

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

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Published in Switzerland

Foreword

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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.

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

Standard

Spatial Distribution of Daylight - CIE Standard General Sky

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

Räumliche Verteilung des Tageslichts - Allgemeiner Himmel nach CIE genormt

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S 011/E:2003

UDC: 628.9.02

Descriptor: Light from celestial bodies and the sky

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FOREWORD

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

This Standard has been prepared by CIE Technical Committee 3-15* of Division 3 (Interior Environment and Lighting Design) "Sky luminance models" and was approved by the National Committees of the CIE. This present standard replaces CIE S003 - 1996 "Spatial distribution of daylight - CIE standard overcast sky and clear sky".

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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
$\varphi(Z)$	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.

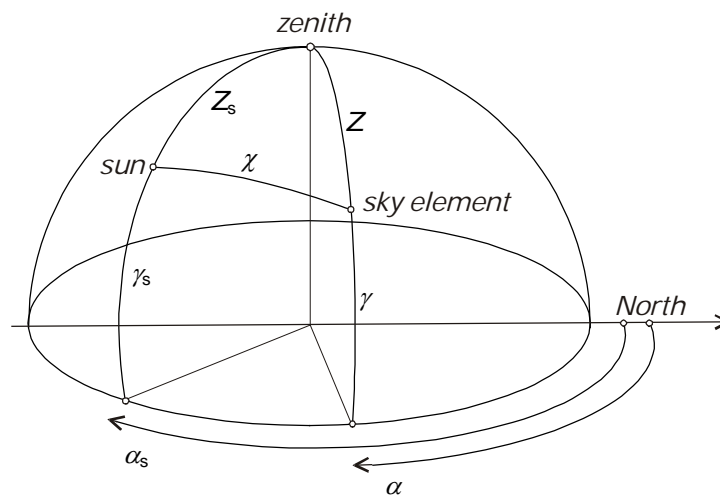


Figure 1. Angles defining the position of the sun and a sky element.

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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

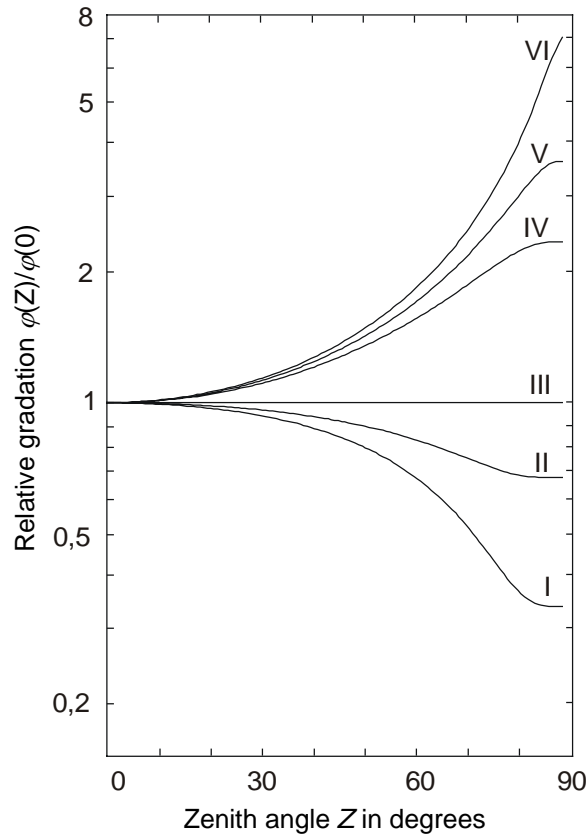


Figure 2. Standard gradation function groups.

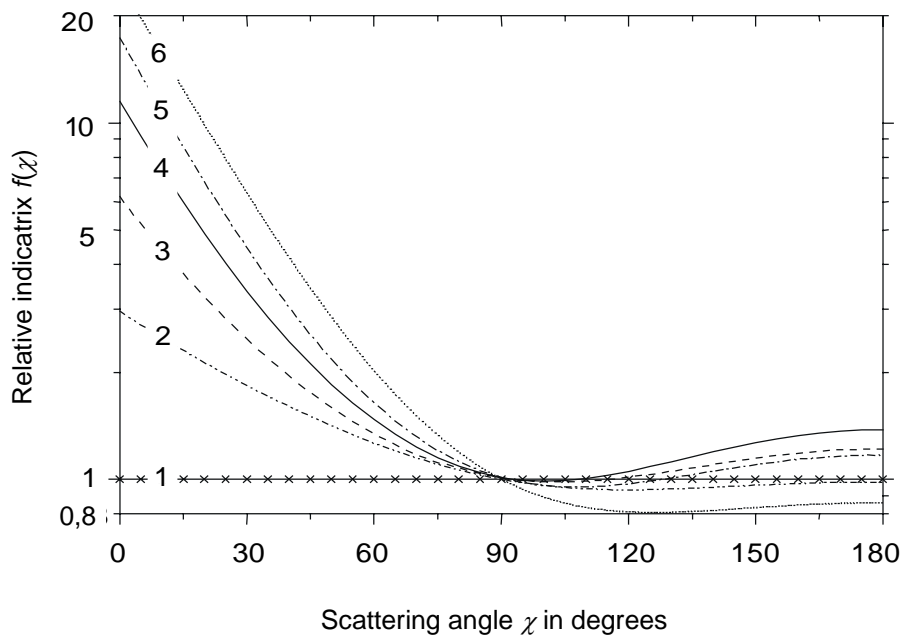


Figure 3. Standard indicatrix function groups.

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} :

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

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.

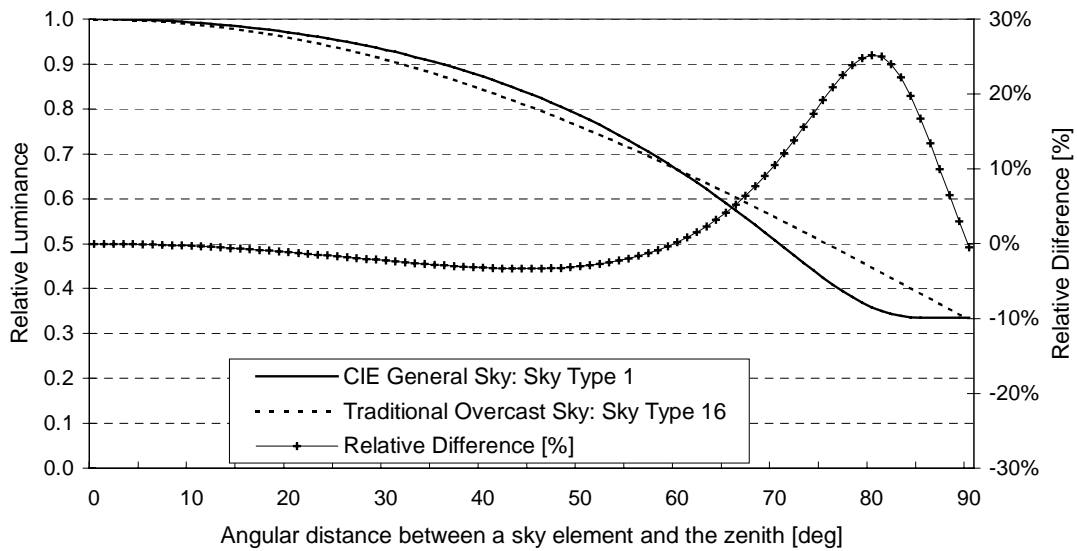


Figure 4. Difference between Sky Types 1 and 16.

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).

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