BS EN 13201-3:2015

BSI Standards Publication

Road lighting

Part 3: Calculation of performance

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of EN 13201-3:2015. It supersedes BS EN 13201-3:2003 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EL/1/2, Road lighting.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2016

ISBN 978 0 580 79684 5

ICS 93.080.40

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2016.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 13201-3

December 2015

ICS 93.080.40

Supersedes EN 13201-3:2003

English Version

Road lighting - Part 3: Calculation of performance

Eclairage public - Partie 3: Calcul des performances

Straßenbeleuchtung - Teil 3: Berechnung der Gütemerkmale

This European Standard was approved by CEN on 6 June 2015.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 13201-3:2015 E

Contents

Page

European foreword

This document (EN 13201-3:2015) has been prepared by Technical Committee CEN/TC 169 “Light and lighting”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2016 and conflicting national standards shall be withdrawn at the latest by June 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13201-3:2003.

In comparison with EN 13201-3:2003, three significant changes were made:

— in the veiling luminance calculation, L_v, there is no more test about the contribution of at least 2 % of the next luminaire in the row to end the calculation before reaching a distance of 500 m (this is to avoid ambiguous interpretations that can produce different results from different software);

— the default option is about 500 m, but there is an alternative to retain only the luminaires of a shorter installation. This last case should be clearly mentioned in the lighting design by the number of luminaires involved in calculation of f_{TI};

— there is a new formula for calculating veiling luminance L_v, for a wider range of θ values. Thus the case where luminaires could be very near to the axis of vision of the observer: $0{,}1° < \theta < 1{,}5°$ can be evaluated with Formula (38).

NOTE for programmers: Calculation of threshold increment f_{TI}, (*new symbol for TI designation*) has changed in the revision of EN 13201-3:2003.

This European Standard was worked out by the Joint Working Group of CEN/TC 169 “Light and lighting” and CEN/TC 226 “Road Equipment”, the secretariat of which is held by AFNOR.

EN 13201, *Road lighting* is a series of documents that consists of the following parts:

— *Part 1: Guidelines on selection of lighting classes* [Technical Report]*;*

— *Part 2: Performance requirements;*

— *Part 3: Calculation of performance* [present document]*;*

— *Part 4: Methods of measuring lighting performance;*

— *Part 5: Energy performance indicators.*

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The calculation methods described in this part of EN 13201 enable road lighting quality characteristics to be calculated by agreed procedures so that results obtained from different designers will have a uniform basis.

1 Scope

This European Standard specifies the conventions and mathematical procedures to be adopted in calculating the photometric performance of road lighting installations designed in accordance with the parameters described in EN 13201-2 to ensure that every lighting calculation is based on the same mathematical principles.

The design procedure of a lighting installation also requires the knowledge of the parameters involved in the described model, their tolerances and variability. These aspects are not considered in this part of EN 13201 but a procedure to analyse their contribution in the expected results is suggested in EN 13201-4 and it can also be used in the design phase.

2 Normative references

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

EN 13032-1, *Light and lighting — Measurement and presentation of photometric data of lamps and luminaires — Part 1: Measurement and file format*

EN 13201-2, *Road lighting — Part 2: Performance requirements*

EN 12665:2011, *Light and lighting — Basic terms and criteria for specifying lighting requirements*

3 Terminology

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12665:2011 and the following apply.

3.1.1
vertical photometric angle
γ
angle between the light path and the downward vertical axis both passing through the luminaire photometric centre

Note 1 to entry: Unit ° (degree).

Note 2 to entry: The direction γ = 0 is therefore oriented to the nadir.

Note 3 to entry: See Figure 1.

3.1.2
azimuth
C
angle between the vertical half plane passing through the light path and the reference half plane

Note 1 to entry: I.e. the vertical half plane passing through the second axis of a luminaire, when the luminaire is at its tilt during measurement.

Note 2 to entry: Unit ° (degree).

Note 3 to entry: See Figure 1.

3.1.3
angle of incidence
ε
angle between the light path at a point on a surface and the normal to the surface

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 4, Figure 12 and Figure 13.

3.1.4
angle of deviation
β
angle between the oriented vertical planes through the observer to the point of observation and from the point of observation through the luminaire (with respect to luminance coefficient)

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 4.

3.1.5
luminance coefficient
q
quotient of the luminance of a surface element in a given direction by the illuminance on the surface element

Note 1 to entry: Unit sr^{-1}.

Note 2 to entry:

$$q = \frac{L}{E} \quad (1)$$

where

q is the luminance coefficient, in reciprocal steradians (sr^{-1});

L is the luminance, in candelas per square metre ($cd \cdot m^{-2}$);

E is the illuminance, in lux (lx).

3.1.6
reduced luminance coefficient
r
luminance coefficient of a surface element multiplied by the cube of the cosine of the angle of incidence of the light on the surface element

Note 1 to entry: Unit sr^{-1}.

Note 2 to entry: This can be expressed by the formula: $r = q \cos^3 \varepsilon$ (refer to CIE 66) (2)

where

q is the luminance coefficient, in reciprocal steradians;

ε is the angle of incidence, in degree.

Note 3 to entry: The angle of observation, α in Figure 4, affects the value of r. In accordance with the requirements specified in EN 13201-2, consider this angle fixed at 1° and this value is adopted for the calculation described in this standard, r is reasonably constant for values of α between 0,5° and 1,5°.

3.1.7
tilt during measurement
$\boldsymbol{\theta}_{\mathbf{m}}$
angle between a defined datum axis on a luminaire and the horizontal when the luminaire is mounted for photometric measurement

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 7.

Note 3 to entry: The defined datum axis can be any feature of the luminaire, but generally for a side-mounted luminaire it lies in the mouth of the luminaire canopy, in line with the spigot axis. Another commonly used feature is the spigot entry axis.

3.1.8
tilt for calculation
$\boldsymbol{\delta}$
difference in angle between the tilt in application and the tilt during measurement of a luminaire

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 7.

3.1.9
tilt in application
$\boldsymbol{\theta}_{\mathbf{f}}$
angle between a defined datum axis on a luminaire and the horizontal when the luminaire is mounted for field use

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 7.

Note 3 to entry: The defined datum axis can be any feature of the luminaire but generally for a side-mounted luminaire it lies in the mouth of the luminaire canopy, in line with the spigot axis. Another commonly used feature is the spigot entry axis.

3.1.10
orientation
$\boldsymbol{\nu}$
angle a chosen reference direction makes with the C = 0°, γ = 90° measurement direction of a luminaire when the first photometric axis of the luminaire is vertical

Note 1 to entry: Unit ° (degree).

Note 2 to entry: When the road is straight the reference direction is longitudinal.

Note 3 to entry: See Figure 6, which illustrates the sign conventions.

3.1.11
rotation
ψ
angle the first photometric axis of a luminaire makes with the nadir of the luminaire in the plane C = 0°, C = 180°, when the tilt during measurement is zero

Note 1 to entry: Unit ° (degree).

Note 2 to entry: See Figure 6, which illustrates the sign conventions.

3.1.12
first photometric axis (of a luminaire when measured in the (C, γ) coordinate system)
axis through the photometric centre of a luminaire and perpendicular to the plane which is representative of the main light emitting area

Note 1 to entry: The polar axis of the (C, γ) coordinate system does not necessarily coincide with the first axis of the luminaire if the luminaire is tilted during measurement.

3.1.13
longitudinal direction
direction parallel to the axis of the road

3.1.14
transverse direction
direction at right angles to the axis of the road

Note 1 to entry: On a curved road the transverse direction is that of the radius of curvature at the point of interest on the road.

3.1.15
installation azimuth
φ
angle a chosen reference direction (which is longitudinal for a straight road) makes with the vertical plane through a given point on the road surface and the photometric centre of a luminaire, when the luminaire is at its tilt during measurement

Note 1 to entry: Unit (degree).

Note 2 to entry: See Figure 4.

3.2 List of symbols and abbreviations

The symbols and abbreviations used in this standard are listed in Table 1.

Table 1 — Symbols and abbreviations

Quantity		
Symbol	**Name or description**	**Unit**
A_y	Age of observer	y
C	Photometric azimuth angle (Figure 1)	°(degree)
D	Spacing between calculation points in the longitudinal direction (see Figure 9 and Figure 14)	m

Quantity		
Symbol	**Name or description**	**Unit**
d	Spacing between calculation points in the transverse direction (see Figure 9 and Figure 14)	m
$\overline{E}$	Generic symbol used for average illuminance	lx
$\overline{E}_{hi}$	Initial average horizontal illuminance of the lit surface (see 8.5.3)	lx
E_h	Horizontal illuminance at a point	lx
E_{hs}	Hemispherical illuminance at a point	lx
E_{sc}	Semi-cylindrical illuminance at a point	lx
E_v	Vertical illuminance at a point	lx
f_M	Overall maintenance factor	–
f_{TI}	Threshold increment	%
H	Mounting height of a luminaire	m
$I(C, y)$	Luminous intensity table in the C, y system. Also named I-table	cd
j, m	Integers indicating the row or column of a table	–
$\overline{L}$	Generic symbol used for average luminance	$cd \cdot m^{-2}$
$\overline{L}_i$	Initial average horizontal luminance of the lit surface (see 8.5.3)	$cd \cdot m^{-2}$
L_v	Equivalent veiling luminance	$cd \cdot m^{-2}$
L	Luminance at a point	$cd \cdot m^{-2}$
N	Number of calculation points in the longitudinal direction of a grid (see Figure 9 and Figure 14)	–
n	Number of calculation points in the transverse direction of a grid (see Figure 9 and Figure 14)	–
n_{lu}	Number of luminaires considered in the calculation	–
q	Luminance coefficient	sr^{-1}
Q_0	Average luminance coefficient	sr^{-1}
r	Reduced luminance coefficient	sr^{-1}
$r(\tan \varepsilon, \beta)$	Reduced luminance coefficient table. Also named r-table	sr^{-1}
R_{EI}	Edge illuminance ratio	–
S	Spacing between luminaires	m
W_L	Width of driving lane	m
W_r	Width of relevant area or of carriageway	m
W_S	Width of strip	m
x	Abscissa in (x, y) coordinate system (Figure 5)	m
y	Ordinate in (x, y) coordinate system (Figure 5)	m
α	Angle of observation of road surface (Figure 4)	°(degree)

Quantity		
Symbol	**Name or description**	**Unit**
α_k	angle between the normal to the flat surface of the semicylinder and the vertical plane containing the light path (Figure 12) or angle between the normal to the selected vertical plane and the vertical plane containing the light path (Figure 13)	°(degree)
β	Angle of deviation (Figure 4)	°(degree)
ρ	Average diffuse reflection factor of a surface (See 8.5.3)	–
γ	Photometric elevation angle (Figure 1)	°(degree)
δ	Luminaire tilt for calculation (Figure 6 and Figure 7)	°(degree)
ε	Angle of incidence (Figure 4)	°(degree)
ε_k	Angle of incidence for semicylindrical and vertical illuminance (Figure 12 and Figure 13)	°(degree)
θ_1	Luminaire tilt in application (Figure 7)	°(degree)
θ_m	Luminaire tilt during measurement (Figure 7)	°(degree)
θ_κ	Angle between the line of sight and the centre of the k^{th} luminaire (See 8.5 in the formulae)	
ν	Orientation of luminaire (Figure 6)	°(degree)
φ	Installation azimuth (Figure 4)	°(degree)
ψ	Rotation of luminaire (Figure 6)	°(degree)

4 Mathematical conventions

4.1 General

The basic conventions made in the mathematical procedures described in this standard are:

a) the luminaire is regarded as a point source;

b) light reflected from the surrounds and inter-reflected light is disregarded;

c) obstruction to the light from luminaires by trees and other objects is disregarded;

d) the atmospheric absorption is zero;

e) the road surface is flat and level and has uniform reflecting properties over the area considered;

f) the evaluation in *I*-tables and *r*-tables shall be obtained by linear interpolation.

In case of continuous lines of luminaires, generally at low mounting height, it is advisable to check whether the distance between the optical centre of each luminaire to the nearest point of the grid of calculation is greater than or equal to five times the length of the luminous area of a single luminaire. If this is not the case it might be necessary to simulate near-field photometry by fragmenting the luminaire into virtual point light sources of the same light distribution as the entire luminaire. The luminous flux of each virtual light source is an equal proportion of the total luminous flux for the luminaire.

4.2 Decimal places of the requirements

The calculation results shall be presented in the form and with at least the number of digits given in the tables of requirements of EN 13201-2, shown in Table 2.

Table 2 — Number of decimal digits of the lighting requirements

	$\overline{L}$	U_o	U_l	f_{TI}	R_{EI}	$\overline{E}$ <10 lx	10 lx ≤ $\overline{E}$ ≤ 20 lx	$\overline{E}$ > 20 lx
Number of decimal places	**2**	**2**	**2**	**0**	**2**	**2**	**1**	**0**

5 Photometric data

5.1 General

Photometric data for the light distribution of the luminaires used in the lighting installation are needed for calculating the lighting quality characteristics in this standard. These data are in the form of an intensity table (*I*-table) which gives the distribution of luminous intensity emitted by the luminaire in all relevant directions. When luminance calculations are to be made, photometric data for the light reflecting properties of the road surface are required in the form of an *r*-table.

Interpolation is needed in using both these tables to enable values to be estimated for directions between the tabulated angles.

5.2 The *I*-table

5.2.1 System of coordinates and advised angular intervals of the *I*-table

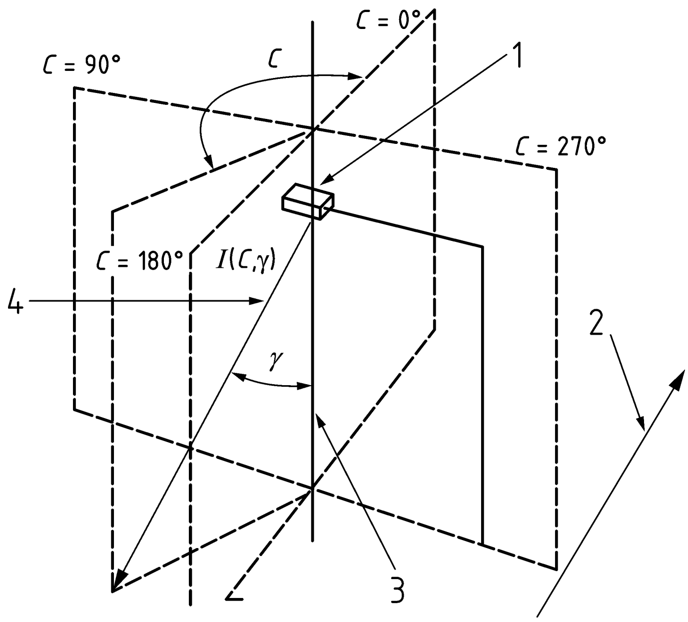
For calculations made in accordance with this standard, an intensity table (*I*-table) that describes the behaviour of the luminaire with the required accuracy by the aim of calculation shall be used. This *I*-table shall be prepared in accordance with EN 13032-1. The coordinate system used for road lighting luminaires is the *C*-planes system, shown in Figure 1. For floodlight installations, the intensity distribution measured in the *B*-planes system may be accepted if the calculation program can transfer the intensity values in the *C*-planes system. In Figure 1, the luminaire is shown at its tilt during measurement.

Luminous intensity shall be expressed in candelas.

The luminous flux used in calculation shall be declared in the calculation report.

Unless specific conditions are mentioned in the calculation report, the luminous flux used shall be that of the light source mentioned in the data sheet of the luminaire.

If the luminous intensity table is given in candelas per kilolumen ($cd \cdot klm^{-1}$), its values shall be converted in candelas, considering the luminous flux of all the light sources in the luminaire.



Key

1 luminaire at tilt during measurement

2 longitudinal direction

3 vertical direction

4 direction of luminous intensity

Figure 1 — Orientation of *C*, *γ* coordinate system in relation to longitudinal direction of carriageway

Maximum angular intervals stipulated in this standard have been selected to give acceptable levels of interpolation accuracy.

In the (C, γ) system of coordinates, luminous intensities shall be provided at the angular intervals stated below.

For all luminaires the angular intervals in vertical planes (γ) shall at most be 2,5° from 0° to 180°. In azimuth the intervals shall be varied according to the symmetry of the light distribution from the luminaire as follows:

a) luminaires with no symmetry: the intervals shall at most be 5°, starting at 0°, when the luminaire is at its tilt during measurement, and ending at 355°;

b) luminaires with nominal symmetry about the C = 270° − 90° plane: the intervals shall at most be 5°, starting at 270°, when the luminaire is at its tilt during measurement, and ending at 90°;

c) luminaires with nominal symmetry about the C = 270° − 90° and C = 0°− 180° planes: the intervals shall at most be 5°, starting at 0°, when the luminaire is at its tilt during measurement, and ending at 90°;

d) luminaires with nominally the same light distribution in all C-planes: only one representative set of measurements in a vertical (C-plane) is needed.

Where standards for specific luminaire typologies exist and prescribe improved angular intervals these shall be applied.

The angular intervals stated above shall be reduced in case of a great gradient variation of consecutive luminous intensities.

NOTE In that case, it is the role of photometric laboratories to provide the *I*-table with relevant reduced angular intervals defined from the angles included in the photometric file.

5.2.2 Linear interpolation in the *I*-table

To estimate the luminous intensity $I(C, \gamma)$ in the direction (C, γ), it is necessary to interpolate between four values of luminous intensity lying closest to the direction, see Figure 2 and Figure 3.

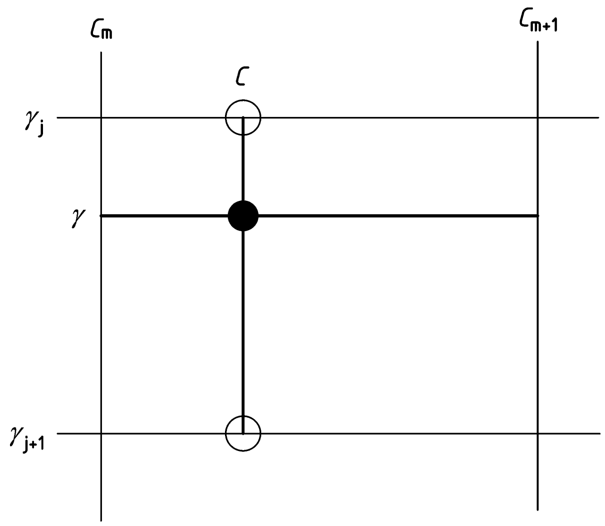


Figure 2 — Angles required for linear interpolation of luminous intensity

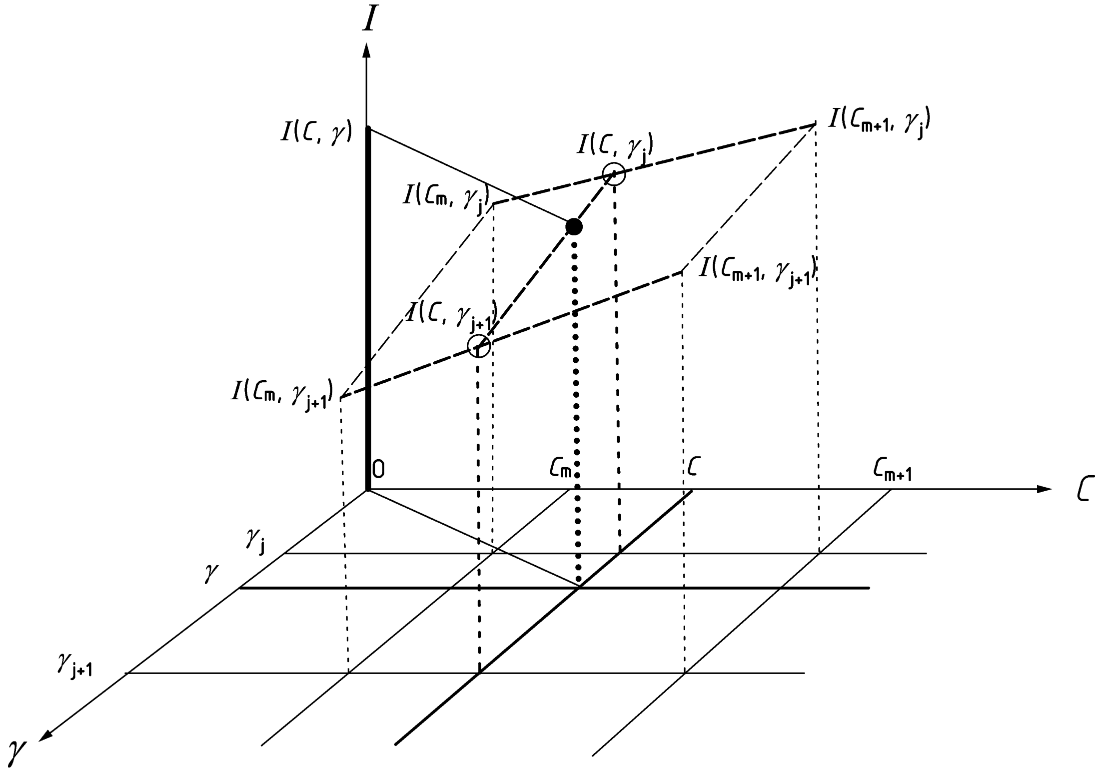


Figure 3 — Angles required for linear interpolation of luminous intensity (from Figure 2 but showing intensity on *z*-axis in perspective)

For this purpose, the following formulae or mathematically equivalent formulae shall be used:

Interpolation on *C* angles

$$\frac{I(C,\gamma_j)-I(C_m,\gamma_j)}{I(C_m+1,\gamma_j)-I(C_m,\gamma_j)}=\frac{C-C_m}{C_{m+1}-C_m} \quad (3)$$

where

$I(C_m, \gamma_j)$	indicates the intensity in column number *m* and row number *j* of the *I*-table, and so on for the other similar symbols;
C	is the azimuth, measured about the first photometric axis;
γ	is the vertical angle measured from the first photometric axis;
j, *m*, *m*+1	are integers indicating the number of the column or row in the *I*-table.

From which:

$$I(C,\gamma_j)=I(C_m,\gamma_j)+\frac{C-C_m}{C_{m+1}-C_m}\cdot\left(I(C_{m+1},\gamma_j)-I(C_m,\gamma_j)\right) \quad (4)$$

Similarly:

$$\frac{I(C,\gamma_{j+1})-I(C_m,\gamma_{j+1})}{I(C_{m+1},\gamma_{j+1})-I(C_m,\gamma_{j+1})}=\frac{C-C_m}{C_{m+1}-C_m} \quad (5)$$

From which:

$$I(C,\gamma_{j+1}) = I(C_m,\gamma_{j+1}) + \frac{C - C_m}{C_{m+1} - C_m} \cdot \left(I(C_{m+1},\gamma_{j+1}) - I(C_m,\gamma_{j+1})\right) \tag{6}$$

At last, interpolation on γ:

$$\frac{I(C,\gamma) - I(C,\gamma_j)}{I(C,\gamma_{j+1}) - I(C,\gamma_j)} = \frac{\gamma - \gamma_j}{\gamma_{j+1} - \gamma_j} \tag{7}$$

From which, finally:

$$I(C,\gamma) = I(C,\gamma_j) + \frac{\gamma - \gamma_j}{\gamma_{j+1} - \gamma_j} \cdot \left(I(C,\gamma_{j+1}) - I(C,\gamma_j)\right) \tag{8}$$

In these formulae interpolation is first carried out in the C half planes, and then in the γ cones. If desired this procedure can be reversed (that is, the interpolation is first carried out in the γ cones followed by the C half planes) and the same result obtained.

5.3 The *r*-table

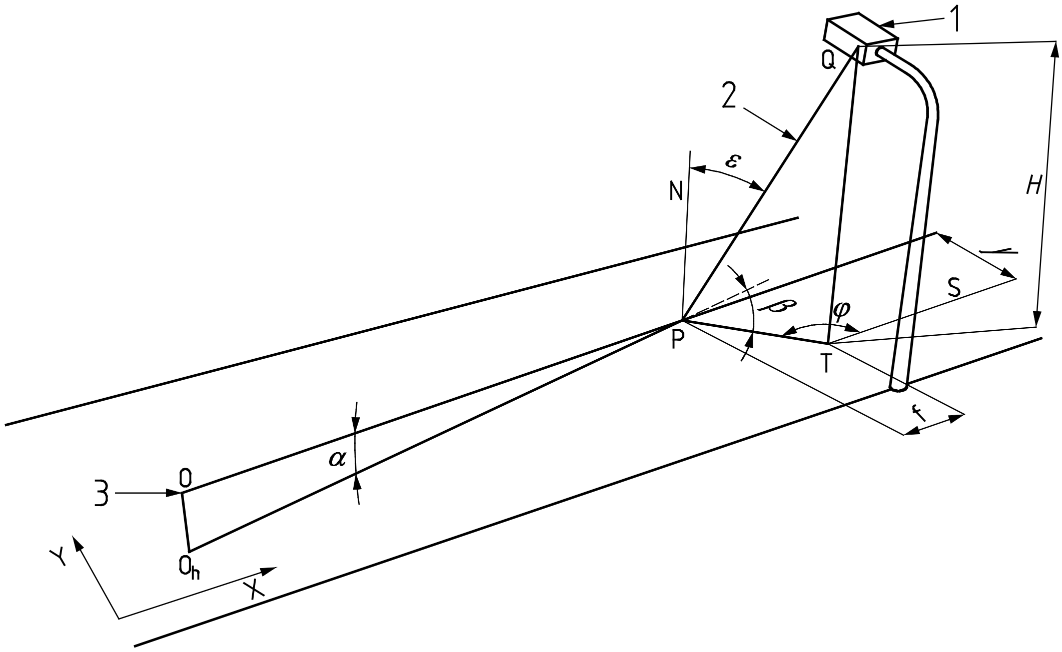
5.3.1 The *r*-table format

Road surface reflection data shall be expressed in terms of the reduced luminance coefficient at the angular intervals and in the directions given in Table 3 for the angles β and ε indicated in Figure 4.

Generally in *r*-tables the values are given multiplied by the factor 10^4. In this case, for calculation purpose, they shall be divided by 10^4.

Table 3 gives the minimum number of angular directions at which the reduced luminance coefficient shall be specified for luminaires placed at heights, above the road surface, higher than 2 m.

For luminaires of the lighting installation placed at heights, above the road surface, less than or equal to 2 m, Annex B suggests the extended set of angular directions for *r* values.



Key

H	mounting height of the luminaire
P	observed point
PN	normal at P to the road surface
Q	photometric centre of the luminaire
QT	vertical passing through the photometric centre of the luminaire
ST	longitudinal direction
O_h	geometrical projection of the observer's eye to the ground
f and *y*	scalar components of the vector TP (evaluation of tan *φ*)
β	angle between the oriented traces of vertical planes in the horizontal plane of the road surface:
–	vertical plane passing through the point of observation and containing P
–	vertical plane containing P and passing through the luminaire.
ε	angle of light incidence at P
α	angle of observation
φ	installation azimuth
1	luminaire
2	light path
3	observer (O is the position of the eye of the observer)

Figure 4 — Angular relationships for luminaire at tilt during measurement, observer, and point of observation

Table 3 — Angular intervals and directions to be used in collecting road surface reflection data

tan ε	**β in degrees**																			
	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,25	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,25	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5,5	X	X	X	X	X	X	X	X	X	X										
6	X	X	X	X	X	X	X	X	X											
6,5	X	X	X	X	X	X	X	X	X											
7	X	X	X	X	X	X	X	X												
7,5	X	X	X	X	X	X	X													
8	X	X	X	X	X	X	X													
8,5	X	X	X	X	X	X	X													
9	X	X	X	X	X	X														
9,5	X	X	X	X	X	X														
10	X	X	X	X	X	X														
10,5	X	X	X	X	X	X														
11	X	X	X	X	X	X														
11,5	X	X	X	X	X															
12	X	X	X	X	X															

A cross in Table 3 indicates the required *r*-value that shall be known.

NOTE In Table 3, blank cells indicate directions that should not be used for calculation, therefore the knowledge of *r* of these directions is not relevant in this standard.

5.3.2 Linear interpolation in the *r*-table

When a value of r is required for values of tan ε and β lying between those given in the r-table, the linear interpolation shall be retained.

The mathematical procedure is similar to that described for the I-table in 5.2.2 with tan ε replacing C half plane angles and β replacing γ angles.

Again, in these formulae, interpolation can be first carried out in the tan ε values and then in the β half planes. If desired this procedure can be reversed (that is the interpolation is first carried out in the β half planes followed by tan ε values) and the same result obtained.

6 Calculation of $I(C, \gamma)$

6.1 General

To determine the luminous intensity from a luminaire to a point it is necessary to find the vertical photometric angle (γ) and photometric azimuth (C) of the light path to the point. To do this, account shall be taken of the tilt in application in relation to the tilt during measurement, the orientation, and rotation of the luminaire. For this purpose it is necessary to establish mathematical sign conventions for measuring distances on the road and for rotations about axes. The system used is a right-handed Cartesian coordinate system. The corrections for turning movements do not allow for any change in the luminous flux of the light source due to turning movements.

6.2 Mathematical conventions for distances measured on the road

A (x, y) rectangular coordinate system is used (Figure 5). The abscissa is aligned with the reference direction, which, for a straight road, lies in the longitudinal direction. Then:

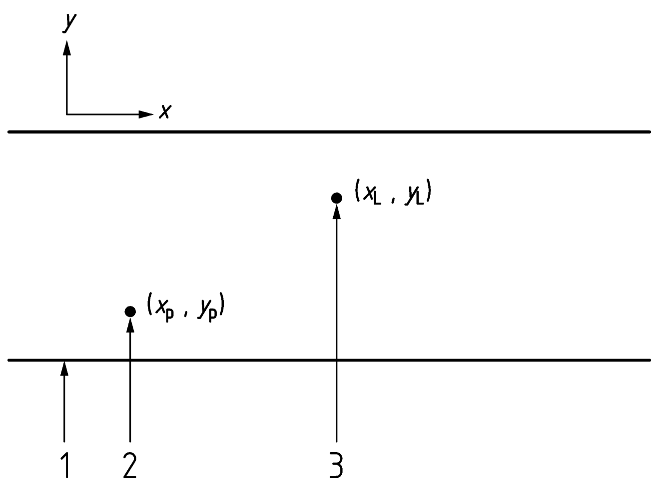
$$x_{LP} = x_P - x_L \tag{9}$$

$$y_{LP} = y_P - y_L \tag{10}$$

where

(x_P, y_P) are the coordinates of the calculation point;

(x_L, y_L) are the coordinates of the luminaire.



Key

1 edge of carriageway

2 calculation point

3 luminaire

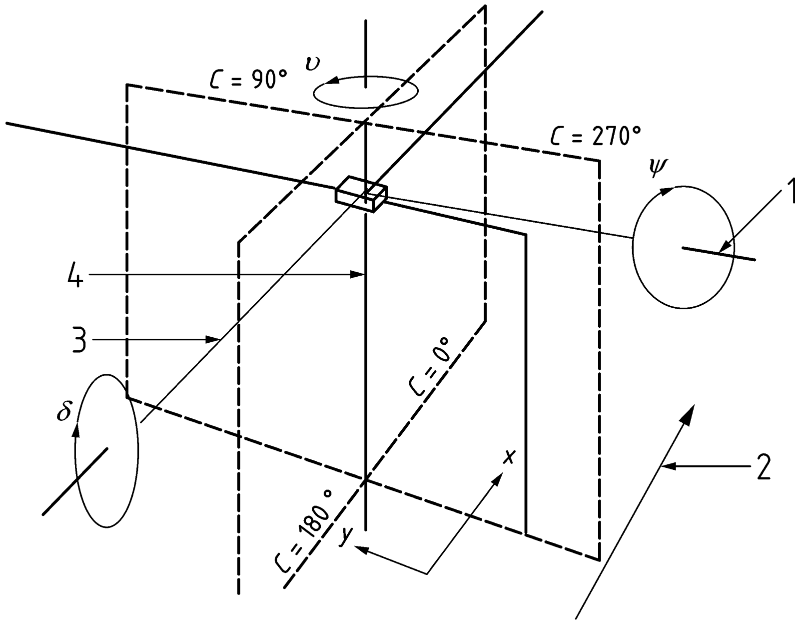
Figure 5 — (*x*, *y*) coordinate system for locating luminaire in plan

NOTE In order to obtain positive *x* and *y* coordinates for all grid points, it is advisable to place the origin in the low left corner of the calculation field. (see Figure A.1).

6.3 Mathematical conventions for rotations

Figure 6 shows the axes of rotation in relation to the (*x y z*) right-handed coordinate system. In this system rotation angles are positive when pointing the right thumb along the third axis in the positive direction, the fingers curl in the direction leading from the first axis toward the second one (right hand rule).

Axis I is fixed in space, axis II and axis Ill can be turned about axis I.



Key

1 axis Ill

2 longitudinal direction

3 axis II

4 axis I: first photometric axis

Figure 6 — Axes of rotation in relation to the (*x*, *y*) coordinate system

Figure 7 shows the relation of tilt for calculation to tilt during measurement and tilt in application. From this it is evident that:

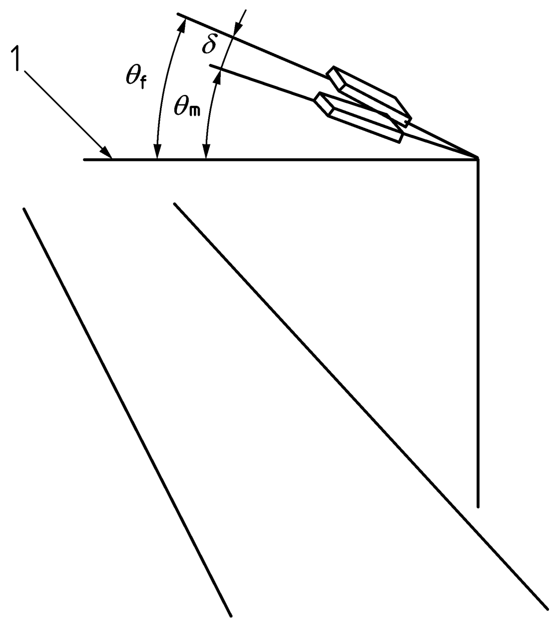
$$\delta = \theta_f - \theta_m \qquad (11)$$

where

δ is the tilt in degree for calculation;

θ_f is the tilt in degree in application;

θ_m is the tilt in degree during measurement.



Key

δ	tilt for calculation
θ_f	tilt in application
θ_m	tilt during measurement
1	horizontal

Figure 7 — Tilt during measurement, tilt in application, tilt for calculation

6.4 Calculation of *C* and *γ*

NOTE These can be determined in four stages:

6.4.1 Calculation of *x*′, *y*′ and *H*′:

$$x' = x(\cos \nu \cos \psi - \sin \nu \sin \delta \sin \psi) + y(\sin \nu \cos\psi + \cos \nu \sin \delta \sin \psi) + H \cos \delta \sin \psi \quad (12)$$

$$y' = -x \sin \nu \cos \delta + y \cos \nu \cos \delta - H \sin \delta \quad (13)$$

$$H' = -x(\sin \nu \sin \delta \cos \psi + \cos y \sin \psi) - y(\sin \nu \sin \psi - \cos \nu \sin \delta \cos \psi) + H \cos \delta \cos \psi \quad (14)$$

where

x and y	are the longitudinal and transverse distances between the calculation point and the nadir of the luminaire in Figure 5;
H	is the height of the luminaire above the calculation point;
ν, δ and ψ	are the orientation, tilt for calculation, and rotation.

NOTE x', y' and H' are used in the calculation of C and γ when the luminaire has been turned through ν, δ, and ψ. They correspond to x, y and H in the unturned coordinate system and for calculation purposes may be regarded as intermediate variables (see Figure 6).

Caution shall be paid in Formulae (12), (13) and (14) to the value of H which is currently the mounting height of the luminaire to the road surface for horizontal or hemispherical illuminance and road luminance evaluations.

For the calculation of veiling luminance in f_{TI} 1,5 (m) stands by default for the height of the eyes of the observer. Similarly in vertical and semicylindrical illuminance evaluations, the calculation points considered are conventionally located at 1,5 m high from the ground. In that case H − 1,5 shall be substituted to H in Formulae (12), (13) and (14) to define correctly the direction of luminous intensity interpolated in the I-table.

6.4.2 Evaluation of installation azimuth *φ*.

Evaluation of arctan $\frac{y}{x}$ gives:

$$-90° \leq \arctan \frac{y}{x} \leq 90° \qquad (15)$$

The angular quadrant in which φ lies is determined by:

For $x > 0, y > 0$	$\varphi = \arctan \frac{y}{x}$	with $0° < \varphi < 90°$	quadrant 1	(16)
For $x < 0, y > 0$	$\varphi = 180° + \arctan \frac{y}{x}$	with $90° < \varphi < 180°$	quadrant 2	(17)
For $x < 0, y < 0$	$\varphi = 180° + \arctan \frac{y}{x}$	with $180° < \varphi < 270°$	quadrant 3	(18)
For $x > 0, y < 0$	$\varphi = 360° + \arctan \frac{y}{x}$	with $270° < \varphi < 360°$	quadrant 4	(19)

6.4.3 Calculation of *C*

$$C = \varphi - v \qquad (20)$$

where

φ is the installation azimuth in degree;

v is the orientation in degree (Figure 6), obtained from the formulae in 6.4, x' and y' being used in place of x and y respectively.

6.4.4 Calculation of *γ*

$$\gamma = \arctan\left(\frac{\sqrt{(x')^2 + (y')^2}}{H'}\right) \qquad (21)$$

7 Calculation of photometric quantities

7.1 Luminance

7.1.1 Luminance at a point

7.1.1.1 General formula

The luminance at a point shall be determined by applying the following formula or a mathematically equivalent formula:

$$L=\sum_{k=1}^{n_{\mathrm{LU}}}\frac{I_{\mathrm{k}}(C,\gamma)\cdot f_{\mathrm{M}}\cdot r_{\mathrm{k}}(\tan\varepsilon,\beta)}{H_{\mathrm{k}}^{2}} \qquad (22)$$

where

L	is the maintained luminance in candelas per square metre;
k	is the index of current luminaire in the summation;
n_{lu}	is the number of luminaires involved in the calculation;
$I_{\mathrm{k}}(C, \gamma)$	is the luminous intensity in candela of the k^{th} luminaire being C_{k} and γ_{k} calculated as indicated in 6.4;
f_{M}	is the overall maintenance factor, depending on light source lumen maintenance factor and luminaire maintenance factor;
$r_{\mathrm{k}}(\tan \varepsilon, \beta)$	is the reduced luminance coefficient for the current incident light path with angular coordinates (ε_{k}, β_{k}), in reciprocal steradians (see 7.1.1.2 and Figure 4);
H_{k}	is the mounting height of k^{th} luminaire above the surface of the road, in metres.

7.1.1.2 Calculation of tan *ε* and *β*

In Formula (22) tan ε and β are the entries of the *r*-table $r_{\mathrm{k}}(\tan \varepsilon; \beta)$

tan ε and β are evaluated for each observer position and each luminaire.

From Figure 4 we can calculate:

$$\tan\varepsilon=\frac{PT}{H}=\frac{\sqrt{(x_{\mathrm{p}}-x_{\mathrm{L}})^{2}+(y_{\mathrm{p}}-y_{\mathrm{L}})^{2}}}{H} \qquad (23)$$

where

PT	is the distance on the ground of the observed point P(x_{p}; y_{p}) to the geometrical projection of the optical centre of the luminaire to the ground T(x_{L}; y_{L});
H	is the mounting height of the luminaire.

Similarly from Figure 4 β is evaluated from the oriented angle between 2 vectors in the horizontal plane of the ground:

$$\beta=\arccos\left(\overrightarrow{O_{\mathrm{h}}P},\overrightarrow{PT}\right)=\arccos\left(\frac{(x_{\mathrm{P}}-x_{\mathrm{Oh}})\cdot(x_{\mathrm{L}}-x_{\mathrm{P}})+(y_{\mathrm{P}}-y_{\mathrm{Oh}})\cdot(y_{\mathrm{L}}-y_{\mathrm{P}})}{\sqrt{(x_{\mathrm{P}}-x_{\mathrm{Oh}})^{2}+(y_{\mathrm{P}}-y_{\mathrm{Oh}})^{2}}\cdot\sqrt{(x_{\mathrm{L}}-x_{\mathrm{P}})^{2}+(y_{\mathrm{L}}-y_{\mathrm{P}})^{2}}}\right) \qquad (24)$$

where

O_h (x_{0h}; y_{0h}) is the projection of the observer eye position on the road surface.

NOTE 1 When the P point lies on the vertical through the luminaire, cos β is indeterminate. In this case β can take any value (see the first line of any *r*-table where the *r* value should be the same for all β angles).

To take account of the mirror symmetry due to the assumed isotropy of the road surface the *r*-table is limited to β varying between 0° and 180° Using another method than the previous formula, β could be in symmetrical quadrants such that :

$$-180° < \beta < 0° \quad (25)$$

In that case, a test is needed to reach the field of definition of β thanks to the sign changed in Formula (26):

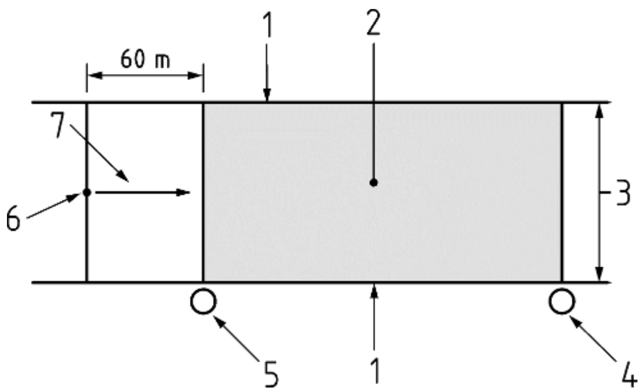
$$\text{If } -180° \leq \beta < 0° \text{ then } \beta = -\beta \quad (26)$$

NOTE 2 The interest to use the inverse cosine function with the algebraic scalar product is to evaluate the β angle directly in the field of definition of the *r*-table: 0° to 180°.

7.1.2 Field of calculation for luminance

In the longitudinal direction of the relevant area, the field of calculation shall enclose two luminaires in the same row (see Figure 8). When there is more than one row of luminaires and the spacing of the luminaires differs between rows, the field of calculation shall lie between two luminaires in the row with the larger or largest spacing.

This last procedure may not give accurate luminances for the whole installation as luminances will differ in the different spans between adjacent luminaires. As calculations are carried out to comply with the requirements of EN 13201-2, the field of calculation that gives the worse results shall be chosen among the possible fields of calculation in the relevant area.



Key

1 edge of relevant area

2 field of calculation

3 width of relevant area W_r

4 last luminaire in field of calculation

5 first luminaire in field of calculation

6 observer

7 observation direction

Figure 8 — Information for luminance calculations; field of luminance calculations for the relevant area

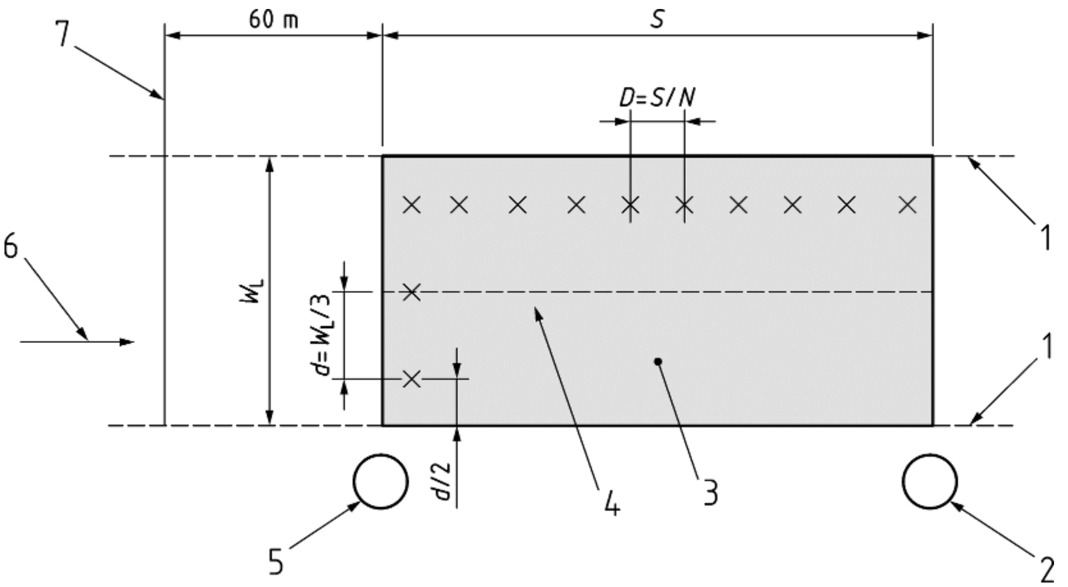
NOTE Relevant area is defined in CEN/TR 13201-1:2014, 3.17.

7.1.3 Position of calculation points

The calculation points shall be evenly spaced in the field of calculation as shown in Figure 9.

The first and last transverse rows of calculation points are spaced at one half the longitudinal spacing between points from the boundaries of the calculation field.

NOTE This grid is similar to the grid used for illuminance calculations as regards the positioning of the first and last row of calculation points in the transverse direction (see Figure 14).



Key

1 edge of lane

2 last luminaire in calculation field

3 field of calculation

4 centre-line of lane

5 first luminaire in calculation field

6 observation direction

7 observer's longitudinal position

X denotes lines of calculation points in the transverse and longitudinal directions.

Figure 9 — Information for luminance calculations; position of calculation points in a driving lane

The spacing of the points in the longitudinal and transverse directions shall be determined as follows:

a) In the longitudinal direction

$$D = \frac{S}{N} \tag{27}$$

where

D is the spacing between points in the longitudinal direction, in metres;

S is the spacing between luminaires in the same row, in metres;

N is the number of calculation points in the longitudinal direction with the following values:

for $S < 30$ m, $N = 10$;

for $S > 30$ m, the smallest integer giving $D \leq 3$ m. The first transverse row of calculation points is spaced at a distance $D/2$ beyond the first luminaire (remote from the observer).

b) In the transverse direction

The spacing (d) in the transverse direction is determined from the formula:

$$d = \frac{W_L}{3} \tag{28}$$

where

d is the spacing between points in the transverse direction, in metres;

W_L is the width of the lane, in metres.

The outermost calculation points are spaced $d/2$ from the edges of the lane.

Where there is a hard shoulder and luminance information is required, the number and spacing of the calculation points shall be the same as for a driving lane.

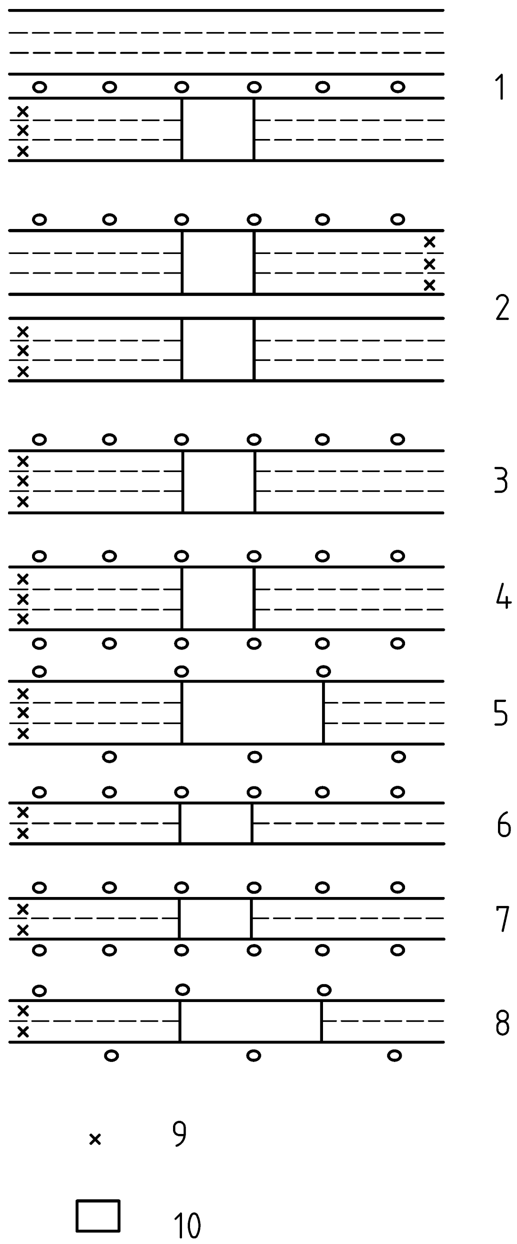
When illuminance calculations are provided together with luminance calculations for the same relevant area on a carriageway the definition of calculation points used for both calculations shall respect the definition of calculation points detailed previously in this paragraph.

7.1.4 Position of observer

For luminance calculations the observer's eye is 1,5 m above the road level and at 60 m ahead the calculation field of the relevant area.

In the transverse direction the observer shall be positioned in the centre of each lane in turn. Average luminance (see 8.2), overall uniformity of luminance (see 8.3) and threshold increment (see 8.5) shall be calculated for the entire carriageway for each position of the observer. Longitudinal uniformity of luminance (see 8.4) shall be calculated for each centre-line. The operative values of average luminance, overall uniformity of luminance, and longitudinal uniformity of luminance shall be the lowest in each case; the operative value of threshold increment shall be the highest value.

Figure 10 gives examples of the observer position in relation to the field of calculation.



Key

1 six lane road with central reservation and twin central luminaire arrangement

2 six lane road with central reservation and single side luminaire arrangement

3 three lane road with single side luminaire arrangement

4 three lane road with double side luminaire arrangement

5 three lane road with staggered luminaire arrangement

6 two lane road with single side luminaire arrangement

7 two lane road with double side luminaire arrangement

8 two lane road with staggered luminaire arrangement

9 observer position

10 calculation field

Figure 10 — Examples of positions of observation points in relation to the field of calculation

7.1.5 Luminaires included in calculation

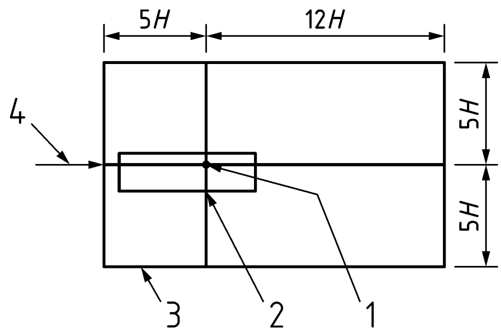
The boundary of the area for locating luminaires to be included in calculating the luminance at a point is determined as follows (see Figure 11):

a) boundary on either side of the observer: at least five times the mounting height H on either side of the calculation points;

b) boundary furthest from the observer: at least 12H from the calculation point in the direction remote from the observer;

c) boundary nearest to the observer: at least 5H from the calculation point in the direction towards the observer.

NOTE The extent of these boundaries is governed by the area covered on the road by the *r*-table. If the mounting height of luminaires is less or equal to 2 m, a distance of 20 times the mounting height around the calculation points for all azimuth angles is necessary. See informative Annex B about the extended *r*-table format needed.



Key

1 calculation point

2 boundary of field of calculation

3 boundary of area for location of luminaires

4 observation direction

Figure 11 — Boundary of area in which luminaires are located for luminance calculation

7.2 Illuminance

7.2.1 General

In this standard any of four different types of illuminance might need to be calculated, depending on the design criteria chosen from EN 13201-2. These might be:

a) horizontal illuminance;

b) hemispherical illuminance;

c) semi-cylindrical illuminance;

d) vertical illuminance.

7.2.2 Horizontal illuminance at a point

Calculation points shall be located on a plane at ground level in the relevant area.

The horizontal illuminance at a point shall be calculated from the formula or a mathematically equivalent formula:

$$E_{\mathrm{h}} = \sum_{k=1}^{n_{\mathrm{LU}}} \frac{I_{\mathrm{k}}(C,\gamma) \cdot f_{\mathrm{M}} \cdot \cos^3 \varepsilon_{\mathrm{k}}}{H_{\mathrm{k}}^2} \tag{29}$$

where

E_{h} is the maintained horizontal illuminance at the point (lx);

k is the index of current luminaire in the summation;

n_{lu} is the number of luminaires involved in the calculation;

$I_{\mathrm{k}}(C, \gamma)$ is the luminous intensity in candela of the k^{th} luminaire being C and γ calculated as indicated in 6.4;

f_{M} is the overall maintenance factor, the product of the light source lumen maintenance factor and the luminaire maintenance factor;

ε_{k} is the angle of incidence of light at the point (°);

H_{k} is the mounting height of k^{th} luminaire (m).

NOTE It is advised not to include lamp survival factor in the overall maintenance factor in road lighting if all failed light sources will be spot replaced.

7.2.3 Hemispherical illuminance at a point

Calculation points shall be located on a plane at ground level in the relevant area.

The hemispherical illuminance at a point shall be calculated from the formula or a mathematically equivalent formula:

$$E_{\mathrm{hs}} = \sum_{k=1}^{n_{\mathrm{LU}}} \frac{I_{\mathrm{k}}(C,\gamma) \cdot f_{\mathrm{M}} \cdot \left[\cos^3 \varepsilon_{\mathrm{k}} + \cos^2 \varepsilon_{\mathrm{k}}\right]}{4H_{\mathrm{k}}^2} \tag{30}$$

where

E_{hs} is the maintained hemispherical illuminance at the point (lx);

k is the index of current luminaire in the summation;

n_{lu} is the number of luminaires involved in the calculation;

$I_{\mathrm{k}}(C, \gamma)$ is the luminous intensity in candela of the k^{th} luminaire being C and γ calculated as indicated in 6.4;

f_{M} is the overall maintenance factor, the product of the light source lumen maintenance factor and the luminaire maintenance factor;

ε_{k} is the angle of incidence of the light at the point (°);

H_{k} is the mounting height of k^{th} luminaire (m).

NOTE It is advised not to include lamp survival factor in the overall maintenance factor in road lighting if all failed light sources will be spot replaced..

7.2.4 Semi-cylindrical illuminance at a point

Calculation points shall be located on a plane 1,5 m above the surface in the relevant area.

Semi-cylindrical illuminance varies with the direction of interest. The vertical plane in Figure 12, at right angles to the rear flat surface, shall be oriented parallel to the main directions of pedestrian movement, which for a road are usually longitudinal.

The semi-cylindrical illuminance at a point shall be calculated from the formula or a mathematically equivalent formula:

$$E_{sc} = \sum_{k=1}^{n_{LU}} \frac{I_k(C,\gamma) \cdot f_M \cdot \sin\varepsilon_k \cdot (1+\cos\alpha_k)}{\pi \cdot {d_{LkP}}^2} \quad (31)$$

where

E_{sc} is the maintained semi-cylindrical illuminance at the point, in lux;

k is the index of current luminaire in the summation;

n_{lu} is the number of luminaires involved in the calculation;

$I_k(C, \gamma)$ is the luminous intensity in candela of the k^{th} luminaire being C and γ calculated as indicated in 6.4 (cd);

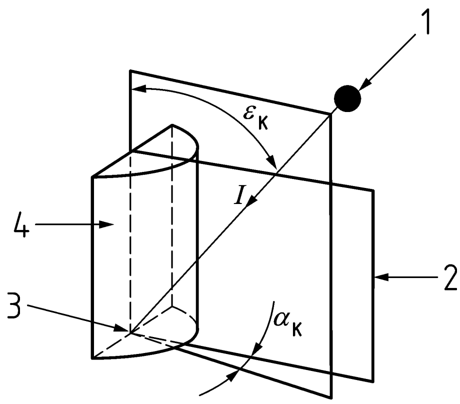
f_M is the overall maintenance factor, the product of the light source lumen maintenance factor and the luminaire maintenance factor;

α_k is the angle between the vertical plane containing the incident light path and the vertical plane at right-angles to the flat surface of the semi-cylinder, as shown in Figure 12 (°);

ε_k is the angle of incidence of the light path at the point (°);

d_{LkP} is the distance between the luminaire, L_k and the point P at the centre of the rectangular basis of the semi-cylinder.

NOTE It is advised not to include lamp survival factor in the overall maintenance factor in road lighting if all failed light sources will be spot replaced..



Key

1 luminaire *k*

2 vertical plane at right-angles to flat surface of semi-cylinder

3 calculation point

4 flat surface of semi-cylinder

Figure 12 — Angles used in the calculation of semicylindrical illuminance

7.2.5 Vertical illuminance at a point

Calculation points shall be located on a plane 1,5 m above the surface in the relevant area.

Vertical illuminance varies with the direction of interest. The vertical illumination plane in Figure 13 shall be oriented at right-angles to the main directions of pedestrian movement, which for a road are usually up and down the road.

The vertical illuminance at a point shall be calculated from the formula or a mathematically equivalent formula:

$$E_v = \sum_{k=1}^{n_{Lu}} \frac{I_k(C,\gamma) \cdot f_M \cdot \sin\varepsilon_k \cdot 1 + \cos\alpha_k}{{d_{LkP}}^2} \qquad (32)$$

where

E_v is the maintained vertical illuminance at the point (lx);

k is the index of current luminaire in the summation;

n_{lu} is the number of luminaires involved in the calculation;

$I_k(C, \gamma)$ is the luminous intensity in candela of the k^{th} luminaire being C and γ calculated as indicated in 6.4 (cd);

f_M is the overall maintenance factor, the product of the light source lumen maintenance factor and the luminaire maintenance factor;

ε_k is the angle of incidence of the light path at the point (°);

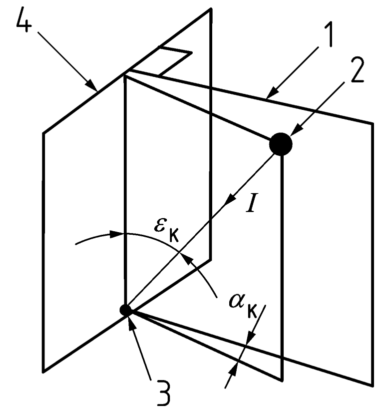
α_k is the angle in degree between the vertical plane containing the incident light path and the vertical plane at right-angles to the vertical plane of calculation, as shown in Figure

13 (°);

d_{LkP} is the distance between the luminaire, L_k and the point at the centre of the basis of the rectangle in the vertical illumination plane (m).

This formula is valid only for $\varepsilon < 90°$ and $\alpha < 90°$.

NOTE It is advised not to include lamp survival factor in the overall maintenance factor in road lighting if all failed light sources will be spot replaced.



Key

1 vertical plane at right-angles to vertical illumination plane

2 luminaire

3 calculation point

4 vertical illumination plane

Figure 13 — Angles used in the calculation of vertical illuminance

7.2.6 Field of calculation for illuminance

The field of calculation shall be the same as that indicated in Figure 10.

NOTE To economize on computer processing time, for staggered installations the calculation field can be taken between consecutive luminaires on opposite sides of the road without affecting the result.

7.2.7 Position of calculation points

The calculation points shall be evenly spaced in the field of calculation (see Figure 14) and their number shall be chosen as follows:

a) In the longitudinal direction

The spacing in the longitudinal direction shall be determined from the formula:

$$D = \frac{S}{N} \quad (33)$$

where

D is the spacing between points in the longitudinal direction, in metres

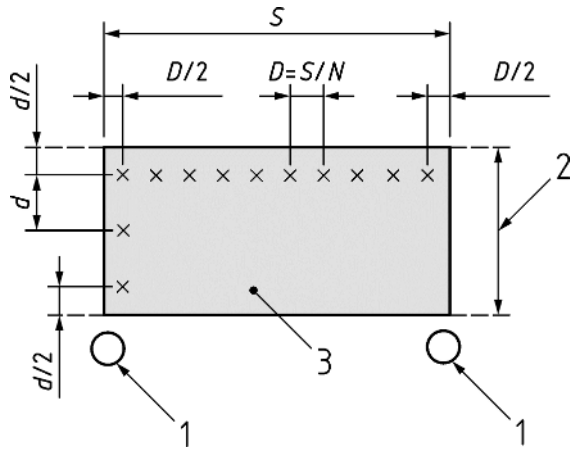
S is the spacing between luminaires, in metres

N is the number of calculation points in the longitudinal direction with the following values:

for $S \leq 30$ m, $N = 10$;

for $S > 30$ m, the smallest integer giving $D \leq 3$ m.

The first row of calculation points is spaced at a distance $D/2$ (in metres) beyond the first luminaire.



Key

1 luminaire

2 width of relevant area W_r

3 field of calculation

x denotes lines of calculation points in the transverse and longitudinal directions

Figure 14 — Information for illuminance calculations; calculation points on relevant area

b) In the transverse direction

$$d = \frac{W_r}{n} \quad (34)$$

where

d is the spacing between points in the transverse direction, in metres;

W_r is the width of the carriageway or relevant area, in metres;

n is the number of points in the transverse direction with a value greater than or equal to 3 and is the smallest integer giving $d \leq 1{,}5$ m.

The spacing of points from the edges of the relevant area is $D/2$ in the longitudinal direction, and $d/2$ in the transverse direction, as indicated in Figure 14.

In the case where the field of illuminance calculation points covers the lanes of a carriageway, the definition of grid points shall respect the definition for luminance calculation given in 7.1.3 and Figure 9.

7.2.8 Luminaires included in calculation

Luminaires that are situated within five times the mounting height from the calculation points shall be included in the calculation.

7.2.9 Illuminance on areas of irregular shape

For these areas it might be necessary to choose a rectangular calculation field which encloses and is therefore larger than the relevant area. Grid points used for the calculation of the quality characteristics should be chosen from those points which lie within the boundary of the relevant area. When the spacing of the luminaires is not regular it might not be possible to link the spacing of the grid points to the spacing of the luminaires, but the spacing in either direction shall not exceed 1,5 m. The principal directions of traffic flow for the calculation of vertical illuminance and semi-cylindrical illuminance shall be decided after considering the use or likely use of the area.

8 Calculation of quality characteristics

8.1 General

Quality characteristics relating to luminance or illuminance shall be obtained from the calculated grids of luminance or illuminance without further interpolation. If the grid points do not coincide with the centre of the lanes, for the calculation of longitudinal uniformity of luminance it shall be necessary to calculate the luminance of points on the centre line of each lane and the hard shoulder, if present, in accordance with 8.4.

For initial average illuminance or initial average luminance, f_M is 1,0 and initial values of the luminous flux shall be taken. For average luminance or average illuminance after a stated period, the f_M for the luminaire after the stated period in the environmental conditions of the installation shall be taken together with the luminous flux after this stated period.

8.2 Average luminance

The average luminance shall be calculated as the arithmetic mean of the luminances at the grid points in the field of calculation.

The calculated value shall be printed or displayed on the form, with the number of digits that are defined in the tables of requirements of EN 13201-2 (summarized in Clause 4 of this Part 3), i.e. two decimal places.

8.3 Overall uniformity

The overall uniformity shall be calculated as the ratio of the lowest luminance, occurring at any grid point in the field of calculation, to the average luminance.

The calculated value shall be printed or displayed on the form, with the number of digits that are defined in the tables of requirements of EN 13201-2 (summarized in Clause 4 of this Part 3), i.e. two decimal places.

8.4 Longitudinal uniformity

The longitudinal uniformity shall be calculated as the ratio of the lowest to the highest luminance on points in the longitudinal direction along each centre line of each lane of the grid used for the calculation of average luminance, (see Figure 9). The observer shall be positioned in the centre of each lane in turn. The operative value is the minimum longitudinal uniformity from all the lanes.

The calculated value shall be printed or displayed on the form, with the number of digits that are defined in the tables of requirements of EN 13201-2 (summarized in Clause 4 of this Part 3), i.e. two decimal places.

8.5 Threshold increment f_{TI}

8.5.1 Definition and conventional hypotheses

The threshold increment is calculated from the formulae or mathematically equivalent formulae:

$$f_{TI} = 65 \frac{L_v}{\left(\overline{L_i}\right)^{0,8}} \% \tag{35}$$

In Formula (35), valid for: 0,05 cd·m⁻² < $\overline{L_i}$ ≤ 5 cd·m⁻², L_v is calculated as follows.

$$L_v = \sum_{k=1}^{n_{Lu}} L_{vk} \tag{36}$$

Where the contribution of the pending luminaire, L_{vk} is:

either:

$$L_{vk} = 9{,}86 \cdot \left[1 + \left(\frac{A_y}{66{,}4}\right)^4\right] \frac{E_k}{\theta_k^2} \qquad \text{when: } 1{,}5° < \theta_k \le 60° \tag{37}$$

or:

$$L_{vk} = E_k \cdot \left(\frac{10}{\theta_k^3} + \left[\frac{5}{\theta_k^2}\right] \cdot \left[1 + \left(\frac{A_y}{62{,}5}\right)^4\right]\right) \qquad \text{when: } 0{,}1° < \theta_k \le 1{,}5° \tag{38}$$

NOTE 1 Formula (38) is drawn from CIE collection on glare: CIE 146:2002 Formula (6) with a nil iris pigmentation factor but with a limited field of view in the range 0,1° to 1,5°. This formula is introduced just as a complement to conventional Formula (37) in order to deal with the rare cases where the luminaires stand very near to the line of sight of the observer, what was not envisaged in previous EN 13201-3:2003.

In these formulae:

$\overline{L_i}$ is the average initial road luminance (cd·m⁻²);

L_v is the equivalent initial veiling luminance (cd·m⁻²);

k is the index of the pending luminaire in the summation;

n_{lu} is the number of luminaires involved in the calculation;

E_k is the initial illuminance (in lux) produced by the k^{th} luminaire in its new state on a plane normal to the line of sight and at the height of the observer's eye;

θ_k is the angle between the line of sight and the centre of the k^{th} luminaire, in degrees;

A_y is the age of the observer, in years.

Conventionally for road lighting installation design the following values are adopted:

— A_y = 23 y;

— the line of sight is 1° below the horizontal and in a vertical plane in the longitudinal direction passing through the observer's eye;

— the observer's eye is positioned at a height 1,5 m above road level and in the centre line of each lane in turn, as indicated in Figure 10;

— the initial longitudinal distance of the observer ahead of the first luminaire L_1 in front of the field of calculation is given by Formula (39):

$$X_{\mathrm{d}} = 2{,}75 \cdot \left| h - 1{,}5 \right| \quad (39)$$

where

H is the mounting height of the luminaire, in m;

1,5 (m) is the default value for the height of the observer's eyes to the road surface.

NOTE 2 See Figure 15 for an example of lighting installation with one row of luminaires.

Consequently, in the evaluation of L_{vk} in Formula (37) or Formula (38), only the luminaires under a screening plane which is inclined at 20° to the horizontal, and which passes through the observer's eye shall be included in calculation.

NOTE 3 In cases where screening above the horizontal does not apply, it is advised to take into account the contributions from all luminaires of the designed road installation in the observer's field of view for angles between the observer's line of sight and the direction of light incidence up to 60°.

The evaluation of θ_{k} in Formula (37) or Formula (38) can be obtained by using the scalar product in Formula (40).

Thereby:

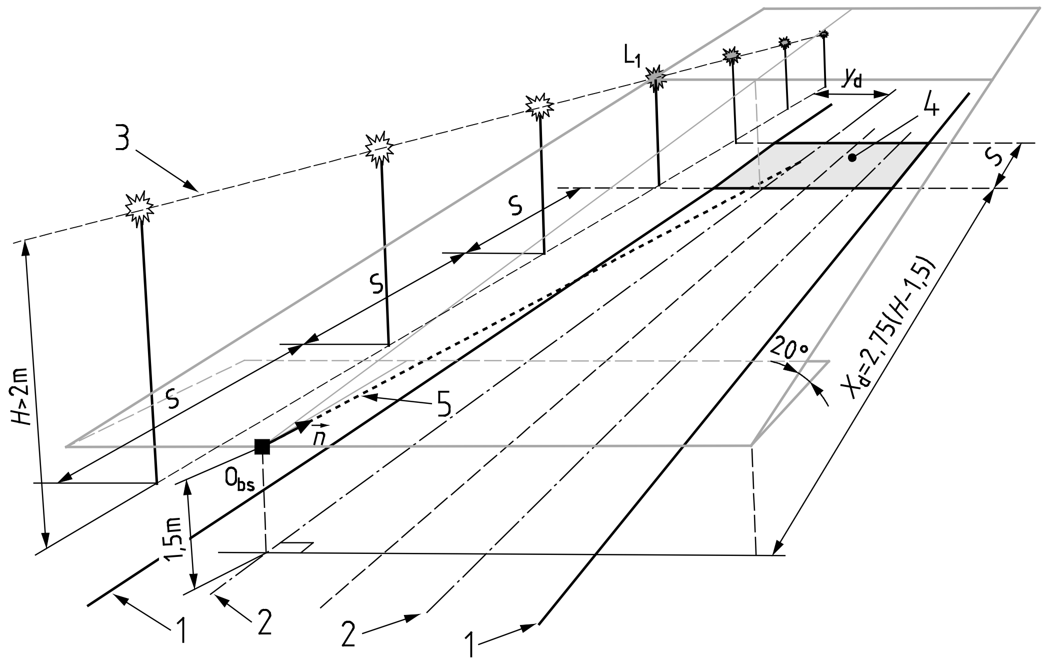
$$\theta_{\mathrm{k}} = \arccos\left[\frac{\left(x_{\mathrm{Lk}} - x_{\mathrm{Obs}}\right)\cos\alpha + \left(z_{\mathrm{Lk}} - z_{\mathrm{Obs}}\right)\sin\alpha}{\sqrt{\left(x_{\mathrm{Lk}} - x_{\mathrm{Obs}}\right)^2 + \left(y_{\mathrm{Lk}} - y_{\mathrm{Obs}}\right)^2 + \left(z_{\mathrm{Lk}} - z_{\mathrm{Obs}}\right)^2}}\right] \quad (40)$$

where

x_{Lk}, y_{Lk} and z_{Lk} are the coordinates of the k^{th} luminaire;

x_{Obs}, y_{Obs} and z_{Obs} are the coordinates of the observer's eyes;

$\alpha = -1°$ is the fixed angle of the line of sight of the observer under the horizontal.



Key

1	edge of the carriageway
2	centre line of a lane
3	focal line of luminaires: luminaire included in calculation; luminaire not included in calculation
4	field of calculation
5	line of sight of the observer
$\vec{n}$	is a unitary vector at the eye of the observer oriented in the run of the road parallel to the carriageway axis and tilted one degree under the horizontal;
O_{bs}	is the point of observation, at the eye of the observer;
L_1	is the first luminaire of the row closer to the calculation field that shall be included in calculation.

Figure 15 — Number of luminaires in front of the field of calculation

8.5.2 Threshold Increment calculation process

The summation is performed from the first luminaire within the observer dihedron of sight at or under the screening plane of 20° (see Figure 15) and luminaires beyond, up to a distance of 500 m in each luminaire row or for the whole installation length if it is lower than 500 m. The distance shall be considered from the actual position of the observer.

The calculation is commenced with the observer in the initial position x_d evaluated from Formula (40), and repeated with the observer moved forward in increments that are the same in number and distance as those used for the longitudinal spacing of luminance points. The procedure is repeated with the observer positioned in the centre line of each lane using the initial average road luminance appropriate to the observer transverse position.

If the road lighting installation has more than one row of luminaires, this process shall be repeated for every initial position of the observer on each lane axis and the maximum value of f_{TI} retained.

The maximum value of f_{TI} found is the operative value. This calculated value shall be printed or displayed on the form, with the number of digits that are defined by the table of requirements of EN 13201-2 (summarized in Clause 4 of this Part 3), i.e. in % with no decimal place.

8.5.3 Threshold increment calculation for C and P lighting classes

In C and P classes the main performance requirement is the average horizontal illuminance and usually luminance is not calculated.

In the conventional hypotheses of road lighting installations, calculations are made assuming the use of identical luminaires using identical light sources with same flux, same adjustment (and therefore same light distribution) evenly spaced along a straight section of road. These criteria are not all fulfilled for C lighting classes. Furthermore for P lighting classes the road surface photometric properties are usually not defined and pedestrians' observation conditions differ from those belonging to drivers of motorised vehicles.

Whilst the evaluation of f_{TI} is not strictly realistic, if based just on the photometric characteristics of the luminaire, a clearly specified calculation method is considered preferable to the simple G* classification based on the luminous intensities of a single luminaire.

For C and P lighting classes, the evaluation of disability glare, f_{TI} following the algorithm described in sections 8.5.1 and 8.5.2, requires the calculation of the average initial road luminance, $\overline{L_i}$ in addition to the average initial horizontal illuminance $\overline{E_{hi}}$.

For C lighting class the missing data to evaluate $\overline{L_i}$ is the *r*-table of the road surface. Considering that the main users are drivers, it is acceptable to use an r-table from those already available for M classes when the lighting design is based on luminance evaluation. Thus, considering a representative section of road with a mean spacing, the evaluation of fTI is possible applying Formulae (35) to (40).

For P lighting classes, it should be noted that the conditions of observation of pedestrians can notably differ from those of drivers of motorised vehicles.

When the lit surface is not seen at low angles (as in motorised traffic conditions where $\alpha = -1°$) it is possible to use Lambert's law to evaluate the average luminance of the assumed diffusing surface whose reflection factor needs to be evaluated and declared as hypothesis of design calculation.

In this last case, the following formula shall be used:

$$\overline{L_i} = \frac{\rho \overline{E_{hi}}}{\pi} \tag{41}$$

where

$\overline{L_i}$ is the initial average horizontal luminance of the lit surface;

$\overline{E_{hi}}$ is the initial average horizontal illuminance of the lit surface;

ρ is the average diffuse reflection factor of the lit surface. If measured data is not available, ρ = 0,2 is taken as default value.

The equivalent initial veiling luminance L_v shall be evaluated following the calculation process described in 8.5.2, i.e. considering all the luminaires of the installation in the observer's dihedron of sight up to 500 m, at most, or the actual number of luminaires for installations shorter than 500 m.

8.6 Edge Illuminance Ratio R_{EI}

The edge illuminance ratio is the minimum from the evaluation on each side of the carriageway of the ratio of the average horizontal illuminance on the longitudinal strip adjacent to the edge of the carriageway, and lying off the carriageway, divided by the average horizontal illuminance on the corresponding longitudinal strip lying on the carriageway. The width of all four strips shall be the same, and equal to the lanes' width of the carriageway or equal to the width of the unobstructed strip lying off the carriageway if lower. For dual carriageways, both carriageways together are treated as a single carriageway unless they are separated by more than 10 m.

The horizontal illuminance shall be calculated by the procedure specified in 7.2.2. The field of calculation shall be as indicated in 7.2.7. The number of luminaires considered shall be the same as indicated in 7.2.9. The position of the calculation points within each strip shall be as indicated in 7.1.3 and Figure 9.

Figure 16 gives examples of the location of the strips and their location for the calculation of the edge illuminance ratio. For this figure, the following formulae apply:

$R_{\mathrm{EI}\ 12}$ for strips 1 and 2:

$$R_{\mathrm{EI}\ 12} = \frac{\overline{E}_{\mathrm{h,\ strip\ 1}}}{\overline{E}_{\mathrm{h,\ strip\ 2}}} \tag{42}$$

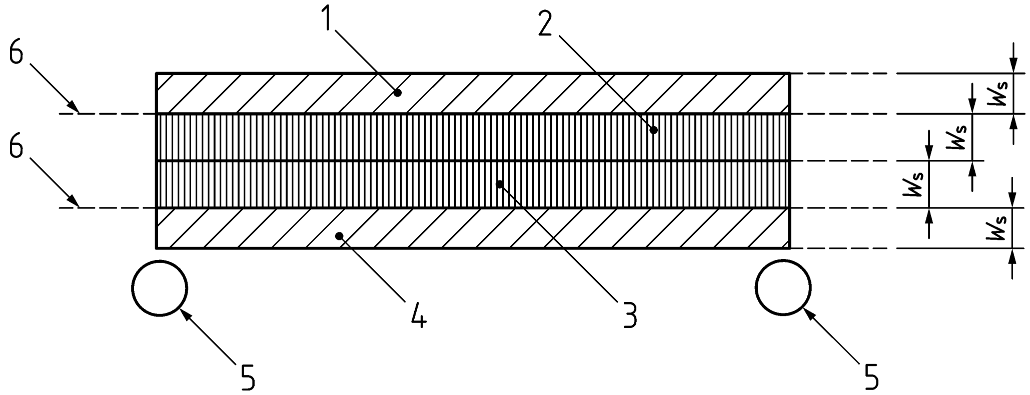
$R_{\mathrm{EI}\ 43}$ for strips 3 and 4:

$$R_{\mathrm{EI}\ 43} = \frac{\overline{E}_{\mathrm{h,\ strip\ 4}}}{\overline{E}_{\mathrm{h,\ strip\ 3}}} \tag{43}$$

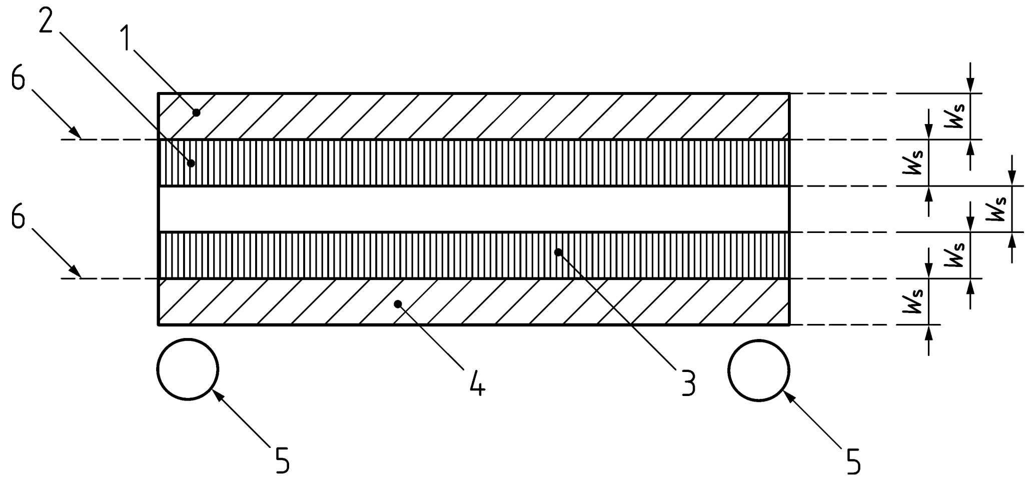
From which the operative R_{EI} is defined:

$$R_{\mathrm{EI}} = \min(R_{\mathrm{EI}\ 12}; R_{\mathrm{EI}\ 43}) \tag{44}$$

The calculated value shall be printed or displayed on the form, with the number of digits that are defined in the tables of requirements of EN 13201-2 (summarized in Clause 4 of this Part 3), i.e. two decimal places.



a) Case of a 2-lane carriageway



b) Case of 3-lane carriageway

Key

1 strip 1

2 strip 2

3 strip 3

4 strip 4

5 luminaire

6 edge of carriageway

W_S width of strips = width of one lane

Figure 16 — Location and width of strips for calculating edge illuminance ratio R_{EI}

9 Ancillary data

When photometric performance data are prepared for an installation, the following ancillary data shall be declared:

a) identification of the luminaires;

b) identification of *I*-table;

c) identification of the *r*-table with a clear declaration of the value of Q_0 used; required for luminance calculations;

d) tilt during measurement of the luminaires;

e) tilt in application of the luminaires;

f) rotation of the luminaires, if different from zero;

g) orientation of the luminaires, if different from zero;

h) identification of the light sources;

i) luminous flux of the light sources on which the calculations are based;

j) maintenance factors applied;

k) definition of the field of calculation, of the origin of the reference system and coordinates of the grid points;

l) position of the luminaires in plan or a numerical description;

m) mounting height of the luminaires;

n) direction of interest for vertical illuminance and semi-cylindrical illuminance;

o) any deviations from the procedures given in this standard, including the calculation of threshold increment for an observer of other than 23 years old or when the mounting height of luminaires is less than or equal to 2 m. In this last case the use of an extended *r*-table is needed for luminance calculation (see Table B.1).

Annex A
(informative)

Mathematical information technology conventions and flow chart diagrams

A.1 Mathematical and Information Technology conventions used in addition to Clause 4 to define the variables used in the following logical flow charts of the lighting calculation program

This annex suggests the use of "friendly" variable names in the source code of software in order to facilitate their maintenance and eventual releases. The linear "do loop" calculation chart is very common in lighting but nothing is said about the accuracy of the variables. For decimal numbers and numerical arrays the "double" accuracy is advised to ensure less difference between the results than those obtained nowadays from different software and corresponding calculation programs.

The algorithms of lighting calculation defined by flow charts in A.3 (Figures A.3 to A.7) is the way to avoid the dependence with a given programming language, even recent and more powerful than those used in the past (like were the FORTRAN [FORmulation TRANslator, an old IT scientific language] listings of the source code of the CIE standard calculation program, "STAN", and that of the more general CIE "LUCI" calculation program both included in CIE 30.2 1982, reprint in 1990 but now obsolete).

The presentation of the results, which is very important for lighting designs, is not dealt with in this annex as it is the role of professional software providers to produce this presentation and the user-friendly, data input and savings in complex designs.

This annex includes the logical flow charts introducing f_{TI}, and R_{EI} calculations but with the general mathematical conventions and limitations given in Clause 4.

The variables and arrays names correspond mainly to three types of "actors" in a lit scene:

P, the current point of calculation;

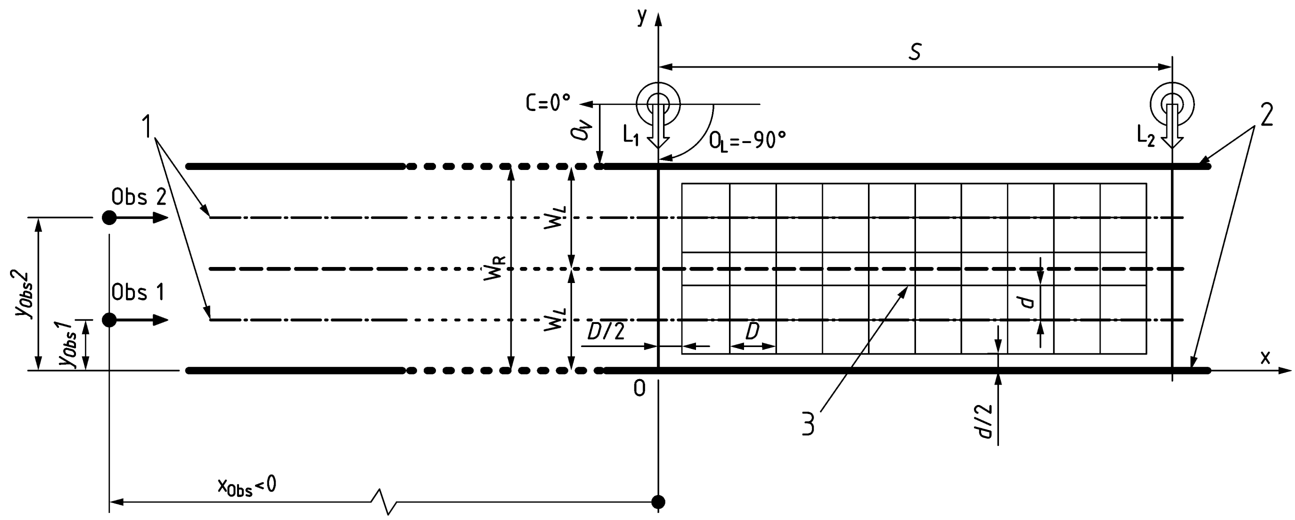
L, the current luminaire;

O_{bs}, the current observer position.

The road surface is defined for luminance calculation thanks to the present CIE *r*-tables files (see CIE 144:2001 mentioned in Bibliography).

A certain number of auxiliary variables and arrays need to be created for the sake of computer algorithms and cumulative variables used in lighting calculations. Programmers are advised to find in the last column of Table A.1 the suggested symbols of parameters, variables and indices of the logical flow charts codified in ASCII.

The system of coordinates of the calculation program can be seen in Figure A.1.



Key

1 lane axis

2 birds eye view of section of road

3 current « P » grid point (x_p, y_p, z_p)

Figure A.1 — System of coordinate: example of road with two lanes

Table A.1 — Symbols and corresponding designations of variables, tables and parameters used in the logical flowchart of the calculation program (in alphabetic order)

Quantity		
Symbol	**Name or description**	**Suggested symbols of IT variables, parameters and arrays in the source code**
A_y	Age of the observer (Default value 23 years)	Ay
Arrangement (see Note below this table)	Arrangement code of the luminaires about the carriageway: 1) Single sided on one side of the carriageway 2) Opposite without central reservation 3) Staggered with the first luminaire just before the calculation field (from the observer point of view) put on the “top” side of the carriageway in Figure A.1 (see also Figure 9) 4) Twin central (central reservation) 5) Opposite with central reservation	Arrangement
C	Photometric azimuth	C
D	Spacing between calculation points in the longitudinal direction	dx
d	Spacing between calculation points in the transverse direction	dy
$\overline{E}$	Average illuminance from the grid points	Eave
E_{Pmin}	Minimal illuminance on the grid points	Epmin

Quantity		
Symbol	**Name or description**	**Suggested symbols of IT variables, parameters and arrays in the source code**
	Array used for horizontal illuminance evaluation of the calculation grid points: ixp varying from 1 to nxp and iyp varying from 1 to nyp	E(1 to nxp;1 to nyp)
F_{la}	Assigned luminous flux of lamp or lamps in a luminaire	Fla
f_M	Overall maintenance factor, depending on lamp lumen maintenance factor and luminaire maintenance factor and, for LEDs, failure fraction F_y.	fM
f_{TI}	Threshold increment : array dimensioned by the number of lanes	TI(nla)
H	Mounting height of a luminaire	H
i	Index used for initial lighting level values (new values)	i
$I(C, \gamma)$	Luminous intensity emanating in the direction defined by the angles C and γ from one luminaire.	I(C,Gamma)
	Index used to define the current lane (from 1 to nlanes)	ila
i_{Obs}	Index of the transverse observer position: lane axis number 1 at bottom to n_{lanes} at top	iObs
	Index varying from 1 to nrow in luminance and veiling luminance calculation	irow
i_{XP}	Index in abscissa (column index of arrays) of the grid points. ton left side to nx_p on right side of the observer	ixP
i_{YP}	Index in ordinate (line index of arrays) of the grid points. ton lower line to ny_p on upper line	iyP
$\overline{L}$	Average luminance from the grid points ($0,05 < \overline{L} < 5$)	Lave
L_{Pmin}	Minimal luminance in the grid points	Lpmin
L_{Pmax}	Maximal luminance on a lane axis	Lpmax
	Luminaire I-table file name	To be input
L_v	Equivalent veiling luminance from one luminaire	Lv
	Array used for luminance evaluation of the calculation grid points for different transverse observer locations	L(nlanes;1 to nxp;1 to nyp)
$L_v(i_{la}, i_{YP})$	Equivalent veiling luminance cumulated from all the luminaires for a given observer	Lv(ila,iyp)
$L_v(i_{la})$	Equivalent veiling luminance cumulated from all luminaires for an observer on a given lane axis	Lv(ila)
	Number of rows of luminaires	nrow
nx_p	Number of points in the longitudinal direction (run of the road, conventionally)	nxp
ny_p	Number of points in the transverse direction (width of the road, conventionally)	nyp
n_L	Number of luminaires considered in the calculation (to be defined: see 7.1.5 for road luminance calculation and 8.5 for veiling luminance calculation in f_{TI})	nL

Quantity		
Symbol	**Name or description**	**Suggested symbols of IT variables, parameters and arrays in the source code**
	Number of luminaires considered for road luminance calculation located on observer side before the field of calculation in abscissa	nLbef_field
	Number of luminaires considered for road luminance calculation located beyond the field of calculation in abscissa	nLafter_field
n_{lanes}	Number of lanes of the carriageway	nlanes
	Array of number of luminaires included in L_v calculation for threshold increment evaluation (irow varying from 1 to nrow)	nL_TI(irow)
	Number of row of luminaires	nrow
$\vec{n}$	Unitary sliding vector at the eye of the current observer aimed at his line of sigh (one degree under the horizon)	
O_L	Orientation of the luminaire for calculation (see in Figure A.1, angular origin parallel to the origin axis: Ox > 0 [up to the arrow luminaire axis => C = 90°])	Ol
O_V	Overhang: distance from the luminaire to the nearer edge of the carriageway. O_V < 0 in case of luminaire set back (luminaire outside the carriageway)	Ov
$r(\tan \varepsilon, \beta)$	Reduced luminance coefficient in the direction $(\tan \varepsilon,\beta)$	r(tanEpsilon, Beta)
R_{EI}	Edge illuminance ratio	EIR
	Road surface *r*-table file name	To be input
S	Spacing between luminaires	S
$\sum E_P$	Cumulated illuminance at a point P from several luminaires	SigmaEP
$\sum L_P$	Cumulated luminance at a point P from several luminaires for one observer position	SigmaLP
U_{oE}	Overall illuminance uniformity on the grid points	UoE
U_o	Overall luminance uniformity on the grid points	Uo
U_I	Minimum longitudinal luminance uniformity from all the lane axes	UI
W_{cr}	Width of the central reservation (if any)	Wcr
W_I	(common) width of lanes	WI
W_r	Width of the carriageway	Wr
W_S	Width of a strip	Ws
x	Abscissa in (O,x.y) coordinate system (Figure 16)	x
y	Ordinate in (O,x.y) coordinate system (Figure 16)	y
z	Height (positive) above the plane surface of the road (origin of z axis)	z
x_{Obs}	Abscissa of the current observer	xObs
y_{Obs}	Ordinate of the current observer	yobs

Quantity		Suggested symbols of IT variables, parameters and arrays in the source code
Symbol	**Name or description**	
z_{Obs}	Height of eyes of the current observer	zObs
x_L	Abscissa of the current luminaire	xL
	Minimum abscissa of the luminaire being included in luminance calculation (auxiliary variable)	xLmin
	Maximum abscissa of the luminaire being included in luminance calculation (auxiliary variable)	xLmax
y_L	Ordinate of the current luminaire	yL
z_L or H	Mounting height of the current luminaire	zL
x_P	Abscissa of a current P point of the calculation grid	xP
y_P	Ordinate of a current P point of the calculation grid	yP
z_P	Height above the plane reference surface of the current P point of the calculatior grid. Default value $z_P = 0$	zP
ε	Angle of light incidence at P on the horizontal surface	Epsilon
β	Azimuth of r-tables	Beta
γ	Photometric elevation	Gamma
θ_k	In L_v calculation: angle between the line of sight of the observer and the line from the observer's eye to a current luminaire L_k.	Thetak
θ_f	Luminaire tilt in application, used for calculation (not visible in Figure 16. Origin: horizontal level in the vertical plane oriented by the arrow. See also Figure 8 in 6.3)	Thetaf
In the last column of the table a designation in ASCCI is suggested for use in the code source of IT calculation programs.		

NOTE It is advised not to confuse the codification of arrangement in this table with the key numbers of Figure 10 in 7.1.4. In this figure, number 2 is not a current layout and can be dealt with the proposed logical flow chart as two single sided installations, one by carriageway, changing simply the overhang of luminaires.

As stipulated in Clause 4, all calculation results are presented with a required number of significant digits and decimal places. The objective is not to express the real accuracy of measured values dealt with in EN 13201-4, but to comply to performance requirements of the tables of EN 13201-2 with an allowed rounding for presentation.

A.2 Linear interpolation in the tables

When the required luminous intensity (or the reduced luminance coefficient) lies between measured values, an interpolation is necessary.

A value $z(x, y)$ can be found for the needed direction (x, y) as shown in Figure A.2.

Be: $z(x1, y1)$, $z(x2, y1)$, $z(x1, y2)$, $z(x2, y2)$

four values in the table corresponding to four directions defined by the table entries:

$(x1, y1)$, $(x2, y1)$, $(x1, y2)$, $(x2, y2)$

closest to and surrounding the direction (x, y).

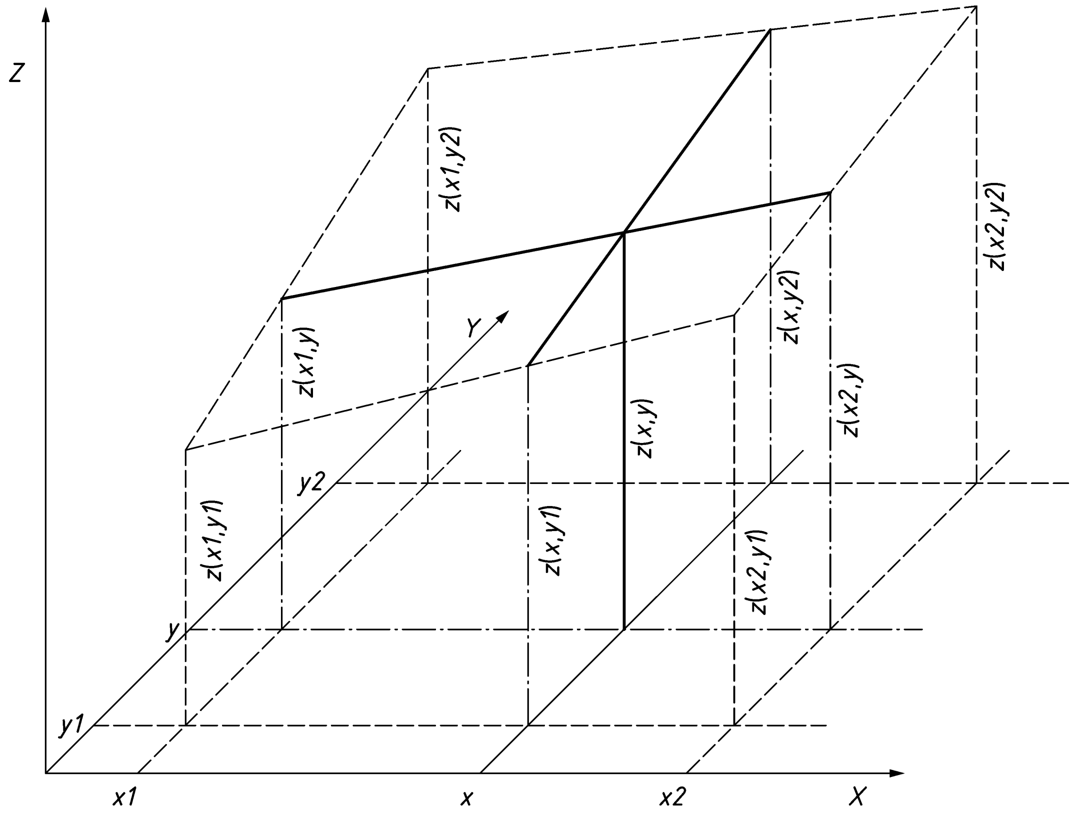


Figure A.2 — Linear interpolation in the tables

There are three equivalent methods to obtain $z(x, y)$:

1) A linear interpolation between $z(x1, y1)$ and $z(x2, y1)$ finding for the direction $(x, y1)$ an intermediate value $z(x, y1)$, followed by a second interpolation between $z(x1, y2)$, and $z(x2, y2)$ producing a $z(x, y2)$ value. A third interpolation between $z(x, y1)$ and $z(x, y2)$ gives the searched $z(x, y)$ value for the direction (x, y).

2) A linear interpolation between $z(x1, y1)$ and $z(x1, y2)$ finding for the direction $(x1, y)$ an intermediate value $z(x1, y)$, followed by a second interpolation between $z(x2, y1)$, and $z(x2, y2)$ producing a $z(x2, y)$ value. A third interpolation between $z(x1, y)$ and $z(x2, y)$ gives the searched $z(x, y)$ value for the direction (x, y).

3) A linear regression directly between $z(x1, y1)$, $z(x2, y1)$, $z(x1, y2)$ and $z(x2, y2)$ in a single interpolation.

Method 1:

For computing purposes the general calculation formulae are:

$$z(x,y)=z(x,y1)+\frac{y-y1}{y2-y1}\left[z(x,y2)-z(x,y1)\right] \tag{A.1}$$

which gives:

$$z(x,y1)=z(x1,y1)+\frac{x-x1}{x2-x1}\left[z(x2,y1)-z(x1,y1)\right] \tag{A.2}$$

and:

$$z(x,y2)=z(x1,y2)+\frac{x-x1}{x2-x1}\left[z(x2,y2)-z(x1,y2)\right] \tag{A.3}$$

Method 2:

Similarly and alternatively to the latter case, producing the same result is:

$$z(x,y)=z(x1,y)+\frac{x-x1}{x2-x1}\left[z(x2,y)-z(x1,y)\right] \tag{A.4}$$

which gives:

$$z(x1,y)=z(x1,y1)+\frac{y-y1}{y2-y1}\left[z(x1,y2)-z(x1,y1)\right] \tag{A.5}$$

$$z(x2,y)=z(x2,y1)+\frac{y-y1}{y2-y1}\left[z(z2,y2)-z(x2,y1)\right] \tag{A.6}$$

Method 3:

In the case of linear interpolation, the recourse to linear regression is also possible directly between the four measured values that make a cell. The general formula using Lagrange polynomial interpolation can be written:

$$z(x,y)=P_{11}\times z(x1,y1)+P_{21}\times z(x2,y1)+P_{12}\times z(x1,y2)+P_{22}\times z(x2,y2) \tag{A.7}$$

Where $P_{ij} \geq 0$ are such that:

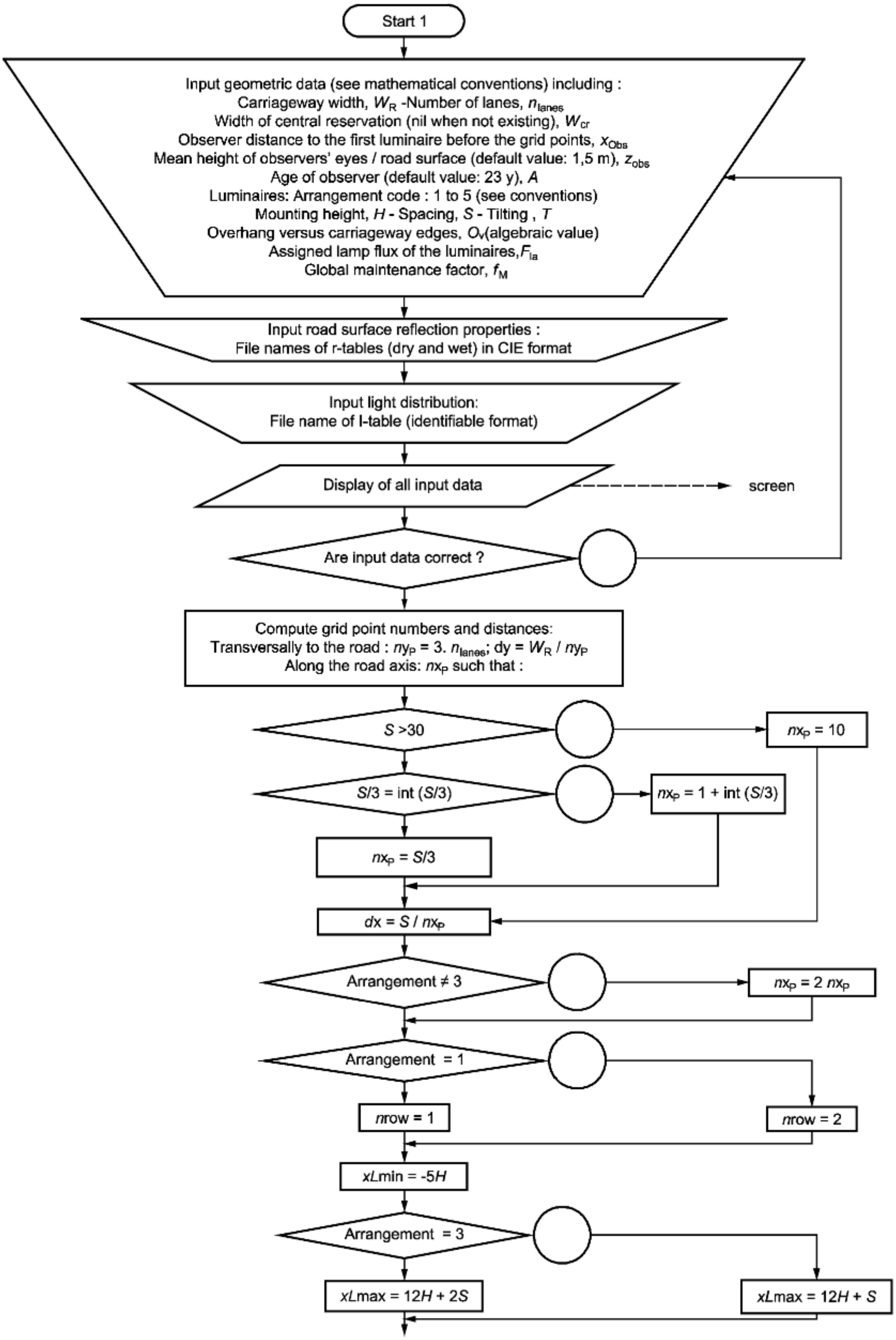
$$P_{11}=\frac{x2-x}{x2-x1}\cdot\frac{y2-y}{y2-y1}\quad P_{21}=\frac{x-x1}{x2-x1}\cdot\frac{y2-y}{y2-y1}\quad P_{12}=\frac{x2-x}{x2-x1}\cdot\frac{y-y1}{y2-y1}\quad P_{22}=\frac{x-x1}{x2-x1}\cdot\frac{y-y1}{y2-y1} \tag{A.8}$$

The choice is given to programmers to create a subroutine "interpolation" among these three equivalent methods. These subroutines are usable for both *I*-tables or *r*-tables with respectively (C, γ) or (tan ε, β) for the defined direction (x, y).

Taking account of standard *r*-tables format defined in Table 2, complementary programming tests are needed to avoid using the blank cells. By default most of programming languages assign 0 values to these blank cells. If there is no test to exclude the calculation when these cells are involved at the border of filled cells, the ensuing interpolation gives an incorrect *r* value (instead of nothing).

A.3 Information Technology requirements

Regarding logical flow charts, programmers are advised to use common shared variables and re-dimensioned arrays all along the different phases which are detailed in the different flow charts, and also in the subroutines. It is anticipated that these flow charts use global variables whose meaning and values do not change during the calculation program. That means all input or calculated data remain available in RAM (Random Access Memory) refreshed in real time as soon as the calculation program is launched. Apart from the edition of input data and calculation results on the computer screen, on a printer or on a plotter, they should be saved in the computer either in a specific format readable by the software or in a file in a portable document format to keep a track of the lighting design.


Start 1
Input geometric data (see mathematical conventions) including :
Carriageway width, W_R -Number of lanes, n_{lanes}
Width of central reservation (nil when not existing), W_{cr}
Observer distance to the first luminaire before the grid points, x_{Obs}
Mean height of observers' eyes / road surface (default value: 1,5 m), z_{obs}
Age of observer (default value: 23 y), A
Luminaires: Arrangement code : 1 to 5 (see conventions)
Mounting height, H - Spacing, S - Tilting , T
Overhang versus carriageway edges, O_v(algebraic value)
Assigned lamp flux of the luminaires,F_{la}
Global maintenance factor, f_M
Input road surface reflection properties :
File names of r-tables (dry and wet) in CIE format
Input light distribution:
File name of I-table (identifiable format)
Display of all input data
screen
Are input data correct ?
Compute grid point numbers and distances:
Transversally to the road : ny_P = 3. n_{lanes}; dy = W_R / ny_P
Along the road axis: nx_P such that :
S >30
nx_P = 10
S/3 = int (S/3)
nx_P = 1 + int (S/3)
nx_P = S/3
dx = S / nx_P
Arrangement ≠ 3
nx_P = 2 nx_P
Arrangement = 1
$n$row = 1
$n$row = 2
xLmin = -5H
Arrangement = 3
xLmax = 12H + 2S
xLmax = 12H + S

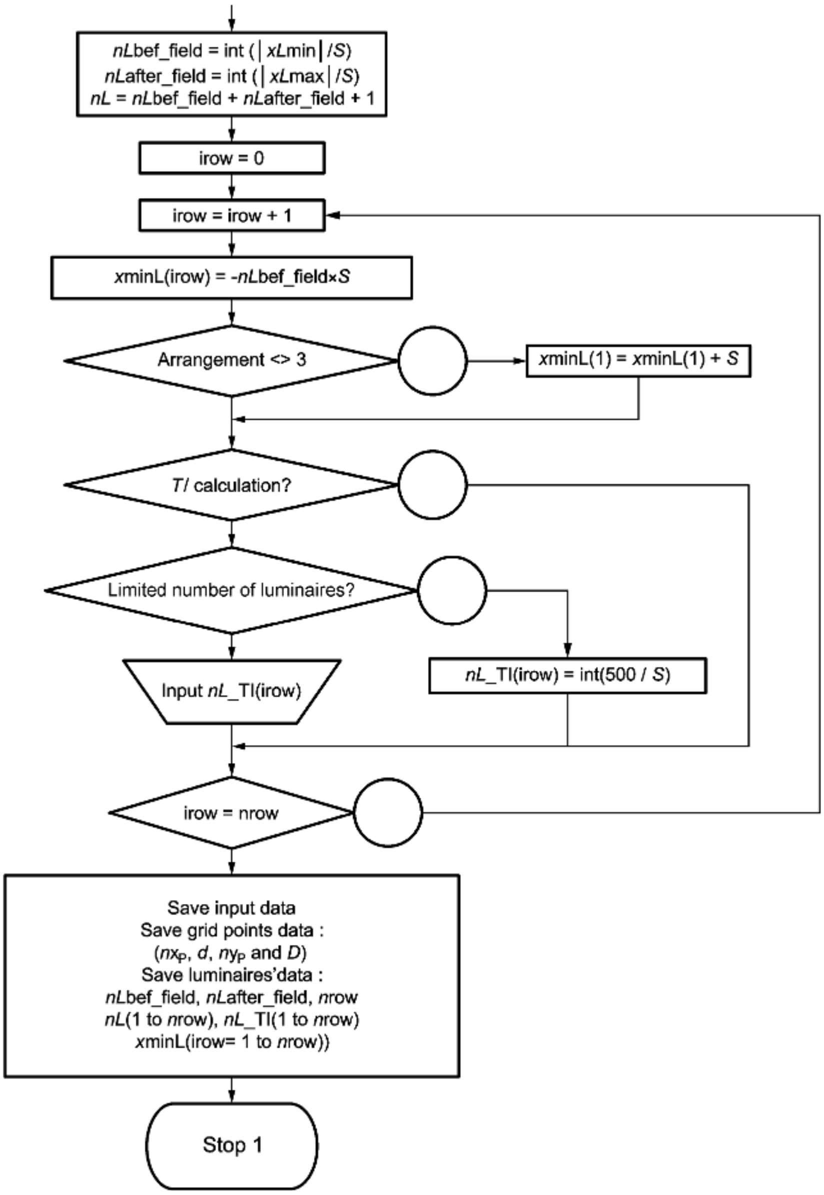
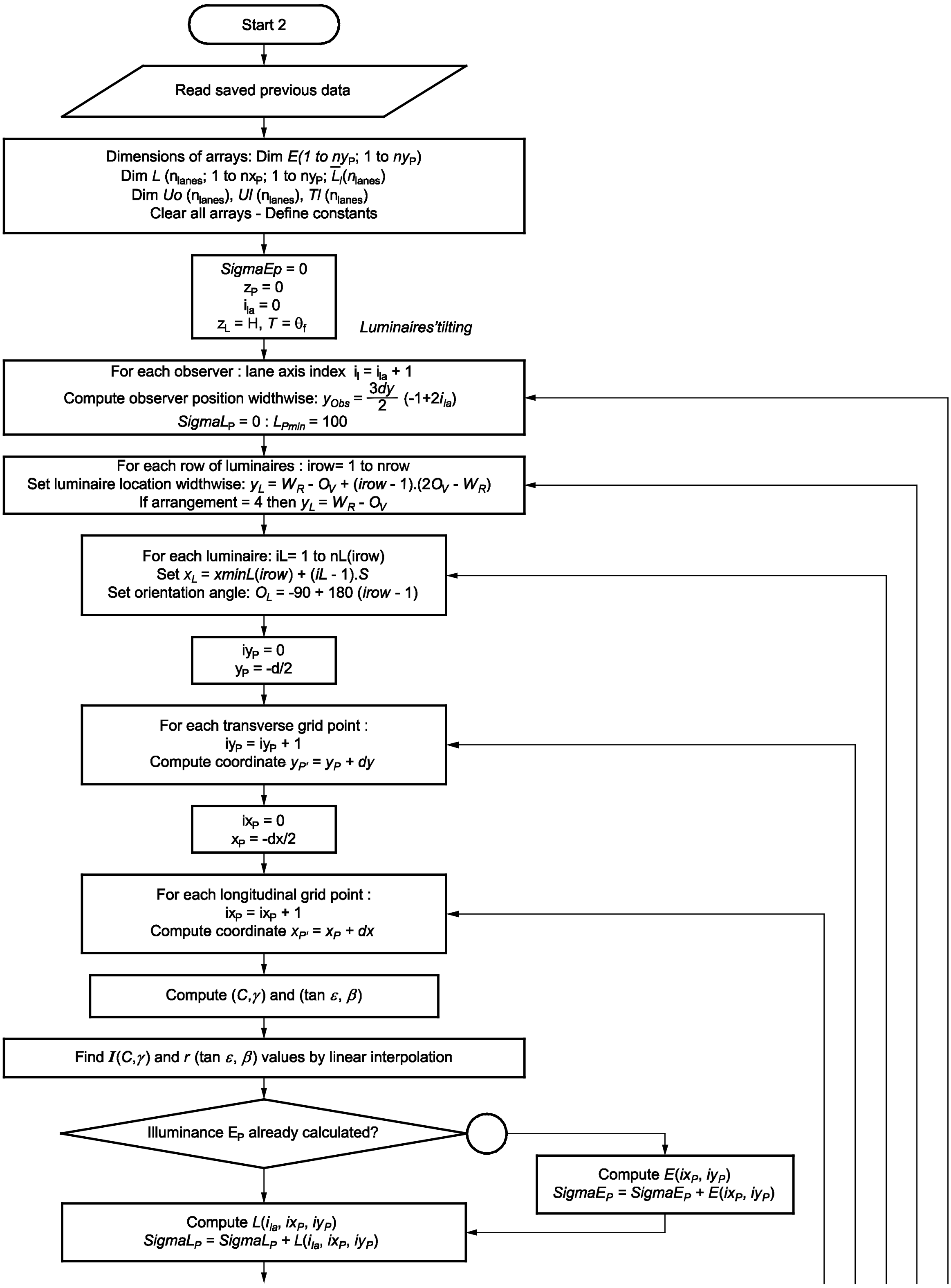


Figure A.3 — Standard program: data input (editor)


Start 2
Read saved previous data
Dimensions of arrays: Dim E(1 to nyP; 1 to nyP)
Dim L (nlanes; 1 to nxP; 1 to nyP; Li(nlanes)
Dim Uo (nlanes), Ul (nlanes), TI (nlanes)
Clear all arrays - Define constants
SigmaEp = 0
zP = 0
ila = 0
zL = H, T = θf
Luminaires'tilting
For each observer : lane axis index il = ila + 1
Compute observer position widthwise: yObs = 3dy/2 (-1+2ila)
SigmaLP = 0 : LPmin = 100
For each row of luminaires : irow= 1 to nrow
Set luminaire location widthwise: yL = WR - OV + (irow - 1).(2OV - WR)
If arrangement = 4 then yL = WR - OV
For each luminaire: iL= 1 to nL(irow)
Set xL = xminL(irow) + (iL - 1).S
Set orientation angle: OL = -90 + 180 (irow - 1)
iyP = 0
yP = -d/2
For each transverse grid point :
iyP = iyP + 1
Compute coordinate yP' = yP + dy
ixP = 0
xP = -dx/2
For each longitudinal grid point :
ixP = ixP + 1
Compute coordinate xP' = xP + dx
Compute (C,γ) and (tan ε, β)
Find I(C,γ) and r (tan ε, β) values by linear interpolation
Illuminance EP already calculated?
Compute E(ixP, iyP)
SigmaEP = SigmaEP + E(ixP, iyP)
Compute L(ila, ixP, iyP)
SigmaLP = SigmaLP + L(ila, ixP, iyP)

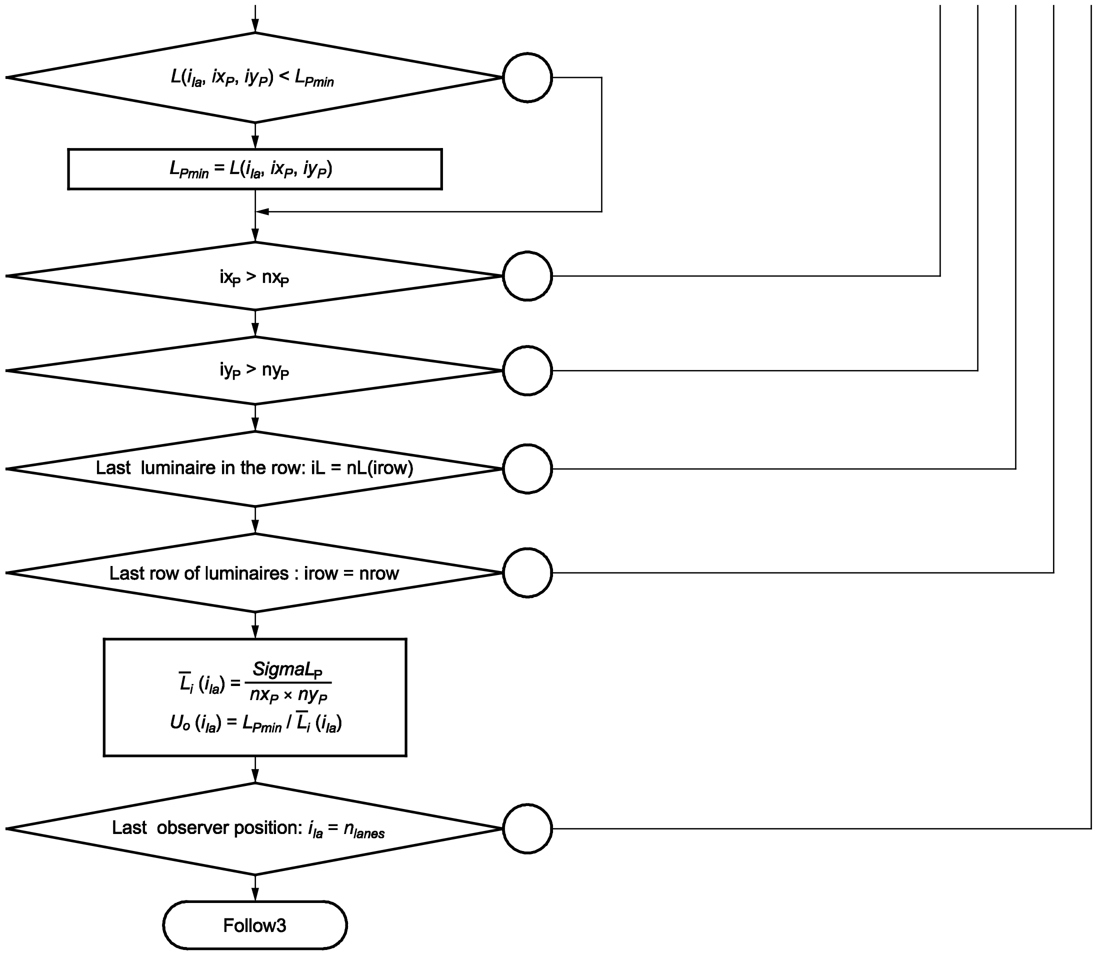


Figure A.4 — Calculation process of point luminances, illuminances and minimum point luminance

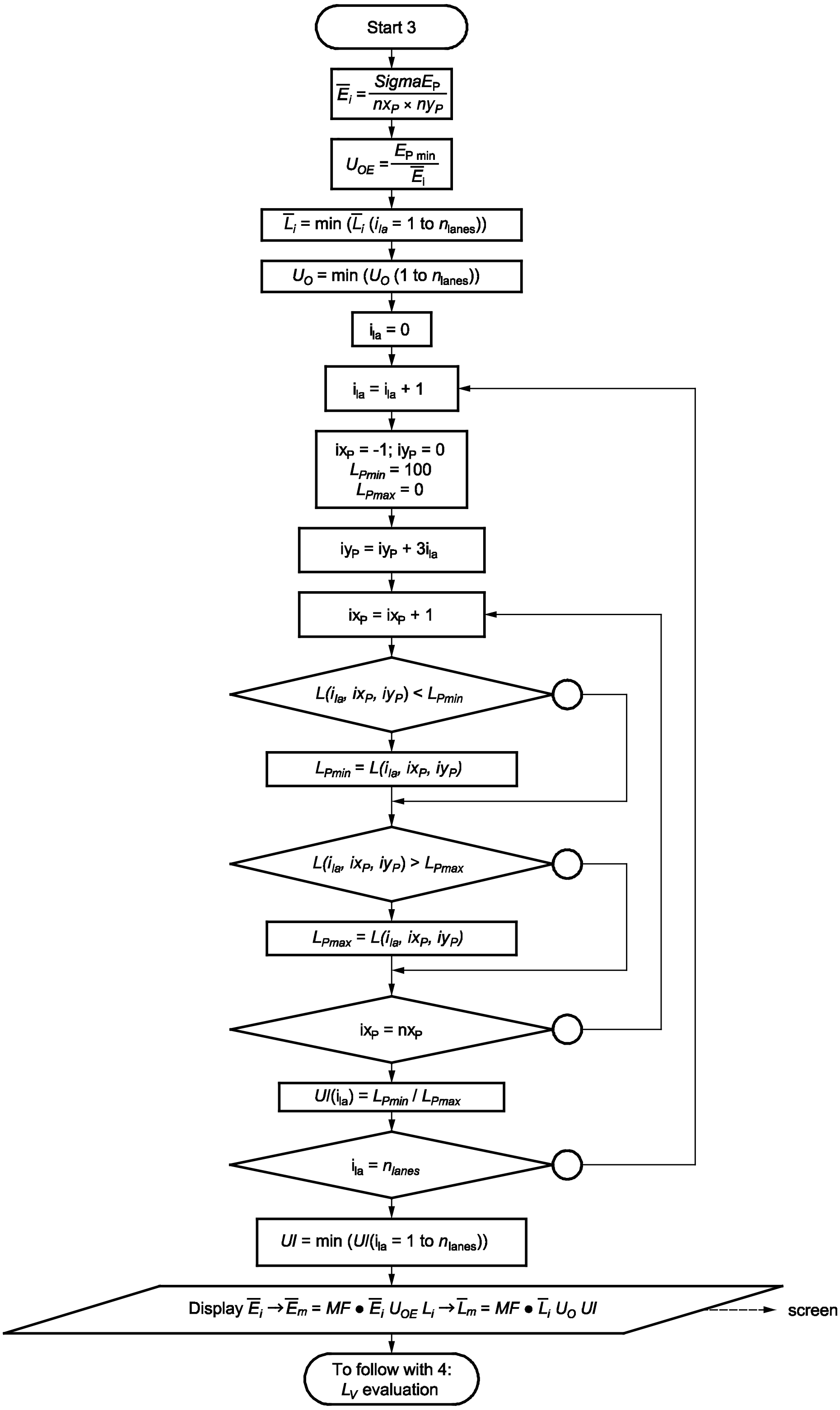
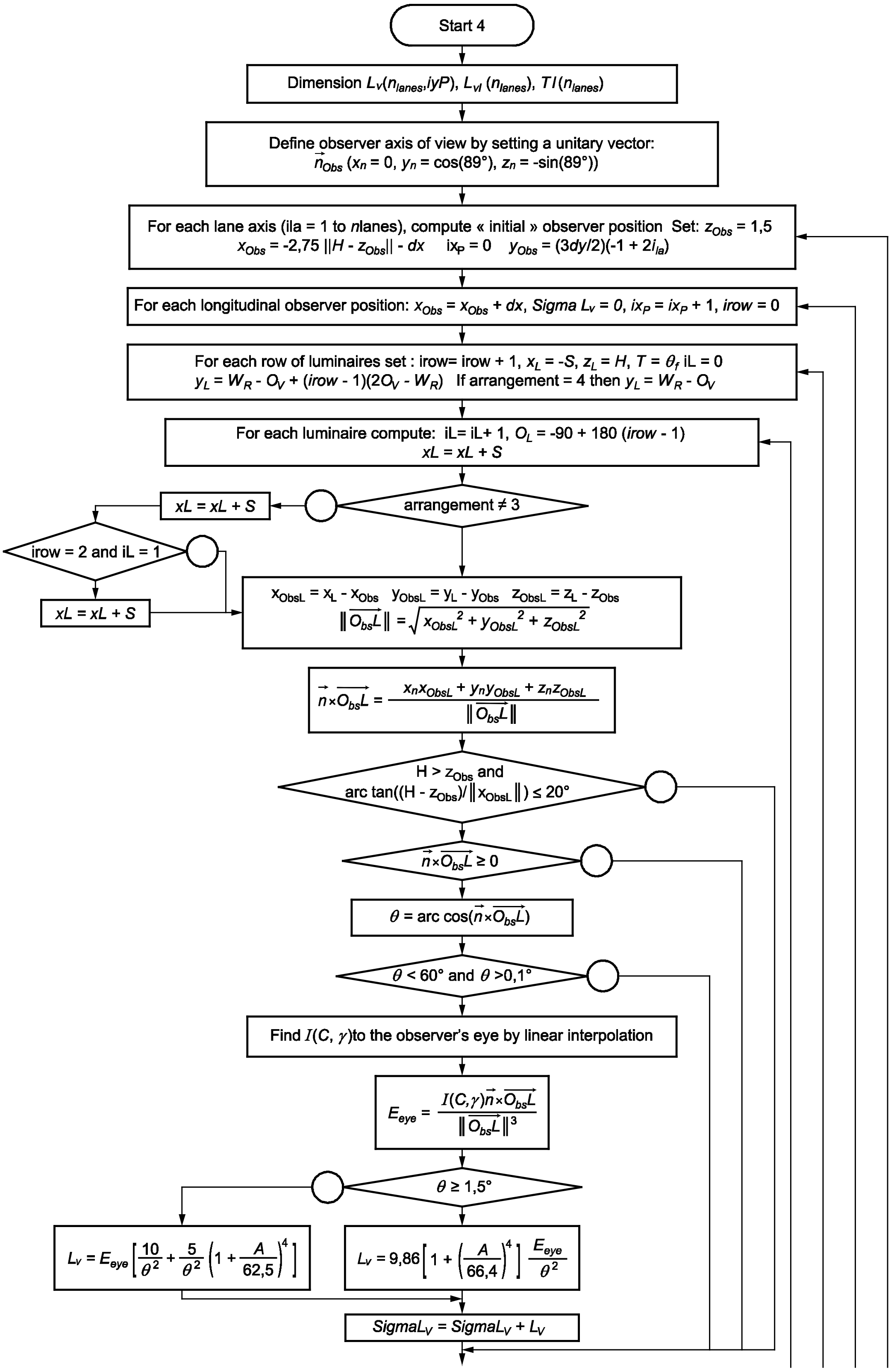


Figure A.5 — Calculation process of average initial illuminance, overall uniformity, average initial luminance


Start 4
Dimension $L_v(n_{lanes}, iyP)$, $L_{vl}(n_{lanes})$, $TI(n_{lanes})$
Define observer axis of view by setting a unitary vector:
$\vec{n}_{Obs}$ (x_n = 0, y_n = cos(89°), z_n = -sin(89°))
For each lane axis (ila = 1 to nlanes), compute « initial » observer position Set: z_{Obs} = 1,5
x_{Obs} = -2,75 $\|H - z_{Obs}\|$ - dx ix_P = 0 y_{Obs} = $(3dy/2)(-1 + 2i_{la})$
For each longitudinal observer position: $x_{Obs} = x_{Obs} + dx$, $Sigma\ L_v = 0$, $ix_P = ix_P + 1$, $irow = 0$
For each row of luminaires set : irow= irow + 1, $x_L = -S$, $z_L = H$, $T = \theta_f$ iL = 0
$y_L = W_R - O_V + (irow - 1)(2O_V - W_R)$ If arrangement = 4 then $y_L = W_R - O_V$
For each luminaire compute: iL= iL+ 1, O_L = -90 + 180 (irow - 1)
$xL = xL + S$
arrangement ≠ 3
$xL = xL + S$
irow = 2 and iL = 1
$xL = xL + S$
$x_{ObsL} = x_L - x_{Obs}$ $y_{ObsL} = y_L - y_{Obs}$ $z_{ObsL} = z_L - z_{Obs}$
$\|\overrightarrow{O_{bs}L}\| = \sqrt{x_{ObsL}^2 + y_{ObsL}^2 + z_{ObsL}^2}$
$\vec{n} \times \overrightarrow{O_{bs}L} = \frac{x_n x_{ObsL} + y_n y_{ObsL} + z_n z_{ObsL}}{\|\overrightarrow{O_{bs}L}\|}$
H > z_{Obs} and
arc tan((H - z_{Obs})/$\|x_{ObsL}\|$) ≤ 20°
$\vec{n} \times \overrightarrow{O_{bs}L} \geq 0$
$\theta = \arccos(\vec{n} \times \overrightarrow{O_{bs}L})$
θ < 60° and θ >0,1°
Find $I(C, \gamma)$ to the observer's eye by linear interpolation
$E_{eye} = \frac{I(C,\gamma)\vec{n} \times \overrightarrow{O_{bs}L}}{\|\overrightarrow{O_{bs}L}\|^3}$
$\theta \geq 1,5°$
$L_v = E_{eye}\left[\frac{10}{\theta^2} + \frac{5}{\theta^2}\left(1 + \frac{A}{62,5}\right)^4\right]$
$L_v = 9,86\left[1 + \left(\frac{A}{66,4}\right)^4\right]\frac{E_{eye}}{\theta^2}$
$SigmaL_V = SigmaL_V + L_V$

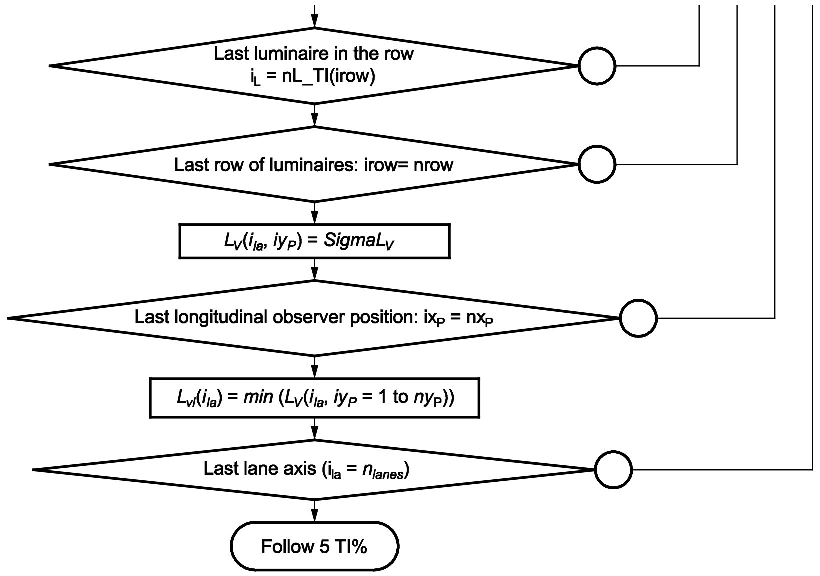


Figure A.6 — Calculation process of veiling luminance (part of f_{TI})

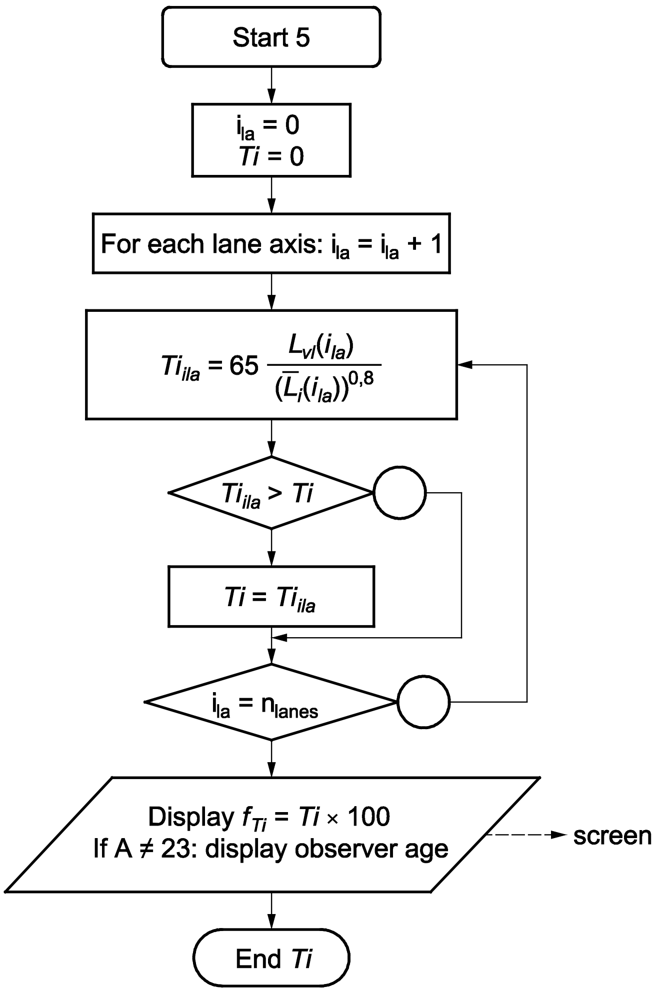


Figure A.7 — Calculation process of threshold increment f_{TI}

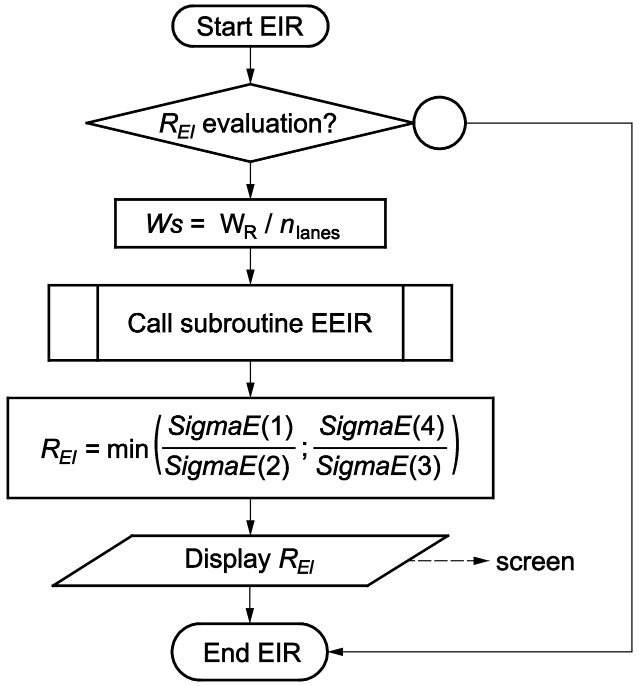
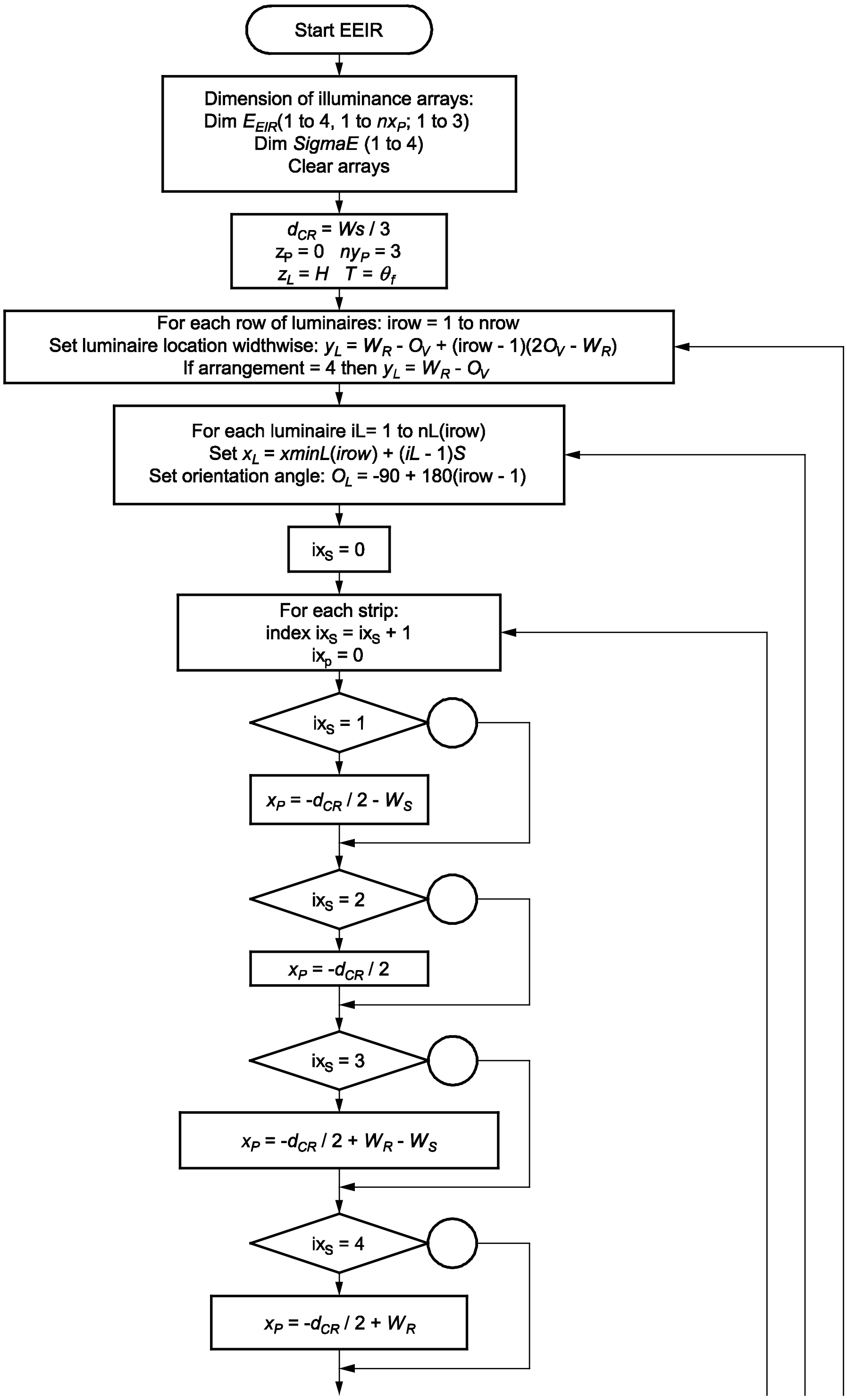


Figure A.8 — Calculation process of edge illuminance ratio R_{EI}


Start EEIR
Dimension of illuminance arrays:
Dim E_{EIR}(1 to 4, 1 to nx_P; 1 to 3)
Dim *SigmaE* (1 to 4)
Clear arrays
$d_{CR} = Ws / 3$
$z_P = 0$ $ny_P = 3$
$z_L = H$ $T = \theta_f$
For each row of luminaires: irow = 1 to nrow
Set luminaire location widthwise: $y_L = W_R - O_V + (irow - 1)(2O_V - W_R)$
If arrangement = 4 then $y_L = W_R - O_V$
For each luminaire iL= 1 to nL(irow)
Set $x_L = xminL(irow) + (iL - 1)S$
Set orientation angle: $O_L = -90 + 180(irow - 1)$
$ix_S = 0$
For each strip:
index $ix_S = ix_S + 1$
$ix_p = 0$
$ix_S = 1$
$x_P = -d_{CR} / 2 - W_S$
$ix_S = 2$
$x_P = -d_{CR} / 2$
$ix_S = 3$
$x_P = -d_{CR} / 2 + W_R - W_S$
$ix_S = 4$
$x_P = -d_{CR} / 2 + W_R$

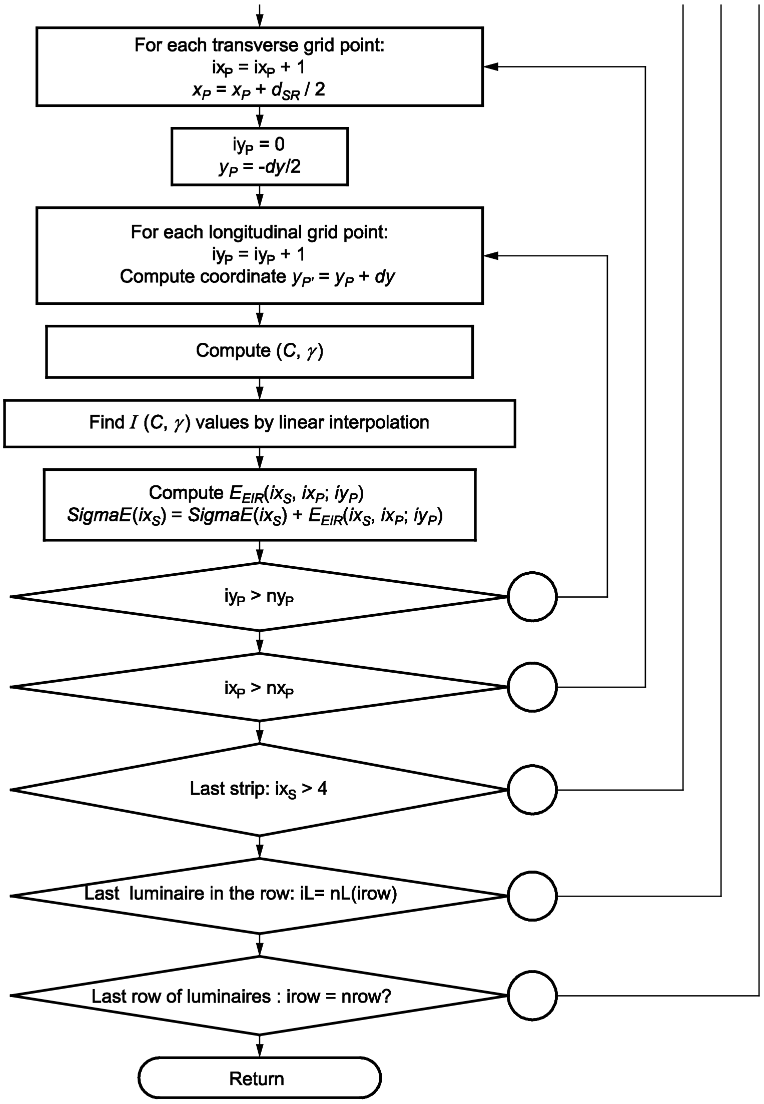


Figure A.9 — Subroutine for edge illuminance ratio evaluation

Annex B
(informative)

Extended *r*-table format for low mounting height luminaire

This extended format in tan ε is needed when the mounting height of luminaires is very low (H < 2 m). In that case, the distance from the luminaires to certain points of the calculation grid is greater than 5H or even 12H and Table 3 cannot be used so that luminance at these points cannot be evaluated.

Table B.1 is therefore extended in tan ε up to 20 by 0,5 increment for every β angle (the number and values of β angles remain the same as those in Table 3).

Similarly to Table 3:

— all values are given for each combination of couple of angles (tan ε; β) but with a format of one decimal place;

— the values of these tables are also $10^4 \times r$ (tan ε; β).

The shaded cells of the Table B.1 show the possible extension from conventional measurements of samples of road surfaces in a photometric laboratory. It should be noted that measurements up to tan ε = 20 become necessary when the mounting height of the light source if less than 1 m. In this last case the measurements are possible only on site, on a section of the road surface.

Table B.1 — Angular intervals and directions to be used in collecting road surface reflection data in the case of extended *r*-tables used with very low mounting heights luminaires or car headlights

tan ε	**β in degrees**																			
	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,25	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0,75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,25	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1,75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

5,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
12	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
12,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
13	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
13,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
16,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
17,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
18	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
18,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
19	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
19,5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Bibliography

[1] CEN/TR 13201-1:2014, *Road lighting — Part 1: Guidelines on selection of lighting classes*

[2] CIE 66:1984, *Road surfaces and lighting (joint technical report CIE/PIARC)*

[3] CIE 140:2000, *Road lighting calculations (pending revision by CIE TC 4.15)*

[4] CIE 144:2001, *Road surface and road marking reflection characteristics*

[5] CIE 146:2002, *TC 1-50 report: CIE equations for disability glare*

[6] CIE S 017/E:2011, *ILV: International Lighting Vocabulary*

[7] LiTG/LTAG Publikation Nr. 14:1991, *Methoden der Beleuchtungsstärke- und Leuchtdichteberechnung für Straßenbeleuchtung*

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™