# MSL Technical Guide 34

# Spectral Mismatch of Illuminance Meters

## Introduction

Illuminance or lux meters, are used in a variety of industries to ensure lighting is at an appropriate level. Commonly, measurements are used to verify lighting levels for inspection, health and safety, and visual discomfort. Often minimum and maximum illuminance levels are specified in documentary standards.

This technical guide provides guidance on one of the important characteristics of an illuminance meter, its spectral mismatch, and the substantial errors that can arise when using a poor quality instrument. Particular focus is given to the grade of illuminance meter commonly used in industry for compliance checks.

## What is an illuminance meter?

An illuminance meter is an instrument used to quantify the intensity of light that would be perceived by the human eye at a given plane.

Commercial illuminance meters consist of an illuminance probe connected by wire to a unit with a digital display. Normally the probe contains a diffuser at the front surface, followed by a coloured glass filter stack and silicon photodiode. This combination of diode and filters is designed to match the CIE photopic response function [1]. For an ideal meter, the measured illuminance, *E*, has units of lux, or equivalently lm/m$^2$, which is a measure of photometric intensity. The integrated product of the light source spectral irradiance, *S(λ)*, and detector response function, *R(λ),* gives the illuminance:

$$E = K_{\mathrm{m}} \int_{360}^{830} S(\lambda) \times R(\lambda) d\lambda, \qquad (1)$$

where $K_{\mathrm{m}}$ is the constant 683 lm/W.

## Spectral Mismatch

The standard "BS ISO/CIE 19476:2014 Characterization of the performance of illuminance meters and luminance meters" [2], describes eighteen qualities that rate the performance of an illuminance meter. Here we focus only on illuminance meter *spectral mismatch* from the CIE defined photopic response function.

In practice, a manufactured illuminance meter will always have some mismatch from the defined CIE photopic response function. Measurement of monochromatic light sources such as lasers, or lamps with spectral structure such as sodium lamps, emission lines in fluorescent lamps, or LEDs can have significant errors if the outputs of these sources coincide with a region where there is significant mismatch from the photopic response function. Errors will be smaller for smooth broad spectrum light sources, but will still occur.

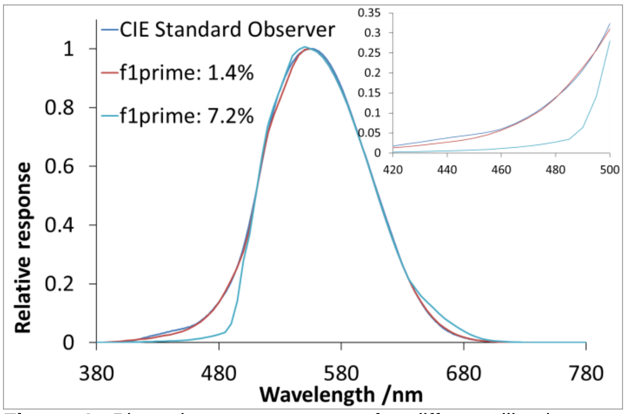


**Figure 1.** Photopic response curve for different illuminance meters.

Spectral response quality is defined by the $f_1'$ value, which rates the quality of fit using an illuminant A source. Instruments with $f_1'$ values between 3 % and 6 % would be considered medium quality, and those with values less than 3 % good quality [3]. Whilst low $f_1'$ values are desirable, they cannot simply be applied as a correction factor or uncertainty. These have to be considered individually taking into account the relative spectral responsivity of the meter, $R_{\mathrm{rel}}(\lambda)$, and the spectral distribution of a test light source, $S_{\mathrm{t}}(\lambda)$. If these are known, then with the CIE-defined photopic response function, $V(\lambda)$, and the known calibration source spectrum, $S_{\mathrm{s}}(\lambda)$, a correction, *C*, can be derived from the equation

$$C = \frac{\int S_{\mathrm{s}}(\lambda) R_{\mathrm{rel}}(\lambda) d\lambda \times \int S_{\mathrm{t}}(\lambda) V(\lambda) d\lambda}{\int S_{\mathrm{s}}(\lambda) V(\lambda) d\lambda \times \int S_{\mathrm{t}}(\lambda) R_{\mathrm{rel}}(\lambda) d\lambda}. \qquad (2)$$

If they are unknown, the light meter should only be used to measure the same type of light source as that used during its calibration. For a general purpose illuminance meter used in industry, this could potentially mean calibrating using an impracticable number of light sources.

See the measurement examples at the end of this guide for the likely magnitude of errors caused by this effect and the next section for custom calibration options.

## Traceability of MSL's Photometric Standards

The primary photometric unit is the candela, one of the seven SI base units established internationally. Its name originates from candles, which were the first photometric standards. Today it is defined by the BIPM as "The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 × 10$^{12}$ hertz and that has a radiant intensity in that direction of 1/682 watt per steradian." [4]

To realise the candela, MSL holds a local detector-based primary standard of illuminance responsivity – a set of three high quality illuminance meters with $f_1'$ values of 1.4 %. These are traceable firstly to MSL's detector spectral responsivity scale, which in turn is traceable to the MSL cryogenic radiometer – the primary standard for measurement of optical power. Additionally, these detectors require well-defined apertures of known area, traceable to MSL's length scale, and amplifiers traceable to MSL's electrical standards. As New Zealand's National Measurement Institute, this scale of illuminance responsivity has been verified by participating in international comparisons. All lamps and detectors used within MSL to provide photometric calibrations are traceable to this scale.

## MSL Illuminance Meter Calibrations

At the Measurement Standards Laboratory, light meter calibrations are performed under our IANZ scope of accreditation to ISO 17025:2005. Beyond the standard calibration against an illuminant A lamp, we are also able to offer calibration against the following light sources:

- cool white fluorescent lamp,
- warm white fluorescent lamp,
- daylight fluorescent lamp,
- daylight LED,
- cool white LED,
- 12000 K LED.

Other sources can be used for calibration if supplied by the client. For instruments with an analogue output, a spectral response calibration can be performed allowing accurate assessment of the spectral mismatch.

For general purpose illuminance meters it may be sufficient to use measurements from a range of different light sources, such as those listed above, to gain an indication of the likely magnitude of spectral mismatch error. Alternatively, coloured glass filters may be used to determine spectral mismatch. Whilst this information shouldn't be used to determine a correction factor for dissimilar light sources, it may be sufficient to gauge the measurement uncertainty due to spectral mismatch.

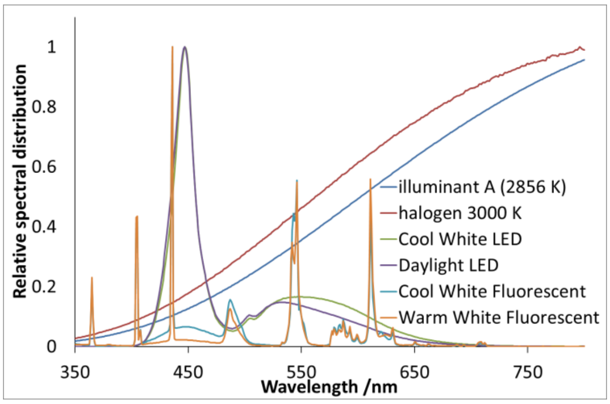


**Figure 2.** Spectral distribution of light sources available at MSL for illuminance meter calibrations.

New light meters are often supplied with the manufacturer's calibration certificate, but often these are the result of an adjustment performed at the factory using a tungsten lamp source, with no indication of accreditation to support confidence in the calibration.

## Examples of Spectral Mismatch

Using four white light sources with different spectral distributions, the Measurement Standards Laboratory conducted an assessment of spectral mismatch corrections for 14 instruments supplied for calibration. The results are presented in table 1.

**Table 1.** Spectral mismatch corrections obtained for instruments calibrated at MSL.

| | Spectral Mismatch Error | | | |
|---|---|---|---|---|
| Instrument | Cool White Fluorescent | Warm White Fluorescent | Daylight LED | Cool White LED |
| A | 0.3% | 0.6% | | |
| B | 7% | 7% | | |
| C | 5% | 12% | | |
| D | 2% | 1% | 2% | 0.9% |
| E | 0.0% | 7% | 13% | 22% |
| F | 15% | 17% | 23% | 13% |
| G | 2% | 1% | 2% | 0.9% |
| H | 1% | 1% | 0.6% | 0.1% |
| I | 0.6% | 0.2% | 0.8% | 1% |
| J | 1% | 2% | 1% | 1% |
| K | 0.5% | 1% | 2% | 0.8% |
| L | 2% | 3% | 2% | 3% |
| M | 3% | 3% | 2% | 2% |
| N | 12% | 14% | 3% | 3% |

As an example of how these errors occur, consider instrument E. If the spectral response of this instrument was similar to that in Figure 1, with an $f_1'$ value of 7.2 %, then the LED errors tabulated could be explained by the combination of instrument spectral mismatch between 380 nm and 500 nm, and the large peaks in the LED spectra shown in Figure 2.

For meters found to have significant spectral mismatch, strong consideration should be given to purchasing an illuminance meter with a lower $f_1'$ value.

## References


[1] CIE 15:2004 Colorimetry

[2] BS ISO/CIE 19476:2014 Characterisation of the performance of illuminance and luminance meters.

[3] Making Light Work, Automation & Control Magazine, October – November 2004.

[4] The International System of Units, 8th edition 2006, Bureau International des Poids et Mesures.


*Prepared by Neil Swift, June 2015*