ANALYSIS OF COMPACT AND PORTABLE GONIOSPECTROMETER SYSTEM FOR TEST OF LED LAMPS

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Abstract

An experimental investigation of a compact and portable goniospectrometer system is described. Measurements are performed in two very different conditions, in a normal office environment and in a photometry laboratory under standard environmental conditions and both are compared to reference measurements in a near-field goniophotometer. A collection of six different types of directional and non-directional integrated LED lamps with three samples of each were used as test devices. It is shown that the main uncertainty comes from the inadequate thermal stabilisation of the LED lamps. With pre-heating relative differences for total luminous flux of ±2,5% were obtained. Reliable photometric data can be obtained for use in market monitoring to identify probable non-compliance LED lamps and hence as an improved method for selecting LED lamps for accredited verification testing.

Keywords: LEDi lamps, Goniophotometry, Goniospectrometry, Solid State Lighting

1 Introduction

The increasing energy efficiency and high light quality of white LEDs is driving the Solid State Lighting (SSL) market, which is growing rapidly. However, the market shows large variations in the quality of LED based products with respect to energy efficiency, total flux and light quality and not all are in compliance with the regulations. The availability of reliable and accurate photometric data for LED devices is a basic requirement for evaluating performance of these products. The new CIE International Standard “Test Method for LED Lamps, LED Luminaires and LED Modules” (CIE 2015) has established the foundation for this.

The growing market is an increasing challenge to the national market monitoring, verification and enforcement (MV&E) programmes, with store monitoring and not many SSL products are going through verification testing since accredited tests of 20 samples of SSL products are very costly and time consuming. In 2014 only 15 directional light sources (DLS) were tested for verification under the Danish MV&E programme (SEE 2014). The complexity of SSL testing of DLS has been increased due to the EU regulations (EU 2012, EU 2012) that require the useful or partial luminous flux to be measured in either a 90° or 120° cone. This means that goniophotometric measurements are required and makes accredited test of LED lamps time consuming, more costly or in some cases unavailable. There are many different goniophotometer systems available and in the CIE test method (CIE 2015) a far-field vertical type C goniophotometer the reference type. In this the device under test is rotated around the vertical axis. Other types of goniophotometers, e.g. near-field goniophotometers and horizontal type C (POIKONEN, 2012) can be used if equivalence to the reference can be demonstrated.

Accredited tests are not always required for all purposes. Hence the possibility of fast and simple photometric measurements is interesting in many cases. It could e.g. be in the market surveillance work performed by national MV&E programmes, where fast and simple photometric measurements at the point of sales could be a valuable tool to complement document and package information review. This is why the Danish Energy Agency has decided to invest in the compact and portable goniospectrometer system for measurement of small light sources, e.g. LED lamps. The system is called LightSpion from Viso Systems. Employees at the Center for Ecodesign and Energy marking (SEE), which are running the MV&E programme in Denmark, are trained in using it. The measurement facility gives the possibility to do a fast and simple investigation of many more LED lamps and through that get a broader overview of how these comply with the demands. These measurements cannot be used as an accredited market surveillance test, but can be used to start a dialog with the supplier. The system makes it possible to perform measurements at the point of sale and start a more detailed dialog on the lamp properties based on the measurement results. Further the measurement results are used as a background for choosing the light sources that are selected for a full verification test measurement in an accredited test laboratory. In order to be able to use the measurements results a more detailed knowledge on the use of the portable facility is needed and the achievable measurement uncertainty under different environmental conditions. This is the purpose of this paper, and in the following section the method applied is described, including the LED lamps used as test devices, the portable goniospectrometer and reference measurements in a near-field goniophotometer. Results on the total luminous flux are compared with the reference measurements.

2 Method

In order to investigate the achievable measurement uncertainty of the portable goniospectrometer system an experimental investigation of a collection of six different types of integrated LED lamps with three samples of each were performed. In this experimental investigation the portable goniospectrometer system has been used under two very different conditions. Firstly, under operation in a normal office environment with daylight and artificial light with a non-stabilized power supply and performed by a person not being a photometry expert called condition A. Secondly, the same measurements were performed in a dark photometry laboratory under standard ambient conditions (CIE 2015) with a stabilized power supply called condition B. A near field goniophotometer (Rigo-801, Technoteam) in the same photometry laboratory is used to perform reference measurements on the DUTs. The most important and influential measurement conditions are summarized in Table 1.

Table 1– Description of conditions for the portable goniospectrometer and the reference measurements.

	Cond. A	Cond. B	Ref.
Ambient temperature	Not monitored	25ºC ±1,2ºC	25ºC ±1,2ºC
Supply voltage	Not stabilised 230 V ±3%	230 V ±0,1%	230 V ±0,1%
DUT stabilisation	None	1 h pre-heating	<0,5% over 15 min.
Operator	Non-skilled	skilled	skilled

Through the goniophotometric and goniospectrometric measurements the DUTs are tested for the following photometric and electrical parameters as described in (CIE 2015):

- Total luminous flux [lm]
- Partial luminous flux [lm]
- Active power [W]
- Luminous efficiency [lm/W]
- Peak intensity [cd]
- Beam angle [deg]

The investigated LED lamps, the portable goniospectrometer system and the reference near-field goniophotometer system are described in the following sections.

2.1 Test LED lamps

Six types of integrated LED lamps are used as devices under test (DUT) in this experimental investigation. They were purchased on the Danish market in 2012-13 by the SEE. Three samples of each LED lamp type were tested. The DUTs includes both directional light source (DLS) and non-directional light sources (NDLS). A DLS is a light source that emits a least 80% of the total flux within a solid angle of π sr, which corresponds to a cone with an angle of 120°. And from this a NDLS is a light source that is not a DLS. The main characteristics of the DUT types are shown in Table 2, with the DUT id number, cap type, size (diameter and length), nominal power and luminous flux, beam angle. From the goniophotometric measurements is has been established whether they are DLS or NDLS. All DUTs are tested at 230 V.

Table 2 – Description of the six different DUTs as given on the packages, incl. cap type, size (diameter and length), nominal power and luminous flux, beam angle and directionality.

ID	Cap	Size	P_{nom}	Φ_{nom}	Angle	Dir.
		[mm]	[W]	[lm]	[deg]	
L30604-06	E27	60x108	7	470	270	NDLS
L30607-09	GU10	50x52	3,3	160	100	DLS
L30610-12	E27	60x100	10	810	-	NDLS
L30613-15	E27	50x74	1,6	-	-	DLS
L30616-18	GU10	50x64	7	400	36	DLS
L30619-21	GU10	50x58	3	200	-	DLS

The DUTs have not been seasoned before being tested in both the portable goniospectrometer and in the reference near-field goniophotometer.

2.2 Portable goniospectrometer

A photo of the portable goniospectrometer system in operation is shown in Figure 1. The system is fitted within a suitcase of dimensions 43x11,5x33,5 cm (L x W x H) and with a weight of 5 kg. When it is opened it extends the detector position to a distance of 66 cm.

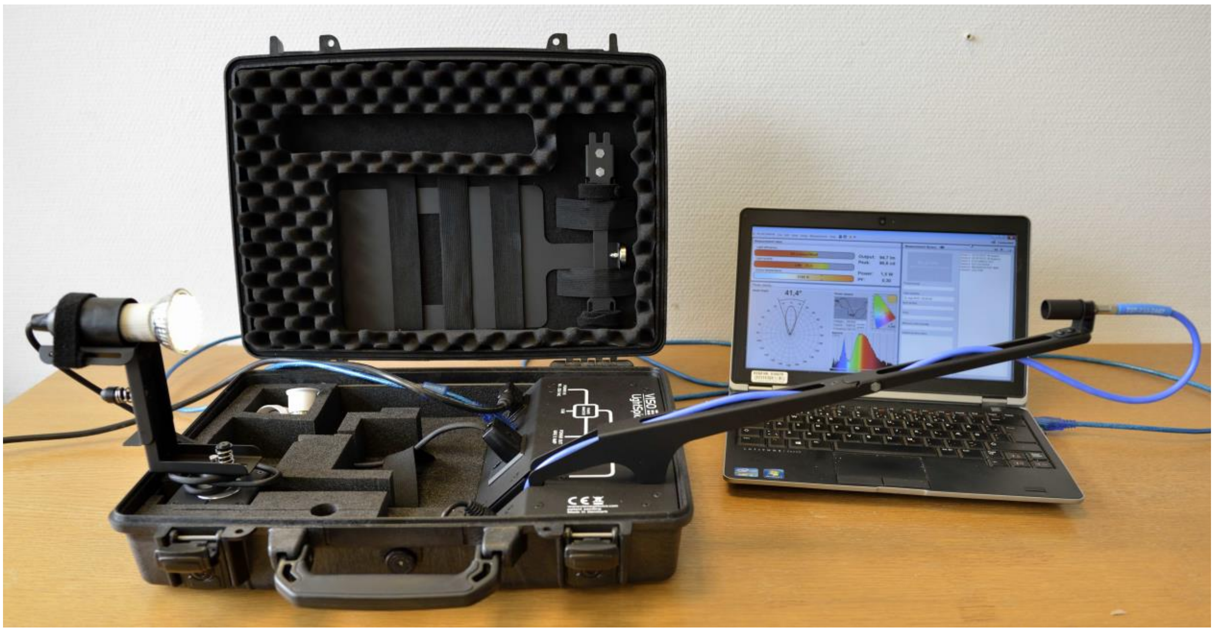

Figure 1 – Photo of the portable spectrometer system in operation with a laptop computer controlling the measurement.

It is a horizontal type C goniospectrometer system where the DUT is mounted with the optical and mechanical axis horizontally, and on a rotational stage that controls the rotation about the vertical axis. Only manual adjustment of the rotation of the DUT about the horizontal axis is possible. In normal conditions for DUTs with rotational symmetry only a single plane is measured. For non-rotational symmetry lamps there is an option to measure in more than one plane, but it requires manual turning of the DUT.

The detector is an input optics including a diffuser for an optical fibre that is connected to an array spectrometer (STS, Ocean Optics). In order to achieve a high throughput the detector assembly does not have a cosine response but a limited field of view, which sets a limit on the diameter of DUT of maximum 80 mm. The system is intended to be able to measure with ambient lights turned on through a zero correction at the start of a measurement. A normal measurement in one plane takes about 1-2 min.

A USB connected computer controls the operation. The system can be powered by supply input of 90-260 VAC at 50/60 Hz and the DUT is tested at the supply voltage and is hence not stabilised. The system includes a power analyser with a voltage range of 30-400 VAC measuring the voltage and current time dependence and power factor. Through the spectrometric measurements the system also measures the average colorimetric parameters; chromaticity, correlated colour temperature, and colour rendering indices.

2.3 Reference measurements

A near-field goniophotometer (Rigo-801, TechnoTeam) in the photometry laboratory is used to perform reference measurements on the DUTs. The goniophotometer incorporates a high dynamic range photometer (f_1' < 1,2 %) for total luminous flux measurements. It is calibrated with a total luminous flux standard halogen lamp and the estimated uncertainty is estimated to be ±4% (k=2). The system is type C in that the DUT is fixed in position in the center of the goniophotometer and can be oriented in any direction according to the desired operation. They DUTs have been measured with the base up. The detector distance is 1,45 m and hence the small DUTs (< 60 mm diameter) investigated here are measured in the far-field with the photometer. The luminous intensity distribution (LID) can be obtained directly from the photometer measurement or as normally done in the near-field goniophotometer with larger DUT through the luminous camera images of the DUT. The angular resolution is 0,1 deg in both angular directions. The goniophotometer is installed in a dark room with standard environment with an ambient temperature of (25 ±1,2)ºC and a relative humidity of maximum

65%. The DUTs are supplied with a stabilised AC power supply (Elgar) and a power analyser (PM1000+) is used for voltage, current and power measurements.

3 Results

Measurements have been performed on six different types of LED lamps, using the portable goniospectrometer system in both a normal office environment and in the photometry laboratory environment. In the normal office environment (condition A) measurements were performed immediately after turning on the DUT (1st) and then two subsequent measurements (2nd and 3rd) were performed with no recording of the time elapsed. In the photometry laboratory environment (condition B) the DUTs were pre-burned (Pre) for more than one hour and for another 5 minutes after turning on the DUT in the portable goniospectrometer. Further a stabilised AC power supply was used. Reference measurements have been performed in the near field goniophotometer, where the flux and power stability according to (CIE 2015) was established prior to the measurements. The relative differences to the reference values of the measured total luminous flux for the condition A, 1st and 3rd measurement, and condition B measurements are shown in Figure 2 for the 18 DUTs.

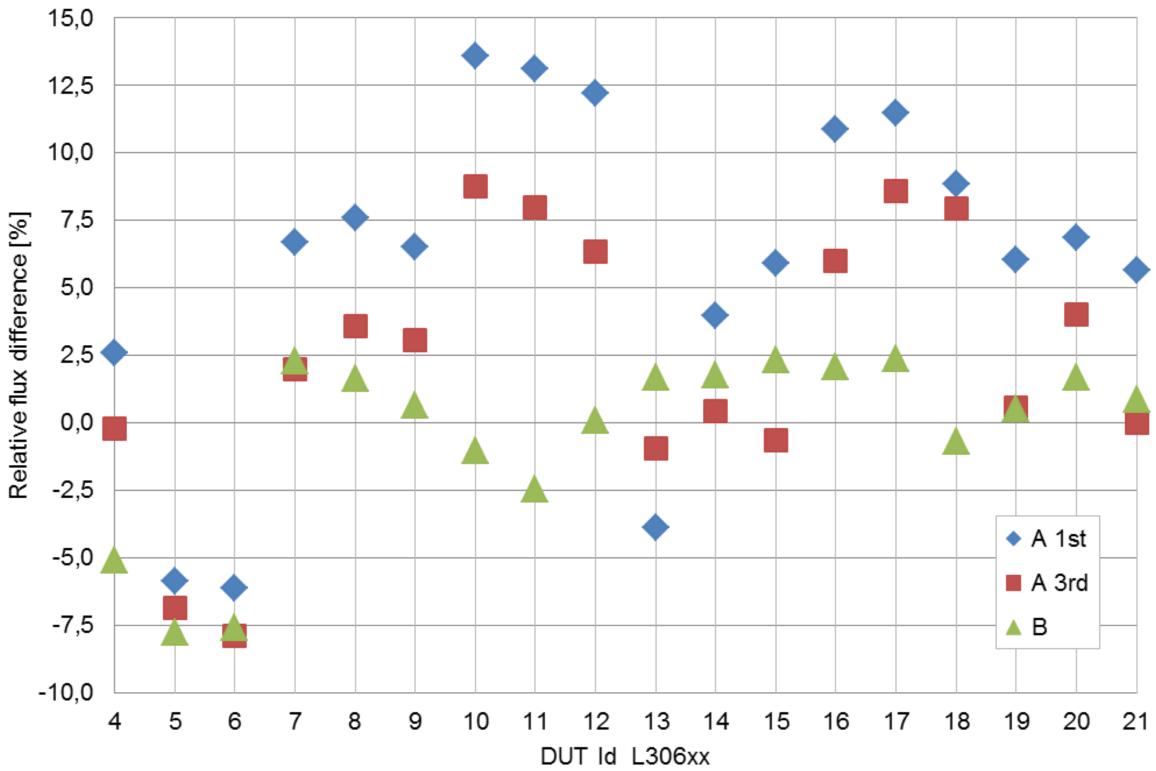

Figure 2 – Relative differences of total luminous flux for DUTs for the three different measurements.

The largest relative differences are observed for the condition A 1st measurement for all DUTs, with the exception of DUT with id 4-6 and 13. The maximum difference is 13,6 % which is observed for DUT 10 indicating an overestimation of the luminous flux. The condition A 3rd measurements generally shows lower and positive differences while the condition B measurement show the lowest differences. For some DUTs the 3rd and B shows equally low differences. The observations are consistent with the fact that the luminous flux is highest immediately after turn on of an LED lamp and that the flux decreases as the LED lamp heats up and finally reaches thermal stability. Figure 3 shows the measured illuminance as a function of time after the DUT is turned on and it has been normalized to the value measured at t = 0. A single representative measurement is shown for each type of DUT. It shows the general decrease in flux or illuminance as the DUT thermally stabilises over time. It is observed that for all except L30610, a stabilised value is reached after 35-50 min, given by a change of less than 0,5 % over a 15 min. time interval. A large difference in the stabilized values is observed for the six different types of DUTs.

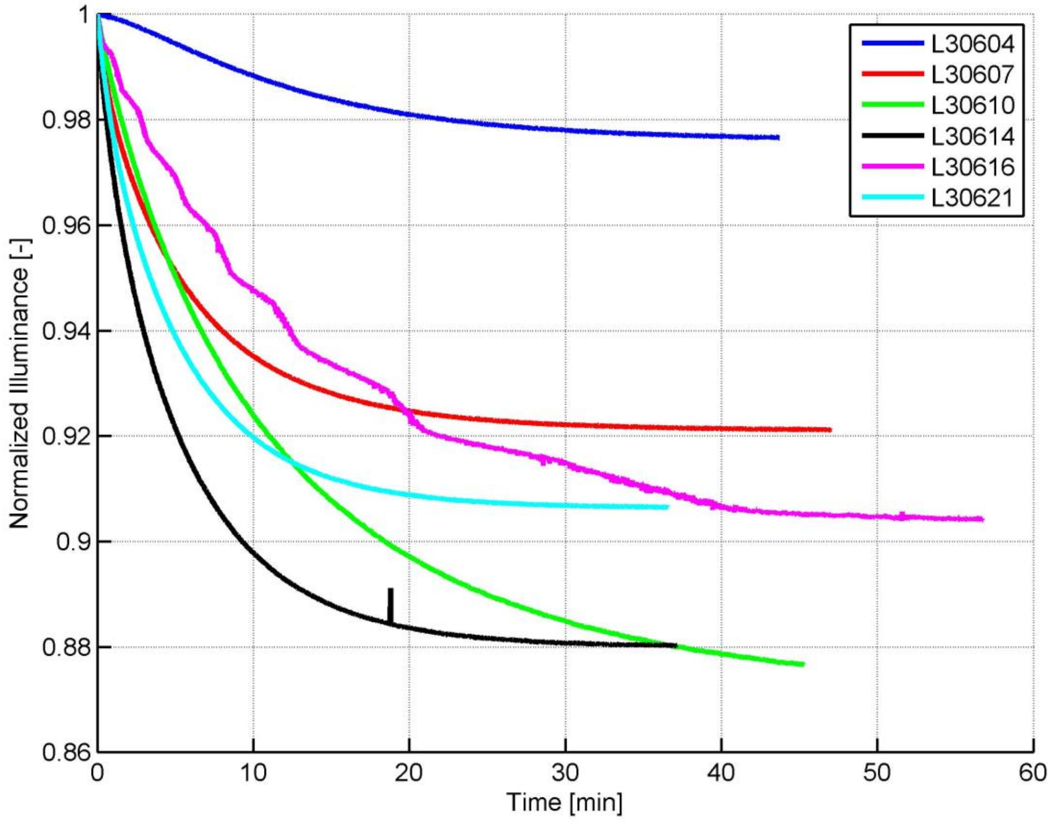

Figure 3 – Measured normalized illuminance as a function of time after the DUT is turned on.

The minimum change in flux is 2.4 % for L30604, and the largest of 12 % is observed for both L30614 and L30610. The latter does not show stability with in the measurement time of 45 min. Slightly different time behaviour is observed for L30616, which may be caused by feedback electronics in the LED lamp. From these measurements it is expected that the preheating of min. 1 h in condition B is adequate for reaching stability for the DUTs investigated here. The relative differences for condition B in Figure 2 are seen to vary by ±2,5 % and the average difference is -0,4%. For some of the condition A 3rd measurements the relative difference are equally low indicating that stabilisation was reached at the 3rd of the subsequent measurements. Hence the relative differences in the measured total luminous flux can be lowered by 3-4 times by allowing the LED lamp to thermally stabilise in the portable goniospectrometer instead of just doing the measurement just after turning the LED lamp on.

The same analysis has been performed on the luminous efficiency, e.g. the ratio of the total luminous flux and the active power and given in [lm/W]. The relative difference to the reference value of the measured values in condition A, 1st and 3rd measurement and under condition B are shown in Figure 4. Here much larger differences are observed than for the luminous flux measurement. An overestimate of the luminous efficiency of up to 21% is seen for L30615 in the condition A 1st measurement. The average value for this measurement is a 9,7 % overestimate. In condition A 3rd measurement the average is lowered to around 6,1 %. In the condition B with pre-heated DUTs and standard environment conditions the average difference is around 3,8 % with both over- and underestimates. So the general dependence is the same as for the luminous flux,

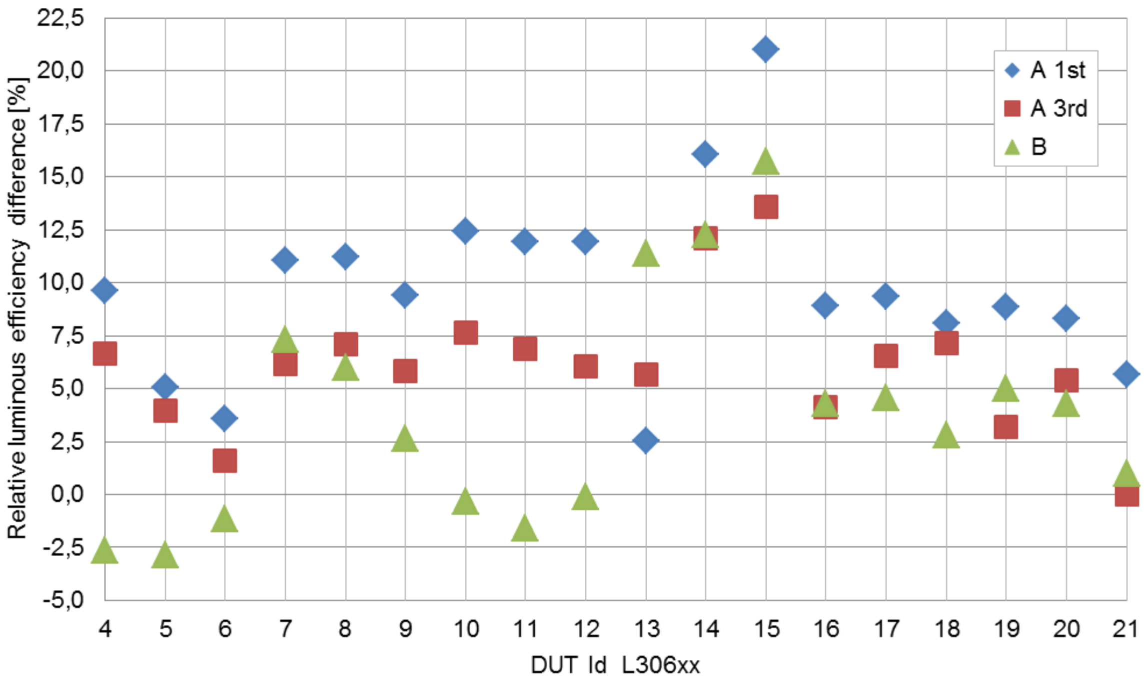

Figure 4 – Relative differences of luminous efficiency for DUTs for the three different measurements.

4 Discussion and conclusion

An experimental investigation and analysis of a compact and portable goniospectrometer system have been performed. Three samples of six different types of integrated LED lamps have been tested including both directional and non-directional light sources (DLS and NDLS). Measurement results using the portable goniospectrometer in two different operation conditions have been compared to the reference measurements from a near-field goniophotometer. Large relative differences of up to 14 % in overestimation of the total luminous flux were observed when using the portable goniospectrometer in an office environment without preheating of the LED lamps. This difference was primarily caused by the non-stability of the DUT, and subsequent measurements shows lower differences. Low differences of ±2,5% were observed when preheating of the DUTs and using the portable goniospectrometer in a photometry laboratory environment under standard conditions.

The investigation shows that the portable goniospectrometer can be used for fast measurements in non-laboratory environments and performed by non-photometric experts. It can give reliable photometric data and it can be improved by letting the LED lamps warm up prior to the measurements. Otherwise large overestimates of in average 5,9 % on luminous flux and 9,7 % on luminous efficiency. After pre-heating in laboratory conditions these are lowered to -0,4% and 3,8 % respectively. It could be advisable to implement a monitoring of the variation in illuminance and active power in the software of the portable goniospectrometer. The fast measurements, however, may be adequate in many cases for product investigation in market monitoring programmes where it could be used at the point of sales. The results can be used to identify probable non-compliance LED lamps and hence as an improved method for selecting LED lamps for accredited verification testing. The system makes it possible to measure the total and partial luminous flux as well as the average colorimetric parameters colorimetric parameters; chromaticity, correlated colour temperature, and colour rendering indices, equally important in the monitoring process.

Further comparisons will be made on the light intensity distributions (LID), partial flux, beam angle and possibly on the colorimetric parameters. Uncertainty budgets will be set up for the measurements on specific DUTs in the different measurement setups. The experimental investigations will be supplemented with measurements on LED lamps with non-rotational symmetry. Further the photometric and electrical data and LIDs will be used to demonstrate equivalence of the portable goniospectrometer to a traditional type C far-field goniophotometer as required in the new test standard (CIE 2015).

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