THE ILLUMINANCE HANDBOOK

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METREL®

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1. INTRODUCTION

The purpose of this handbook is to better acquaint the reader with the challenges of illumination measurements.
In the first part of the book the standards and regulations in this field are described.
In the second part basics of light measurements are introduced in a simple manner. The most important definitions and terminology are applied, including some illustrative pictures which help to better understand the topics.
The third and last part presents the measurement methodology. Many useful hints are given in order to perform fast and accurate measurements.
Two tables of most frequently used illuminance limits are added at the end of this handbook.

It has to be stressed that all METREL illuminance probes and testers are designed to perform light measurements in a fast and accurate manner.
All Metrel's probes are precisely V(λ) adapted and cosine corrected and they are in complete compliance with the DIN 5032/7 Class C (Luxmeter Type C) and Class B (Luxmeter Class B) accuracy regulations. The instruments can perform spot or long term measurements and have recording facilities. All important data (max, min, avg) can be stored, recalled or compared with preseted limits. Powerful PC SW packages enable further analysis of test data and their documentation.
In addition to professional measurement instruments, Metrel offers also the complete application support, know-how on measuring techniques and the latest information about standards and drafts.

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(The authors would appreciate any comment or additional suggestion which would help us supplement the handbook and Metrel's products.)

2. MAIN FEATURE STANDARDS FOR FIELD ILLUMINANCE (LUX) METERS

The International Commission on Illumination (abbreviated as CIE from its French title) is an organization devoted to international cooperation and exchange of information between its member countries on all matters relating to the science and art of lighting. In accordance with an agreement between ISO (the International Organization for Standardization) and CIE, standards are published as double logo standards by ISO. Standards produced by the CIE are a concise documentation of data defining aspects of light and lighting, for which international harmony requires a unique definition. CIE Standards are therefore a primary source of internationally accepted and agreed data which can be taken, essentially unaltered, into universal standard systems.

CIE 69 Methods of Characterizing Illuminance Meters and Luminance Meters

The properties of photometers and photometer heads for the measurements of illuminance and luminance are defined. Methods of calibration are given and sources of
errors are described.

BS 667 The requirements for field instruments (type F) meters for the measurement of planar illuminance are specified in this standard. The main definitions and requirements regarding the performance of measurements and construction of measurement instrument are also included.

DIN 5032 /7 Light Measurement Classifications for illuminance and brightness measurement instruments

There are four classes of illuminance meters due to the German DIN 5032 standard: L, A, B and C. Requirements for type F (field instruments) meters for the measurement of planar illuminance are specified in classes A, B and C.

In table 1 the maximum allowed error over the effective range is specified:

Parameter	***DIN 5032 – 7 Class B***	***DIN 5032 – 7 Class C***
Matching to V(λ) function	6%	9%
Ultraviolet response	2%	4%
Infra-red response	2%	4%
Cosine correction	3%	6%
Non-linearity	2%	5%
Fatigue	1%	2%
Temperature change	1%/degreeK	2% / degree K
Modulated light	0.5%	1%

Table 1: Accuracy of field illuminance meters

All Metrel illuminance testers and probes are Class C or Class B compliant.

2.1 Main application standards for field illuminance (lux) meters

There is a series of DIN (German Industrial Standards) standards with detailed descriptions (definitions, precautions, measurements, worst values etc) of light measuring in different privat and public places.

DIN 5035 Illumination with artificial lights
- general precautions, measurements,
- terms, definitions and calculations,
- illumination in hospitals, schools, working places, offices,
- illumination in places with screens.

DIN 5034 Daylight in indoor rooms
- general precautions, measurements,
- terms, definitions and calculations,
- definition of minimum window size apartmans and loft rooms.

DIN 5037 Headlights (automotive, studio, theater...)
DIN 5044 Traffic illumination with street lights
DIN 33400 Workplace definition
DIN 67526 Lighting for sport facilities

3. GENERAL ABOUT ILLUMINANCE

3.1 The origin of light

Light is a part of the electromagnetic waves. The electromagnetic spectrum covers an extremely broad range, from very low frequencies or infra-frequencies over the radio waves with wavelengths of a meter or more on one side, to x-rays and gamma-rays with wavelengths of less than a billionth of a meter. But the part of the light which we are interested in is the optical portion of the electromagnetic spectrum (Figure 1). It lies between radio waves and x-rays, to be exact, it borders on infrared light on one side and ultraviolet on the other.

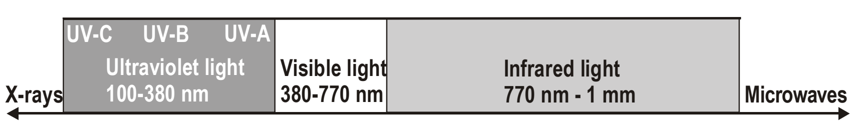

Figure 1: Electromagnetic spectrum

3.2 Radiometric and Photometric values

The two approaches on how to measure light are:
- radiometric (based on energy),
- photometric (weighted to match the responsivity of the human eye).

The values that are weighted to match the responsivity of the human eye (luminous flux, illuminance, luminance and luminous intensity)

are measured by photometric light units, the others (radiant flux, irradiance, radiance and radiant intensity) by energetic units.
The lumen, for example, is the photometric equivalent of the watt. If one wants to measure visible light, one must use photometric quantities. If one wants to measure energy of light, one must use radiometric quantities.

3.3 Basic photometric definitions

Luminous Flux *P [lm]*
Luminous flux is a measure of flow of visible light. The unit of the measure is Lumen. There are two kinds of luminous flux:
- photopic flux (weighted to match the responsivity of the eye in normal light condition)
- scotopic flux (weighted to the sensitivity of the human eye in the dark adapted state)

Luminous intensity *I[lm/sr]*
Luminous intensity is a measure of luminous flux emitted per unit solid angle.
The unit of solid viewing angle is steradian. One steradian covers one square meter on the surface of a sphere of 1 meter radius.

Illuminance *E [lm/m^2=lux]*
Illuminance is the density of a luminous flux incident on a given point on a surface and is measured in Lux. 1 Lux is caused by a light source with the intensity of 1 candela at the distance of 1 meter.

Luminance *L [lm/m^2/sr=cd/m^2]*
Luminance is a measure of luminous flux emitted from an element of a surface into a small solid angle per unit of projected area of the surface.

3.4 Photometric units conversion Table

Candela [cd], Lumen [lm], Lux [lux]

lm/m^2 = lux (lx)
lm/cm^2 = phot (ph)
lm/ft^2 = foot candle (fc)
lm/sr = cd

Units fc and lux are dominating in the field.
Conversion between fc and lux is made according to the following equation:

1 fc =10.764 lux

3.5 FAQ: Illuminance vs Luminance

Luminance is a measure of the perceived brightness of the source when you look at it. The definition implies a small source, because the energy stream from it is defined as energy within a given solid angle, independent of distance to the observer. If the source is very small, a tiny quartz halogen torch bulb for example, the brightness will appear to be intense, even if its emission is one candela. If the source is, like a candle, small but not really a point, you will get an impression of a small area of light of moderate brightness, even though the light intensity is also one candela.

For measuring Luminance, the sensors must be equipped with special optics to provide the desired effective viewing angle.

Illuminance is the light flux of one or more different light sources that are striking a certain area. Only the flux portion orthogonal to the surface is considered. The viewing angle is 180% (plane) and weighted with the cosinus correction function.

Example:

The moon may be considered very much as a point source. On the other hand moonlight, refracted and reflected by the atmosphere, contributes significantly to the overall amount of light reaching the earth's surface. As a result moonlight is a combination of a point source and a 2π steradian area source. If you aimed the detector directly at the moon and tracked the moon's path, you would be measuring the maximum illuminance. Luminance measurements require a narrow viewing angle (< 4º) in order to satisfy the conditions underlying the measurement units.

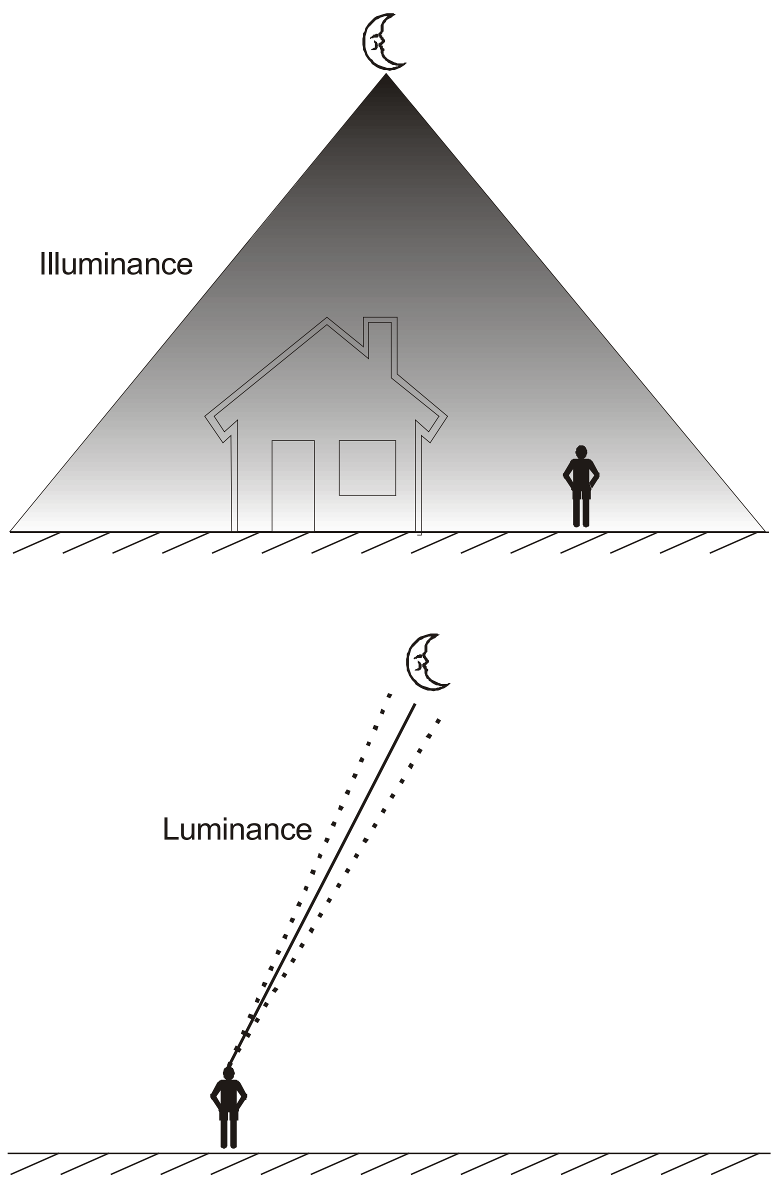

Figure 2: Illuminance vs Luminance

3.6 What is the CIE V(λ) curve?

The photometric system defines light in terms of how it is perceived by the human eye. The eye's sensitivity depends on the wavelength or color of the light. The spectral response of the human eye also changes with light intensity. The eye has two distinctive spectral responses, which are defined according to the brightness of the light entering the eye:

- photopic light conditions response (light adapted eye):
  defined for light intensity greater than 0.1 lux. In these conditions, the eye has a peak sensitivity in the green part of the visible spectrum, at 555 nm and it is normalized to 1 at that wavelength, while the eye's response to infrared or ultraviolet is zero.
- scotopic light conditions response (dark adapted eye):
  occurs under low light conditions (scotopic) defined for light intensity between 0.0001 and 0.01 lux. In these conditions, the eye has a peak sensitivity at about 500 nm.

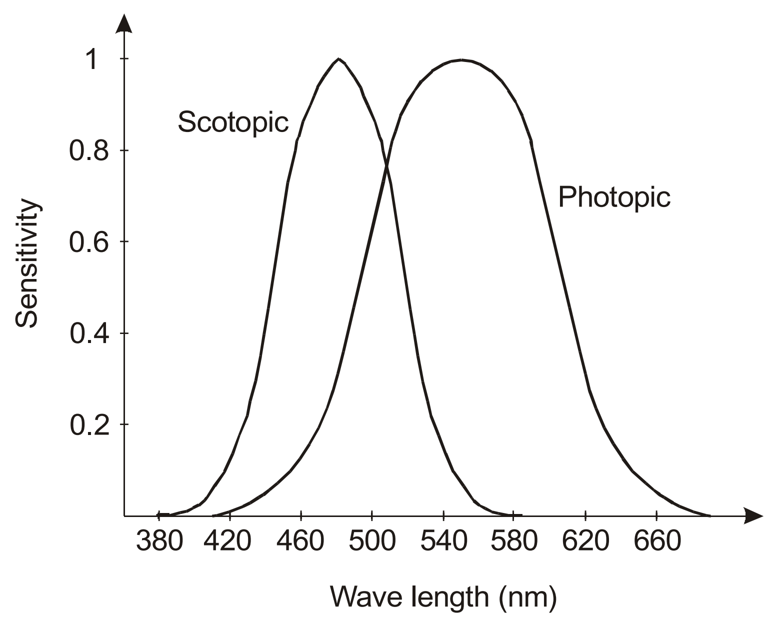

Figure 3: V(λ) curve for both eye responses

The response is named the CIE or V(λ) curve and is defined in the document CIE 10527. Sensors in illuminance meters must use special colour filters to adapt to the response.

3.7 What is cosine correction?

Light falling at an angle on an object tends to be increasingly reflected as the angle of incidence increases. This causes illuminance meters to read too low when measuring light falling obliquely, unless a cosine correcting mount or a cosine diffuser is used in the meter head assuring an angular response close to the cosine function.

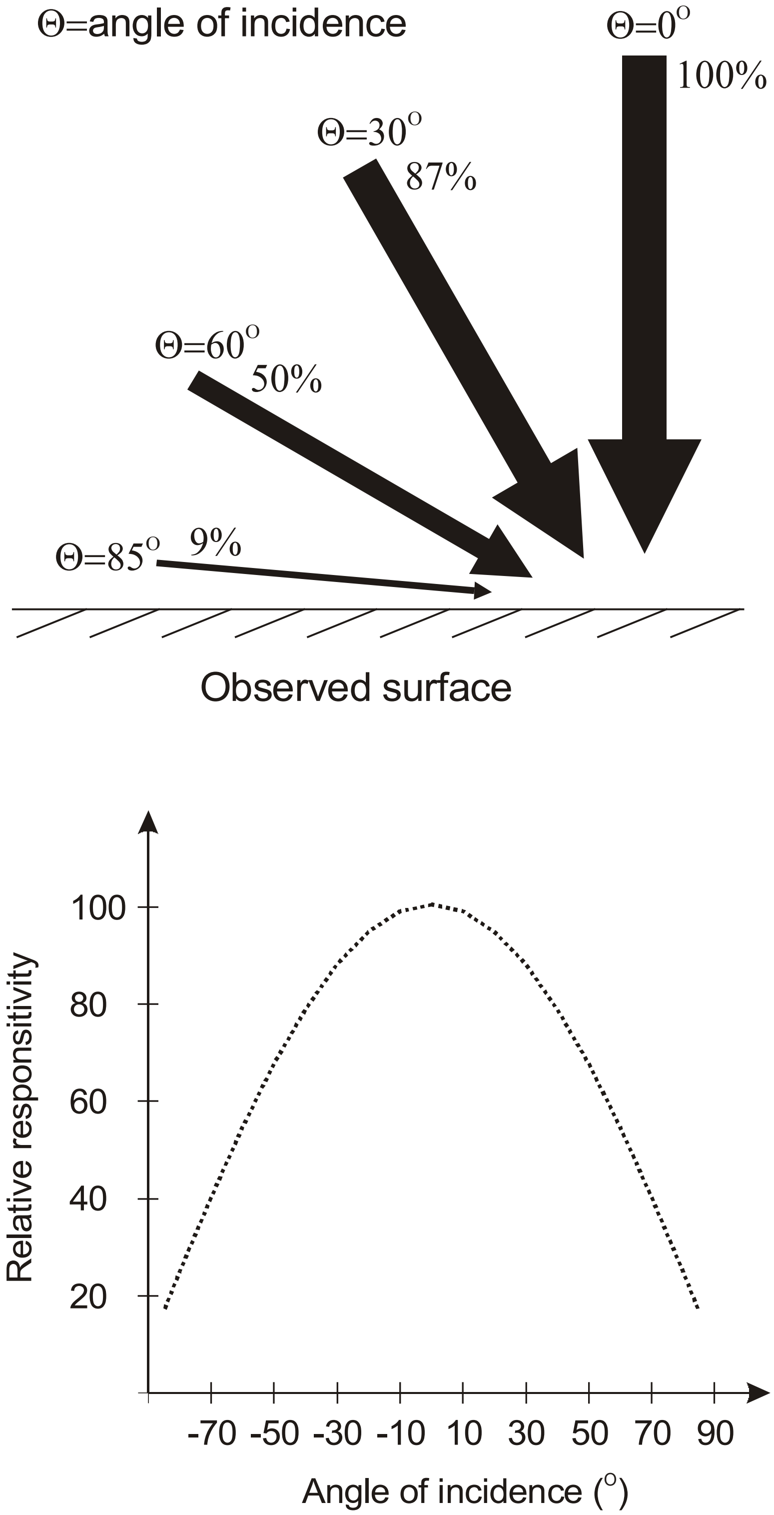

Figure 4: Cosine correction

4. ILLUMINANCE MEASUREMENTS

Practical measurement instruments contain semiconductor sensors which convert the absorbed light into electric current. For accurate measurements, luxmeters of the photocell type should be used which have been cosine and color corrected.

4.1 When and why to measure illuminance

The illuminance measurements should be performed whenever planning or installing indoor or outdoor lighting.
Too high or too low illuminance could influence the health and cause safety and psychological problems.

4.2 Some useful hints to ensure accurate measurements

- When measuring illumination at working places, hold the sensor in front (up to 0.2 m) and parallel to the measured object (table, command plate, desk etc).
- When measuring horizontal illumination, hold the sensor in front of the object to be measured so that the window of the sensor faces the ceiling. The distance between floor and sensor is 0.85 m for routine room measurements and 0.2 m for in-door traffic way measurements.
- During the measurement ensure that light incidence onto the sensor is not impaired by the operator or any objects not being part of the measurement (shields or reflections).
- Check the zero setting of the scale when the sensor is fully covered
- Check the condition of the battery in the instrument
- An installation of discharge or fluorescent lamps should be switched on for some time (15 minutes, if possible) before the measurements are taken in order to allow the lamps to be completely warmed up. If the luminary is of the fully enclosed type, even longer stabilization time may be needed.
- The procedure adopted for the measurement process will depend on whether the space is furnished or unfurnished, occupied or unoccupied. In some instances the effects of body shadow should be taken into account.
- For ***planning*** purposes the nominal ***illuminance*** value (see table 4) should be multiplied by at least x 1.25
- The ***average illuminance*** is not allowed to be below x 0.8 of the nominal value.
- The ***minimal illuminance*** must never drop below x 0.6 of the nominal value.

Other recommendations can be found in DIN 5035.

4.3 How to measure average illuminance?

Sometimes the average illuminance in a room must be found out.
A luxmeter indicates the illuminance at the point of measurement only, and not the average illuminance in the space. To find out the average illuminance in an area at the time, it is necessary to divide the area into a number of equal areas which should be as nearly square as possible. The illuminance at the centre of each square is then measured, and the results are averaged. The minimum number of equal areas required for accuracy can be determined by number n:

$$n = \frac{L \cdot W}{(L + W) \cdot H_m}$$

where L is the length, W is the width of the indoor place and H_m is the height of the luminaries above the plane of measurement.
The height of working plane is usually 0.85 m for work benches or 0.72 m for desk top height unless the main plane of the work is known to be some other height above floor level. If the work is performed down to floor level, then the floor is taken as the working plane of measurement.
The number of measurement points depends on value n.

n	Minimum number of measurement points for uncertainty of ±5 %	Minimum number of measurement points for uncertainty of ±10 %
n < 1	8	4
1 ≤ n < 2	18	9
2 ≤ n < 3	32	16
3 < n	50	25

Table 2: Number of measurement points

4.4 Calibration of illumination testers

As a general rule silicon diode type meter should be re-calibrated every two years. Companies conforming to the ISO 9000 standards should have their meters calibrated every 12 months. It is recommended to recalibrate probe frequently to maintain specified accuracy. It is important to check the previous calibration report to see if there has been a significant shift in the percentage error. This error could have a bearing on the readings taken since the last calibration, and may indicate that the meter has suffered some damage since last calibration.

5. STANDARD ILLUMINATION VALUES

Type of visual task	**PRACTICAL EXAMPLES**	**Normal illumination (lighting intensity) in lux**
Orientation	Traffic zones, subordinate rooms	20
	Filled storage rooms, hallways in buildings for persons	50
Easy visual tasks	Production plants with occasional activities, toilet facilities, engine rooms, traffic ways for vehicles in buildings, staircases, conveyor belts, medical rooms	100
	Crude works, continuously occupied working places in production plants, storage rooms with reading tasks, canteens	200
Normal visual tasks	Conference rooms gymnasiums	300
	Offices, medical facilities (urgenices)	500
	Technical drawing rooms	750
Difficult visual tasks	Supervision places, technical drawings, open plan offices, assembly rooms, testing stations	1000
Very difficult visual tasks	Assembly rooms for small components, show windows	1500

Table 3: Standard values of inside working environment due to the DIN 5035 standard

The nominal values listed above are reference values. Generally they refer to horizontally working surfaces at a height of 0.85 m above floor and a mean ageing condition of the lighting.

Condition	**Illuminance (lux)**
Bright sun	50,000 - 100,000
Hazy day	25,000 - 50,000
Cloudy bright	10,000 - 25,000
Cloudy dull	2,000 - 10,000
Very dull	100 - 2,000
Sunset	1 – 100
Good street lighting	≈20
Poor street lighting	≈0.1
Full moon	0.01 - 0.1
Starlight	0.001 - 0.001
Overcast night	0.00001 - 0.0001

Table 4: Typical Illuminance levels at outdoor places