



ISBN 3 900 734 74 7

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

TECHNICAL REPORT

**THE PHOTOMETRY AND
GONIOPHOTOMETRY OF
LUMINAIRES**

CIE 121 - 1996

UDC: 535.241.427
628.94
681.785.4
681.786

Descriptor: Light distribution
Luminaires
Photometers
Goniophotometers

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FOREWORD

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THE PHOTOMETRY AND GONIOPHOTOMETRY OF LUMINAIRES

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The Photometry and Goniophotometry of Luminaires

SUMMARY

This technical report provides general requirements for the photometry of luminaires of most types and includes the following information:

- standard test conditions under which the tests should be carried out, with acceptable practical tolerances;
- selection procedures for lamps and luminaires;
- procedures for measurement of the photometric characteristics of luminaires and assessment of the possible sources of error;
- correction factors and service conversion factors;
- presentation of test results.

The report is considered to be sufficiently comprehensive to form a practical guide for industrial laboratories and contains sufficient information to replace publication CIE 24-1973 "Photometry of indoor type luminaires" and CIE 27-1973 "Photometry of luminaires for street lighting". CIE will publish supplementary reports covering these types of luminaires more specifically.

Photométrie et goniophotométrie des luminaires

RESUME

Le présent rapport technique formule les exigences photométriques générales pour différents types de luminaires et comprend les informations ci-après:

- les conditions d'essai normalisées à adopter pour la réalisation des essais, avec les tolérances pratiques acceptables;
- les procédures de sélection de lampes et luminaires;
- les procédures de mesure des caractéristiques photométriques de luminaires et les sources d'erreur possibles;
- les facteurs de correction et les facteurs de conversion en service;
- la présentation des résultats d'essais.

Le rapport est considéré comme une synthèse pouvant constituer un guide pratique pour les laboratoires industriels et contient suffisamment d'informations pour remplacer les publications CIE 24-1973 "Photometry of indoor type luminaires" et CIE 27-1973 "Photometry of luminaires for street lighting". Il est toutefois de l'intention de la CIE de publier des rapports complémentaires couvrant plus spécifiquement ces types de luminaire.

Photometrie und Goniophotometrie von Leuchten

ZUSAMMENFASSUNG

Die allgemeinen Anforderungen in diesem technischen Bericht beziehen sich auf Photometrie vieler Typen von Leuchten. Die folgende Information ist also eingeschlossen:

- die für die Prüfung erforderlichen normierten Bedingungen, zugleich mit den im Betrieb annehmbaren Begrenzungen;
- Auswahlverfahren für Lampen und Leuchten;
- Prozeduren für Messungen der photometrischen Eigenschaften und zugleich mögliche Fehlerursachen;
- Korrekturfaktoren und Umsetzungsfaktoren im Betrieb;
- Darstellung der Prüfergebnisse.

Der Bericht bildet eine Synthese und ist deshalb als praktische Anleitung für industrielle Laboratorien geeignet. Er enthält genügend Informationen, um die Publikationen CIE 24-1973 "Photometry of indoor type luminaires" und CIE 27-1973 "Photometry of luminaires for street lighting" zu ersetzen. Die CIE wird jedoch noch ergänzende Berichte veröffentlichen, die diese Leuchtentypen genauer behandeln.

1. INTRODUCTION

1.1 Scope

This report covers general requirements for the photometry of luminaires which are considered to be applicable to most types of luminaire.

The report sets out to provide specifications for the standard conditions under which photometric tests should be carried out and to recommend testing procedures which will give sufficiently accurate and reproducible results when determining and reporting the photometric characteristics of luminaires. These specifications are intended to provide a basis for uniform national standards and to give guidance to photometric laboratories in the conduct of tests and in the presentation of luminaire performance data. The report also gives specifications for the measurement of correction factors applicable to luminaires operated under practical test conditions different from the standard test conditions.

Detailed descriptions of photometric methods are primarily of value to laboratory personnel and engineers, but are also important to users of the data. Proper interpretation of data often depends on a full knowledge of the testing procedures involved and this report also sets out to provide the user with the information needed to understand photometric testing procedures and data presentation.

Where there is felt to be a need for specific recommendations relating to the measurement and data presentation requirements of particular types of luminaire designed for specialist applications, which could not be covered in a general report of this kind, it is intended that the need shall be met by the publication of a number of supplementary technical reports. These supplementary reports will refer back to the appropriate sections in the present report, and will define, where necessary, special requirements and measurement conditions.

For types of luminaire not covered by a specific report, the requirements of the most appropriate report, together with this general report may be used as a guide to the test procedures to be employed.

1.2 Photometric characteristics

Photometric characteristics can be divided into measured characteristics, i.e. those directly measured with laboratory instruments, and derived characteristics, i.e. characteristics which can be calculated from the measured ones. The derived characteristics are more closely related to lighting applications. This report deals mainly with measured photometric characteristics.

2. TERMINOLOGY

Only definitions of immediate interest are included. The terminology used in this report is preferred, but some of the terms may be found in other publications under different names. These other names are given in square brackets.

For other relevant definitions see Publication CIE/IEC 17.4-1987 [1].

2.1 Terms related to the luminaire

2.1.1 Luminaire

Apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for supporting, fixing and protecting the lamps and; where necessary, circuit auxiliaries together with the means for connecting them to the electricity supply.

2.1.2 Design attitude (of a luminaire) [also tilt normal in application]

The attitude in which a luminaire is designed to operate (as determined by reference to the manufacturer's instructions or to common practice).

2.1.3 *Measurement attitude (of a luminaire) [also tilt during measurement]*

The attitude in which a luminaire is measured.

Note: If not otherwise indicated, assumed to coincide with the design attitude.

2.1.4 *Light centre (of a source)*

Point used as origin for photometric measurements and calculations.

2.1.5 *Photometric centre*

The point in a luminaire or lamp from which the photometric distance law operates most closely in the direction of maximum intensity.

Note: This is a term widely used in national standards specifications relating to luminaire photometry. For bare lamps it is equivalent to the International Lighting Vocabulary definition light centre.

2.1.6 *First axis (of a luminaire) [also reference axis]*

An axis containing the photometric centre, used in photometric measurements as a reference direction to correlate the photometric measurements with the attitude of the luminaire.

2.1.7 *Second axis (of a luminaire) [also auxiliary axis]*

An axis containing the photometric centre, perpendicular to the first (reference) axis, linked to the luminaire and used together with the first axis for defining the attitude of the luminaire.

Note: The identification of the first axis and the second (auxiliary) axis must be defined by the manufacturer or, if not, by the photometric laboratory.

A third axis is also used in defining the attitude of a luminaire : it is the axis containing the photometric centre and perpendicular to the two first axes.

2.1.8 *Practical ballast*

A ballast which is representative of the range of production ballasts appropriate to the luminaire and lamp(s) under test.

2.2 **Terms related to measured quantities for luminaires**

2.2.1 *Luminaire data per 1 000 lm (of lamp flux)*

Photometric data of a luminaire relative to a total theoretical luminous flux of 1 000 lm from all the lamps of the luminaire, when these are operated outside the luminaire under reference conditions but with the same ballast(s).

2.2.2 *Luminous intensity distribution (of a luminaire)*

The distribution of luminous intensity with direction. The luminous intensity distribution may be represented by numerical tables or by graphics and is usually expressed in units of candelas per 1 000 lm of lamp flux.

2.2.3 *Ballast lumen factor*

Ratio of the luminous flux emitted by a reference lamp when operated with a practical ballast at the rated voltage of the ballast to the luminous flux emitted by the same lamp when operated with its reference ballast.

Abbreviation: *BLF*

2.2.4 *Light output ratio (of a luminaire) [luminaire efficiency (USA)]*

The ratio of the luminous flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment under specified conditions.

Abbreviation: *LOR*

Note : Specified practical conditions are normally the standard test conditions as described under 4.2. If different, the practical conditions should be specified.

The luminous fluxes of the lamp(s) outside the luminaire are those obtained with the lamp position and the lamp operating temperature for which the lamp catalogue data are published.

2.2.5 *Light output ratio working (of a luminaire)*

The ratio of the luminous flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire under reference conditions and with a reference ballast.

Abbreviation: *LORW*

Note: $LORW = LOR \times BLF$; *LOR* is preferred to *LORW* as most luminaires can be delivered with different ballasts characterised by their *BLF*.

2.2.6 *Upward (downward) flux fraction (of a luminaire)*

The fraction of the total luminous flux of a luminaire emitted above (below) the horizontal plane containing the photometric centre of the luminaire.

Abbreviation: *UFF (DFF)*

2.2.7 *Upward (downward) light output ratio (of a luminaire)*

The product of the light output ratio of a luminaire and the upward (downward) flux fraction. The light output ratio may be the light output ratio or the light output ratio working as appropriate.

Abbreviation: *ULOR (DLOR)*

2.2.8 *Average luminance (of a luminaire)*

The luminous intensity per unit projected luminous area in a given direction of a luminaire.

2.2.9 *Service conversion factor*

Factor to convert photometric data related to the standard test conditions to data related to service conditions which differ from the standard conditions.

2.3 **Terms related to measurements**

2.3.1 *Absolute measurement*

A measurement scaled in the appropriate SI units.

2.3.2 *Relative measurement*

A measurement obtained as a ratio of two quantities of the same type expressed in arbitrary units or a measurement in SI units relative to specified bare lamp flux.

2.3.3 *Bare lamp measurement*

A measurement in which a lamp is photometered separately from a luminaire in order to determine light output ratio or luminaire data per 1 000 lm of lamp flux.

2.3.4 Reference conditions (luminaire)

The conditions under which photometric measurements on luminaires are performed in accordance with the provisions of chapter 4 of this report.

2.3.5 Reference conditions (lamps)

The conditions under which lamp flux is measured in accordance with the provisions of the appropriate IEC Lamp Specification [5-11].

2.3.6 Reference ballast

A special inductive type ballast designed for the purpose of providing a comparison standard for use in testing ballasts, for selection of reference lamps and for testing regular production lamps under standardised conditions.

Note: The electrical parameters of reference ballasts for each type of lamp are given in the appropriate IEC Lamp Specification [5-11] but the electrical requirements are given in the appropriate IEC Ballast Specifications [12-16].

2.4 Terms related to measuring instruments

2.4.1 Photometer

Instrument for measuring photometric quantities.

2.4.2 Goniophotometer [also distribution photometer]

Photometer for measuring the directional light distribution characteristics of sources, luminaires, media or surfaces.

2.4.3 Photometer head

That part of the goniophotometer comprising the photometer itself (normally a silicon photodiode with colour filters for the spectral correction of the detector responsivity). It may also contain means for the directional evaluation of the light (e.g. diffusing windows, lenses, apertures). The photometer converts the incident light into an electrical quantity.

2.4.4 Illuminance meter

Photometer for the measurement of illuminance.

3. CO-ORDINATE SYSTEMS FOR THE PHOTOMETRY OF LUMINAIRES

3.1 General aspects

The basic photometric data of a luminaire consist of a set of values of the luminous intensity in different directions, produced by direct photometric measurements.

Measurements of intensity distribution involve photometric and angular measurements (the goniophotometer), under controlled working conditions of the luminaire (electrical and temperature measurements).

For such photometric measurements involving direction, it is necessary to define a spatial framework around the luminaire (the co-ordinate system).

3.2 Basic goniophotometers

For the measurements of the luminous intensity in different directions, the luminaires are mounted in a goniometer to facilitate the positioning at definite angles. A goniophotometer usually consists of a mechanical device for the support and positioning of the luminaire or lamp and the photometer head, together with associated devices for acquiring and processing data.

Basically, three types of goniophotometer can be distinguished.

- A goniophotometer which rotates the luminaire around two mutually perpendicular axes whose intersection is the photometric centre of the goniophotometer. This type of goniophotometer is normally used with a single photometer head positioned at an adequate distance from the centre.
- A goniophotometer which rotates the luminaire around one axis only, the second rotation being given by a relative movement between the luminaire and the photometer head around a second axis at right angles to the first and crossing it at the photometric centre of the goniophotometer.
- A goniophotometer in which the luminaire does not move at all. The photometer head rotates around two mutually perpendicular axes whose crossing is the photometric centre of the goniophotometer.

Note : In the first type, the burning position of the lamp changes continuously during measurements which restricts the use of this type of goniophotometer.

In the second type, the burning position of the lamp is the burning position considering the normal use of the luminaire even if the luminaire moves in space or rotates during measurements

Since practical considerations limit the overall dimensions of the two last types of goniophotometer, the use of mirrors to increase the light path between the photometer head and the luminaire, or the use of a luminance meter of appropriate dimensions as a detector, is usually adopted with these types of goniophotometer. Mirrors may also be used to maintain the photometer in a fixed position.

The three basic types of goniophotometer listed above can be used in a variety of configurations, each one fitting a particular purpose. Differences lie in the mounting position of the goniophotometer with respect to the ground, in the orientation of the reference axis with respect to the goniophotometer, and in the way in which the luminaire is mounted in the goniophotometer.

Principles of construction and selection of goniophotometers are covered in publication CIE 70 1987[17].

3.3 The co-ordinate system

The determination of the intensity distribution of a luminaire in space involves the use of a co-ordinate system to define the direction in which the intensity measurements are made. The system used is a spherical co-ordinate system with the centre coincident with the photometric centre of the luminaire.

From a general point of view the co-ordinate system consists of a set of planes with a single axis of intersection. A direction in space is characterised by two angles:

- the angle between one half-plane, taken as an origin, and the half-plane containing the direction considered,
- the angle between the axis of intersection and the direction considered or the complement of this angle.

The orientation of this system with respect to the first (or reference) axis and the second (or auxiliary) axis of the luminaire is chosen with particular regard to the type of luminaire, the type of lamp, the mounting attitude of the luminaire and its application, in order to perform more accurate measurements or to simplify the consequent lighting calculations.

Current practice has limited the possibilities to a finite number of orientations. The axis of the intersection should be either vertical or horizontal; in the latter case the axis may be perpendicular to, or coincident with, the second axis of the luminaire.

3.4 Systems of measurement planes

In general the luminous intensity of a luminaire is measured in a number of planes. From the variety of possible measurement planes three systems of planes have proven specially useful.

3.4.1 A-planes

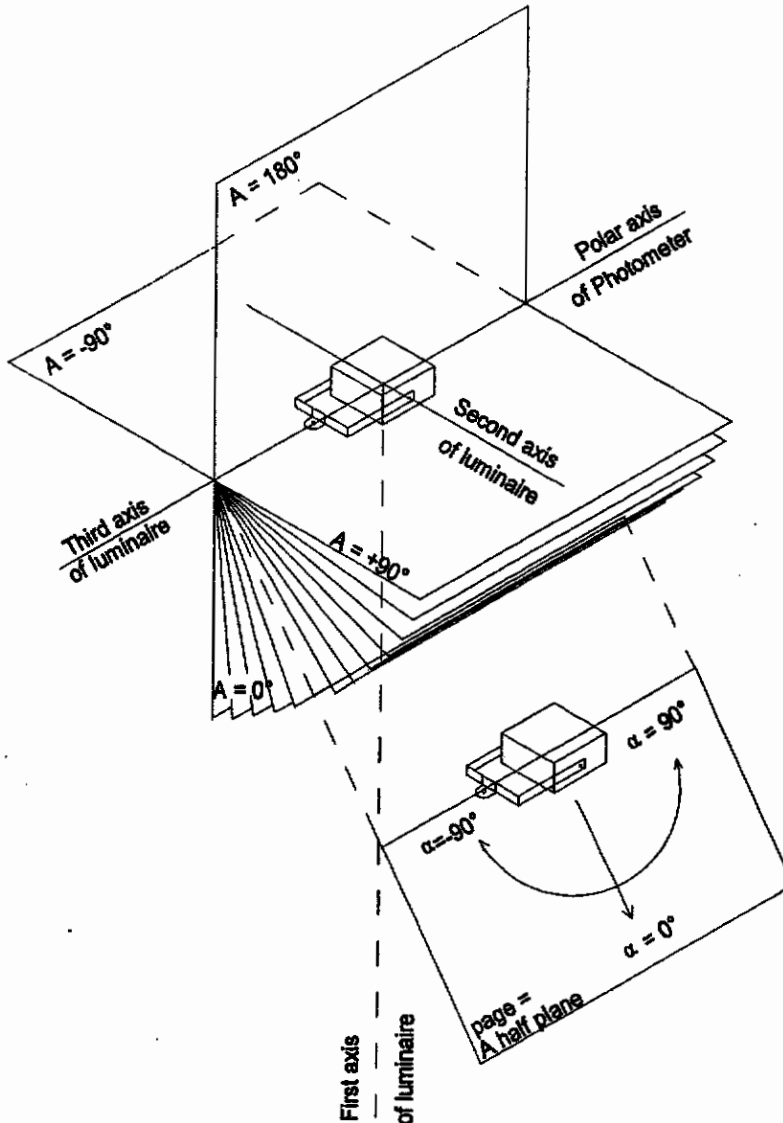


Figure 1. Luminaire orientation for A, α goniophotometry.

The system of A-planes is the group of planes for which the line of intersection (polar axis) goes through the photometric centre and is perpendicular to the plane containing the first and the second axes of the luminaire.

The system of A-planes is coupled rigidly to the luminaire and follows its tilt if the luminaire is tilted. The first axis is the axis going through the photometric centre and perpendicular to the light emitting area. It lies in the $A = 0^\circ$ half-plane, usually in the direction $\alpha = 0^\circ$. The second axis also passes through the photometric centre of the luminaire and is perpendicular to $A = 0^\circ$ plane.

Some types of goniometer provide data in this system and are used in the photometry of interior lighting luminaire. The conversion formulas given in 3.4.4 are applicable if the third axis of the luminaire (coincident with the polar axis) is the long axis of the luminaire.

3.4.2 B-planes

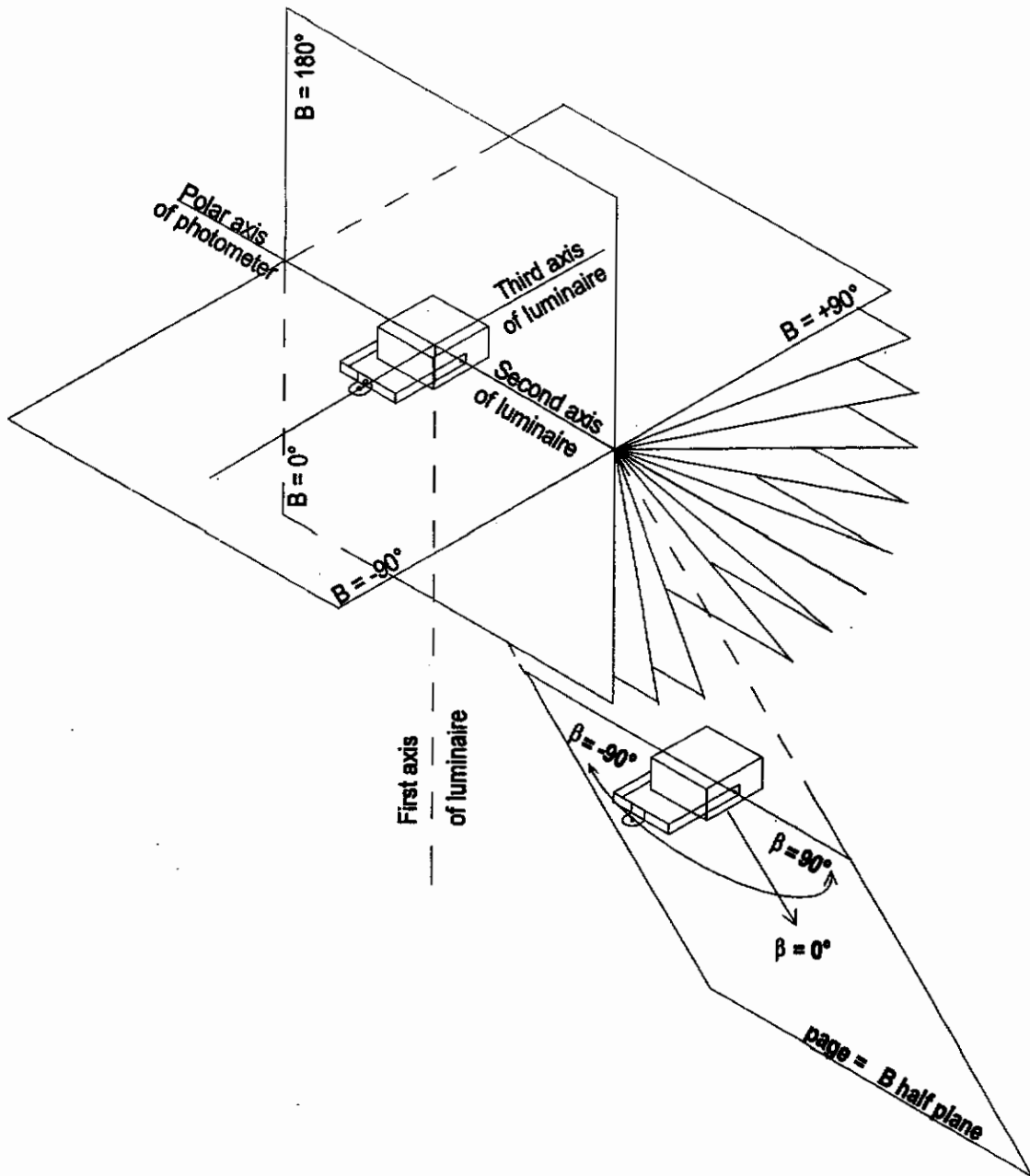


Figure 2. Luminaire orientation for B, β goniophotometry.

The system of B-planes is the group of planes for which the line of intersection (polar axis) goes through the photometric centre and is parallel to the second axis of the luminaire.

The system of B-planes is coupled rigidly to the luminaire and follows its tilt if the luminaire is tilted. The first axis is the axis going through the photometric centre and perpendicular to the light emitting area. It lies in the $B = 0^\circ$ half-plane, usually in the direction $\beta = 0^\circ$. The second axis is coincident with the line of intersection of the B-planes.

The system is commonly used in the photometry of floodlights. However the reference axis, perpendicular to the light emitting area, is often set horizontal and a variant of this system (V,H system) may be used. See Publication CIE N° 43, 1979 [18].

3.4.3 C-planes

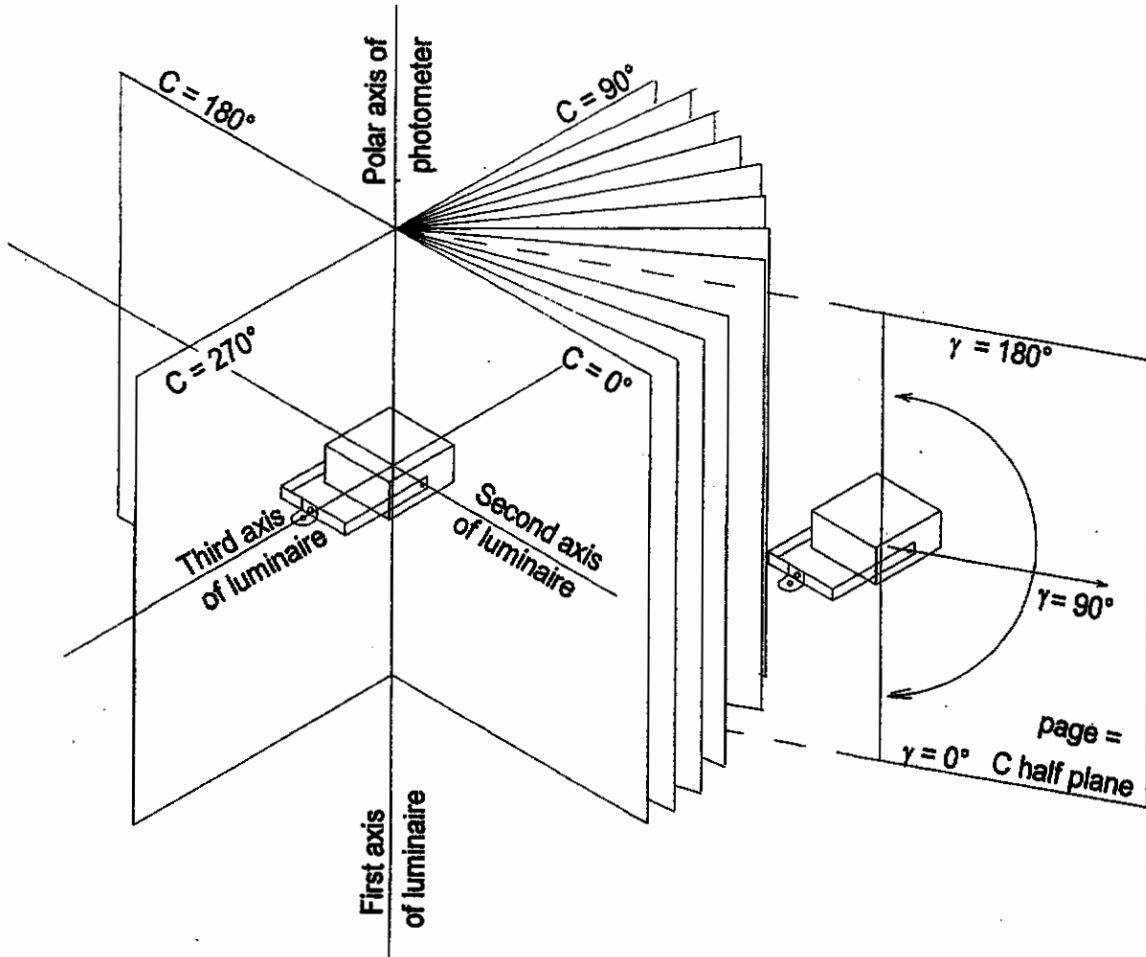


Figure 3.3. Luminaire orientation for C, γ goniophotometry.

The system of C-planes is the group of planes for which the line of intersection (polar axis) is the vertical line through the photometric centre.

The system of C-planes is generally oriented rigidly in space and does not follow the tilt of the luminaire. The line of intersection of the C-planes is only perpendicular to the lines of intersection of the A- and B-planes for zero tilt of the luminaire. It does not necessarily coincide with the first axis of the luminaire except in case of zero tilt. This first axis is usually the axis going through the photometric centre and perpendicular to the light emitting area. The second axis lies within the plane $C = 0$.

The system is commonly used in the photometry of interior and street lighting. In interior lighting, the third axis of the luminaire is the long axis, while in public lighting (see Publication 34-1977 [19]) the second axis of the luminaire is usually parallel to the road axis.

3.4.4 Relationships

A certain direction in each system of planes is characterised respectively by two angles:

- an angle A, B or C for the tilt of the plane A, B or C ;
- an angle α, β or γ in the associated A, B or C half-plane.

The angles α (or β) in an A-plane (or a B-plane) are measured up to $\pm 90^\circ$ from the direction of the perpendicular to the axis of intersection of the A (or B) planes. The A (or B) half-plane, taken as 0° plane, contains the first axis and is normal to the second axis of the luminaire (A-plane) or contains the second axis (B-plane). A and B-planes are taken from 0° to $\pm 180^\circ$.

The angles γ in a C-plane are measured up to 180° from the direction of the perpendicular to the axis of intersection of the C-planes. This axis does not necessarily coincide with the first axis of the

luminaire, as the luminaire may be tilted. The C half-plane, taken as 0°, contains the second axis of the luminaire. Other half-planes are denoted up to 360°, measured from the 0° half-plane anti-clockwise viewed from above the luminaire. If the luminaire has one plane of symmetry, this plane contains the third axis of the luminaire and is chosen to be coincident with the planes C = 90/270. If the luminaire has two planes of symmetry, the transverse plane contains the second axis of the luminaire and is usually chosen to be coincident with the plane C = 0/180.

The conversion equations listed in Table 1 below can be used to transform co-ordinates between the different systems and are valid with the above mentioned conventions (orientation of the luminaire axes in the coordinate systems)

Table 1. Conversion equations between systems of planes

Direction		Conversion formulae	
given	wanted	for planes	for angles
A, α	B, β	$\tan B = \tan \alpha / \cos A$	$\sin \beta = \sin A \times \cos \alpha$
A, α	C, γ	$\tan C = \tan \alpha / \sin A$	$\cos \gamma = \cos A \times \cos \alpha$
B, β	A, α	$\tan A = \tan \beta / \cos B$	$\sin \alpha = \sin B \times \cos \beta$
B, β	C, γ	$\tan C = \sin B / \tan \beta$	$\cos \gamma = \cos B \times \cos \beta$
C, γ	A, α	$\tan A = \cos C \times \tan \gamma$	$\sin \alpha = \sin C \times \sin \gamma$
C, γ	B, β	$\tan B = \sin C \times \tan \gamma$	$\sin \beta = \cos C \times \sin \gamma$

4. LABORATORY REQUIREMENTS FOR TESTS

4.1 General

The object of the tests is to measure the characteristics of the luminaire by means of appropriate equipment and procedures which are comparable between laboratories and which relate as closely as practicable to the typical conditions of service for which the luminaire is designed.

Photometric tests on luminaires shall be carried out under the conditions laid down in this chapter and reported as relating to the relevant standard test conditions. In particular, where a measurement of Light Output Ratio is reported without indicating specified practical working conditions, the practical conditions in question, both for bare lamps and for luminaires, shall be the standard conditions specified below.

Note: If it is not possible to achieve a specified condition then a measurement correction factor should be applied (see chapter 7).

If the conditions for operation of the luminaire in service do not comply with the standard test conditions, then a service conversion factor (see chapter 7) should be determined. In this case it is recommended that the measurements be reported as related to the standard test conditions and that the service correction factor related to that specific service condition should also be reported.

4.2 Standard test conditions

4.2.1 Test room

a) Measurement location

The luminaire shall be measured in surroundings so arranged that the photometer head receives only light from the luminaire direct or with intended reflection.

b) Air movement, ambient temperature

Measurements shall be made in still air free from smoke, dust and mist. The air temperature around the luminaire or the bare lamp should be $25 \pm 1^\circ\text{C}$ unless otherwise specified. For lamps which are not thermally sensitive, larger temperature tolerances may be acceptable (see sections 4.3.1 and 4.5.4).

4.2.2 Test lamps

The lamps should comply with and be measured according to the relevant IEC recommendation [2-11]. If relevant recommendations do not exist, the lamps should comply as close as possible with the nominal specifications of the lamp manufacturer.

If the lamps is of a type for which the luminous flux published in the lamp manufacture catalogue relates to an operating ambient temperature other than 25°C , measurements of the bare lamps are done at 25°C , but a temperature correction factor, supplied by the lamp manufacturer or determined by the laboratory, shall be applied to these measurements as to relate bare lamps measurements more closely to the lamp catalogue data.

Lamps should be selected in accordance with the recommendations given in chapter 5.

4.2.3 Test ballasts

The built-in ballasts should be used for testing the luminaire and the bare lamps. If the ballast is not built in, the ballast type should be of a type approved by the luminaire manufacturer and the same ballast should be used for testing the luminaire and the bare lamps.

For type testing, ballasts should be selected in accordance with the recommendations given in chapter 5.

4.2.4 Test luminaires

The luminaire should be representative of the manufacturer's regular product.

The luminaire shall normally be mounted in the position in which it is designed to operate in service. However, the measurement attitude, provided that it is declared, may differ slightly from this. With public lighting luminaires, for example, it is common practice to measure the luminaire with the exit plane of the canopy in a horizontal plane.

For type testing, luminaires should be selected in accordance with the recommendations given in chapter 5.

4.2.5 Test voltage

The test voltage at the supply terminals shall be the rated lamp voltage or the rated circuit voltage appropriate to the ballast in use, if any.

The voltage should be controlled in accordance with the recommendations given in chapter 5.

4.3 Practical test conditions

As it is virtually impossible to carry out photometry on a lamp or luminaire without some variation in ambient temperature and some movement of air within its vicinity, tests should be made to ensure that the laboratory conditions are satisfactory.

Where the output of a lamp or luminaire is affected by changes in ambient temperature or air movement the recommendations of sections 4.3.1 and 4.3.2 should be observed. Usually these

considerations only apply when testing tubular fluorescent lamps or the luminaires incorporating them, but may also be important for certain other types of discharge lamp.

4.3.1 Ambient temperature variation

The mean ambient temperature should equal $25 \pm 1^\circ \text{C}$ throughout the test of the lamp or luminaire.

As indicated in chapter 5, larger tolerance may be acceptable for certain types of lamp.

If measurements are made outside the tolerances, then a correction factor should be determined, as described in section 7.3.2.2 and applied to the individual readings. A correction factor is necessary if the luminous flux of the lamp or the luminaire has been changed by more than 1% due to the test not being carried out at 25°C .

If photometric measurements are made in accordance with these requirements then they can be taken to relate to the standard ambient temperature of 25°C .

4.3.2 Air movement

The movement of air around the bare lamp or luminaire under test may reduce the operating temperature, thereby altering the light output of some types of lamp. Such movement of air may be caused by draughts, air conditioning or the motion of the luminaire in the measuring equipment. Air movement in the vicinity of the luminaire should not exceed $0,2 \text{ m}\cdot\text{s}^{-1}$. For lamps for which larger tolerances for ambient temperature are allowed, a faster air movement may be acceptable.

To ensure that the laboratory conditions are satisfactory, the following tests should be made. The checks are particularly important in the measurement of low pressure mercury fluorescent lamps.

4.3.2.1 Motion of the lamp or luminaire

A reading of luminous intensity in a specified direction should be taken after stabilisation of a bare lamp. The lamp should then be moved at normal speed through the equivalent of 360° of movement of the photometer head in a vertical plane, after which the luminous intensity should immediately be remeasured. The two readings of luminous intensity should otherwise be measured under the same conditions and in the same direction, usually at the nadir. The difference between the two readings should not exceed 2%. A second and similar test should be made to check the effect of rotating the lamp at normal speed through 360° in azimuth.

Similar tests should be carried out on the luminaire over the full vertical and horizontal ranges of the goniophotometric equipment.

The tests do not, of course, apply to those systems in which the relative movement between lamp and photometer head is obtained with the lamp or luminaire fixed in space.

4.3.2.2 Draughts and air conditioning

A bare lamp mounted on the photometer should be stabilised in the proposed laboratory conditions and the luminous intensity in a specified direction measured at a known ambient temperature. The air conditioning plant should then be switched off, any remaining draughts reduced as far as practicable, and the lamp restabilised. The luminous intensity should then again be measured at the same ambient temperature. The difference between the two readings should not exceed 2%.

A similar test should be carried out on the luminaire.

These tests should be repeated for a number of different positions of the lamp or luminaire in the goniophotometer.

4.4 Photometric apparatus

The reliability of the illuminance meter which is used in a goniophotometer is of crucial importance in the photometry of luminaires. Illuminance meters usually consist of a built-in or detachable photometer head and associated apparatus.

4.4.1 Requirements for illuminance meters used in goniophotometers

Illuminance meters used in conjunction with goniophotometers or integrators should ideally meet the requirements given in Table 2. This table lists representative error values which have been estimated for good available commercial instruments based on CIE 69-1987 [20] (some countries have national standards where maximum permissible error values may be different, see e.g. DIN 5032-7 [21]). Table 2 should be read in conjunction with the individual sub-sections below. Values for individual meters should be checked initially and the necessary data should be provided by the manufacturer. The user must consider the measurement errors in relation to the measurement task. It is usually sufficient to verify the overall response of the photometer at each recalibration but, if a significant variation is observed, spectral responsivity and linearity should also be checked.

Table 2. Error tolerances for photometers

Characteristic	Symbol for associated error parameter	Maximum value
$V(\lambda)$ match	f_1	2 %
UV response	u	0,2 %
IR response	r	0,2 %
Cosine response *	f_2	1,5 %
Polarization dependence	f_6	0,2 %
Influence of non-uniform illumination	f_9	0,2 %
Linearity	f_3	0,2 %
Fatigue	f_5	0,2 %
Temperature dependence *	a	0,2 %/K
Evaluation of modulated light	f_7	0,1 %
Error of display unit	f_4	0,2 %
Range change	f_{11}	0,1 %

* only when applicable: see sections 4.4.1.6 and 4.4.1.7 below

In the photometry of luminaires, particular attention should be paid to the properties and requirements commented on below. These should be read in conjunction with Publication CIE 69-1987[20], which provides objective means for evaluating errors where numerical assessments are possible.

4.4.1.1 Calibration

The calibration factor of the photometer, measured under standard calibration conditions (homogenous normal illumination with standard illuminant A), should be known to an accuracy of $\pm 1,5\%$ throughout the measuring ranges, up to the maximum illuminance at which the photometer is intended to be used.

Overall performance should be checked initially and repeat checks made at regular intervals to ensure that it keeps within the required limits.

4.4.1.2 Linearity

The photometer response should be linear over its working range. The error in linearity (f_3) should not exceed 0,2% within the usable portion of the display range (e.g. above 10% of the full-scale value of the range).

It is recommended that the linearity of response of the photometer head be measured by a method similar to that described in Publication CIE Report 69-1987.

Examples of equipment designed to carry out this measurement may be found in the papers by Sanders (1962) [22] or Hoppmann (1958) [23].

4.4.1.3 Fatigue

The photometer should be stable when receiving a constant illuminance, during any one measuring sequence. The error due to fatigue (f_5), measured at 1 000 lx, should not exceed 0,2%.

Response to a light source of stable output should be checked at points throughout the measuring ranges, up to the maximum illuminance for which the photometer is used. The reading should remain constant within $\pm 0,2\%$ for a period of at least 30 minutes. This check should be made with dark periods interposed between repeat readings to detect whether the photometer is unduly affected by long periods of light or darkness. Photocells shown by this test to exhibit excessive fatigue should be discarded as no correction of measurement errors due to this effect can be made.

Care should be taken to avoid exposing the photometer head to an illuminance above the safe limit stated by the manufacturer. Aperture stops or calibrated neutral filters, used to reduce the illuminance, must do so evenly over the whole of the sensitive surface. Each setting of a stop should be located uniquely and held firmly. The operation of the stop should not affect the "view" of the photometer head or of any attachment to the photometer head e.g. for correcting for oblique light incidence.

4.4.1.4 Response time

The photometer should respond promptly to any change in illuminance.

Where automated equipment is used for recording the readings, the whole equipment should be checked for dynamic errors. Examples of such errors are delays due to the time constant of the analogue part of the photometer, conversion rate of an analogue-to-digital converter, or switching time for auto-ranging meters.

In goniophotometers with a continuously movable photometer head or luminaire it is also necessary to check that there are no dynamic errors in recording the appropriate angle. The time response of the photometer and/or the speed of the movable parts should be adapted so as to guarantee sufficient accuracy, also taking account of the smoothness of the light intensity distributions to be measured. The user should check the equipment by recording an appropriate light intensity distribution in the intended way and comparing the results with those obtained using a step by step method. These checks should, if necessary, be repeated for different light intensity distributions.

4.4.1.5 Spectral responsivity

The spectral responsivity of the photometer head should closely follow the CIE photopic luminous efficiency function $V(\lambda)$.

For absolute measurements on discharge lamps, if the error in the $V(\lambda)$ fit (f_1) exceeds 2 % then a systematic spectral correction factor should be applied. To determine such a correction factor, the spectral responsivity of the photometer head and the spectral distribution of the source to be measured must be known.

For relative measurements, the error in the $V(\lambda)$ fit (f_1) should not exceed 3 %. This requirement arises because a luminaire may modify the light from the lamp spectrally.

The initial measurement of spectral responsivity is usually made by the manufacturer of the photometer head.

The user should check periodically that there has been no significant change. This can be done by using the photometer to make measurements of the luminous transmittances of three stable colour filters. The measurements should always be made under the same test conditions to minimise errors due to extraneous effects. The light source should be an incandescent lamp operated at the same

colour temperature on each occasion, usually 2 856 K (CIE Illuminant A). Filters with characteristics similar to the following are suitable for this measurement.

Blue Filter: Schott Glass Type BG 28, 2 mm or Kopp CS 5-59, Glass Type 5433

Green Filter: Schott Glass Type VG 14, 2 mm or Kopp CS 4-64, Glass Type 4010

Red Filter: Schott Glass Type RG 610, 2 - 3 mm or Kopp CS 2-61, Glass Type 2412

Note: Kopp filter glasses were formerly marketed under the brand name Corning.

The transmittance of the filters, especially the red filters, may be sensitive to temperature change. For this reason, they should not be mounted close to the light source.

4.4.1.6 Temperature dependence

The photometer output may be affected by variations in the ambient air temperature. For example, the responsivity of a silicon photodiode can fall by approximately 0,1% for each 1°C rise in the temperature.

Problems due to this effect can be eliminated if the temperature of the photometer is thermostatically controlled. If this facility is not provided, then the air temperature in the vicinity of the photometer head should be controlled within the following limits.

- Relative measurements: air temperature to be held within $\pm 2^\circ\text{C}$ of the target value (preferably 25°C).
- Absolute measurements: as for relative measurements. The target temperature during the test measurements should be the same as the temperature prevailing during the calibration.

Correction factors may be applied if there is a linear relationship between temperature and responsivity.

4.4.1.7 Cosine response

The response of the photometer head to a given illuminance should not vary significantly over the working range of angles of incidence.

Most common types of photocell will only need correction if the photometer head, as installed, receives light at angles of incidence greater than about 20° to the normal. The error in the angular response (f_2) should not exceed 2 %.

4.4.2 Requirements for the auxiliary detector used to monitor the light source

With some types of goniophotometer, the luminaire may not be measured in its designed attitude and certain types of discharge lamp can change their light output if tilted. It is sometimes possible to correct for such a change by monitoring the light output with an auxiliary detector.

The auxiliary detector used for this purpose need not be closely corrected for spectral response or oblique light incidence. The only stringent requirements are for low fatigue and drift parameters.

The auxiliary detector must be fixed rigidly to the luminaire to be monitored so that it follows its movements. It should, preferably be illuminated by all parts of the emitting area and should be shielded so as to respond only to direct light from the luminaire. The position chosen should not cause any disturbance to the light reaching the main photometer head when in any of the normal measuring positions.

4.4.3 Requirements for a collimating photometer head

In specialist applications where the goniophotometer has a collimating photometer head, the head should be sensitive only to light which falls on its measuring surface within an angle α to the normal to the detector.

The angle α should not be greater than $2,5^\circ$. Even this angle may not be sufficiently narrow for special types of luminaire with sharp variations in intensity distribution.

The photometer head should be of a size which permits it to view effectively the whole of the luminaire. The diameter d of the detector must be at least:

$$d = D + 2r \tan \alpha$$

where

D is the maximum dimension of the luminaire,

r is the distance between the luminaire and the surface of the detector.

The responsivity of the photometer head must be essentially the same all over its measuring surface.

Descriptions of this type of photometer may be found in Frederiksen (1967) [24], Soardo et al (1979) [25], or CIE 70-1987 [18].

4.4.4 Requirements for goniophotometers

See section 6.2.1.

4.5 Other laboratory equipment

4.5.1 Electrical power supply

a) Current capacity

The power supply should be of ample current handling capacity for the loads to be connected. In particular the supply, including ancillary transformers, should be of very low impedance.

b) Voltage stability

The voltage at the supply terminals of the luminaire or bare lamp should be set and maintained constant in accordance with the requirements given in chapter 5.

c) AC frequency

For luminaires with discharge lamps, the frequency of the ac power supply should be maintained constant within $\pm 0,2$ % of the required frequency.

d) AC waveform

The harmonic content of the voltage waveform of the ac supply should be as low as possible, and should not exceed 3% of the fundamental. This requirement may however be relaxed if only tungsten-filament lamp luminaires are to be measured.

Note: The harmonic content is the r.m.s. sum of the individual harmonic components, taking the fundamental as 100 %.

e) DC ripple

If the supply is dc, the ac component of the voltage at the terminals of the luminaire should not exceed 0,5 %.

f) Electro-magnetic field

The electro-magnetic field generated by the electric power supply and by the luminaire or bare lamp supply circuit should be negligible and must not result in any electro-motive force in the photo-detector circuit. A check of the dark current of the photodetector should be performed under the most adverse conditions in order to check the amount by which readings are affected. Attention should also be paid to possible disturbances caused by computers and video screens in the vicinity.

4.5.2 Electrical measuring instruments

Voltmeters, ammeters and wattmeters should comply with the requirements for Class Index 0,5, or better.

Note: The requirement to hold the supply voltage within $\pm 0,2 \%$ of a set value does not necessarily imply a voltmeter of greater accuracy than Class Index 0,5, since an adequate correction of readings may be made after calibration.

Instruments intended for measuring r.m.s. values should be substantially free from errors due to waveform distortion. When measuring high frequency discharge lamps, special attention must be paid to the frequency range of the instruments.

Since electrical measuring instruments are liable to changes of accuracy with time, attention is drawn to the necessity for periodic checking and calibration at appropriate intervals.

Potential circuits: voltmeters and the potential circuits of wattmeters connected across a discharge lamp should not draw more than 0,5% of the rated running current.

Current circuits: ammeters and currents circuits of wattmeters in series with a discharge lamp should have an impedance low enough to ensure that the voltage drop does not exceed 0,5% of the rated lamp voltage.

4.5.3 *Electrical circuits*

All leads and connections should be securely made and of sufficient low impedance that the whole voltage drop does not exceed 0,5% of the rated lamp or luminaire voltage. The measurement circuits should comply with the relevant IEC lamp recommendation [2-11].

4.5.4 *Temperature measuring instruments*

Air temperature may be measured with a thermometer of any convenient type (e.g. liquid-in-glass, thermocouple, thermistor) which is accurate within $\pm 0,5^\circ \text{C}$. The thermometer should be enclosed in a metal housing polished on its outside surface so as to reflect radiation (but baffled, if necessary, to prevent reflected light reaching the photometer head). Care should be taken, however, to ensure that the thermometer does not prevent any direct light from the luminaire reaching the photometer head.

5. PREPARATION OF LAMPS, BALLASTS AND LUMINAIRES FOR TESTS

5.1 Lamps

5.1.1 *General requirements for all types of lamp*

The lamps selected for type testing of luminaires should comply with the relevant IEC lamp publications [2-11]. If such recommendations do not exist, the lamps should comply with the specifications of the lamp manufacturer.

a) Physical characteristics

The dimensions of the lamps, in so far as they are relevant to the measurements, should be as close as possible to the nominal values. Lamp caps and lamp bulbs should be assembled as closely as possible on their nominal alignments.

Lamp should be as free as possible from inhomogeneities.

b) Electrical characteristics

The power of the lamp should be within $\pm 5 \%$ of the rated value when tested under reference conditions according to the relevant IEC lamp publications[2-11].

c) Photometric characteristics

Lamps of stable luminous output are needed for photometric purposes. They should be constant in light output for constant supply voltage and repeated operation.

All lamps should be aged by cyclic operation until the light output is shown to be stable. Lamps may provisionally be regarded as stable and suitable for test purposes if, after thermal stabilisation,

the differences in light output between three successive readings, made at intervals of 15 minutes, are less than 1%. After this, test lamps should be allowed to cool to room ambient temperature, and should then be relit. When the light output has become steady its value should be within 2 % of the last of the three former readings. Such lamps may then be taken as test lamps. Repeat checks should be made regularly.

Lamps for multiple lamp luminaires, if intended to be of the same type and wattage, should be matched for light output within a spread of 3 % when operated under the same reference conditions.

d) Operation and handling

During successive bare lamp measurements, a test lamp should be operated in a consistent position and with consistent electrical connections. To facilitate this, lamps should be suitably marked. As far as possible, lamps should be inserted in luminaires with consistency of electrical connection. The bare lamp should operate in the attitude in which it is run for the measurement of rated flux, according to the relevant IEC lamp recommendation [2-11], while the lamp(s) in the luminaire should operate in the designed attitude for the luminaire.

For fluorescent lamps the current path should be defined before ageing.

e) Alignment of the lamp in the luminaire

The light distribution of a luminaire is frequently dependent upon the alignment of the lamp in relation to the position of a filament gap, arc tube support, cap and socket tolerances, etc.. Care must be taken to comply with manufacturers specifications.

5.1.2 Photometric light centre of the lamp

For measurements on bare lamps, the position of the light centre (photometric centre) of the lamp should be determined in accordance with the following criteria, see also figure 4.

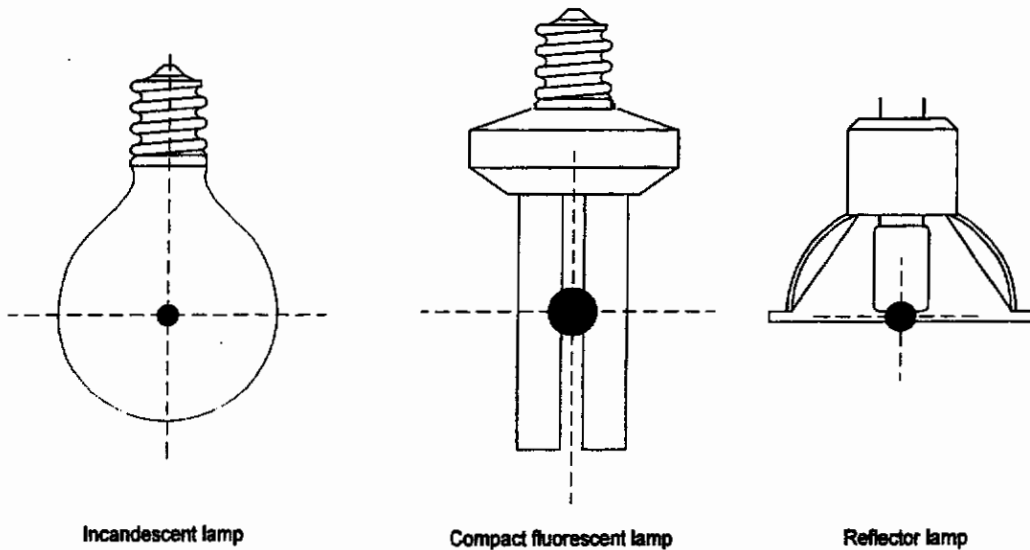


Figure 4. The photometric centre of incandescent, compact fluorescent and reflector lamps.

a) Tungsten-filament lamps, clear or lightly diffusing bulb

The centre of the solid figure bounded in outline by the filament.

b) Lamps with diffusing or fluorescent bulb

The centre of the diffusing portion of the lamp envelope.

Note: This category includes straight fluorescent lamps and tubular discharge lamps with diffusing or colour-correcting envelopes.

c) Discharge lamps, curved-arc

The centre of gravity of the plane figure formed in outline by the centre line of the arc discharge.

Note: This category includes U-limb sodium lamps, and circular and curved fluorescent lamps.

d) Lamps with an internal reflector

The centre of gravity of the plane figure formed in outline by the main opening of the reflector.

5.1.3 Specific requirements of different types of lamp

5.1.3.1 Incandescent tungsten-filament lamps

a) Physical characteristics

For lamps with a diffuse coating of the bulb, the diffusing quality of the lamp bulb should correspond to the average of the production.

Note: A method of measuring the diffusing quality of a lamp bulb is under consideration.

When lamps with clear bulbs are used in luminaires equipped with mirrors, the filaments must be centred within the limits specified by the relevant IEC publication [2-4].

b) Electrical characteristics

During measurement the voltage should be held within 0,1 % of the test voltage.

For bare lamp measurements a special quadri-pole type of lampholder is recommended so as to facilitate accurate electrical measurements. This measurement socket consists of two separate galvanic connections, each of which shall have a point of contact with the lamp, one for the supply of the lamp and the other for the voltage measurement.

Note: Where a lamp is to be used for large numbers of measurements involving repeated operation of the lamp, a reduced test voltage (preferably about 95 % of the rated volts) may be adopted to reduce drift in the output and increase the life of the lamp. This technique cannot be used if the luminaire is strongly coloured.

For measurements in absolute units, the test voltage should be the rated voltage.

c) Photometric characteristics

The luminous flux of incandescent lamps is strongly dependent on the supply voltage. Care must be taken to avoid variable resistive contacts and voltage drop in the leads.

If the proper current with respect to the test voltage is established for a specific test lamp, then current control of the lamp is recommended. It should be noted, however, that since luminous flux is more sensitive to changes in current than to changes in voltage, the permissible tolerance for current control is only half that for voltage control.

The repeatability of successive luminous flux measurements should be within $\pm 1\%$. If a stable reference lamp is employed for a series of measurements, it should not be necessary to release the luminous flux of the bare lamp every time.

Ageing: 1 % of the rated life (or 1 hour if the rated life is shorter than 100 hours) at rated voltage.

Burning position: vertical, cap-up unless otherwise specified by the lamp manufacturer.

d) Operation and handling

Bare lamps should be operated only in positions allowed by the manufacturer. Lamps with clear bulbs should be marked on the cap to ensure that they are always operated in the same position in the luminaire.

The ambient temperature should be within the range 20°C to 27°C. During measurements, it should not vary by more than $\pm 3^\circ\text{C}$.

Tungsten halogen lamps should not be moved while hot. After accidental finger contact, even when cold, these lamps must be cleaned carefully with alcohol to eliminate all grease deposits.

5.1.3.2 Tubular and compact fluorescent lamps (including amalgam lamps)

a) Physical characteristics

The diffusing quality of the lamp tube should correspond to the average of the production.

The lamps should have no apparent end-blackening and in the central plane normal to the axis the intensity in any direction should not differ by more than 3 % from the mean intensity.

b) Electrical characteristics

The test voltage should be the rated circuit voltage of the luminaire.

During measurement the applied voltage should be within $\pm 0,5$ % of that specified.

c) Photometric characteristics

The luminous flux of tubular fluorescent lamps is strongly dependent on ambient air temperature, air movement and lamp position.

The repeatability of successive luminous flux measurements should be within ± 2 %.

Ageing: At least 100 hours on a ballast complying with the requirements of the relevant IEC lamp publication (e.g. 81,901,969 [5-8]), at rated circuit voltage, with off periods of 10 minutes minimum 8 times in every 24 hours. Vapour pressure controlled lamps should be aged for at least 200 hours. Ageing position of the lamp: horizontal or according to the relevant IEC lamp publication..

d) Operation and handling

Bare lamps should be operated in burning position as defined by the lamp manufacturer.

The lamps in the luminaire should be operated in the designed attitude for the luminaire. Lamp circuit pins and ballast connections should be marked so that the pin and ballast connections remain unchanged throughout the test.

The ambient temperature should be $25 \pm 1^\circ\text{C}$. The air around a lamp should be kept as free as possible from draughts.

For other operating conditions, it may be necessary to introduce measurement correction factors (see chapter 7).

Single-capped compact fluorescent lamps: Experience shows that during normal handling of the lamps any excess amount of mercury may be distributed in small droplets within the discharge tube. Stabilisation of such lamps may require up to 15 hours in order to move the excess mercury to the coldest spot in the tube. Once it has passed through this burn-in period, the lamp will normally only need 15 minutes for restablising each time it is relit, provided that it has been kept in the same position and not subjected to shocks and vibration.

Self-ballasted lamp: The stabilisation of self-ballasted lamps may require up to 15 hours.

5.1.3.3 High pressure mercury vapour lamps

a) Physical characteristics

For lamps with a phosphor or diffuse coating, the quality of the lamp bulb should correspond to the average of the production.

b) Electrical characteristics

The test voltage should be the rated circuit voltage appropriate to the ballast in use. During measurements the voltage should be within $\pm 0,2$ % of that specified.

c) Photometric characteristics

The luminous flux of high pressure mercury vapour lamps is dependent on lamp position. The light distribution of clear bulb lamps can vary with lamp position, as a result of a displacement of the discharge within the arc tube.

Ageing: At least 100 hours on a ballast complying with IEC publications 188 and 923 [8,13], at rated circuit voltage, with off periods of 30 minutes every 6 hours. Ageing position of the lamp: vertical, cap up unless otherwise specified by the manufacturer.

d) Operation and handling

Bare lamps will normally be operated in a vertical position, cap-up.

The lamp in the luminaire should operate in the designed attitude for the luminaire. In other operating conditions, measurement correction factors must be introduced.

The ambient temperature should be within the range 20°C to 27°C. During measurement, it should not vary by more than $\pm 3^\circ\text{C}$.

5.1.3.4 Metal halide Lamps

a) Physical characteristics

For lamps with a phosphor or diffuse coating, the quality of the lamp bulb should correspond to the average of the production.

Note: A method for measuring the diffusing quality of a lamp bulb is under consideration.

b) Electrical characteristics

The test voltage should be the rated circuit voltage appropriate to the ballast in use. During measurements the voltage should be within $\pm 0,2\%$ of that specified.

c) Photometric characteristics

The luminous flux of metal halide lamps is strongly dependent on the operating position and the immediate prior history of operation: the geometry, colour and flux of the light flux varies with position.

Ageing: 100 hours at rated circuit voltage, with off periods of 30 minutes every 6 hours in the position to be used for the test on a ballast complying with IEC publications 1167 and 923 [9,13] or complying with the manufacturer specifications. If lamps are required for more than one burning position, a different lamp should be prepared for each burning position. If a lamp exhibits arc spiralling during ageing, another lamp should be tried. If no lamps can be found that have a geometrically stable arc in a given burning position (spiralling usually occurs in the vertical position), then tests may have to be run at a tilted position within the lamps operating range.

Reorientation burn-in period: If a lamp is used in a burning position other than the one in which it was aged, a reorientation burn-in period is required until stable output is again achieved.

d) Operation and handling

The bare lamps should only be operated in the position in which they were burnt-in. The lamps in the luminaire should normally be operated in the designed attitude for the luminaire. This may require the ageing of a different lamp for each of the different burning positions involved.

The ambient temperature should be within the range 20°C to 27°C. During measurement, it should not vary by more than $\pm 3^\circ\text{C}$.

This type of lamp should not be moved while hot as this can effect the distribution of metal in the lamp and so change its characteristics. After switch-off the lamp must cool down for at least 5 minutes. Lamps should be stored in the position in which they will be operated. Lamps should be marked on the cap to indicate the operating position.

5.1.3.5 Low pressure sodium vapour lamps

a) Physical characteristics

Low pressure sodium lamps should have an even distribution of sodium globules.

b) Electrical characteristics

The test voltage should be the rated circuit voltage appropriate to the ballast in use. During measurements the voltage should be within 0,2% of that specified.

c) Photometric characteristics

Ageing: At least 100 hours on a ballast complying with IEC publications 192 and 923 [10,13], at rated circuit voltage, with off periods of 30 minutes every 6 hours. Ageing position of the lamp: horizontal, axes of the U-tube usually in a vertical plane.

d) Operation and handling

Bare lamps should be operated in a horizontal position.

The lamp in the luminaire should be operated in the designed attitude for the luminaire. The permitted orientation of the lamps in operation is limited by the movement of sodium. Lamps with no sodium retaining facilities are limited to horizontal burning within 5° cap down and 15° cap up. Other lamps can be operated within 20° of the horizontal unless otherwise specified by the manufacturer.

The ambient temperature should be within the range 20°C to 27°C. During measurement, it should not vary by more than $\pm 3^\circ\text{C}$.

Special care is needed in handling low pressure sodium lamps. They should not be moved while hot as this can affect the distribution of metal in the lamps and so change their characteristics. They should still be handled gently, even when cold.

5.1.3.6 High pressure sodium vapour lamps

a) Physical characteristics

For lamps with a diffuse coating of the bulb the diffusing quality of the lamp bulb should correspond to the average of the production.

For lamps with a clear bulb, the axis of the discharge tube should not deviate by more than 3 degrees from that of the cap.

b) Electrical characteristics

The test voltage should be the rated circuit voltage appropriate to the ballast in use. During measurements the voltage should be within $\pm 0,2\%$ of that specified. Lamp voltage should comply with the requirements of IEC recommendation [11].

c) Photometric characteristics

Ambient temperature affects lamp operation to a small extent, but more serious effects may occur in an enclosed luminaire due to infrared reflections. Measurements on lamps in the luminaires should only be carried out after arc voltage stabilisation.

Ageing: At least 100 hours on a ballast complying on a ballast complying with IEC publications 662 and 923 [11,13] or with the specifications of the lamp manufacturer, at rated circuit voltage with off periods of 30 minutes every 6 hours. Ageing position of the lamp: horizontal.

d) Operation and handling

Bare lamps should normally be operated in a horizontal position. The lamp in the luminaire should be operated in the designed attitude for the luminaire.

The ambient temperature should be within the range 20°C to 27°C. During measurement, it should not vary by more than $\pm 3^\circ\text{C}$.

5.2 Test ballasts

The test ballast for the luminaire test should be the ballast incorporated in the luminaire or supplied with it for external operation. The ballast should comply with the electrical requirements of the relevant IEC publications [12-15] or with the specifications of the lamp manufacturer.. The ballast setting (lamp power delivered under reference conditions) should be within $\pm 5\%$ of the corresponding reference ballast and should be representative of the production ballast in setting and in power loss. If the ballast setting is outside these limits then a ballast lumen factor should be introduced.

Note: For the measurement of light output ratio working (LORW) the ballast for the bare lamp measurement should be a reference ballast. The electrical characteristics of reference ballasts are given in the relevant IEC lamp publications [2-11].

5.3 Luminaires for test

5.3.1 Selection and handling of the luminaire

The luminaire selected should be representative of the manufacturer's regular product. Its dimensions should be checked for compliance with the manufacturer's data.

Attention should be paid to all features which may affect photometric performance. Optical parts should be clean, and all components rigidly located in their designed positions. Adjustable lampholders should be correctly set according to the manufacturer's instructions.

The luminaire should be mounted according to the manufacturer's instructions so that its alignment is mechanically true. If specific instructions are not provided, then the plane containing the lower edge of the luminaire canopy (or the plane containing the reflector opening if this is lower) should be taken as one reference and the longitudinal axis, determined from the outer edges of the luminaire when viewed in plan, should be taken as the second reference.

5.3.2 Photometric centre of the luminaire

The position of the photometric centre of a luminaire should be determined in accordance with the following paragraphs and with reference to figure 5. For special types of luminaire, however, other criteria may be specified.

a) Luminaires with substantially opaque sides

At the centre of the main luminaire opening (or of any diffusing or prismatic material fitted across the opening) if the lamp compartment is substantially white or luminous, but at the light centre of the lamp if this is outside the plane of the luminaire opening or if the lamp compartment is substantially black or non-luminous and there is no diffusing or prismatic material across the opening.

b) Luminaires with diffusing/prismatic sides

At the centre of the solid figure bounded in outline by the luminous surfaces, but at the light centre of the lamp if it is outside this solid figure.

c) Luminaires with transparent sides or without side members

At the light centre of the lamp.

Note: For a luminaire with two or more lamps (of approximately equal light output), the photometric centre is the geometric centre of the individual light centres of the lamps.

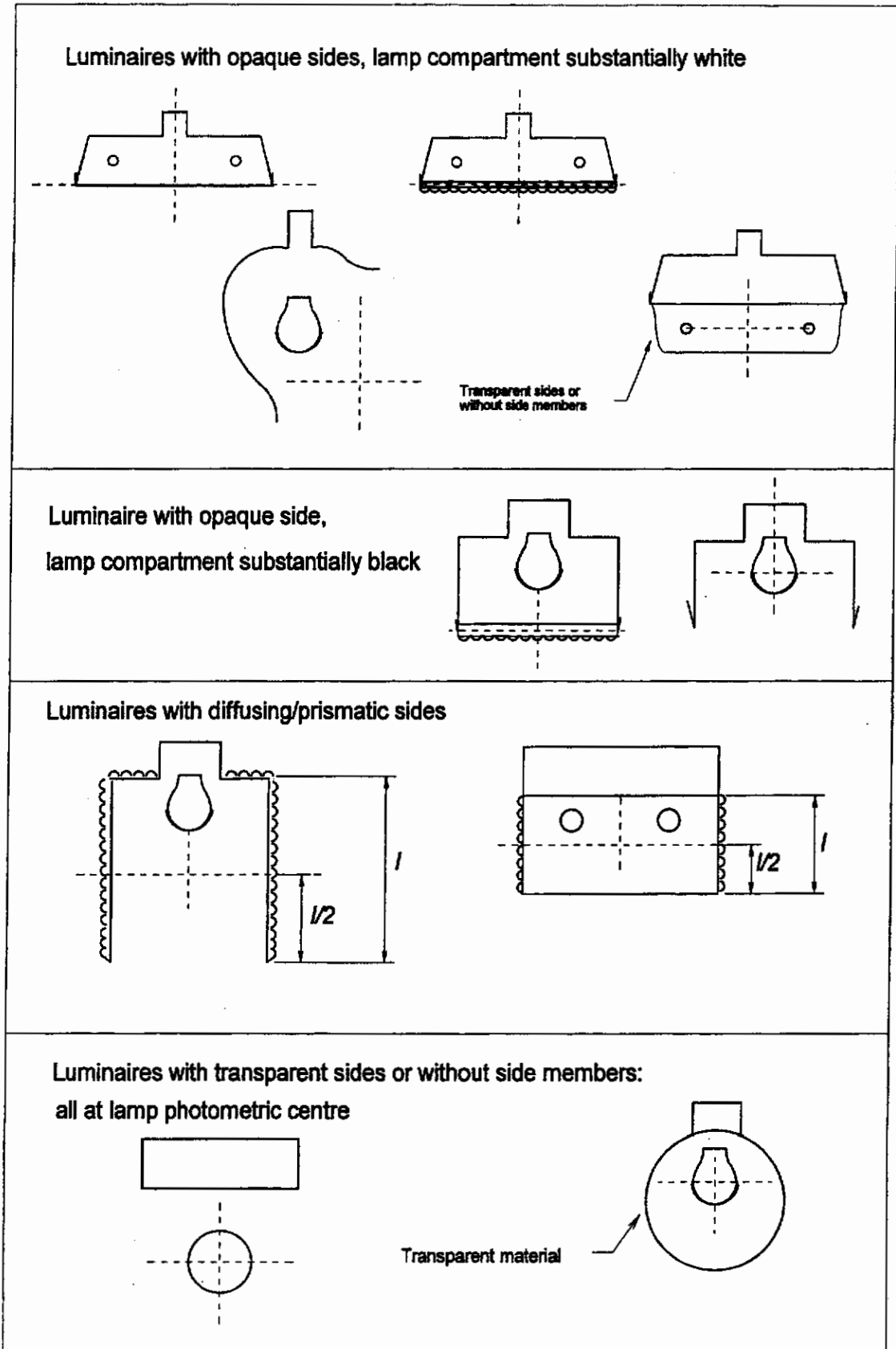


Figure 5. Photometric centres of various types of luminaire

6. PHOTOMETRIC METHODS AND PRACTICAL TEST PROCEDURES

6.1 General

6.1.1 Absolute measurements

Absolute measurements involve measurements by instruments calibrated in the appropriate SI units.

The goniophotometer itself must, therefore, be calibrated. In the case of a measurement of luminous intensity distribution this can be done either by using a calibrated luminous intensity standard lamp or by using a previously calibrated photometer head to measure illuminance and converting to intensity using the photometric distance law.

6.1.2 Relative measurements

Absolute photometric measurements on luminaires are often unnecessary.

Luminaire output is often specified relative to that of the lamp, both being measured in arbitrary units on the same goniophotometer with the lamp operated on the luminaire ballast, if any. The results of the measurements can then be expressed per 1 000 lm of lamp flux.

This method of expressing results as ratios allows all photometric measurements from which they are derived to be made in arbitrary units: Provided that the same measuring instrument is used to measure the output of both the luminaire and the bare lamp, the scale factor of the instrument will cancel out, as will many of the measuring errors.

6.1.3 Photometric measurements on luminaires

6.1.3.1 Principal photometric measurements

a) Light output ratio (LOR)

Requires measurements of the luminous flux of the luminaire and of the bare lamp. May be determined in a photometric integrator (see section 6.3.2) or may be derived from measurements of intensity distribution made on a goniophotometer (see section 6.3.1).

b) Intensity distribution (relative)

Measured on a goniophotometer (see section 6.2.1). Does not require measurement of the bare lamp.

c) Intensity distribution (in cd)

As for (b), but requires a calibrated goniophotometer. Results are expressed in candelas.

d) Intensity distribution (in cd per 1000 lm of lamp flux)

Measured on a goniophotometer (not necessarily calibrated), but also requires measurement of the bare lamp(s).

e) Luminaire luminance (in cd m^{-2} or cd m^{-2} per 1 000 lm of lamp flux)

Luminance may be measured or may be calculated from intensity and projected luminous area in the specified direction in accordance with section 6.5.

f) Illuminance distribution (in lx or lx per 1 000 lm of lamp flux)

Measured on a plane or a series of planes in accordance with section 6.6.

6.1.3.2 Subsidiary measurements

The following subsidiary measurements may also be required (see section 7).

a) Measurement correction factors

Factors for correcting measurements made in non-standard conditions in order to relate the measurements to the standard test conditions.

b) Service conversion factors

Factors for modifying standard data to non-standard service conditions.

c) Ballast lumen factor

This factor is usually required to take into account the influence of the specific ballasts supplied with luminaires. It may be determined with any of the apparatus used for the principal photometric measurements.

6.1.3.3 Derived values

Other photometric characteristics of luminaires may be derived from the principal and subsidiary measurements listed in sections 6.1.3.1 and 6.1.3.2. In particular zonal flux values may be derived from either absolute or relative intensity distributions.

Isocandela data or isolux data in standard configurations are derived values which are also widely used.

6.1.4 General measurement requirements

Luminaires and lamps should be photometered under the standard measurement conditions prescribed in section 4.2 and in accordance with the requirements of the appropriate sections of this report. Lamps should all be handled in accordance with the requirements of section 5.1.

Measurements should not begin until the luminaire or lamp have stabilized photometrically. The measuring instruments should also have stabilized before use.

Check measurements (e.g. of intensity) should be made at regular intervals (e.g. every 5 minutes). The criterion for photometric stabilisation is that the change in intensity over a 15 minute period is less than 1%.

Before readings are taken, checks should be made for stray light and the zero reading checked with the photometer head covered.

During a measurement and for any preceding period that may affect results, supply voltage and ambient temperature should be closely controlled in accordance with the requirements of sections 4.2 and 5.1. If reactive circuits are being operated on an ac supply, a check should also be made of supply frequency.

During an extended measurement (e.g. with a goniophotometer), regular checks should be made that stabilisation is maintained. At the end of the measurement (and regularly during a long series of measurements) a return should be made to the initial position (in the case of the goniophotometer 0° in elevation) to check that the initial photometric reading is maintained within $\pm 1\%$. This kind of check is extremely important.

If it is not possible to achieve a standard measuring condition, a measurement correction factor should be determined in conjunction with the main measurement, see chapter 7. It should be applied to readings before they are used for any further stage of calculation.

Where relevant, a ballast lumen factor should be determined. A ballast lumen factor should be declared when different from $1 \pm 0,05$.

6.2 Luminous intensity distribution measurements

6.2.1 Goniophotometer

The basic types of goniophotometer are summarised briefly in section 3.2. The principles of intensity distribution measurement and the characteristics of the different types of goniophotometer are dealt with more fully in Publication CIE 70-1987.

6.2.1.1 Purpose

In the photometry of luminaires, a goniophotometer is principally used to measure the intensity of a luminaire in selected directions. The measurements may be used to derive photometric characteristics or may be transformed for publication in graphical form, such as a polar curve. Curves may be relative (i.e. scaled in arbitrary units) or may be expressed in cd per 1 000 lm of lamp flux.

A goniophotometer may also be used to measure the light output ratio of a luminaire. This requires measurement of both the bare lamp and the luminaire in the same units.

Alternatively, light output ratio may be measured in a photometric integrator (see section 6.3.2) and only a relative intensity distribution measured on the goniophotometer. The light output ratio may then be used to evaluate the relative distribution in terms of cd per 1 000 lm of lamp flux.

A goniophotometer may also be used to determine photometric correction factors (see chapter 7) and to measure luminaire luminance (see section 6.5).

6.2.1.2 Construction

In the design of a goniophotometer, the principal objectives are to achieve an adequate optical path length in the space available and to maintain luminaires in their designed attitudes.

A goniophotometer should be capable of supporting the luminaire rigidly and the largest luminaire that the goniophotometer is designed to measure should be completely visible from every point of the sensitive surface of the photometer head at all directions of measurement. In many goniophotometers, part of the luminaire support structure may cause obstruction to the light path. This obstruction should be minimized.

The construction must provide an accurate angular measurement of the luminaire position relative to the photometer head. The measured position should be correct within $\pm 0,5^\circ$. More severe requirements may apply depending on the light intensity distribution of the luminaires e.g. for floodlights.

Any mirror used in the construction of the goniophotometer should be rigidly supported and remain flat in all normal positions of rotation.

6.2.1.3 Screening against stray light

Stray light is any light which reaches the photometer head other than directly from the source to be measured, due to reflections or to the presence of other light sources. The following steps should be taken to keep it to a minimum.

The photometer head should be screened so that as far as possible it sees only the luminaire and, where appropriate, the lower surface of the mounting board. Where a mirror is used, the photometer head should be screened so that it can see only the image of the luminaire and does not receive light directly from any part of the luminaire itself.

All surfaces that the photometer head sees should be finished matt black, including the bevelled edges of mirrors. It should be noted that many so-called matt black paints have a luminance factor which can be as high as 4% near the normal to the surface and even higher at glancing angles of incidence. Screens should be arranged so that stray light from the luminaire only reaches the photometer head after two or more reflections. Where this is not possible, surfaces should be covered with black velvet, black carpet, etc. Any surface such as the edges of screens which are parallel with the photometer head/luminaire axis, should be grooved, angled or chamfered to a sharp edge to minimize reflections onto the photometer head.

All that part of the background to the luminaire which might be viewed by the photometer head should be matt black. This may include the floor and the ceiling. The remainder of the room can be of a lighter colour, provided that precautions have been taken to eliminate stray light.

Possible paths of stray light which should not be overlooked are:

- a) luminaire - blackened surface (floor, screen, etc.) - mirror - photometer head,
- b) luminaire - blackened surface (floor, screen, etc.) - luminaire - mirror - photometer head,
- c) luminaire - mirror - luminaire - mirror - photometer head.

Stray light that cannot be eliminated should be subtracted from the readings taking into account the variation of stray light with luminaire position.

Residual stray light may be difficult to measure. For example, any screen placed between the luminaire and the photometer head for the purpose of making such a measurement may also screen the path of stray light via the mirror to the photometer head.

6.2.1.4 Test distance (for measurements based on the photometric distance law)

The photometric test distance is the distance from the photometric centre of the luminaire (see section 5.3.2) to the surface of the photometer head.

Measurements of intensity should be made at a distance such that the inverse square law applies within practical limits. In general the test distance should not be less than 15 times the maximum dimension of the light emitting area of the luminaire. However, for luminaires with an approximately cosine distribution in planes passing through the long axis of the luminaire, the minimum test distance can be determined as 15 times the dimension of the light emitting area normal to the lamp axis or 5 times the dimension of the light emitting area parallel to the lamp axis. The minimum test distance to be used should be the greater of these two distances.

It should be noted that in certain cases, e.g. luminaires with a very narrow beam, even a test distance ratio of fifteen may not be sufficient.

6.2.1.5 Selection of lamps, ballasts and luminaires

The requirements of chapter 5 apply.

6.2.2 Measurement of luminaires

6.2.2.1 Mounting

The luminaire should be mounted on the goniophotometer in its design attitude. Its photometric centre (see section 5.3.2) should be coincident with the effective centre of rotation of the goniophotometer. Its orientation should be correct with respect to the azimuth scale of the goniophotometer and to the azimuth reference of the luminaire.

Note: Many luminaires are so constructed that they should be photometered only in their normal mounting position. This precaution may be necessary to avoid mechanical disturbances due to sag, warpage or shift in the position of critical light components.

A luminaire intended for direct fixing to a ceiling or wall should be fixed to a mounting surface comprising a wood or wood-fibre board. The board should not extend beyond the normal projection of the smoothed outline of the luminaire.

6.2.2.2 Measurement

The requirements of section 6.1.4 apply.

Unless otherwise specified, the C, γ co-ordinate system shall apply (see chapter 3). The number of readings of intensity in various vertical planes and the angular spacing between measurement points should be such as to permit interpolating intensity values during light calculations with an acceptable accuracy. The number of planes should be determined by the nature of the distribution

having regard to symmetry or irregularity and to the end results desired from the test, notably the required accuracy of any subsequent lighting calculations.

The luminaire should move smoothly, without rocking, and, in the case of luminaires using thermally sensitive lamps, sufficiently slowly to minimize disturbance to the thermal equilibrium of the luminaire. The velocity of the ambient air of the rotating fluorescent lamps in an open luminaire should not exceed 0,2 m/s.

Light output characteristics of lamps, in particular discharge lamps (see chapter 5), may change significantly when the lamps are operated in other than in their normal operating position. Measurement correction factors should be applied (see section 7.2).

Due to minor variations in optical components, luminaires designed to provide symmetrical distribution should always be measured in the two half-planes of symmetry.

It is advisable to make a trial run so as to find the location and rate of the maximum changes in intensity.

Measurements should be corrected for the effects of any obstruction due to supports or to the framework of the goniophotometer. This may require a temporary change in the attitude of the luminaire.

6.2.2.3 Polarization measurement

For the measurement of the percentage of polarization (typically vertical polarization) of light from a luminaire in a given direction, means must be provided to make the photometer head respond either to horizontally or to vertically polarized light. Since polarizers have appreciable light absorption characteristics, it is necessary to measure both the horizontal and vertical components of polarization to obtain the percentage of polarized light in each plane.

It should be noted that the presence of a mirror in the goniophotometer may introduce errors in polarization measurements due to the polarizing characteristics of the mirror itself.

6.2.3 Measurement of bare lamps

6.2.3.1 Mounting

The bare lamp should be mounted in the orientation for which it was designed and to which the lamp photometric data relate. For the operation and handling requirements of lamps, see section 5.1.

Lamps of the type designed for universal mounting (e.g. some types of high pressure mercury vapour lamp) can be mounted in any position provided that the lamp photometric data available relates to the position chosen, which should, preferably, be the same position as the operating position in the luminaire. In such cases the orientation of the lamp during measurement should be specified in the test report.

The light centre (photometric centre) of the lamp should be at the effective centre of rotation of the goniophotometer (see section 5.1.2).

The lamp should be correctly aligned. Some lamps, e.g. lamps fitted with bayonet caps, may require a modified lampholder to provide a sufficiently rigid support. For incandescent lamps, a special quadri-pole type of lampholder is recommended so as to facilitate accurate electrical measurements.

6.2.3.2 Measurement

Intensity measurements of bare lamps are made to calibrate the photometer head or to calculate the luminous flux of the bare lamp (see section 6.3.1).

The requirements of section 6.1.4 apply.

Measurement of the bare lamp should preferably be made just prior to, or immediately after, measurement of the luminaire. Measurements of intensity should be made in the same units as for the measurement of the luminaire. Either a complete measurement of the intensity distribution of the lamp

may be made, or a simplified method used which relates the intensity in a selected direction to the luminous flux of the lamp.

If the optical path length is variable, it may be shortened in order to increase the photometer reading, provided that the requirements of section 6.2.1.4 are met.

a) Complete measurement

Readings of intensity should be taken in a number of directions. The procedure is analogous to that for measurement of the luminaire (see section 6.2.2.2).

b) Simplified method

This requires a previously calibrated lamp. Most lamps if carefully handled maintain a nearly constant ratio of the luminous flux A to the luminous intensity B in selected direction. This ratio can be established during a complete measurement as in (a) above. In subsequent measurements, only the intensity C in the selected direction is measured. The luminous flux ϕ of the bare lamp can then be determined from the expression

$$\phi = C \cdot A / B.$$

It is recommended that both B and C are measured in two directions and the mean value calculated. The directions chosen should be in regions where the intensity from the lamp is near to the maximum but where intensity does not change rapidly with direction.

Measurements are usually made at 90° to the axis of the lamp, on opposite sides. If the intensity of the lamp changes rapidly with direction, multiple readings should be taken and averaged. The ratio A/B should be checked regularly for all lamps except tubular fluorescent lamps. This method is not recommended for lamps with clear bulbs.

c) Multi-lamp luminaires

In the case of a multi-lamp luminaire, it will be necessary to repeat the measurement for each lamp separately (where relevant, each on its appropriate ballast). All lamps that operate from a single ballast should be operating during measurement in the same ambient temperature conditions.

6.3 Luminous flux measurements on luminaires

6.3.1 General

In the photometry of luminaires, luminous flux measurements are necessary to determine light output ratio, total luminous flux, or upward and downward flux, and zonal luminous fluxes of the luminaire. Luminous flux measurements on the bare lamp(s) permit the luminaire output characteristics to be expressed per 1 000 lm of lamp flux.

6.3.2 Intensity integration methods

6.3.2.1 Purpose

These methods necessarily apply for computation of zonal fluxes or total upward or downward fluxes. The luminous flux is determined from a number of intensity readings and calculated by means of a suitable procedure e.g. direct calculations, Russell angles, zone factors, etc..

6.3.2.2 Relative calibration of the goniophotometer

The calculation of the luminous flux of the bare lamp by an intensity integration method permits conversion of the intensity distribution measurements made on the luminaire in arbitrary scale units to candelas per 1 000 lm of lamp flux from the bare lamp, provided that the lamp has been measured in the same arbitrary scale units. It is not necessary to calibrate the system in absolute units.

The principle underlying this relative method of calibration is the following (measurements in a C, γ system). The luminous intensity $I_{c,\gamma}$ of the luminaire in a given direction C, γ , related to a luminous flux of 1 000 lm from the lamp is given by

$$I_{C,Y} = k R_{C,Y} \cdot 1\,000 / \Phi \quad (1)$$

where

$R_{C,Y}$ is the reading in arbitrary scale units on the photometer,

k is a constant scale factor,

Φ is the luminous flux of the lamp(s).

If the lamp is measured in the same arbitrary scale units on the photometer, the luminous flux of the lamp is given by

$$\Phi = \int_0^{2\pi} \int_0^{\pi} I_{C,Y} \sin \gamma \, d\varphi \, dC = k \int_0^{2\pi} \int_0^{\pi} R_{C,Y} \sin \gamma \, d\varphi \, dC = k \Phi_R$$

where

Φ_R is the relative luminous flux calculated from readings in the arbitrary scale units.

Formula (1) can then be converted to

$$I_{C,Y} = k R_{C,Y} 1\,000 / k \Phi_R = R_{C,Y} 1\,000 / \Phi_R$$

Since the scale factor k has been eliminated from the formula, the measurement can be carried out entirely in arbitrary scale units.

Note: When using this method the illuminance at the photometer head from the bare lamp is often very much lower than that given by the luminaire. This could introduce problems of low measuring sensitivity and of linearity. The bare lamp may, therefore, be measured at a shorter distance in order to obtain an adequate illuminance and the results converted, using the inverse square law, to the longer distance used for the luminaire photometry.

6.3.3 Integrating photometer

6.3.3.1 Purpose

In the photometry of luminaires an integrating photometer is convenient for luminous flux measurements on bare lamps in absolute photometry. It may be used for the determination of various photometric factors, including ballast lumen factor (see chapter 7).

The measurement of luminous flux with an integrator involves considerably fewer readings than measurement with a goniophotometer and thermal stability of luminaire or lamp is more easily controlled.

The determination of light output ratio in an integrator is not recommended if there is a substantial difference between the luminous intensity distributions of the lamp and the luminaire.

6.3.3.2 Construction

An integrator should be large with respect to the measured objects and preferably spherical in shape.

An auxiliary lamp should be provided so that a correction can be made for absorption of inter-reflected light by the luminaire or lamp under test.

Means should be provided to control the air temperature within the integrator. The system used must not however create draughts around the luminaire while it is being operated.

Experience has shown that other shapes than spherical can be used in some circumstances, but their use should be limited to comparing the performances of luminaires of the same type or determining photometric correction factors.

These and other aspects of the design and use of integrators are discussed in more detail in publication CIE 84-1989 [26].

6.3.3.3 Selection of lamps, ballast and luminaire

The requirements of chapter 5 apply.

6.3.3.4 Mounting and measurement of the bare lamp

The bare lamp should be mounted in the orientation in which it is designed to operate and to which the lamp photometric data refer. For operation and handling requirements for lamps, see section 5.1.

Lamps of the type designed for universal mounting (e.g. some types of high pressure mercury vapour lamp) can be mounted in any position provided lamp photometric data are available for the position chosen, which should preferably be the same position as the operating position in the luminaire. In such cases the orientation of the lamp during measurement should be specified in the test report.

The bare lamp should be positioned with its light centre at the centre of the integrator. If the lamp is operated horizontally, its long axis should be parallel with the line from the centre of the integrator to the centre of the photometer head. The direct-light screen should be secured in the same position for measurements on the bare lamp as for measurements on the luminaire.

The requirements of section 6.1.4 apply to the measurements.

6.3.3.5 Mounting and measurement of the luminaire

The luminaire should be positioned with its photometric centre (see section 5.3.2) at the centre of the integrator. If the luminaire is linear in shape and is operated horizontally, it should be positioned parallel with the line from the centre of the integrator to the centre of the photometer head. A check should be made that the direct light screen is securely fixed and just screens the luminaire and any mounting board when viewed from the photometer head. If the bare lamp is to be operated in an attitude different from its attitude in the luminaire, the direct light screen should be adjusted so that it will also cover the bare lamp.

The requirements of section 6.1.4 apply to the measurements.

6.3.3.6 Sources of error

The results of luminous flux measurements made in an integrating photometer can be influenced by the following factors:

- different spectral and/or spatial flux distribution of the luminous flux standard and the light source to be measured,
- different spatial flux distribution of the bare lamp and the luminaire,
- different dimensions and absorption properties of the bare lamp and the luminaire,
- screen of inadequate size,
- changes in the reflectance of the inner sphere wall.

If the photometric integrator is used for light output ratio measurements, the values of light output ratio obtained for a series of luminaires of various sizes and light distribution should be compared with the values obtained on a goniophotometer which complies with the requirements of section 6.2 and in particular with the requirements for the correct lamp operating position (see chapter 5).

For each luminaire the value of light output ratio obtained by each of the two methods should not differ by more than $\pm 2\%$ from their mean value. In the event of a greater difference, a detailed investigation should be made. Methods of checking the integrator are discussed in publication CIE 84-1989.

6.4 Light output ratio of a luminaire

6.4.1 General

The light output ratio of a luminaire is affected by the following factors:

- change in the luminous flux of the lamp due to change in operating temperatures,
- change in the luminous flux of the lamp due to an operating position in the luminaire different from the designed position to which the lamp photometric data apply,
- difference between the lamp power delivered by the practical ballast and the lamp power delivered by the reference ballast.

Light output ratio (LOR): The first two effects are taken into account in *LOR*. It should be noticed that when determining the luminous flux of the bare lamp needed to calculate *LOR*, the lamp operates with the same practical ballast at rated voltage but lamp position and lamp operating temperature are those to which the lamp data relate. Lamp position and lamp operating temperature can be very critical, in particular with new energy saving lamps. Lamp position and lamp operating temperature are defined in the relevant IEC lamp specifications or if not, should be declared by the lamp manufacturer [2-11].

Note: In some countries *LOR* is also called *LORL* (Light Output Ration Luminaire).

Light output ratio working (LORW): All three effects are taken into account in *LORW*.

6.4.2 Recommended light output ratio

It should be noted that:

- some luminaires require separate ballasts which are selected by the user, for example for mounting in road lighting columns,
- luminaires incorporating ballasts may be offered with a choice of ballast types and ballast designs may be changed during the production of a luminaire,
- ballast specifications permit divergence up to approximately $\pm 10\%$ of objective power. With newer types of ballast, including electronic ballasts, even more divergence can be expected.

Values for the *LOR* of luminaires incorporating ballasts should be accompanied by a statement of ballast lumen factor *BLF* (see chapter 7) for the ballast as a type. It is necessary for users of published photometric data to multiply *LOR* by the appropriate *BLF* to obtain *LORW* for working purposes. In instances where *LORW* is quoted, the appropriate *BLF* should already have been taken into account in the method of measurement. If a practical ballast delivers objective lamp flux (i.e. *BLF* is unity) then the values of *LOR* and *LORW* are equal.

To summarise, the flux of a luminaire should be calculated using the relation:

$$\text{Luminous flux}_{\text{Luminaire}} = \text{Lamp flux}_{\text{Reference Ballast}} \times \text{LOR} \times \text{BLF}.$$

Correctly measured and reported luminaire performances may differ from the field performances for the following specific reasons:

- during photometric testing the luminaire is operated in free air while in practical field conditions some interruption of the air flows can be created e.g. by the ceiling and plenum structure in indoor lighting,
- during photometric testing the luminaire is operated at an ambient temperature of $25 \pm 1^\circ\text{C}$ and rated supply voltage, while in practical field conditions these operating conditions can be significantly different,
- it is assumed that the lamp/reference ballast combination will produce the luminous flux declared by the manufacturer. Lamp specifications permit divergences of up to minus 10% from the rated value for individual lamps,
- depreciation of the luminaires (dust, humidity).

When field conditions can be specified clearly, service conversion factors must be provided (see chapter 7).

Note: The above mentioned considerations for light output ratio apply also to all luminaire data expressed with respect to lamp performance. If luminaire data per 1 000 lm are quoted without qualification the user should assume that the luminous flux of the bare lamps has been measured under the same test conditions as for LOR, and, where necessary, BLF should be taken into account in the lighting calculations.

6.4.3 Measurement procedure for light output ratio

6.4.3.1 Single-lamp luminaires.

To determine the light output ratio of a luminaire, the following measurements of luminous flux should be made, preferably, but not necessarily, in the order shown in table 3 below.

Table 3. Measurement sequence to determine the light output ratio of a luminaire

Reading	Sphere Arrangement	Lamps	Auxiliary lamp
A	Luminaire in sphere	ON in luminaire	OFF
B	Luminaire in sphere	OFF in luminaire	ON
C	Lamp alone	Bare lamp OFF	ON
D	Lamp alone	Bare lamp ON	OFF

Readings can be in arbitrary units but the units for A should be the same as for D and the units for B the same as for C. Ideally it should also be arranged that no change in the measurement range is required. For example, for a single lamp luminaire overall sensitivity should be set so that the reading for D is as near as possible to full-scale.

The light output ratio of the luminaire can be calculated from the formula:

$$LOR = (A / D) \cdot (C / B).$$

6.4.3.2 Multi-lamp luminaires.

The light output ratio for a multi-lamp luminaire should be measured in the same way as for a single-lamp luminaire. The bare lamp measurements D should be made separately for each lamp. All lamps that operate from a single ballast should operate during the measurement at the same ambient temperature.

6.5 Luminance measurements

6.5.1 General

This section standardizes procedures for making luminance measurements on a luminaire.

One or both of the following types of luminance measurement may be required, the average luminance of the luminaire in a given direction or the luminance of a specific luminous area in a given direction.

Unless otherwise specified, the directions for both types of measurement, in azimuth and elevation, should be spaced approximately as for measurements of intensity.

Both types of measurement may be calibrated in units of cd m⁻² per 1 000 lm of lamp flux, or, if only the pattern of the luminance distribution is required, they may be relative. Directions should be identified as

for measurements of intensity (see chapter 3) with the origin of the co-ordinates at the photometric centre of the luminaire (see section 5.3.2). Unless otherwise specified, they should also be spaced, both in azimuth and elevation, as for measurements of intensity.

The relevant requirements of chapters 4 and 5 apply.

6.5.2 Average luminance

This measurement may be required either in a single direction or for a number of different directions of view.

The intensity in the relevant directions should be measured in accordance with section 6.2. For each direction, the intensity should then be divided by the orthogonally projected area (in m^2) of all those parts of the luminaire which emit light in that direction. Significant non luminous area should not be included.

6.5.3 Patch luminance

These measurements are frequently used to scan the luminous surface of a luminaire in order to determine the maximum luminance in a given direction. The scan may be repeated for different directions of view.

The size of the patch measured should normally be an orthogonally projected area of between 450 mm^2 and 550 mm^2 , substantially circular or square, but in some cases an area of this size may not necessarily be suitable for the detailed luminance mapping of a light source. For the limitation of reflected glare in video display units, the patch size can usefully be reduced to 100 mm^2 .

The measurements may be made either with a luminance meter or with a goniophotometer.

6.5.3.1 Measurement with a luminance meter

A luminance meter should be set up to measure the required patch size. It is an advantage if the meter forms an image of the area being measured to assist aim. The distance between the patch and the entrance pupil of the luminance meter should be at least 100 mm. The luminaire should be traversed by the meter, which should be aimed in a constant direction. The meter may, however, be aimed at the photometric centre of the luminaire and swivelled if the distance is at least 10 times the luminous length being scanned. It may be necessary to scan the luminaire several times in order to include all the luminous area. Checks should be made that the initial measurements repeat.

If a luminous patch is measured from close range, directions should be identified by translating the system of co-ordinates, without rotation, from the photometric centre of the luminaire to the centre of the patch.

Measurements made in absolute units could be changed to the more usual form, i.e. $cd\ m^{-2}$ per 1 000 lm of lamp flux. This requires values to be divided by the lamp light output (per 1 000 lm) as measured for determining LOR (see section 6.4).

Where applicable, the ballast lumen factor (BLF) should be indicated.

6.5.3.2 Measurement with a goniophotometer

The goniophotometer should be set for the relevant direction. A large mask, finished matt black and with an aperture of the appropriate patch size should be inserted orthogonally in front of the luminaire. The luminaire should then be traversed by the aperture, possibly several times, in order to include all the luminous area. The luminance at any position is then proportional to the intensity reading.

Care must be taken to see that only light from the aperture reaches the photometer head.

The inserting of the mask should not influence the ambient temperature of the luminaire in case of temperature sensitive lamps.

If calibrated results are required, comparison should be made with a single value of intensity for the whole luminaire, calibrated in cd per 1 000 lm of lamp flux. The intensity of a patch is then known in cd per 1 000 lm of lamp flux and division by the area of the aperture in m^2 leads to the luminance in $cd\ m^{-2}$ per 1 000 lm of lamp flux

6.6 Illuminance measurements

6.6.1 General

The direct illuminance from a single luminaire is normally calculated using the inverse square law or by aspect factors or similar area source formula where the luminaire is large compared with mounting heights typical of service conditions. Where a direct measurement is preferred, the procedure specified in this section should be used.

Measurements of illuminance should be made at one or more mounting heights typical of the service conditions. The mounting height is the vertical distance between the measuring plane and the photometric centre of the luminaire.

6.6.2 General measurement requirements

6.6.2.1 Measurement apparatus

Arrangements should be made to ensure that the photometer head receives only direct light. Co-ordinates of a measuring grid, usually rectangular, should be set out from an origin vertically below the photometric centre of the luminaire, with a suitable orientation relative to the luminaire.

The photometer head and associated apparatus should comply with the requirements of section 4.4. Special attention should be paid to correction for oblique light incidence and to the acceptance area of the photometer head. The area should be small enough to take account of any strong gradients in the illuminance distribution.

6.6.2.2 Selection of lamps, ballasts and luminaires

The requirements of chapter 5 apply.

6.6.3 Measurement procedure

The requirements of section 6.1.4 apply.

Measurements of illuminance should be made at appropriate intervals on the measuring grid, and should include checks that measurements made at the starting point repeat.

Intermediate measurements should be made wherever the difference in illuminance between any two adjacent positions is greater than about 20 % of the maximum. The area covered should include all positions having an illuminance greater than about 2 % of the maximum.

Measurements made in absolute units should be changed to the standard form, i.e. lx per 1 000 lm of lamp flux. This requires values to be divided by the lamp light output (per 1 000 lm) as measured for the determination of LORL. Where applicable, the ballast lumen factor (BLF) should be indicated.

7. PHOTOMETRIC CORRECTION FACTORS

7.1 General

Photometric tests on luminaires should be carried out under the standard test conditions given in chapter 4. As far as possible direct measurements should be made in accordance with all conditions specified, otherwise photometric factors should be introduced :

7.2 Measurement correction factors

7.2.1 Purpose

Measurement correction factors apply when it is not possible to measure a luminaire or a bare lamp in the laboratory under standard test conditions. They may be required to correct light output ratios or

calibrated photometric values in order to relate the measurements to standard test conditions. Measurement correction factors are not required for relative values.

The following are examples of conditions for which measurement correction factors are required:

- a) when the ambient temperature in the laboratory is different from 25°C and the measured lamps are thermally sensitive,
- b) when measurements have to be made at an ambient temperature different from 25°C (e.g. measurements on bare lamps such as vapour pressure controlled lamps and certain types of single capped compact fluorescent lamp for which rated flux values are declared for higher values, mostly 35°C),
- c) when the mounting attitude is not standard (e.g. with a goniophotometer where the luminaire is turned around a horizontal as well as a vertical axis).

7.2.2 Determination

7.2.2.1 General method

To determine a measurement correction factor, one measurement should be made under standard test conditions and a second corresponding measurement made with just the appropriate test condition varied. The correction factor is the ratio of the first measurement to the second.

7.2.2.2 Correction factor for measurements of a luminaire in a non-standard position (Monitored light source method)

This method applies to goniophotometers where the orientation of the luminaire is altered during measurement resulting in a change in the total light output of the luminaire, but without any change in the geometrical shape of the light distribution.

An auxiliary detector rigidly mounted at a small fixed distance from the lamp or luminaire follows the movement of the lamp or luminaire and is used to continuously monitor changes in light output. This detector should meet the requirements of section 4.4.2.

Correction factors should be determined using the formula:

$$k_{\theta} = E_{st} / E_{\theta}$$

where

- k_{θ} is the correction factor to be applied to photometric measurements of the lamp or luminaire when tilted at the angle θ to correct to the standard test conditions,
- E_{st} is the illuminance measured by the auxiliary detector when the luminaire is mounted in the attitude in which it is normally designed to operate in service,
- E_{θ} is the illuminance measured by the auxiliary detector as for E_{st} with the lamp or luminaire tilted at the angle θ for which the correction factor is required.

A different correction factor will usually be applied for each of the intensity measurements.

Note: E_{θ} should be measured at the same time as the main measurements.

E_{st} should be measured in standard conditions after lamp stabilisation.

Another way to apply the auxiliary detector method is to maintain E_{θ} equal to E_{st} by adjusting the supply voltage.

7.2.2.3 Temperature correction factor

This factor applies to thermally sensitive lamps for which performance data are published for a temperature above 25°C because the lamps operate optimally at the higher temperature. It may also be applied for lamps (e.g. some fluorescent lamps for public lighting) which operate optimally at a temperature lower than 25°C and performances of these lamps are sometimes given for this temperature.

Bare lamp measurements (see 6.4.1) imply measurements made in conditions corresponding to published data and must be made consequently at these declared temperatures. As there are difficulties in carrying out photometric measurements of bare lamps with an integrator or a goniometer at temperatures different from 25°C, the lamps are measured at 25°C and results multiplied by k_T .

$$k_T = F_T / F_{25}$$

where

F_T is the flux measured at the temperature declared by the manufacturer

F_{25} is the flux measured at 25°C

This factor should be declared by the lamp manufacturer or measured. The measurement method is similar to the method described under 7.3.2.2 except that the measurements apply to the bare lamp.

7.3 Service conversion factors

7.3.1 Purpose

Service conversion factors apply when the operating conditions for the luminaire in service differ from the standard test conditions. They are for use by lighting designers.

These factors are determined in the laboratory so that light output ratios and calibrated photometric values may be converted to allow for service conditions which differ from the standard conditions. They are required for use by lighting engineers. Service conversion factors are not required for relative values.

The following are examples of conditions for which service conversion factors are required:

- when the ambient temperature in service differs from 25°C and the lamps are thermally sensitive,
- when the mounting attitude in service is different from the standard attitude and affects the photometric data,
- when the lamp to be used in the luminaire in service has light output versus temperature characteristics differing from those of the test lamp (e.g. amalgam lamps),
- when air-handling luminaires are to be used in service at selected rates of air flow. The standard test condition is without a forced air flow and with the air slots stopped up,
- when the mean supply voltage in service differs from the rated voltage of the lamp or luminaire.

7.3.2 Determination

7.3.2.1 General

A service conversion factor should be determined in the same way as a measurement correction factor (see section 7.2.2) except that the ratio is reversed, i.e. it is the ratio of the measurements under the varied conditions to the measurement under standard test conditions. Where there are two or more different service conditions each service conversion factor should, if necessary, be determined and reported separately.

7.3.2.2 Service conversion factor for ambient temperatures other than 25°C

The conversion factor is given by:

$$k_T = E_T / E_{25}$$

where

- k_T is the conversion factor applied to photometric measurements made under the standard test conditions for conversion to an ambient air temperature T differing from 25°C,
- E_{25} is the illuminance measured at a fixed distance and in a fixed direction from the luminaire with the luminaire mounted in the orientation in which it was designed to operate and operating in an ambient air temperature of $25 \pm 1^\circ\text{C}$,
- E_T is the illuminance measured as for E_{25} but with the luminaire operating in air at the ambient temperature T for which the conversion factor k_T is required.

Note: The measurements of E_{25} and E_T may be carried out in a room (e.g. a refrigerator) without the need for stray light screening, provided the reflection conditions in the room are not changed between the measurements. The measurements should be made in a draught free area after lamp stabilisation.

7.3.2.3 Conversion factor for amalgam lamps (Simulated light source method)

An amalgam lamp is a fluorescent lamp containing an amalgam designed to control the vapour pressure during operation. Performance data for vapour pressure controlled lamps are usually given for a temperature above 25°C because the lamps operate optimally at the higher temperature.

There are difficulties in carrying out full photometric measurements on a luminaire incorporating amalgam lamps. Stabilisation may take considerably longer than for conventional types of lamp and it may be impractical, especially for measurements of a bare amalgam lamp on a goniophotometer, to achieve the ambient temperature applicable to the declared light output of the lamp.

The standard procedure is, therefore, to make photometric measurements of the luminaire using non-amalgam fluorescent lamps incorporated at an ambient temperature of 25°C and to determine an amalgam lamp factor as described below. The amalgam lamp factor can then be applied as a measurement correction factor (see section 7.2) and the photometric data reported as if the measurement had been made with an amalgam lamp in the luminaire. An amalgam lamp factor may also be determined for luminaires for which information is already published in terms of non-amalgam lamps. The amalgam lamp factor can then be issued as a service conversion factor to be applied by users of the data.

The amalgam lamp factor should be calculated using the formula:

$$k_A = (A / B) \cdot (C / D)$$

where

- k_A is the amalgam lamp factor,
- A is the reading obtained with an amalgam lamp in the luminaire measured under the standard measurement conditions for the luminaire,
- B is the reading obtained with a non-amalgam lamp in the luminaire measured under the standard measurement conditions for the luminaire,
- C is the reading obtained for the bare non-amalgam lamp measured under the standard measurement conditions for the lamp,
- D is the reading obtained for the bare amalgam lamp with the measurement conditions as for C but with the lamp operating at the ambient temperature corresponding to its declared light output.

The measurements of A and B must be of the same quantity and in the same units. The units may be relative values or absolute values of intensity, luminance or illuminance. The measurements of C and D must be made in the same units as each other, but not necessarily in the same units as A and B . When an amalgam lamp factor is published as a service conversion factor for data based on normal lamps, users of the published information should multiply the photometric quantities and the LOR by the amalgam lamp factor.

Note : A similar method may also be applied if a lamp of a certain type is substituted by another type of lamp having same luminous intensity distribution and similar physical size and shape but whose luminous flux behaves differently in the luminaire (e.g. : replacement of a ordinary high pressure sodium lamp by a mercury free high pressure sodium lamp).

7.4 Ballast lumen factor

7.4.1 Purpose

Ballast lumen factor is defined in section 2.2.3.

Lighting calculations based on photometric data, expressed in terms of output from the luminaire per 1000 lm of total lamp flux from the lamps, assume essentially that the lamps, when operated from the ballast supplied with the luminaire, deliver rated luminous flux when operating under standard test conditions. This may well not be true in practice. For technical or commercial reasons underrated ballasts may be used in the luminaire and the user will in this case get a lower luminous flux than expected.

In all lighting calculations the photometric data (and LOR) should therefore be corrected by multiplying these values by the ballast lumen factor if it differs by more than 5 % from unity.

7.4.2 Determination

The ballast lumen factor is usually determined in an integrating sphere during measurements on the bare lamp but can also be determined in the same way as a service conversion factor (see section 7.3.2.).

One measurement should be made under standard test conditions using a reference ballast and a second corresponding measurement should be made under the same standard test conditions but with the practical ballast in use. The ballast lumen factor is the ratio of the second measurement to the first one, given by the formula:

$$BLF = \Phi_B / \Phi_R$$

where

BLF is the ballast lumen factor of the practical ballast,

Φ_R is the luminous flux of the bare lamp under standard test conditions with the reference ballast,

Φ_B is the luminous flux of the bare lamp under standard test conditions but with the practical ballast.

The test lamp should meet the requirements of section 4.2.2.

8. ACCURACY REQUIREMENTS AND PRESENTATION OF TEST RESULTS

8.1 Accuracy of the measurements

The accuracy of a lighting design depends upon a knowledge of the characteristics of the area which has to be illuminated, the performances of the luminaires and of the associated lamps. The performance of the final installation will, therefore, depend to some extent upon the tolerances accepted in the measurement of the luminaire.

The accuracy of photometric measurement depends in turn on the apparatus used, and also on the testing procedure adopted. Thus, before selecting a photometric procedure and a design for the test apparatus, it is necessary to consider the probable accuracy of the resultant measurements. However, this accuracy is difficult to quantify as it will depend strongly on the measured luminaire (type of light distribution, dimension of luminaire, type of lamp, etc.). Errors may compensate or add. In this situation, it is more realistic to specify individual uncertainties for the various different characteristics which could influence the measurements.

8.1.1 Sources of error

Practical photometry involves so many factors that a study of possible sources of error is essential.

It is possible to distinguish two types of error, errors arising from a systematic effect, inherent in the test method used, or caused by imperfections in the instruments, and random errors, due to variations in test conditions outside the photometrist's control. It is random errors which affect repeatability.

Repeatability, and thus the effect of random errors can be checked by simply repeating measurements on the same luminaire. Systematic errors, on the other hand are much less easily quantified. If they could be quantified, they would be eliminated, since the results would be corrected for them. The only kind of check available on systematic error is likely to be a comparison with similar measurements made on the same luminaire elsewhere.

8.1.1.1 Possible systematic errors

Room:

- measurement of temperature,
- stray light,
- obstruction of light.

Goniometer:

- mechanical alignment and mechanical deformation,
- stray light and obstruction of light,
- measurement of angles,
- burning position of luminaire and movement (smoothness and speed),
- mirror defects; general non-flatness (e.g. due to sag), local non-flatness (e.g. due to ripples in the glass), light scattering due to scratches, variation of reflectance with wavelength, variation of reflectance over the surface, polarization,
- variation in reflection properties of mirror due to dust.

Photometer head and associated equipment:

- calibration,
- non-linearity and fatigue,
- spectral responsivity,
- variation of responsivity over the measuring surface,
- angular aperture of collimated photometer heads,
- vignetting,
- misalignment and measurement of distance,
- distance too short,
- time response and integration time.

Luminaire:

- incorrect positioning of lamp,
- incorrect positioning of optical components,
- choice of photometric centre,
- misalignment of the luminaire in the goniometer,
- mechanical deformation of the luminaire during movement.

Lamp and auxiliary apparatus:

- electrical setting of the ballast,
- luminous flux measurement (where results are reported per 1 000 lm of lamp flux),
- incorrect supply voltage (voltmeter calibration, voltage drop in supply leads).

8.1.1.2 Possible random errors

- variation in voltage or frequency of power supply,
- instability of lamp (fluctuations of luminous flux, arc displacement or instability),
- variation of lamp characteristics between different burning periods,
- temperature variation and air movement due to movement of the luminaire,
- effect of draughts due to air conditioning.

Note: The distinction between systematic errors and random errors is not quite as simple as the list above might suggest. For example, a wrong assembly of a luminaire (e.g. reflector, refractor, lamp) for a particular test represents a systematic error. However with regard to the luminaire type it represents a random error.

As another example; variations in the responsivity of the photometer head due to fatigue can be positive or negative according the illumination level. It could, therefore, be argued that the effect of fatigue, taken over the whole measurement sequence, represents a random error.

8.1.2 Uncertainties

Uncertainties which can be evaluated by the statistical analysis of a series of observations are known as type A uncertainties. These are generally due to the random errors referred to above. An example might be the calculation of the standard deviation of the mean of a series of measurements, e.g. evaluating the stability of the test lamp.

Uncertainties that cannot be evaluated in this way are known as type B uncertainties. Type B uncertainties are generally the result of the systematic errors referred to above and are usually based on scientific judgement. One approach is to estimate lower and upper limits for the value of a given quantity and to assume that the measured value lies somewhere within the interval Δ between these limits. The best estimate of the standard deviation of the uncertainty is then $(\Delta/2) / \sqrt{3}$ (rectangular probability distribution).

For light intensity distribution, the uncertainties on intensity measurements and angular measurements should be quoted separately. For further guidelines see: BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML (1993) [27], and NIST TN 1297[28].

8.2 Presentation of test results

8.2.1 General

The test report should provide all the useful information necessary to permit proper interpretation of photometric data and consequent lighting calculations.

The purpose of the information provided should be:

- a) to correctly inform the user of the data as to the nature of the various controlled conditions under which the luminaire was measured,
- b) to give sufficient information to relate the photometric information to the particular luminaire tested.

8.2.2 Test report

The following list is intended as a guide to the information which should be included in a test report covering photometric measurements of a luminaire.

8.2.2.1 General information

Types of test:

- descriptive title to indicate what is being reported,
- testing agency name, report number and date.

Description of the luminaire:

- manufacturer's name, type, catalogue number,
- photograph for identification or detailed description of the luminaire including a description of the optical components such as refractors, reflectors, etc., especially if the luminaire is available in several versions,
- relevant dimensions,
- other essential information, including the method of sample selection.

Description of auxiliary equipment (ballasts, capacitors, starters):

- manufacturer's name, type, catalogue number,
- type of circuit,
- rated voltage, wattage and frequency.

Description of the test lamps:

- manufacturer's name, type, catalogue number,
- rated wattage, colour and bulb shape, type of lamp cap,
- number of lamps and how selected.

Test procedure:

- short description of the photometric procedure and equipment used,
- test distance.

Test conditions:

- reference to standard conditions of this CIE publication or to specific service conditions: any relevant measurement correction factors should be applied before reporting,
- alignment of lamp (discharge tube or filament for lamps with clear bulbs) in the luminaire,
- attitude of mounted luminaire, angle of tilt for measurement,
- reference centre of the luminaire for the measurements and relative position of the luminaire to the co-ordinate-system,
- test voltage and frequency,
- uncertainties.

8.2.2.2 Photometric data

The photometric data provided in the test report relates to a particular luminaire, but its purpose is to provide the basis for further calculations, e.g. for the design of practical lighting installations. The information may include luminous flux values for the bare lamp(s), light output ratios, light intensity distributions, luminance figures, etc.

Units must be quoted and should be SI units. The results should be expressed per 1 000 lm of lamp flux unless otherwise specified.

The following information should be included, where appropriate:

- a) for discharge lamp luminaires, the ballast lumen factor, if not within $1 \pm 0,05^\circ$,
- b) service conversion factors.

Supplementary reports dealing with specific types of luminaire (see comments in section 1.1) may specify a preferred form of presentation for the test results.

References

Note : IEC references : *IEC Lamp Publications relate to performance of lamps (dimensions, electrical and luminous characteristics, also electrical parameters of associated reference ballasts, if applicable) while the referenced IEC Ballasts Publications relate to the performance of ballasts.*

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- [2] IEC 64, Tungsten filament lamps for domestic and similar general lighting purposes
- [3] IEC 357, Tungsten halogen lamps

- [4] IEC 1341, Method of measurement of centre beam intensity and beam angle(s) of reflector lamps
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