flux distribution which is greatly affecting the value of the direct-ratio does affect the correction factor to a much lesser extent.

8. EXISTING METHODS

As indicated already in the Introduction 1.1, methods as they exist and as they are used in practice will in general lead to the same result within their domain of validity and within the accuracy limits. The principles of various methods and their domain of validity will be outlined in this section. For some examples, the results obtained using the various methods considered are given in a table in 8.7 illustrating the extent of agreement between them.

8.1 Utilization Factor Tables

A utilization factor table for each luminaire in his range is provided by the luminaire manufacturer. Using such tables, the average illuminances at the working plane can be calculated. Each table can only be used for the luminaire and the installation geometry specified. Within their domain of validity, utilization factor tables give the most specific results in the fastest way.

The calculation procedure is perfectly straight forward:

Taking E_4 = the illuminance at the working plane
 $PHID$ = the lamp flux density
 UF = the utilization factor
 and NM = the number of luminaires
 n = the number of lamps per luminaire
 PHI = the nominal luminous flux of the lamp
 A_4 = the area of the working plane
 then $PHID = NM * n * PHI / A_4$
 so $E_4 = PHID * UF$

The way in which to calculate a utilization factor table for a given luminaire is explained in Appendix B.4.

8.2 Tables of Reduced Utilization Factors

Tables of reduced utilization factors for each luminaire are provided by the luminaire manufacturer for use in calculating the average illuminances at the room surfaces. Each table is valid only for the luminaire and installation geometry specified. Within their domain of validity tables of reduced utilization factor tables give the most specific results in the fastest way.

The calculation procedure is perfectly straight forward:

Taking E_1 = the illuminance on the ceiling
 E_3 = the illuminance on the walls
 E_4 = the illuminance at the working plane
 RUF_1 = the reduced utilization factor for the ceiling
 RUF_3 = the reduced utilization factor for the walls
 RUF_4 = the reduced utilization factor for the working plane
 $PHID$ = the lamp flux density
 and NM = the number of luminaires
 n = the number of lamps per luminaire
 PHI = the nominal lamp flux
 A_4 = the area of the working plane
 then $PHID = NM * n * PHI / A_4$

so E1 = PHID * RUF1
 E3 = PHID * RUF3
 E4 = PHID * RUF4

The way in which the tables of reduced utilization factor tables are calculated is explained in appendix B.4.

An example of reduced utilization factor tables is given in fig. C.6.

8.3 The British Method for Calculating Average Illuminance

This has recently been revised and now covers the calculation of average illuminance for the working plane, the walls and the ceiling.

The calculation of utilization factors has been separated into two parts.

In the first part the direct fluxes to the ceiling cavity, walls and floor cavity are calculated by the zonal multiplier method and expressed as a proportion of the total lamp flux. This gives the distribution factor DF.

There are three distribution factors.

For the working plane:

$$DF(F) = \frac{\text{Flux received by W.P. directly}}{\text{Total installed lamp flux}}$$

For the walls:

$$DF(W) = \frac{\text{Flux received by the walls directly}}{\text{Total installed lamp flux}}$$

For the ceiling:

$$DF(C) = \frac{\text{Flux received by ceiling cavity directly}}{\text{Total installed lamp flux}}$$

In the second part the distribution factors are multiplied by the transfer factors TF, and added to obtain the utilization factors, UF(F) for the working plane, UF(W) for the walls and UF(C) for the ceiling.

The Transfer Factor TF(S1,S2) - from one surface "S1" to another "S2" is the ratio of the final flux on the surface "S2" to the direct flux on the surface "S1" which caused it.

For the working plane:

$$UF(F) = DF(F)TF(F,F) + DF(W)TF(W,F) + DF(C)TF(C,F).$$

For the walls:

$$UF(W) = DF(F)TF(F,W) + DF(W)TF(W,W) + DF(C)TF(C,W).$$

For the ceiling:

$$UF(C) = DF(F)TF(F,C) + DF(W)TF(W,C) + DF(C)TF(C,C)$$

The average illuminance of any of the three surfaces (S) is then given by:

$$\frac{\text{Lamp flux} * \text{Number of Lamps} * \text{Utilization Factor}}{\text{Area of Surface}}$$

Tables of Transfer Factors are provided in terms of room index and surface reflectance.

8.4 The French Method

The French system consists of a basic method (AFNOR S40 001) and an applied method (UTE 71 121).

The UTE 71 121 makes use of a luminaire classification. The criterion for this classification is the flux triplet of the luminaires. For each class a range of values for each of the three identifiers has been defined. A luminaire with a flux triplet in which each of the identifiers belongs to the corresponding defined range for a given class is said to belong to that class.

For each class, for the usual series of room index values direct-ratio values are tabulated for a rectangular/regular arrangement characterized by its grid index K_m and its proximity index K_p :

$$K_m = \frac{2 * SL * SC}{H3 * (SL + SC)}$$

$$K_p = \frac{A * PL + B * PC}{H3 * (A + B)}$$

in which:

A = room width
 B = room length
 H3 = mounting height
 SL = spacing lengthwise
 SC = spacing crosswise
 PL = proximity lengthwise
 PC = proximity crosswise

Coefficients for the calculation of the reduced utilances for the room surfaces are given in separate tables.

8.5 The German Method for the Calculation of Illuminances for Interior Lighting

In this method 33 tables are given of the utilance and luminance coefficients.

In this method utilances and luminance coefficients are tabulated for 33 different luminaire types, for 12 different reflectance combinations, for the standard series of room index values and for suspension ratios 0 and 1/3.

The luminance coefficients can be used to calculate the luminance of the ceiling, the walls and the working plane as the product of the appropriate coefficient and the illuminance on the working plane.

Luminaires are characterized by means of three quantities: the lower flux fraction, the direct ratio and the direct ceiling ratio for one specified luminaire arrangement ($M = 4$, $N = 2$, $PM = PN = 0,5$) in an interior with a room index $K = 1,23$.

The direct ceiling ratio is the proportion of the flux in the upper hemisphere that is directly emitted to the ceiling. The three luminaire characteristics are calculated from the average luminous intensities by means of working sheets, which are provided for symmetrical luminaires and for luminaires with tubular fluorescent lamps.

8.6 The American Method for Calculating Average Illuminance

This deals with the calculation of the average illuminance onto the working plane. As published it also allows the calculation of wall and ceiling luminance for 20% floor reflectance.

Note: The data is provided in terms of Room Cavity Ratio RCR and not room index as in the other systems.

$$RCR = \frac{5h \text{ (length + width)}}{\text{length} * \text{width}}$$

Also the term Utilization factor is used in place of utilance and the term Coefficient of Utilization is used in place of the term Utilization Factor.

The direct Ratio is calculated by means of the zonal multiplier method:

$$DR = \frac{\text{Direct Flux received by W.P.}}{\text{Total downward flux}}$$

The Downward Reflected Component DRC is obtained from a graph where it is plotted in terms of RCR and the surface reflectances.

The Downward Utilization Factor is given by:

$$DR + DRC$$

The Downward Coefficient = (DR + DRC)DLOR

The Upward Utilization Factor is obtained from a table where it is given in terms of RCR and surface reflectances.

The Upward Coefficient is given by:

$$\text{Upward Utilization Factor} * ULOR$$

The final Coefficient of Utilization

$$= \text{Downward Coefficient} + \text{Upward Coefficient}$$

The average illuminance of the W.P. is then given by:

$$\frac{\text{Lamp flux} * \text{number of lamps} * \text{Coefficient of Utilization}}{\text{Area of W.P.}}$$

Wall luminance coefficients and ceiling luminance coefficients may be calculated from worksheets given in the American I.E.S. handbook for the case of a 20% floor reflectance.

The worksheets require: the Direct Ratio, the upward luminaire flux, the downward luminaire flux and the total lamp flux as well as the room cavity ratio and the wall and ceiling reflectance.