INTERNATIONAL STANDARD

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CIE S 003

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Spatial distribution of daylight — CIE standard overcast sky and clear sky

Répartition spatiale de la lumière du jour — Ciel ouvert et ciel serein normalisés CIE

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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.

International Standard ISO 15469 was prepared as Standard CIE S 003 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.

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

Annex A of this International Standard is for information only.

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Standard

Spatial Distribution of Daylight - CIE Standard Overcast Sky and Clear Sky

Répartition spatiale de la lumière du jour -
Ciel couvert et ciel serein normalisés CIE

Räumliche Verteilung des Tageslichts -
Bedeckter Himmel und klarer Himmel nach CIE genormt

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Spatial Distribution of Daylight - CIE Standard Overcast Sky and Clear Sky

Contents

Foreword

Standards produced by the Commission Internationale d'Éclairage are concise documents on aspects of light and lighting that require a unique definition. They are 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 Division 3 (Interior Environment and Lighting Design) of the Commission Internationale de l'Eclairage and approved by the National Committees of the Commission.

This Standard summarizes the results described in Proc. 13th Session of the CIE, Zürich, 1955, Vol. II, Part 3-2 on the Overcast Sky and in the publication CIE 22-1972 "Standardisation of luminance distribution on clear skies". These definitions represent recommended standard outdoor natural daylight conditions which can be used in calculations, modelling and for the design and evaluation of interior daylighting. They represent two extreme cases. Other CIE reports, based on more recent research, will provide further guidance in selecting the most appropriate luminance distribution to perform calculations.

Introduction

The luminance distribution of the sky varies with weather and climate. This Standard defines two conditions which tend to occur under stable conditions and which may be taken as extreme cases. They are described by relative luminance distributions: the luminance of any point in the sky is given as a function of the zenith luminance.

The "CIE Overcast Sky" was originally prepared by CIE Technical Committee E-3.2 (Natural Daylight) and published as an official recommendation in 1955 [1]. The "CIE Clear Sky" was published by CIE Technical Committee 4.2 (Daylight) in 1973 [2].
The two documents are now superseded by this Standard. Background information and further details are described in a Technical Report on the spatial distribution of daylight [3].

1. Scope

The Standard defines the relative luminance distributions of the CIE Standard Overcast Sky and the CIE Standard Clear Sky as outdoor daylight conditions for theoretical and practical purposes.

(1) CIE Standard Overcast Sky represents the sky luminance pattern associated with deep layers of stratus clouds [1]. Under these conditions the sun's disk is usually invisible from the ground. The luminance distribution of the Standard Overcast Sky is a function only of the angle of elevation above the horizon. It is therefore symmetrical about the zenith and independent of the sun's position.

The luminance of clouds is affected by light reflected from the ground surface. The Standard Overcast Sky is based on the assumption of a dark terrain. It should not be applied when the ground is covered with snow or when the surface consists mainly of other material of high reflectance, such as white sand.

(2) CIE Standard Clear Sky represents cloudless conditions [2]. The luminance of the sky depends on both the angle of elevation and the position of the sun. It is symmetrical about the solar meridian.

The luminance of a cloudless sky is affected by pollution and by other sources of atmospheric particles. The Standard Clear Sky is given in two forms: for application to clean rural conditions and for polluted or industrial atmospheres.

2. Normative References

The following standards contain provisions which, through reference in this 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 this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of CIE, IEC and ISO maintain registers of currently valid international standards.

1 Publication CIE 17.4-1987: International Lighting Vocabulary, 4th ed. (joint publication IEC/CIE)

2 ISO 31-1992: Quantities and units, Part 6: Light and related electromagnetic radiations

3 Publication CIE 16-1970: Daylight

4 Publication CIE 110-1994: Spatial distribution of daylight - Luminance distributions of various reference skies.

3. List of Symbols

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

α	azimuth angle of a sky element (clockwise from north) [rad]
α_s	azimuth angle of the sun position (clockwise from north) [rad]
E_{vcl}	illuminance from an unobstructed clear sky on a horizontal surface [lx]
E_{voc}	illuminance from an unobstructed overcast sky on a horizontal surface [lx]
γ	angle of elevation of a sky element above the horizon [rad]
γ_s	angle of elevation of a sun position above the horizon [rad]
$f(\zeta)$	relative diffusion indicatrix of clear rural atmosphere
$f'(\zeta)$	relative diffusion indicatrix for polluted atmosphere
$\phi(\gamma)$	transmission function of the atmosphere
ζ	angle between the sun and the sky element [rad]
L_{cl}	clear sky luminance of a sky element [cd/m^2]
L_{oc}	overcast sky luminance of a sky element [cd/m^2]
L_{zcl}	clear sky luminance at the zenith [cd/m^2]
L_{zoc}	overcast sky luminance at the zenith [cd/m^2]

For quantities and units used see Normative References 1 & 2.

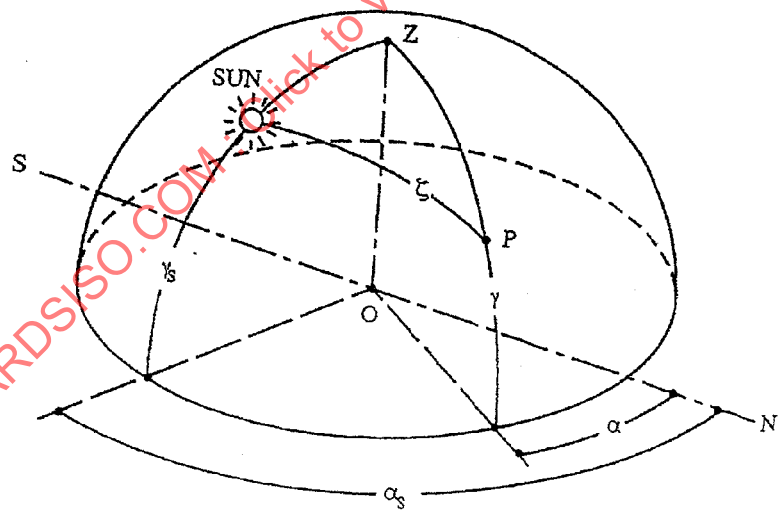

Figure 1 - Angles defining the position of the sun and a sky element P.

4. Specification

4.1 CIE Standard Overcast Sky

This luminance distribution shall be expressed by the ratio of the luminance of a sky element, $L_{oc}(\gamma)$, to the zenith luminance, L_{zoc}:

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

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

4.2 CIE Standard Clear Sky

The position of an element in the clear sky is defined by its angle of elevation, γ, and by its azimuth angle from the sun (α_S-α). The ratio of the luminance of the element, L_{cl} (γ_s, γ, ζ), to the zenith luminance, L_{zcl} (γ_s), is:

$$\frac{L_{cl}(\gamma_s,\gamma,\zeta)}{L_{zcl}(\gamma_s)} = \frac{f(\zeta)\times\Phi(\gamma)}{f\left(\frac{\pi}{2}-\gamma_s\right)\times\Phi\left(\frac{\pi}{2}\right)}$$

where ζ is the angle between the sun and the sky element:

$$\zeta = \arccos\left[\left(\sin\gamma_s \times \sin\gamma\right) + \left(\cos\gamma_s \times \cos\gamma \times \cos|\alpha_s - \alpha|\right)\right]$$

The function $f(\zeta)$ is a relative diffusion indicatrix by Kittler. It is associated with clean rural atmospheres having a Linke Turbidity Factor of 2,45*.

$$f(\zeta) = 0{,}91 + 10\exp(-3\zeta) + 0{,}45\cos^2\zeta$$

The zenith value is

$$f\left(\frac{\pi}{2}-\gamma_s\right) = 0{,}91+10\exp\left\{-3\left(\frac{\pi}{2}-\gamma_s\right)\right\}+0{,}45\cos^2\left(\frac{\pi}{2}-\gamma_s\right)$$

For polluted or turbid atmospheres the function $f'(\zeta)$ should be used instead of $f(\zeta)$. This is applicable to conditions where the Linke Turbidity factor is about 5,5. It was proposed by Gusev.

$$f'(\zeta) = 0{,}856 + 16\exp(-3\zeta) + 0{,}3\cos^2\zeta$$

The zenith value is:

$$f'\left(\frac{\pi}{2}-\gamma_s\right) = 0{,}856+16\exp\left\{-3\left(\frac{\pi}{2}-\gamma_s\right)\right\}+0{,}3\cos^2\left(\frac{\pi}{2}-\gamma_s\right),$$

$\phi(\gamma)$ is a transmission function of the atmosphere, by Kittler:

$$\phi(\gamma) = 1-\exp\left(\frac{-0{,}32}{\sin\gamma}\right)$$

At the zenith

$$\phi\left(\frac{\pi}{2}\right) = 0{,}273\,85$$

* Note: The value of 2,45 is for clear rural atmospheres, in some countries, e.g. Germany, a value of 5 is considered, which is more typical for an industrial environment.

5. Derivation of the Standard Skies

5.1 CIE Standard Overcast Sky

This sky was originally presented in a paper by Kähler in 1908 [4] and tested by Moon and Spencer in 1942 [5] using analysis of measurements by Kimball in the early 1920's. After two further series of measurements, in Southern England and in Sweden, it was confirmed that this formula was applicable to densely overcast skies, at least at middle latitudes. It was adopted as an official recommendation by CIE Technical Committee E-3.2 in 1955 [1].

5.2 CIE Standard Clear Sky

The original form of this sky was proposed by Kittler at the meeting of CIE Technical Committee E-3.2 at Newcastle upon Tyne in 1965. It was also presented in a paper to the CIE Intersessional Conference on Sunlight [6]. This conference included detailed discussion on the scientific basis of the standardization and also comparisons between calculated and measured luminance distribution data.

The additional indicatrix, $f'(\zeta)$, by Gusev for industrial and other polluted atmospheres was included in the draft standard at the 1969 CIE intersessional meetings in Bratislava and Smolenice [7].

The Linke Turbidity Factor is described in [8]. Further background literature was published in [3].

6. Practical application of the Standard Skies

6.1 CIE Standard Overcast Sky

This sky may be used to calculate daylight factors under densely overcast skies associated with stable conditions of low illuminance *. If the horizontal illuminance from an unobstructed sky is known, the interior illuminance may be found from this and the daylight factor. If the absolute zenith luminance is known, the corresponding horizontal illuminance, E_{voc}, from the CIE Standard Overcast Sky is given by:

$$E_{voc} = \frac{7\pi}{9} L_{zoc}$$

6.2 CIE Standard Clear Sky

Interior luminances and illuminances on a cloudless day can be calculated when the absolute zenith luminance and the direct solar illuminance are known [3]. Under cloudless conditions the lighting conditions may be stable, varying only with the sun's position. The interior values enable psychological effects of the daylight environment to be assessed. Estimates can be made also of glare and of energy savings.

* Note: It has been shown that the model can also be used for the tropical overcast sky [9].