Illuminance meters — Requirements and test methods

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Contents

Foreword

This British Standard has been prepared by Subcommittee CPL/34/5. Together with BS EN 13032-1:2004, it supersedes BS 667:1996, which is withdrawn.

This British Standard specifies the requirements for two types of illuminance meter: Type L: laboratory instruments, and Type F: field instruments. The error tolerances have been considered in a similar manner to that used in CIE Publication 69 [1], and the definitions are based on CIE Publication 17.4 [2].

Error tolerances for Type L meters have been aligned with those given in BS EN 13032-1:2004, Table 3.

BS EN 13032-1 specifies laboratory illuminance meters for testing luminaires only. It does not cover illuminance meters for other laboratory purposes or for field use.

This new edition of BS 667 incorporates changes necessitated by the publication of BS EN 13032-1:2004. It does not reflect a full review or revision of the standard which will be undertaken in due course.

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

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Summary of pages

This document consists of a front cover, an inside front cover, pages i and ii, pages 1 to 13 and a back cover.

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Introduction

As lighting levels reduce, the response characteristics of the human eye change from photopic during the day through an intermediate mesopic region at dusk to a scotopic response at night time.

At present, eye response functions have not been defined in the mesopic region; research work is still in progress on this subject. Although photopic measurements are generally only applicable at lighting levels above about 10 lux, in practice lighting levels for installations are specified at values significantly below this. It is therefore necessary to make illuminance measurements with known accuracy at these lower levels to check performance against such specifications, whilst accepting that these measurements do not accurately represent the visual response.

Photometric measurements, even under laboratory conditions, are more difficult to determine precisely than many other kinds of physical measurement, and in the case of illuminance meters, liability to error is increased by the fact that many of the essential components of such instruments are susceptible to variation with time and use. These errors can be minimized by care in the design of the instrument as a whole, and also by the user in not exposing it to deleterious conditions of temperature, illumination or atmosphere.

It is recommended that illuminance meters should be returned to the manufacturer, or a competent photometric testing authority at intervals as recommended by the manufacturer for checking and, if necessary, recalibration.

1 Scope

This British Standard specifies performance requirements for illuminance meters for the measurement of photopic illuminance for applications other than the measurement of luminaires. It specifies the performance requirements for two types of illuminance meter, Type L (laboratory instruments) and Type F (field instruments). This British Standard is applicable to meters for the measurement of planar illuminance. This standard is intended for use by meter manufacturers and users.

NOTE 1 The requirements specified for a Type L meter in this standard are identical to the requirements specified for an illuminance meter in BS EN 13032-1. However, BS EN 13032-1 specifies additional requirements which are not specified in this standard.

NOTE 2 If other types of illuminance e.g. semi-cylindrical, are used, reference should be made to CIE Publication 69:1987 [1].

NOTE 3 Annex A gives recommendations for the choice of meter range.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS ISO 10526:1999, *CIE standard illuminants for colorimetry.*

CIE Publication 18.2:1983, *The basis of physical photometry*. Second edition.

3 Terms and definitions

For the purposes of this British Standard the following terms and definitions apply.

3.1
illuminance
the luminous flux per unit area falling on a surface, usually measured in lux (lumens per square metre)

3.2
illuminance meter
instrument for measuring illuminance

3.3
photoelectric cell
detector of optical radiation in which the absorption of photons results in the generation of an electric current or voltage, or causes a change in electrical resistance

NOTE The term "photoelectric detector" is also in use.

3.4
selective or coloured filter
medium which changes the spectral distribution of radiation by transmission

3.5
colour temperature
temperature of the full radiator which emits radiation of the same (or nearly the same) chromaticity as the radiation considered

3.6
photometer head
light sensitive detector the spectral response of which is weighted (usually by means of coloured filters) to approximate the CIE spectral luminous efficiency function $V(\lambda)$ of the human eye for photopic vision, as defined in CIE 18.2, together with any cosine correction required

NOTE More information on the spectral response and cosine correction is given in **C.2** and in **C.5** respectively.

3.7
calibration plane
plane normal to the axis of the photometer head to which the measured illuminance values relate

NOTE This plane should be chosen so that the readings are in accordance with the inverse square law when using a point source. In the case of a photometer head without a diffuser, this plane is the plane of the limiting aperture; for a photometer head with a plane diffuser, it is the front of the diffuser.

3.8
effective range
range over which the instrument conforms to the accuracy requirements of this specification

3.9
secondary standard lamp
lamp, the photometric characteristics of which are accurately known and calibrated directly against a national standard

3.10
working standard lamp
lamp in regular use which is calibrated at regular intervals by reference to a secondary standard lamp

3.11
secondary standard illuminance meter
illuminance meter, the photometric characteristics of which are accurately known and calibrated directly against a national standard

NOTE Further definitions related to photometry are given in CIE Publication 17.4 [2].

4 Classification

Illuminance meters shall be classified as one of the following two types:

a) laboratory illuminance meters, designated Type L, which are generally retained in a laboratory or standardizing area, and against which other equipment may be calibrated and the highest precision readings obtained. Such meters may not be suitable for site or field measurements;

b) field illuminance meters, designated Type F, which are for use in the field, on site and in the working environment. Some accuracy may have to be sacrificed in the interests of the ease of use, robustness and versatility of field meters.

5 Digital ranges and readouts

NOTE 1 Many illuminance meters are provided with a digital readout with the ranges either selected by the user, or the instrument automatically selecting the range (auto-ranging).

The display shall read either directly in lux, or indicate a value to be multiplied or divided by 10, 100 or 1 000. The appropriate factor shall be clear from the instrument marking. The display shall show at least three digits.

NOTE 2 This allows a factor of 10 between ranges, whilst still allowing the resolution to be within ±1 % at the lower end of the range. Extra digits, such as a display reading up to 1999, are useful either to give an overlap between the ranges, or to give greater sensitivity; moving decimal points, and fixed zeros are helpful, particularly to less experienced users, when covering a number of ranges, as they enable direct readings in lux to be made. However, final dancing digits, which vary in a random manner, should be avoided.

The digits themselves shall be large and clear enough to be easily read at a convenient angle and distance without shading the sensor.

NOTE 3 Liquid crystal displays (LCDs) are frequently used because of their low power consumption compared with light emitting diodes (LEDs).

NOTE 4 For meters with LCDs covering low lighting levels, a built-in lamp is useful to enable it to be read. It is essential that care is taken both with this lamp, and with an LED display, that the reading is not affected by stray light reaching the sensor.

NOTE 5 A "hold" facility for the display can be useful, enabling extra light to be switched on, or the instrument to be moved, without altering the reading.

NOTE 6 The meter may be self-zeroing or it may be fitted with a zero adjustment.

6 Analogue scales

For multi-range analogue illuminance meters, the factor between adjacent ranges shall not exceed four.

The scales of the illuminance meters shall be marked in lux or multiples of lux with bold graduations, and so figured as to minimize the chance of error in reading, even in a poor light.

NOTE 1 A built-in lamp is useful for reading the scale in poor illumination, but care should be taken that this light does not affect the readings.

NOTE 2 BS 3693 gives recommendations for scale marking and figuring.

NOTE 3 The part of the scale below the effective range of the illuminance meter may be unmarked.

7 Calibration and testing temperature

The calibration and testing of illuminance meters shall be performed in an ambient temperature of 20 °C ± 2 °C unless otherwise indicated by the manufacturer of the instrument.

NOTE Care should be taken when calibrating or using the illuminance meters at high levels of illuminance, in order to minimize the effect of high temperature.

8 Power supply

For battery operated instruments a battery check or other warning shall be provided to show when the battery should be replaced to ensure accuracy. Mains powered instruments shall conform to Clause **9** for input voltages within the range 207 V to 253 V.

9 Performance requirements for laboratory and field illuminance meters

When calibrated and tested in accordance with the clauses listed in Table 1, the meter reading error due to each factor shall not be greater than the relevant value specified in Table 2.

Table 1 — Test and calibration methods

Source of error	Clause
Calibration uncertainty	Annex B
Non-linearity	**C.1**
Spectral correction	**C.2**
Infra-red response	**C.3**
Ultraviolet response	**C.4**
Cosine correction	**C.5**
Fatigue	**C.6**
Temperature change	**C.7**
Range change	**C.8**

Table 2 — Error tolerances for illuminance meters

Source of error (Terms in parentheses are corresponding terms used in BS EN 13032-1, where these differ)	**Maximum acceptable error over effective range** % of reading	
	Type L **Laboratory meter**	**Type F** **Field meter**
Calibration uncertainty[a] in the range:		
Less than 10 000 lux	1.0	2.5
10 000 lux to 100 000 lux	1.0	3.0
Non-linearity (Linearity) in the range:		
Less than 10 000 lux	0.2	1.0
10 000 lux to 100 000 lux	0.2	2.0
Spectral correction [$V(\lambda)$ match]	1.5	3.5
Infra-red response	0.2	0.2
Ultraviolet response	0.2	0.5
Cosine correction (Cosine response) (unless marked as uncorrected)	1.5	2.5
Fatigue	0.1	0.4
Temperature change (Temperature dependence)	0.2[b]	0.25[b]
Range change	0.1	1.0

[a] The standard used and errors involved should be stated.
[b] Percent per kelvin.

NOTE 1 For digital displays displaying three significant digits there is a tolerance of ±1 on the least significant digit, which corresponds to 1 % for a reading of 100 and 0.2 % for a reading of 500.

NOTE 2 A meter which just meets the requirements of this standard would have a best measurement capability of ±4 % (Type L) or ±6 % (Type F) when used on any of its calibrated ranges. For highly coloured sources, such as light emitting diodes (LEDs), larger uncertainties would apply in practice.

10 Marking

The following information shall be distinctly and durably marked on the illuminance meter:

a) the mark of origin (this may take the form of a trade mark, the manufacturer's identification mark or the name of the vendor);

b) the number of this British Standard, i.e. BS 667:2005[1)];

c) type, i.e. L or F;

d) instrument identification number.

To ensure proper use and maintenance, the following shall be marked on the illuminance meters or otherwise made available to the purchaser:

1) spectral correction error;

2) the calibration and testing temperature;

3) the date, source used and error of the last calibration and the recommended date of the next calibration;

4) where the photoelectric cell can be disconnected from the indicating instrument they shall both be marked to ensure that the correct combination of photoelectric cell and indicating instrument are used together;

5) correction factors for differences between the ambient temperature and testing temperature;

6) the location of the calibration plane; and

7) if the photometer head is not cosine corrected, this shall be stated.

NOTE Correction factors for specified non-Plankian light sources may also be given, see **C.9**.

[1)] Marking BS 667:2005 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the standard. The accuracy of the claim is solely the claimant's responsibility. Such a declaration is not to be confused with third party certification of conformity.

Annex A (informative) Guidance on choice of meter range

A.1 General

Most illuminance meters cover more than one range; there is usually a small but sometimes significant difference between the readings made at the top of the lower range and the bottom of the next higher range. This applies to both analogue and digital meters, but the effect is generally more obvious with digital meters because the lower figure is usually read more easily with greater precision, and it is not seen in comparison with the full scale as with an analogue meter.

A.2 Choice of range

Sometimes use can be made of the overlap between the ranges, or it may be worth working in a higher range to avoid the problem of making range change corrections. However, where practical, the lower range should be used, as it is more sensitive, the maximum reading in the range is frequently taken as the calibration point, and zero and linearity errors will tend to increase towards the minimum reading in the range.

Annex B (normative) Calibration

B.1 General

Meters shall be calibrated using one of the methods given in **B.2**. The uncertainty of the calibration including the uncertainty of the standard lamp or reference meter shall not exceed the value given in Table 2. If, following calibration, the meter is adjusted, it shall be recalibrated before use.

B.2 Calibration methods

B.2.1 ***Using a reference lamp***

B.2.1.1 *Apparatus*

B.2.1.1.1 *Reference lamp*, comprising a standard tungsten filament lamp calibrated for directional intensity and having a colour temperature of 2 856 K ± 20 K. The lamp shall be operated under the conditions for which it was standardized for luminous intensity and colour temperature, using a power supply which can control the stability of supplied current to within 0.02 %.

NOTE It is good practice to use a second working standard lamp to check the calibration.

B.2.1.1.2 *Photometric bench*, or other suitable rigid structure on which the reference lamp and photometer head cell are mounted, and on which distances can be measured accurately.

B.2.1.1.3 *Baffles or diaphragms*, which exclude all but direct rays from the reference lamp from the photometer head.

B.2.1.2 *Procedure*

Adjust the position of the photometer head so that the illumination is normal to its geometric centre.

Adjust the illuminance meter before calibration testing to indicate zero with zero illuminance on the photometer head.

Adjust the distance between the reference lamp and the calibration plane of the photometer head to achieve suitable illuminance values; at least one value for each meter range.

The minimum distance between the reference lamp and the photometer head shall be greater than 10 times the maximum lamp filament dimension or 10 times the photometer head acceptance dimension if greater.

Cover the photometer head between taking measurements at each successive point of calibration and expose it to the illuminant for sufficient time for the reading to settle before taking a measurement.

Adjust the meter to give the same illuminance reading as that calculated in **B.2.1.3**.

B.2.1.3 *Calculation of actual illuminance at photometer head*

Calculate the illuminance at the photometer head from the following equation:

$$E = \frac{I}{d^2}$$

where

- E is the illuminance, in lux;
- I is the luminous intensity, in candelas, of the reference lamp in the marked direction;
- d is the distance, in metres, from the optical centre of the reference lamp filament to the calibration plane of the photometer head.

Record the results of this calibration.

NOTE These results may be used to maintain a calibration history of the meter.

B.2.2 ***Using a reference meter***

B.2.2.1 *Principle*

An alternative procedure to the method given in **B.2.1** is to employ a secondary standard illuminance meter. In this method, the meter to be calibrated is compared with the secondary standard meter when both are exposed to the same illuminance from a given light source.

B.2.2.2 *Apparatus*

B.2.2.2.1 *Photometric bench*, or other rigid structure on which distances can be accurately reproduced.

B.2.2.2.2 *Tungsten filament source*, of a suitable output to give appropriate illuminance values, operating at a colour temperature of 2 856 K ± 20 K and run from a power supply which can control the stability of supplied current to better than 0.02 %.

B.2.2.2.3 *Baffles or diaphragms*, which exclude all but direct light from the lamp from the photometer heads.

B.2.2.3 *Procedure*

Adjust the position of each photometer head so that the illuminance is normal to its geometric centre.

Adjust each illuminance meter before calibration testing to indicate zero with zero illuminance on its photometer head.

Vary the distance of the lamp filament from the secondary standard illuminance meter mounted on the bench to achieve suitable illuminance values; at least one value for each meter range. The minimum distance between the lamp filament and the photometer head should be greater than 10 times the maximum lamp filament dimension or 10 times the photometer head acceptance dimension if greater.

Record the illuminance values given by the meter. Replace the standard photometer head with the head of the meter to be calibrated and repeat the measurements. Then use the standard photometer head again to perform the original measurement.

NOTE 1 If convenient, the equivalent measurements may be performed in a different order.

Cover the photometer heads between taking measurements at each successive point of calibration and expose the heads to the illuminant for sufficient time for the reading to settle before taking a measurement.

Use the corresponding illuminance values at a given distance for the two meters to perform the calibration.

Record the results from this calibration.

NOTE 2 These results may be used to maintain a calibration history of the meter.

Annex C (normative) Test methods

C.1 Test for linearity

C.1.1 *Apparatus*

Means of illumination for checking linearity that can be varied by a physical method such as varying the distance from the light source to the photometer head or using a series of light sources which are exposed separately and in combination.

C.1.2 *Procedure*

Expose the photometer head to an illuminance of within ±5 % of the value used to calibrate the meter range being used. Expose the photometer head to a series of illuminances covering each range on the meter being tested, and note the values displayed by the meter together with the settings of the apparatus producing the illuminance.

C.1.3 *Calculation of non-linearity*

Calculate the percentage non-linearity (N) using the following equation:

$$N = \left(1 - \left[\frac{AB}{CD}\right]\right) \times 100$$

where

A	is the meter reading at the test illuminance;
C	is the meter reading when exposed to the illuminance within ±5 % of the calibration point;
B/D	is the ratio of the illuminance, within ±5 %, of the calibration point to the illuminance at the check point.

C.2 Calculation of spectral correction error

The spectral correction error is a measure of the departure of the actual spectral responsivity of the meter from the spectral luminous efficiency of the human eye. The percentage spectral correction error f_1' is given by the following equation:

$$f_1' = \frac{\sum_{380}^{780} \left| s*(\lambda)_{\mathrm{rel}} - V(\lambda) \right|}{\sum_{380}^{780} V(\lambda)} \times 100$$

where

$s*(\lambda)_{\mathrm{rel}}$	is the normalized relative spectral responsivity as given by the following equation: $$s*(\lambda)_{\mathrm{rel}} = \frac{\sum_{380}^{780} S(\lambda)_{\mathrm{A}} V(\lambda)}{\sum_{380}^{780} S(\lambda)_{\mathrm{A}} s(\lambda)_{\mathrm{rel}}} s(\lambda)_{\mathrm{rel}}$$
$S(\lambda)_{\mathrm{A}}$	is the spectral distribution of the illuminant used in the calibration (standard illuminant A in accordance with BS ISO 10526:1999);
$s(\lambda)_{\mathrm{rel}}$	is the relative spectral responsivity normalized at an arbitrary wavelength;
$V(\lambda)$	is the spectral luminous efficiency of the human eye for photopic vision, as defined in CIE 18.2.

C.3 Infra-red response test

C.3.1 *Apparatus*

C.3.1.1 *Tungsten filament lamp*, operating at a colour temperature of 2 856 K ± 40 K.

C.3.1.2 *Infra-red transmitting filter*, which excludes visible radiation[2].

C.3.2 *Procedure*

Record the illuminance reading with the filter placed between the photometer head and the lamp and the reading without the filter.

C.3.3 *Expression of results*

Express the infra-red response as the ratio of the illuminance recorded when the filter is placed between the photometer head and the lamp to that recorded with the lamp and no filter.

C.4 Ultraviolet response test

C.4.1 *Apparatus*

C.4.1.1 *Low pressure mercury discharge lamp.*

C.4.1.2 *A 365 nm interference filter*, or other UV transmitting, visible radiation absorbing filter[3].

C.4.2 *Procedure*

Record the illuminance reading with the filter placed between the photometer head and the lamp and the reading without the filter.

C.4.3 *Expression of results*

Express the UV response as the ratio of the illuminance recorded when the filter is placed between the photometer head and the lamp to that recorded with the lamp and no filter.

NOTE It should be noted that misleading results are obtained if a medium/high pressure mercury lamp or fluorescent lamp is used, or if the UV filter transmits significant visible radiation. The latter can be checked using a tungsten filament lamp operating at a colour temperature of 2 856 K ± 40 K; zero illuminance should be recorded when the UV filter is placed between the photometer head and the tungsten lamp.

C.5 Determination of cosine correction error

C.5.1 *Principle*

Light falling at an angle on a photoelectric cell tends to be increasingly reflected as the angle of incidence increases; this and other factors cause illuminance meters to read too low when measuring light falling obliquely, unless a cosine correcting mount is used in the photometer head.

C.5.2 *Procedure*

C.5.2.1 Set up a small light source at a distance from the detector corresponding to at least 20 times the largest dimension of either the light source or the acceptance area of the photometer head, which can be considered as a point source.

NOTE Special precautions should be taken to prevent stray light, i.e. light which does not come directly from the light source but is scattered off the walls, floor and ceiling, from reaching the detector.

Align the beam from this point source normal to the photometer head and arrange the distance to give full scale deflection, or a maximum in the range chosen, or, where there is a problem with over-ranging, the highest practical deflection.

C.5.2.2 Take readings with the measuring head at the same distance from the point source at 5° intervals from +85° to –85° from the normal, and express values as decimal fractions, $f(\theta)$, of the normal reading, where θ is the angle from the normal.

[2] For information on the availability of infra-red transmitting, visible radiation absorbing filters contact BSI Customer Services, British Standards House, 389 Chiswick High Road, London W4 4AL.
[3] For information on the availability of UV transmitting, visible radiation absorbing filters contact BSI Customer Services, British Standards House, 389 Chiswick High Road, London W4 4AL.

C.5.2.3 Repeat the process as in **C.5.2.2**, but in a plane at right angles to that first chosen.

C.5.3 ***Expression of results***

Calculate the sum (σ) of the moduli of the errors at each angle from the following equation:

$$\sigma = \sum_{-85°}^{+85°} \left| f(\theta) - \cos(\theta) \right|$$

Calculate the percentage cosine correction error (T) given by the equation:

$$T = \frac{\sigma}{22.9 \times 2} \times 100$$

NOTE 22.9 = {cos 85°+ cos 80° + cos 75° +,...,+ cos (–85°)}

C.6 Test for error due to fatigue

Shield the photometer head for at least 1 h and then expose it for 10 min to an illuminance equal to 90 % of the maximum value for which the illuminance meter is calibrated.

C.7 Test for error due to temperature change

Vary the temperature of the whole equipment from 0 °C to +40 °C and record the change in the illuminance reading. Record the illuminance at +20 °C.

Express the error as a percentage of the illuminance at 20 °C.

C.8 Test for error due to range change

Adjust the illuminance incident on the photometer head to give a reading of at least 95 % of the true maximum in the lower range. Switch the instrument to the next higher range and take a reading with the same incident illuminance.

Calculate the percentage range change error (R) using the following equation:

$$R = \frac{H - L}{L} \times 100$$

where

L is the reading, in lux, on the lower range; and

H is the reading, in lux, on the higher range.

C.9 Determination of spectral correction factor

C.9.1 ***Principle***

A tungsten lamp operated at a colour temperature of 2 856 K (i.e. CIE standard illuminant A in accordance with BS ISO 10526:1999) has been adopted as the reference light source against which the illuminance meter is calibrated.

When the illuminance meter is to be used for measurements with other light sources, it may be necessary to provide a multiplying factor or other suitable means to correct the meter reading. The magnitude of the correction which is required depends upon the difference between the spectral power distributions of the calibration source and the other light source in question, and upon the relative spectral responsivity of the photometer head [i.e. the degree of deviation from the $V(\lambda)$ curve].

NOTE These data should be obtained from the manufacturer or measured by a suitably equipped laboratory.

The correct value of illuminance (E) of the test source is given by:

$$E = F \times E_t$$

where

E_t is the measured value of the test source illuminance;

F is the spectral correction factor.

C.9.2 *Calculation of F*

Calculate F from the following equation:

$$F = \frac{\sum_{380}^{780} S_t(\lambda) V(\lambda) \times \sum_{380}^{780} S_r(\lambda) s(\lambda)}{\sum_{380}^{780} S_t(\lambda) s(\lambda) \times \sum_{380}^{780} S_r(\lambda) V(\lambda)}$$

where

$s(\lambda)$ is the relative spectral responsivity of the illuminance meter;

$S_r(\lambda)$ is the spectral power distribution of the reference source used to calibrate the illuminance meter;

$S_t(\lambda)$ is the spectral power distribution of the source to be measured;

$V(\lambda)$ is the CIE spectral luminous efficiency function of the meter, as defined in CIE 18.2;

and the summations are carried out over the range 380 nm to 780 nm in maximum steps of 10 nm.

C.9.3 *Example of calculation of correction factor for high pressure sodium lamp*

Example data for the calculation of the correction factor for a high pressure sodium lamp is given in Table C.1.

Table C.1 — Example of calculation of correction factor for a high pressure sodium lamp

Wavelength nm	$V(\lambda)$	$s(\lambda)$	$S_r(\lambda)$	$S_t(\lambda)$	$S_t(\lambda)V(\lambda)$	$S_r(\lambda)s(\lambda)$	$S_t(\lambda)s(\lambda)$	$S_r(\lambda)V(\lambda)$
380	0.000 0	0.000 0	0.098	0.010 7	0.000 0	0.000 0	0.000 0	0.000 0
390	0.000 1	0.000 0	0.121	0.013 9	0.000 0	0.000 0	0.000 0	0.000 0
400	0.000 4	0.000 0	0.147	0.018 6	0.000 0	0.000 0	0.000 0	0.000 1
410	0.001 2	0.000 1	0.177	0.022 7	0.000 0	0.000 0	0.000 0	0.000 2
420	0.004 0	0.000 2	0.210	0.027 5	0.000 1	0.000 0	0.000 0	0.000 8
430	0.011 6	0.001 1	0.247	0.034 4	0.000 4	0.000 3	0.000 0	0.002 9
440	0.023 0	0.003 8	0.287	0.041 8	0.001 0	0.001 1	0.000 2	0.006 6
450	0.038 0	0.005 8	0.331	0.058 3	0.002 2	0.001 9	0.000 3	0.012 6
460	0.060 0	0.025 2	0.378	0.033 8	0.002 0	0.009 5	0.000 9	0.022 7
470	0.091 0	0.066 3	0.429	0.961 0	0.087 5	0.028 4	0.063 7	0.039 0
480	0.139 0	0.136 2	0.482	0.017 8	0.002 5	0.065 6	0.002 4	0.067 0
490	0.208 0	0.214 5	0.539	0.020 1	0.004 2	0.115 6	0.004 3	0.112 1
500	0.323 0	0.382 4	0.599	0.221 0	0.071 4	0.229 1	0.084 5	0.193 5
510	0.503 0	0.544 2	0.661	0.025 8	0.013 0	0.359 7	0.014 0	0.332 5
520	0.710 0	0.732 5	0.725	0.037 1	0.026 3	0.531 1	0.027 2	0.514 8
530	0.862 0	0.896 7	0.791	0.012 3	0.010 6	0.709 3	0.011 0	0.681 8
540	0.954 0	0.969 3	0.859	0.016 6	0.015 8	0.832 6	0.016 1	0.819 5
550	0.995 0	1.002 0	0.929	0.061 7	0.061 4	0.930 9	0.061 8	0.924 4
560	0.995 0	0.964 3	1.000	0.137 1	0.136 4	0.964 3	0.132 2	0.995 0
570	0.952 0	0.905 8	1.072	0.839 0	0.798 7	0.971 0	0.760 0	1.020 5
580	0.870 0	0.834 7	1.144	0.665 9	0.579 3	0.954 9	0.555 8	0.995 3
590	0.757 0	0.721 1	1.217	0.997 6	0.755 2	0.877 6	0.719 4	0.921 3
600	0.631 0	0.583 2	1.290	1.000 0	0.631 0	0.752 3	0.583 2	0.814 0
610	0.503 0	0.464 2	1.363	0.478 5	0.240 7	0.632 7	0.222 1	0.685 6
620	0.381 0	0.339 9	1.436	0.343 4	0.130 8	0.488 1	0.116 7	0.547 1
630	0.265 0	0.235 5	1.508	0.175 1	0.046 4	0.355 1	0.041 2	0.399 6
640	0.175 0	0.158 2	1.580	0.135 4	0.023 7	0.250 0	0.021 4	0.276 5
650	0.107 0	0.099 2	1.650	0.110 7	0.011 8	0.163 7	0.011 0	0.176 6
660	0.061 0	0.058 9	1.720	0.095 9	0.005 8	0.101 3	0.005 6	0.104 9
670	0.032 0	0.033 8	1.788	0.095 9	0.003 1	0.060 4	0.003 2	0.057 2
680	0.017 0	0.018 2	1.854	0.074 9	0.001 3	0.033 7	0.001 4	0.031 5
690	0.008 2	0.009 1	1.919	0.046 8	0.000 4	0.017 5	0.000 4	0.015 7
700	0.004 1	0.004 5	1.983	0.038 6	0.000 2	0.008 9	0.000 2	0.008 1
710	0.002 1	0.002 1	2.044	0.035 9	0.000 1	0.004 3	0.000 1	0.004 3
720	0.001 0	0.001 0	2.104	0.033 8	0.000 0	0.002 1	0.000 0	0.002 1
730	0.000 5	0.000 4	2.161	0.032 5	0.000 0	0.000 9	0.000 0	0.001 1
740	0.000 2	0.000 2	2.217	0.032 0	0.000 0	0.000 4	0.000 0	0.000 4
750	0.000 1	0.000 1	2.270	0.034 4	0.000 0	0.000 2	0.000 0	0.000 2
760	0.000 1	0.000 0	2.321	0.043 1	0.000 0	0.000 0	0.000 0	0.000 2
770	0.000 0	0.000 0	2.370	0.780 0	0.000 0	0.000 0	0.000 0	0.000 0
780	0.000 0	0.000 0	2.417	0.034 9	0.000 0	0.000 0	0.000 0	0.000 0
Sum =					3.633	10.455	3.461	10.788
F = (3.663 × 10.455)/(3.461 × 10.788); i.e. F = 1.026 (2.6 %)								

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[1] CIE Publication 69:1987, *Methods of characterizing illuminance meters and luminance meters: Performance, characteristics and specifications.*

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