

Spatial distribution of daylight — CIE standard general sky

ICS 17.180.20

National foreword

This British Standard reproduces verbatim ISO 15469:2004 and implements it as the UK national standard. It supersedes BS ISO 15469:1997 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CPL/34, Lamps and related equipment, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

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

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the ISO title page, page ii, pages 1 to 7 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

Amendments issued since publication

| Amd. No. | Date | Comments |
|----------|------|----------|
| | | |
| | | |
| | | |
| | | |
| | | |

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 5 April 2004

© BSI 5 April 2004

ISBN 0 580 43610 1

INTERNATIONAL STANDARD

ISO
15469
CIE S 011/E

Second edition
2004-02-15

Spatial distribution of daylight — CIE standard general sky

Répartition spatiale de la lumière du jour — Ciel général normalisé CIE



Reference number
ISO 15469:2004(E)
CIE S 011/E:2003

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

ISO 15469 was prepared as Standard CIE S 011/E by the International Commission on Illumination, which has been recognized by the ISO Council as an international standardizing body. It was adopted by ISO under a special procedure which requires approval by at least 75 % of the member bodies casting a vote, and is published as a joint ISO/CIE edition.

The International Commission on Illumination (abbreviated as CIE from its French title) is an organization devoted to international cooperation and exchange of information among its member countries on all matters relating to the science and art of lighting.

ISO 15469 was prepared by Division 3 (Interior Environment and Lighting Design) of the CIE.

This second edition cancels and replaces the first edition (ISO 15469:1997), of which it constitutes a technical revision.

SPATIAL DISTRIBUTION OF DAYLIGHT - CIE STANDARD GENERAL SKY

INTRODUCTION

The luminance distribution of the sky depends on weather and climate, and it changes during the course of a day with the position of the sun. This standard lists a set of luminance distributions, which model the sky under a wide range of conditions, from the heavily overcast sky to cloudless weather. It is intended for two purposes:

- i. to be a universal basis for the classification of measured sky luminance distributions
- ii. to give a method for calculating sky luminance in daylighting design procedures.

The Standard defines relative luminance distributions: the luminance of the sky at any point is given as a function of the zenith luminance. For daylighting calculation purposes it may be used with values of zenith luminance or of horizontal illuminance to obtain absolute luminance distributions.

The Standard incorporates both the CIE Standard Clear Sky and the CIE Standard Overcast Sky, which are treated as particular cases of the General Sky. The Overcast Sky is retained as a separate formula because there are many calculation procedures that embody the mathematical formulation of this particular distribution.

1. SCOPE

This Standard defines a set of outdoor daylight conditions linking sunlight and skylight for theoretical and practical purposes.

The luminance distributions given have the following characteristics:

- i. They are symmetrical about the solar meridian and are functions of the angular distance, Z_s , between the sun and the zenith.
- ii. They are defined by smooth continuous functions. Such distributions are typical of cloudless skies and of those where the cloud cover is homogeneous. They provide an approximation to skies of broken cloud that is sufficiently accurate for many practical daylight calculation purposes.
- iii. The relative luminance at any point in the sky depends on the angle, χ , between that sky element and the sun, and on the angle, Z , between the sky element and the zenith. It is given in terms of two functions: the relative scattering indicatrix, $f(\chi)$, and the luminance gradation between horizon and zenith, $\phi(Z)$.

2. NORMATIVE REFERENCES

The following standards contain provisions, which through reference in the text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on the Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of the CIE, IEC and ISO maintain registers of currently valid international standards.

1. CIE 17.4-1987 *International Lighting Vocabulary*, ILV (joint publication IEC/CIE).
2. ISO 31:1992 *Quantities and Units, Part 6: Light and Related Electromagnetic Radiations*.

3. LIST OF SYMBOLS

For the purposes of this Standard, the following symbols apply:

| | |
|------------|---|
| a, b | luminance gradation parameters |
| α | azimuth of a sky element (clockwise from north) [rad] |
| α_s | azimuth of the sun (clockwise from north) [rad] |
| c, d, e | scattering indicatrix parameters |
| χ | shortest angular distance between a sky element and the sun [rad] |
| $f(\chi)$ | scattering indicatrix function |
| $\phi(Z)$ | luminance gradation function |
| γ | angle of elevation of a sky element above the horizon [rad] |
| γ_s | angle of elevation of the sun above the horizon [rad] |
| L_a | luminance of a sky element [cd/m^2] |
| L_z | zenith luminance [cd/m^2] |
| Z | angular distance between a sky element and the zenith [rad] |
| Z_s | angular distance between the sun and zenith [rad] |

For quantities and units see Normative References 1 & 2.

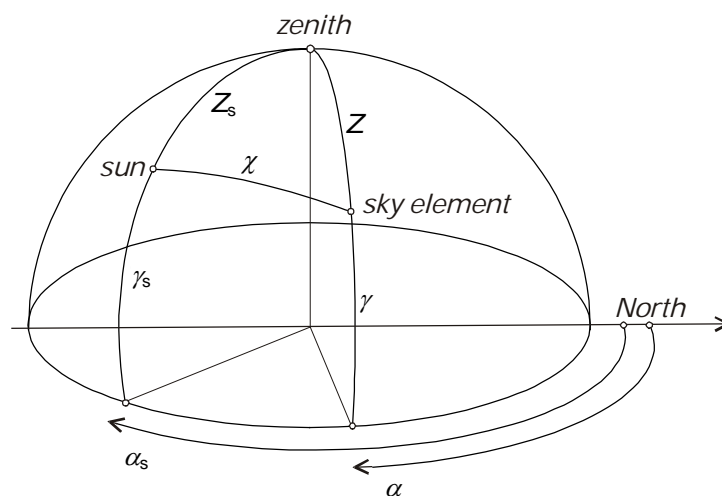


Figure 1. Angles defining the position of the sun and a sky element.

4. SPECIFICATION: THE RELATIVE SKY LUMINANCE DISTRIBUTION

The position of an arbitrary sky element is defined by its zenith angle, Z , and by the azimuth difference between the element and the sun, $|\alpha - \alpha_s|$. If Z_s is the zenith angle of the sun, the angular distance between the element and the sun is

$$\chi = \arccos(\cos Z_s \cdot \cos Z + \sin Z_s \cdot \sin Z \cdot \cos|\alpha - \alpha_s|) \quad (1)$$

Alternatively, the angle of elevation, γ , may be used instead of the zenith angle, Z , to define the position of an element. Then

$$Z = \frac{\pi}{2} - \gamma \quad (2)$$

Similarly the zenith angle of the sun may be obtained from the solar elevation by

$$Z_s = \frac{\pi}{2} - \gamma_s \quad (3)$$

The ratio of the luminance, L_a , of an arbitrary sky element to the zenith luminance, L_z , is

$$\frac{L_a}{L_z} = \frac{f(\chi) \cdot \varphi(Z)}{f(Z_s) \cdot \varphi(0)} \quad (4)$$

The luminance gradation function, φ , relates the luminance of a sky element to its zenith angle:

$$\begin{aligned} \varphi(Z) &= 1 + a \cdot \exp\left(\frac{b}{\cos Z}\right), \quad \text{when } 0 \leq Z < \frac{\pi}{2} \\ \varphi\left(\frac{\pi}{2}\right) &= 1, \quad \text{at the horizon} \end{aligned} \quad (5)$$

The parameters a and b are given in Table 1 for standard sky types.

Equation 4 requires the value at the zenith. This is

$$\varphi(0) = 1 + a \cdot \exp b \quad (6)$$

The function f is a scattering indicatrix which relates the relative luminance of a sky element to its angular distance from the sun:

$$f(\chi) = 1 + c \cdot \left[\exp(d\chi) - \exp\left(d\frac{\pi}{2}\right) \right] + e \cdot \cos^2 \chi \quad (7)$$

Its value at the zenith is

$$f(Z_s) = 1 + c \cdot \left[\exp(dZ_s) - \exp\left(d\frac{\pi}{2}\right) \right] + e \cdot \cos^2 Z_s \quad (8)$$

5. SPECIFICATION: STANDARD PARAMETERS

For purposes of classification and description, the parameters a to e in equations 5 - 8 shall be selected from Table 1. This lists fifteen standard relative luminance distributions which are based on six groups of a and b values for the gradation function and six groups of c , d and e values for the indicatrix function. The resulting curves are illustrated in Figs. 2 and 3.

Table 1. Standard parameters.

| Type | Grada- tion group | Indica- trix group | <i>a</i> | <i>b</i> | <i>c</i> | <i>d</i> | <i>e</i> | Description of luminance distribution |
|------|-------------------------|--------------------------|----------|----------|----------|----------|----------|--|
| 1 | I | 1 | 4,0 | -0,70 | 0 | -1,0 | 0 | CIE Standard Overcast Sky, Steep luminance gradation towards zenith, azimuthal uniformity |
| 2 | I | 2 | 4,0 | -0,70 | 2 | -1,5 | 0,15 | Overcast, with steep luminance gradation and slight brightening towards the sun |
| 3 | II | 1 | 1,1 | -0,8 | 0 | -1,0 | 0 | Overcast, moderately graded with azimuthal uniformity |
| 4 | II | 2 | 1,1 | -0,8 | 2 | -1,5 | 0,15 | Overcast, moderately graded and slight brightening towards the sun |
| 5 | III | 1 | 0 | -1,0 | 0 | -1,0 | 0 | Sky of uniform luminance |
| 6 | III | 2 | 0 | -1,0 | 2 | -1,5 | 0,15 | Partly cloudy sky, no gradation towards zenith, slight brightening towards the sun |
| 7 | III | 3 | 0 | -1,0 | 5 | -2,5 | 0,30 | Partly cloudy sky, no gradation towards zenith, brighter circumsolar region |
| 8 | III | 4 | 0 | -1,0 | 10 | -3,0 | 0,45 | Partly cloudy sky, no gradation towards zenith, distinct solar corona |
| 9 | IV | 2 | -1,0 | -0,55 | 2 | -1,5 | 0,15 | Partly cloudy, with the obscured sun |
| 10 | IV | 3 | -1,0 | -0,55 | 5 | -2,5 | 0,30 | Partly cloudy, with brighter circumsolar region |
| 11 | IV | 4 | -1,0 | -0,55 | 10 | -3,0 | 0,45 | White-blue sky with distinct solar corona |
| 12 | V | 4 | -1,0 | -0,32 | 10 | -3,0 | 0,45 | CIE Standard Clear Sky, low luminance turbidity |
| 13 | V | 5 | -1,0 | -0,32 | 16 | -3,0 | 0,30 | CIE Standard Clear Sky, polluted atmosphere |
| 14 | VI | 5 | -1,0 | -0,15 | 16 | -3,0 | 0,30 | Cloudless turbid sky with broad solar corona |
| 15 | VI | 6 | -1,0 | -0,15 | 24 | -2,8 | 0,15 | White-blue turbid sky with broad solar corona |

6. SPECIFICATION: THE TRADITIONAL OVERCAST SKY

The Standard General Sky integrates the traditional overcast sky formula as the 16th sky* that may be used as an alternate to Sky Type 1 when only overcast skies are to be modelled. This luminance distribution should be expressed by the ratio of the luminance of a sky element, $L_{oc}(\gamma)$, to the zenith luminance, L_{zoc} :

$$\frac{L_{oc}(\gamma)}{L_{zoc}} = \frac{1 + 2 \cdot \sin \gamma}{3} \quad (9)$$

where γ is the angle of elevation of the sky element above the horizon.

The difference between Sky Types 1 and 16 is shown on Fig. 4.

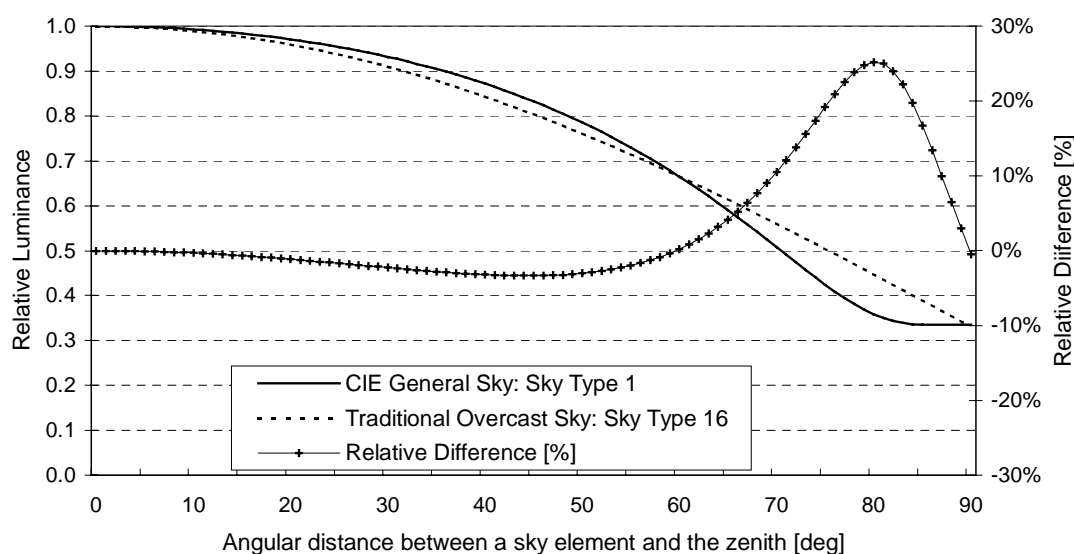


Figure 4. Difference between Sky Types 1 and 16.

7. DERIVATION OF THE STANDARD SKY

The CIE Standard Overcast Sky and the CIE Standard Clear Sky were developed in a series of publications between 1955 and 1994 [1-4].

The CIE Standard General Sky is a generalisation of the CIE Clear Sky formula [5]. It has been shown to be a good model of skies with smoothly varying luminous distributions occurring in various climatic conditions [7,8]. Formulae of this type have also been shown to provide a good approximation to skies of broken cloud in maritime climates [9,11]. It has also been shown that approximately four types of the General Sky can give a good characterisation of the exterior daylight conditions, although the particular sky types may differ between climates [11].

Absolute values of sky luminance vary with solar elevation, and therefore with latitude. Empirical equations for zenith luminance and horizontal illuminance have been published for various climates [6,10,12,13].

* Same as CIE Standard Overcast Sky of CIE S003/E-1996.

ANNEX A (INFORMATIVE): REFERENCES

1. Compte Rendu CIE 13 Session 1955. Natural Daylight. Official Recommendation, **2**, part 3.2, II-IV & 35-37 (1955).
2. CIE 22-1973. *Standardisation of luminance distribution on clear skies*.
3. CIE 110-1994. *Spatial distribution of daylight – Luminance distribution of various reference skies*.
4. CIE S 003/E-1996. *Spatial Distribution of Daylight – CIE Standard Overcast Sky and Clear Sky*
5. KITTLER, R., PEREZ, R. and DARULA S. A new generation of sky standards. *Proc. Lux Europa Conf.* 359-373 (1997).
6. KITTLER, R. and DARULA, S. Parameterisation problems of the very bright cloudy sky conditions. *Solar Energy*, **62** (2), 93-100 (1998).
7. PEREZ, R., SEALS, R., and MICHALSKY, J. All-Weather Model for Sky Luminance Distribution - Preliminary Configuration and Validation. *Solar Energy*, **50** (3), 235-245 (1993).
8. KITTLER, R., PEREZ, R. and DARULA, S. *A set of standard skies characterising daylight conditions for computer and energy conscious design*. Final Report of the U.S.-Slovak Grant Project US-SK 92 052. Without appendices published by Polygrafia, Bratislava. (1998).
9. MATSUZAWA, T., NAKAMURA, H., IGAWA, N. KOGA, Y, GOTO, K. and KOJO, S. Sky luminance distribution between two CIE Standard Skies (Part 1), Arrangement of the sky luminance distribution data measured. *Proc. Lux Pacifica '97*, Nagoya, Japan, E.7 – E.12 (1997).
10. IGAWA, N., NAKAMURA, H., MATSUZAWA, T., KOGA, Y., GOTO, K. and KOJO, S. Sky luminance distribution between two CIE Standard Skies (Part 2). Numerical equation for relative sky luminance distributions. *Proc. Lux Pacifica '97*, Nagoya, Japan, E.13 – E.18 (1997).
11. TREGENZA, P. R. Standard skies for maritime climates. *Lighting Res. & Technol*, **31** (3), 97-106 (1999).
12. KITTLER, R., PEREZ, R. and DARULA, S. Universal models of reference daylight conditions based on new sky standards. In *Proc. 24th Session of the CIE*. CIE 133 - 1999, Vol.1 Part 1, 243-247.
13. IGAWA, N., NAKAMURA, H. and MATSUURA, K. Sky luminance distribution model for simulation of daylight environment. *Proc. Building Simulation '99*, Kyoto, 969-975 (1999).

Copies of CIE Publications are available from the National Committees of most CIE member countries. Purchasers in other countries may obtain them from the CIE Central Bureau, Kegelgasse 27, A-1030 Wien, Austria.

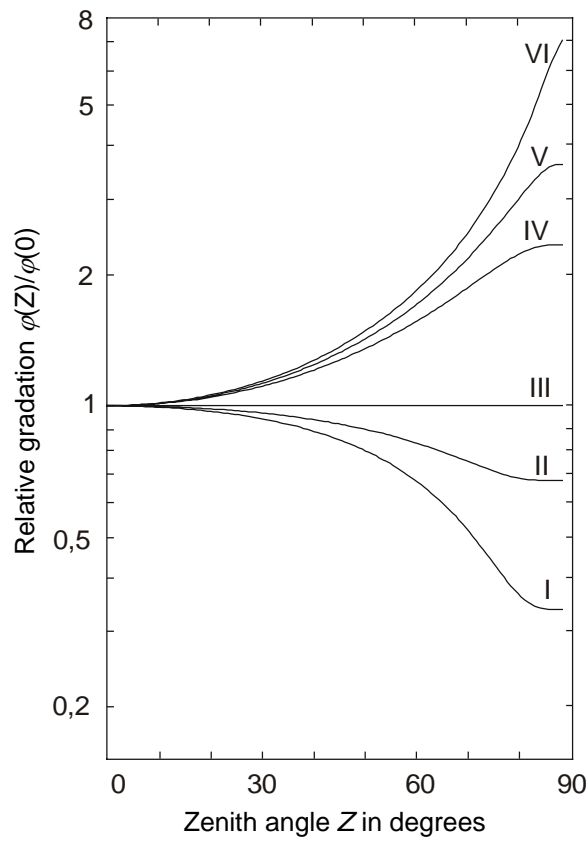


Figure 2. Standard gradation function groups.

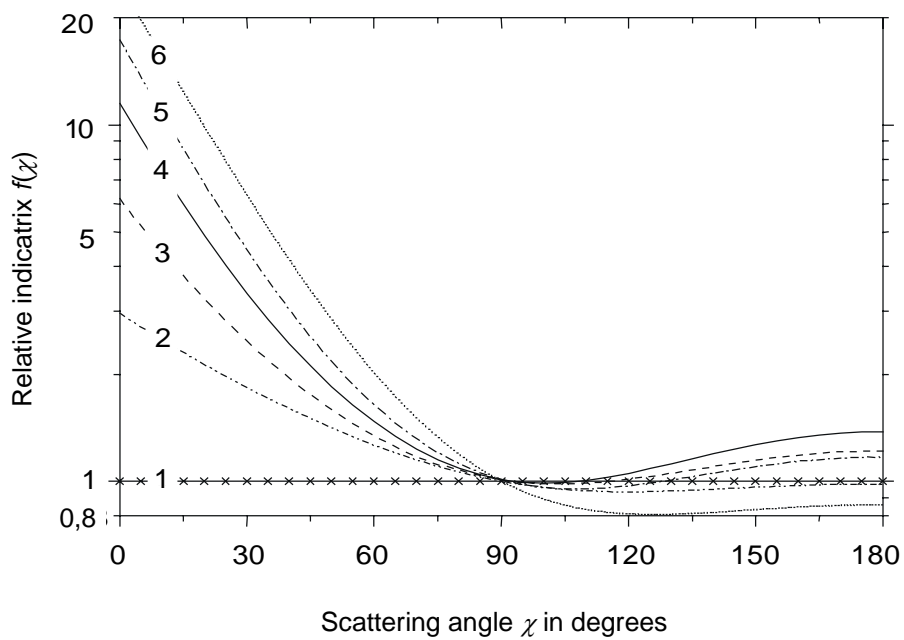


Figure 3. Standard indicatrix function groups.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at <http://www.bsi-global.com>.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at <http://www.bsi-global.com/bsonline>.

Further information about BSI is available on the BSI website at <http://www.bsi-global.com>.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI.

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager. Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553. Email: copyright@bsi-global.com.