Measuring the photometric quantities of an LED

Anyone who buys an LED lighting fixture will be confronted with a plethora of technical data. The only remedy is the establishment of standards to enable precise measurement of photometric quantities and the comparison of values.

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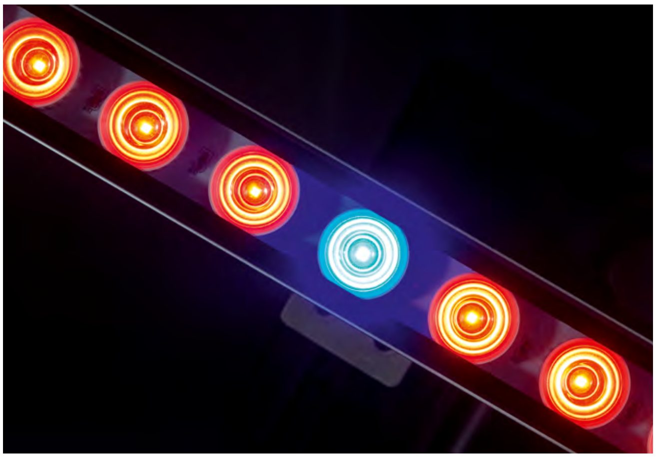

LED light sources: high-end measuring instruments are indispensable for consistent and highly accurate readings. Uniform and implementable standards also play a critical role.

Before the LED began its conquest of the lighting market, the world of incandescent light bulbs was simple. In the event of a defect it was an easy matter to purchase a 40W incandescent light bulb from the DIY store. But LED technology presents a new horizon: the user has to grapple with numerous new terms such as luminous flux, color temperature and color rendering index (CRI) as stated on the sales packaging, but not explained. The purchase of a 40W bulb became a “checklist for the purchase of a new LED bulb from a retailer” [1]. The user must familiarize him- or herself with the new quantities and terms, and expects consistency. That is in turn a challenge for the manufacturers of lamps and luminaires. How are these quantities correctly measured on a comparable basis? What constitutes a precise measurement?

Figure 1 shows a sample package of a LED bulb from a retailer. It provides information on the relevant optical quantities such as luminous flux and specifies the total optical power in the visible spectral range emitted in all directions, as perceived by the human eye. It replaces the wattage of the incandescent bulb: a luminous flux of about 800 lm is approximately equal to the brightness of a 60W bulb.

Likewise, the energy efficiency class is displayed with its own label. Besides the luminous flux and electrical power consumed, the spatial radiation properties of the sample are also important for assigning a light source to a specific energy efficiency class. An angle-dependent, goniophotometric measurement is necessary for the classification. Further quantities that are critical to the decision to purchase relate to the colorimetric range. The terms warm white, neutral white or cold white refer to the correlated color temperature, or CCT in short. The number in Kelvin provides guidance as to whether the bulb emits warm or cool light. The higher the Kelvin value, the cooler the lighting effect. The color rendering index R_a or CRI is also shown, and is often a source of confusion. This value is an indication of how naturally the colors of illuminated objects are reproduced. The maximum value of $R_a = 100$ is the most natural color rendering, but a value of $R_a = 80$ is normally sufficient. The color rendering index can only be determined with a spectrometer as used in sphere photometry.

Figure 1: Information on light fixture packaging can lead to confusion among consumers.

\\ OPTICAL MEASUREMENT WITH AN INTEGRATING SPHERE

The optical measurement of a LED-based light source with the aid of an integrating sphere is called sphere photometry (Figure 2). The spatial radiation properties of the light source are basically unimportant for this technology. The inner surface of the sphere, with the object to be measured in its center, is coated with a diffusely reflecting material such as barium sulfate [$BaSO_4$]. The light is reflected as often as possible on the walls, resulting in a mixing of light. This leads to an even luminous intensity on the sphere wall that can be measured with a suitable detector such as a high-end spectroradiometer with cosine-shaped response characteristics at any random position on the sphere wall. The sphere photometry is a relative measurement and requires a benchmark. The measured luminous intensity is calibrated with the intensity of a luminous flux standard lamp. The luminous flux of the test sample can thus be directly determined. If a spectroradiometer is used as a detector, spatially integrated colorimetric measurands such as CCT, CRI or color coordinates can also be determined.

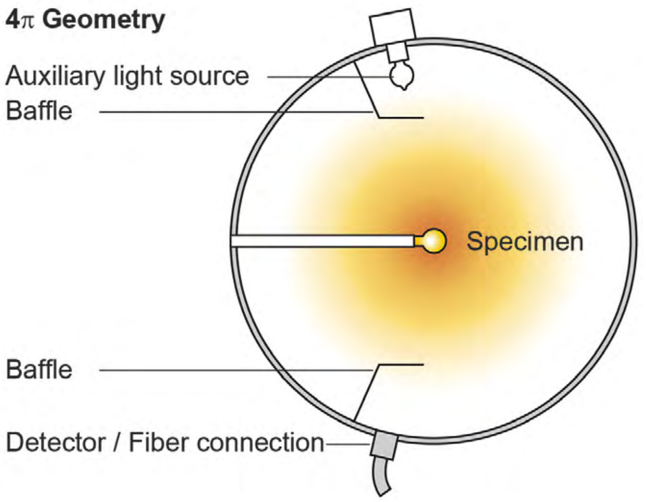

Figure 2: Fast measurements of luminous flux and spatially integrated colorimetric quantities are possible with sphere photometry.

Sphere photometry is an extremely fast measuring procedure and takes only a few milliseconds. The measuring equipment involved is relatively inexpensive and easy to operate. For this reason, this method is frequently used. However, sphere manufacturing calls for a high degree of quality and experience. The sphere typically contains apertures, openings for the detector and an auxiliary light source, and must be opened and closed. The configuration or design of these elements should be carefully thought out, as it has a direct impact on the quality of measurement. The correct burn-in of the light source, self-absorption correction and sphere size all contribute to measurement quality and are potential sources of error.

Each light source should be allowed sufficient time for burn-in prior to measurement. If this is neglected, measurement errors in excess of 10% may occur. The optical radiation and electrical power consumption of the light source that is burning in should be observed over a standard defined period of time, and certain fluctuation limits in this period should not be exceeded. Only then can the light source be deemed stable. The sphere must be kept open during burn-in to avoid a heating effect. If the light source is stable, the sphere is gently closed and the measurement can begin.

\\ SELF-ABSORPTION AND SPHERE SIZE

The larger and darker a light source, the more optical radiation it absorbs, including self-emitted. This portion is missing in the measurement. Self-absorption must therefore be determined individually for each test sample with a so-called auxiliary light source and this behavior corrected in the measurement. Here again, double-digit errors are not uncommon. A spectral broadband halogen lamp is normally used as an auxiliary light source. The measurements in the sphere are compared with and without the auxiliary light source, and are used to calculate a spectral correction factor. In good sphere systems this routine and calculation is assumed by the software.

The size of the sphere used must be selected to accord with the size of the test object. The larger the test sample, the larger the sphere should be, enabling the measuring principle of multiple reflections. A sphere that is too large may have an inadequate optical throughput, resulting in a reduction in the signal-noise ratio. Tips and guidelines for the size of the sphere are to be found in the relevant measurement standards. A surface of the light source that is no more than 2% of the inside surface of the sphere is recommended. In the case of doubt, a larger sphere should be selected.

\\ GONIOPHOTOMETRY AS AN ABSOLUTE MEASURING PROCEDURE

In contrast to sphere photometry, goniophotometry is an absolute measuring procedure. A luminous flux standard is not needed. In contrast, standard lamps for the luminous flux are calibrated with goniophotometers. In addition to luminous flux, the photometric spatial radiation properties, so-called luminous intensity distribution curves, and the colorimetric distribution of emitted radiation of the light source can be determined with the aid of goniophotometry. Besides total luminous flux, it is also possible to measure partial luminous flux, i.e. the photometric radiant flux in a restricted solid angle range. Partial luminous flux is needed, for example, to determine the energy efficiency class of a test sample.

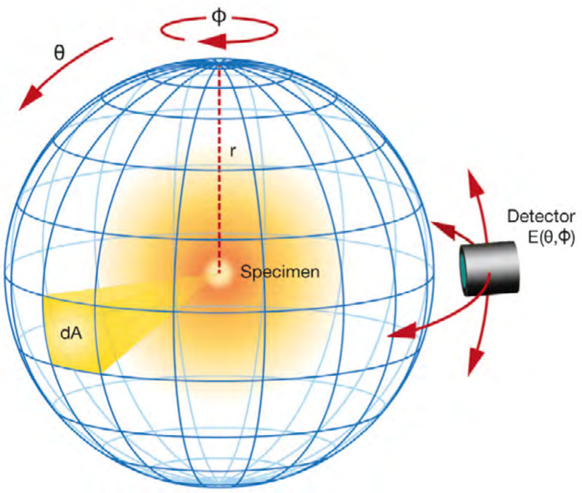

Figure 3: Goniophotometry offers higher measurement accuracy and enables the comprehensive characterization of luminaires.

Measuring principle: The detector is located at a fixed distance from the light source and rotated around the latter (equivalent: the light source is rotated around the stationary detector). In a given grid it measures the spectral irradiance under different angles (Figure 3). This full set of angle-dependent data enables all characteristic values such as luminous intensity distribution, colorimetric distribution, luminous flux and partial luminous flux to be calculated. For this purpose, the relationship of detector size irradiance E and source size luminous intensity I ($I = E \times r^2$) of the test sample in the far field is exploited. The far field is defined by the so-called photometric limiting distance, from which the test sample can be regarded as a point light source. Accordingly, a large light source has a large limiting distance. As a general rule of thumb: the distance is 10x larger than the maximum reach of the light source. A 50 cm sample requires a measuring path of at least five meters.

\\ GONIOPHOTOMETRY VERSUS SPHERE PHOTOMETRY

Goniophotometry is an almost all-embracing measuring procedure that achieves a higher level of precision compared to sphere photometry. Various far-field goniophotometer models are available, such as mirror goniometers or goniometers with a moving detector. They are compact and easy to operate, and have multiple uses. The turning luminaire is the most widespread version. In all versions the goniophotometric measurement is time-consuming: from several 10 minutes to hours. Furthermore, they call for expensive measuring equipment and involve complex procedures. Nor is goniophotometry free from typical error sources: while correct burn-in of the light source is equally important as in sphere photometry, the square of the distance between the detector and the light source is entered into the measurement equation and thus has a major influence on the anticipated result. For this reason, a precise laser range finder should be used that allows for the calibrated reference surface of the detector and precise determination of the light-reflecting surface of the test sample.

Further error sources are to be found in the equipment of the measurement laboratory and in the burning position of the test sample. The measurement laboratory must permit good extraneous light suppression, be adequately dimensioned and preferably have a highly absorbent black finish (Figure 4). Reflections on the wall behind the goniometer are frequently overlooked. The wall is located as far as possible from the detector, but in a direct beam of light from the source. Even with a stray light shielding tube, reflected extraneous light is easily detected and can seriously impact the measurement. If a turning luminaire is used, possible position dependence of the test sample must be taken into account. Some light sources require a constant burning position or require correction if the test sample is moved. With passively cooled LED bulbs, the reason for this position dependence is usually interruption of the convective air flows by the cooling fins. Measurements of such light sources should be corrected by the so-called auxiliary photometer procedure.

Internationally recognized measurement standards are fundamental to satisfactory and comparable readings. For sphere- and goniophotometry the most important standard is CIE S025. This standard contains no restrictions in the measurement techniques to be used.

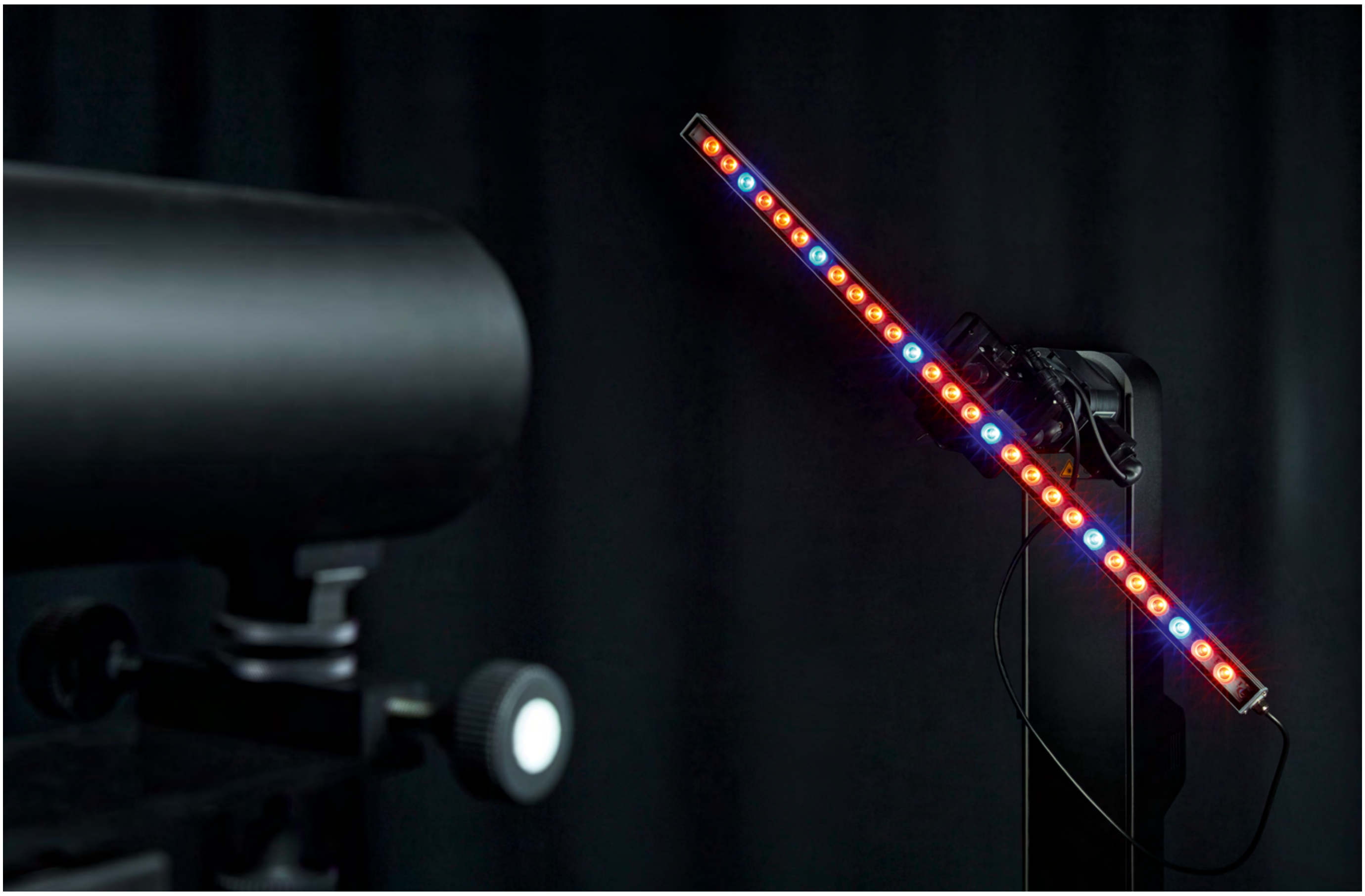

Figure 4: Turning luminaire with a detector tube. Insufficient extraneous light suppression is a typical source of error in the measurement lab.

Methods that are not explicitly mentioned may also be used if proof of equivalence to established methods is furnished. CIE S025 was the first to require the user to prepare a detailed measurement uncertainty budget according to ISO/ IEC Guide 98-3 (GUM) or CIE 198. The standard defines the requirements for measurement setups by standard test conditions and tolerance intervals. There is a benchmark and a tolerance interval for each standard test condition. Reducing the tolerance interval by this measurement uncertainty results in the acceptance interval (Figure 5). A measurement conforms to the standard when it lies within the acceptance interval. This is larger for high-end measuring instruments, which simplifies the measurement: a measurement only conforms to the standard if it lies within the acceptance interval.

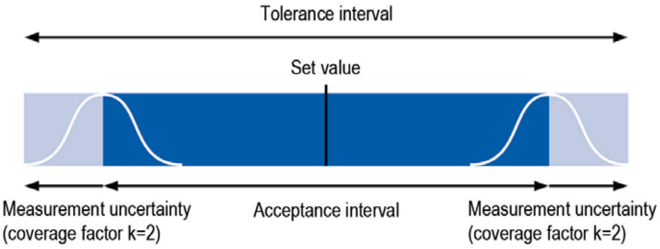

Figure 5: Reducing the tolerance interval by this measurement uncertainty results in the acceptance interval. A measurement conforms to the standard when it lies within the acceptance interval.

\\ MEASUREMENT UNCERTAINTIES AND THE QUALITY OF RESULTS

Metrologists must pay special attention to measurement uncertainties. Each measurement incurs measurement uncertainties, and a reading is only final when it is accompanied by an estimation of measurement uncertainty. The detailed list of measurement uncertainties should conform to the Guide to Measurement Uncertainties (GUM) that specifies the evaluation of measurement quality, the test sample and its quality. If the measurement uncertainty is considered in detail, a comparison of results from various different measurement labs and an assessment of conformity standards (good/poor evaluation of tolerance intervals) is possible. It also enables the measurement setup to be optimized. Dominant contributions can be identified and reduced.

\\ REFERENCES

[1] Federal Ministry for Economic Affairs and Energy
www.deutschland-machts-effizient.de

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