MEASUREMENT CHALLENGES FOR ABSOLUTE PHOTOMETRY OF SOLID-STATE LIGHTING: SPATIAL DISTRIBUTION AND INTEGRATION

Paul Miller and Louise Wright

Optical Technologies and Scientific Computing Team, National Physical Laboratory, Teddington, TW11 0LW, UK

Traditional lighting metrics do not apply to solid-state lighting (SSL) luminaires because LEDs cannot be conveniently removed from the luminaire, and because LED performance depends on the thermal, electrical, and optical designs of the system or luminaire. The IESNA standard LM-79 "Electrical and Photometric Measurements of Solid-State Lighting Products" recommends the measurement of absolute total luminous flux (TLF) of the integrated luminaire, which can be carried out with an integrating sphere or a goniophotometer. The latter method is well documented for generic lighting products but several of the corrections recommended for goniophotometry must be reconsidered for SSL products.

The measurement of SSL products is complicated by the spectral intensity distribution of LEDs, and in particular their spatial variation and temperature sensitivity, the directional output, non-uniformity and, in some cases pulsed operation. The colour correction factor (CCF), is caused by the differences in the spectral intensity distribution of the reference and test sources and departures of the goniophotometer from true photopic response. With SSL products, this correction is further complicated by the fact that the spectral intensity distribution can vary spatially (luminaires are often “yellower” to the side and “bluer” for a direct line of sight). Furthermore both the spectral intensity distribution and the luminous flux can be affected by luminaire temperature and operational mode (pulsed or continuous).

For a reliable determination of the total flux it is necessary to carefully choose the number and distribution of the spatial measurement positions. In practice this requires a trade-off between ensuring an adequate number of spatial sampling points to capture the variation in the output of the source, and ensuring that the overall measurement time is sufficiently short that thermal stability effects are not significant. This trade-off can be improved by concentrating the measurements within the main “beam” of the luminaire, as long as the integration method is appropriate. If these effects are not considered sufficiently, errors will be present in the reported photometric properties of SSL. This can result in distortion of the luminous intensity distribution and light output ratio (LOR). Errors in CCF and spatial integration will lead to errors in total luminous flux (TLF) and therefore in claimed luminous efficacy.

NPL’s goniospectroradiometer is able to make full spectral measurements at a specified set of spatial positions. TLF is calculated by spatial (and spectral) integration of the measured spectral radiant intensity values. A procedure has been developed to optimise the choice of spatial points and the numerical integration. By calculating photometric quantities from spectroradiometric data, no correction is required for colour temperature.

Measurements have been made of several commercial SSL luminaires. These showed both a highly anisotropic luminous intensity distribution, as shown in Figure 1, and a correlated colour temperature (CCT) variation of over 20% with elevation angle.

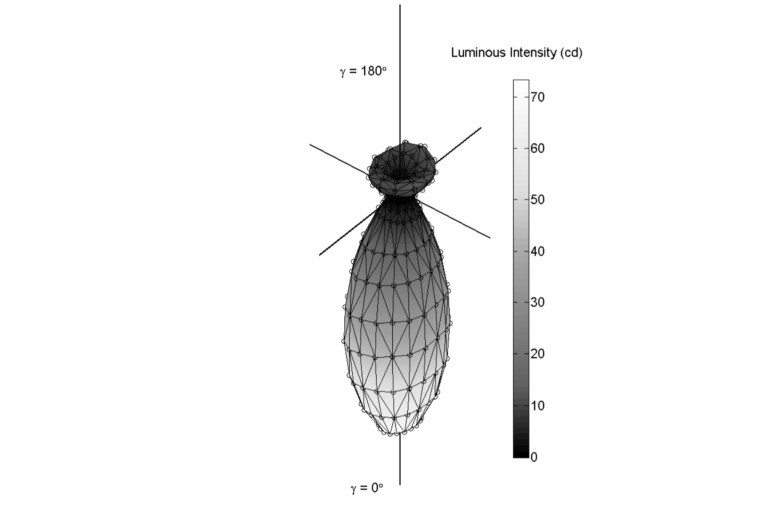

Figure 1. Measured luminous intensity distribution of a white LED cluster.

The highest CCTs were recorded directly underneath the source and the value decreased towards the equatorial plane. Had these measurements been made goniophotometrically, rather than goniospectrometrically, there would have been a considerable variation in CCF with angle. The variation in CCFs for this source with either the NPL goniophotometer or a commercially photometer are shown in Figure 2. This demonstrates a requirement to apply CCF as a function for angle, otherwise an error of up to 5% in TLF can be present. For uncertainties of less than 2% it is vital that a photometer with well matched photopic response is used.

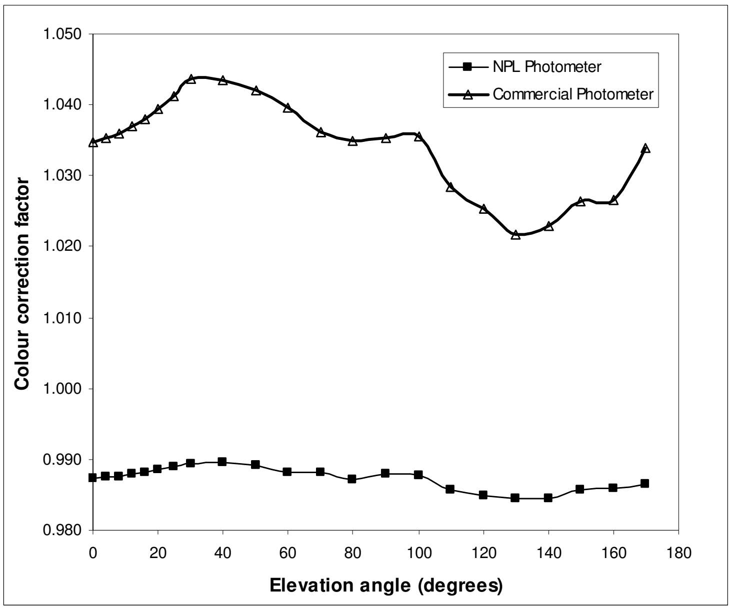

Figure 2. Variation in colour correction factor for a white LED cluster and two different photometers.

In this paper we describe a measurement procedure and mathematical method to enable appropriate selection of position and number of measurement points. A range of commercially available SSL products was tested using these goniospectroradiometric methods. Measurements of these sources were also made on NPL's two photometer based facilities – the short path goniophotometer and long path mirror goniophotometer. Comparison of these measurements demonstrate the impact of spatial and spectral non-uniformity of SSL sources on integrated quantities and requirements to correct luminous intensity distributions as a function of position.

The increased measurement time necessary for these measurements is a concern. Faster measurement is possible with multi-cell goniophotometers, but with the requirement to produce a CCF for each photometer. The impact of poorly matched photometers measuring a spatial and spectrally non-uniform source is such that calibration and correction of each photometer is required to accurately report the photometric properties of SSL luminaires.

Goniospectroradiometric measurements reveal non-uniformity of SSL products that may not be seen with goniophotometers. The work presented here demonstrates the requirement for calibration and correction of photometers as a function of angle. In addition our results should assist in making absolute measurements of SSL luminaires according to the spirit of the new standard.