



COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

Spatial Distribution of Daylight - Luminance Distributions of Various Reference Skies

CIE 110-1994

CIE 110.1-1995 Revision 1

UDC: 551.521.1
628.9.021
681.782.43

Descriptor: Solar radiation
Sunlight
Photometers for global radiation measurement



COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

Spatial Distribution of Daylight - Luminance Distributions of Various Reference Skies

CIE 110-1994

CIE 110.1-1995 Revision 1

Revision No.	Revision Date	Note
1	May 1995	p.8: typing error in equation 4.3 corrected

UDC: 551.521.1
628.9.021
681.782.43

Descriptor: Solar radiation
Sunlight
Photometers for global radiation measurement

"The following members of TC 3-09 took part in the preparation of this Technical Report. The committee comes under CIE Division 3".

Chairman:	K. MATSUURA	Japan
Members:	S. AYDINLI	Germany
	P. CHAUVEL	France
	R. DOGNIAUX	Belgium
	J. D. KENDRICK	Australia
	R. KITTLER	Slovakia
	P. LITTLEFAIR	Great Britain
	T. NAGATA	Japan
	H. NAKAMURA	Japan
	E. NE'EMAN	Israel
	S. SELKOWITZ	USA

CONTENTS

	page
1. INTRODUCTION	1
2. DEFINITIONS OF VARIOUS REFERENCE SKIES	2
2.1 Reference skies to be defined	2
2.2 Three basic reference skies	2
2.3 Reference skies for specified application	4
3. CLEAR SKY AND OVERCAST SKY AS REFERENCE SKIES	5
3.1 Clear sky	5
3.2 Overcast sky	6
4. GENERAL SKY INCLUDING INTERMEDIATE SKY	7
4.1 Studies mainly by experimental method	7
4.2 Studies mainly by theoretical method	7
4.3 Averaged intermediate sky luminance	8
5. AVERAGED SKIES FOR SPECIFIED APPLICATION	9
5.1 BRE average sky	9
5.2 Mean sky by Nakamura, Oki et al.	9
5.3 Composition of average sky and mean sky as reference skies	9
6. APPENDICES AND LIST OF SYMBOLS	11
6.1 Studies on the various skies	11
6.2 Method of composing average sky and mean sky	14
6.3 Illuminances from direct sunlight to be combined with the three basic skies and average sky	21
6.4 List of symbols	23
7. REFERENCES AND BIBLIOGRAPHY	25
7.1 Luminance distribution	25
7.2 Zenith luminance	26
7.3 Horizontal illuminance from unobstructed sky	27
7.4 Radiance distribution	28
7.5 Others	29
7.6 References in Appendices	29
7.7 Further reading	30

Spatial distribution of daylight -

Luminance distributions of various reference skies

Summary

This technical report is a review of studies on various sky luminances and specification of reference skies, with a method of composing average sky and mean sky as an appendix. Several reference skies including the average sky and mean sky are given definitions and various studies on these sky luminances are introduced, with a bibliography, in three appendices.

Répartition spatiale du lumière de jour -

Répartition de luminance de plusieurs ciels de référence

SOMMAIRE

Ce rapport technique est une revue des études sur les luminances de différents ciels et sur la spécification des ciels de référence, avec en annexe une méthode de détermination d'un "average sky" et d'un "mean sky". On donne la définition de plusieurs ciels de référence incluant le "average sky" et le "mean sky" et on présente différentes études sur ces luminances de ciel, avec une bibliographie, dans trois annexes.

Räumliche Verteilung des Tageslichts -

Leuchtdichteverteilung verschiedener Bezugshimmel

Zusammenfassung

Dieser technische Bericht ist ein Überblick über Untersuchungen über verschiedene Himmelsleuchtdichten und Beschreibung von Bezugshimmelszuständen, mit einer Methode zur Zusammenfügung von mittlerem Himmel "average sky" und mittlerem Himmel für eine bestimmte Zeitdauer "mean sky" als Anhang. Verschiedene Bezugshimmelszustände, die sowohl den "average sky" als auch den "mean sky" beinhalten, sind angegeben. Definitionen und verschiedene Untersuchungen über diese Himmelsleuchtdichten werden mit einem Literaturverzeichnis in drei Anhängen eingeführt.

1. INTRODUCTION

Although several kinds of average and mean skies have been proposed in Europe, USA and Japan since 1981, their definitions and the methods of composing them were not standardized. This Technical Committee, TC 3-09, was formed at the CIE Amsterdam Session in 1983, and the aim of the committee was suggested in the minutes of the Division 3 Cambridge meeting in April 1984 as follows. "The aim is not to make a list of various sky situations, but to try to develop as few as possible sky standards between the two skies already standardized: clear sky and overcast sky."

According to this suggestion the terms of reference of TC 3-09 were decided as, "To study standard reference skies between the two skies already standardized, clear sky and overcast sky, and to propose a method of composing average and mean skies."

However, because of insufficient data and lack of time, it became difficult to propose standard skies (i.e. standard intermediate skies) between the two already standardized skies by the time of the CIE Venice Session in 1987. Therefore, the purpose of our TC 3-09 was changed to presentation of a technical paper which would review studies on various skies, specify reference skies, and introduce a method of composing average sky and mean sky as an appendix. Also the two CIE Standard skies (Clear sky and overcast sky) are reviewed in the present publication, thus publication CIE 22-1973 is now outdated and withdrawn. The standardization of reference skies between the two standard skies was left to a new technical committee, TC 3-15 (Standardization of intermediate sky luminance), which was formed at the CIE Venice Session in June 1987.

In this report a *reference sky* means a clearly defined sky to be used for daylighting design and calculation methods. For example, one reference sky is the uniform sky which has been used for a number of theoretical application and for certain design purpose.

The skies treated in this report do not include direct sunlight, though the BRE average sky developed by Littlefair consists of two components, direct sunlight and the sky [1.3-1, 1.3-3, 1.3-4]. (Numbers in square brackets mean reference numbers from Chapter 7. REFERENCES AND BIBLIOGRAPHY). In order to estimate annual energy consumption of electrical lighting, the effect of direct sunlight should be taken into consideration in calculating illuminance on the interior working plane, whether this is done for every weather condition or for a certain average condition. Hence, each standard sky luminance has to be combined with a standard direct sunlight illuminance. These items are to be decided in another technical committee in future, but a proposal is tentatively shown in 6.3 for reference.

2. DEFINITIONS OF VARIOUS REFERENCE SKIES

2.1 *Reference skies to be defined*

In this chapter the following five reference skies are defined.

- 1 CIE standard clear sky
- 2 CIE standard overcast sky
- 3 Intermediate sky
- 4 Average sky
- 5 Mean sky

The first and second skies are already standardized by CIE in terms of the relative luminance distributions. The third one might in the future be recommended as a CIE standard sky, or as a set of standard skies. A recommendation for more than one sky will be made only if absolutely necessary, and the number of skies will be as few as possible. The 4th and 5th skies are for specified application and will not necessarily be recommended as CIE standard.

2.2 *Three basic reference skies*

2.2.1 CIE standard clear sky

This is a "cloudless sky" for which the relative luminance distribution was first described in Publication CIE 22-1973 [1.1-4] and has been standardized by the CIE [1.1-6]. Absolute luminance will be standardized in future.

2.2.2 CIE standard overcast sky

This is a "completely overcast sky for which the ratio of its luminance in the direction at angle γ above the horizon to its luminance at the zenith is standardized [1.4-1, 1.1-6]. Absolute luminance will be standardized in future.

2.2.3 Intermediate sky

This is a sky (or skies) for which the luminance of any given sky element will be defined for a given sun position under an intermediate weather condition (or conditions) which occurs between the CIE standard clear and overcast skies (see Fig.2.1).

This luminance depends on the solar altitude in the same way as does the CIE standard clear sky. The sun and aureole close to it are excluded from this luminance distribution. Absolute luminance and luminance distributions are to be defined for the CIE standard intermediate sky (or skies) in the future.

2.2.4 Weather conditions

For design purposes, these reference skies may be taken to represent real skies under the following weather conditions:

- 1 Under the clear weather condition, adopt the CIE standard clear sky.
- 2 Under the overcast weather condition, adopt the CIE standard overcast sky.
- 3 Under intermediate weather conditions, which include hazy cloudy skies and partly cloudy skies, adopt an intermediate sky.

It is proposed that these weather conditions, which will include as many intermediate weather conditions as there are intermediate skies, will be classified in terms that will enable the proportions of time for which each reference sky applies to be determined within a defined time period for a chosen location and climate (see Fig.2.1).

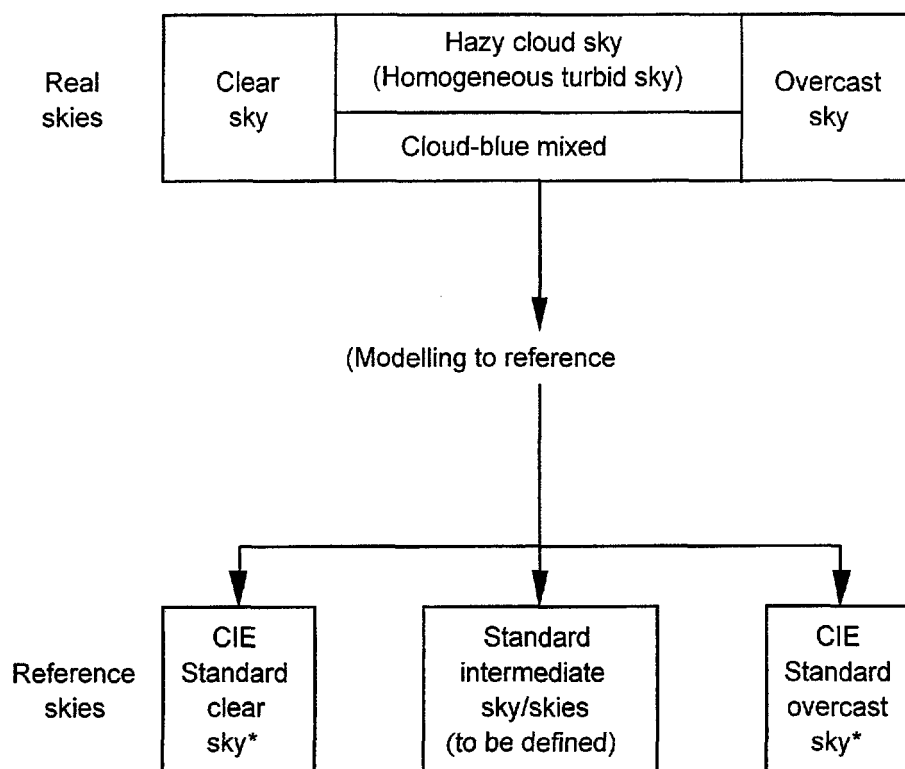


Fig.2.1. Modelling to reference skies
 (* for which absolute sky luminance is to be defined)

CIE 110-1994

2.3 Reference skies for specified application

2.3.1 Average sky

This is a sky for which time-average luminance of a sky element at an arbitrary position of the sky is defined for each hour of the day throughout a typical year, for all weather conditions. This luminance depends on solar altitude alone in the same way as does the CIE standard clear sky. The sun and the aureole close to it are excluded from this luminance distribution. The period of averaging for this sky can be changed to a period other than one year according to the specified application.

2.3.2 Mean sky

This is a sky for which the time-average luminance of a sky element at an arbitrary position of the sky is defined for some specified duration (usually, the sum of working hours, for example, duration from 9:00 to 17:00 of each day) throughout a typical year. Effects of the sun and of the aureole close to it are excluded from this luminance distribution.

3. CLEAR SKY AND OVERCAST SKY AS REFERENCE SKIES

3.1 Clear sky

3.1.1 Relative luminance distribution

Expression of the CIE standard clear sky [1.1-4, 1.1-6] is one of the reference skies.

For practical purposes the sky luminance $L_{cl}(\gamma_s, \gamma, \zeta)$ at an arbitrary position P of the sky shown with γ, ζ, α and α_s in Fig.3.1 depends on the solar altitude γ_s and is expressed as a relative value. (Symbols are listed in 6.4 of Chapter 6.)

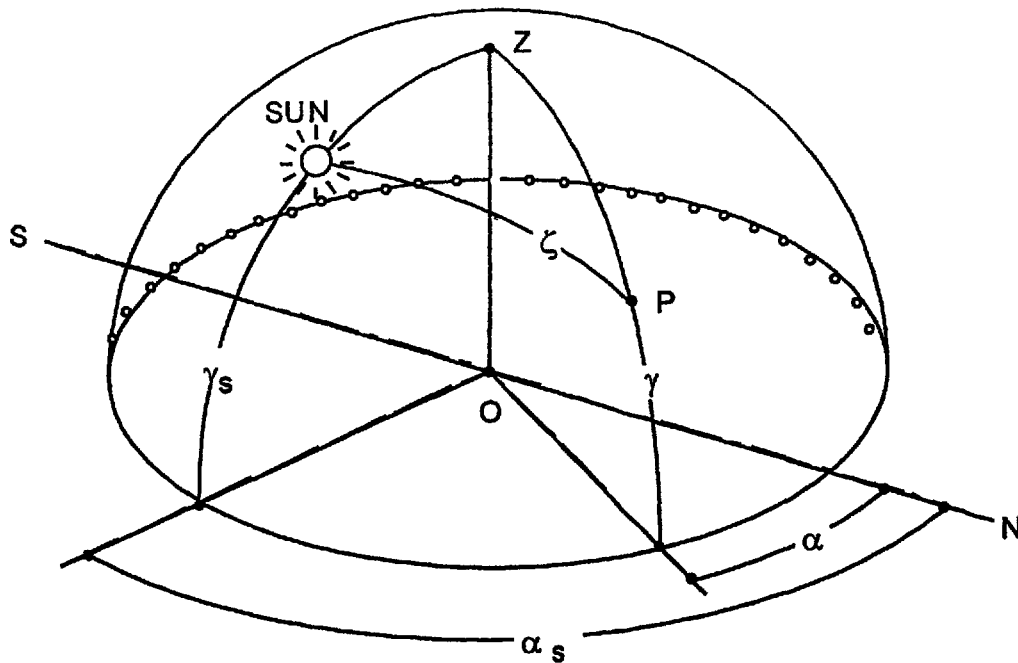


Fig.3.1. Angle signification for the positions of the sun and a sky element P

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

(3.1)

where, $L_{zcl}(\gamma_s)$: clear sky luminance of the zenith

$$\phi(\gamma) = 1 - \exp(-0,32/\sin \gamma), \quad \phi(\pi/2) = 0,27385$$

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

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

$$\zeta = \arccos (\sin \gamma_s \sin \gamma + \cos \gamma_s \cos \gamma \cos |\alpha_s - \alpha|)$$

For polluted atmosphere, $f'(\zeta)$ and $f'(\pi/2 - \gamma_s)$ are used for $f(\zeta)$ and $f(\pi/2 - \gamma_s)$ respectively.

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

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

$$\gamma_s, \gamma, \zeta, \alpha \text{ and } \alpha_s : \text{units [rad]}$$

CIE 110-1994

Recently Kittler [1.2-13] has pointed out that the CIE standard indicatrices $f(\zeta)$ (by Kittler) and $f(\zeta)$ (by Gusev) correspond to $T_{vL} = 2,45$ and $5,5$ respectively, where T_{vL} is illuminance turbidity factor (see 6.1, equation (6.1)).

3.1.2 Zenith luminance

According to the climate condition in a given geographical location an appropriate equation can be adopted from the equations shown in 6.1.2.1. Turbidity factor (T_L) or illuminance turbidity factor (T_{vL}) can be used as climate index of clear sky in the location. (It is desirable to know the relationship between the horizontal illuminance from unobstructed clear sky and the zenith luminance of the same sky with distribution expressed by eq.(3.1). Krochmann and Aydinli [5.1-1] proposed a method of obtaining such a relationship. (See 6.1.2.1.) To know this relation is also desirable for the overcast or intermediate sky, and this is described in the following sections 3.2 and 4)

3.2 Overcast sky

3.2.1 Relative luminance distribution

Expression of the CIE standard overcast sky [1.4-1, 1.1-6] is one of the reference skies. It is given by

$$\frac{L_{oc}(\gamma)}{L_{zoc}(\gamma_s)} = \frac{1+2 \sin \gamma}{3} \quad (3.2)$$

3.2.2 Zenith luminance

Several equations shown in 6.1.2.3 have been proposed. According to purposes of calculation an appropriate equation can be adopted from these equations.

The horizontal illuminance from the unobstructed overcast sky is $E_{voc}(\gamma_s) = (7/9) \pi \cdot L_{zoc}(\gamma_s)$, where $L_{zoc}(\gamma_s)$ is the zenith luminance.