PHOTOMETRIC AND ELECTRICAL PERFORMANCE OF LED LAMPS FOR REPLACEMENT OF GU10 HALOGEN SPOT LAMPS

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Summary

This paper presents the results of photometric and electric tests of various LED lamps that promoted as replacements of the widely used halogen reflector lamps with GU10 base. The tests included the luminous flux, the maximum luminous intensity, the colour temperature, the colour rendering, the luminous efficacy as well as major electric characteristics. The tests show that the lamps produce the nominal luminous flux and the maximum luminous intensity. Issues are raised in colour rendering as well as in the power factor and the harmonic distortion of the current. In general, all tested lamps can be acceptable replacements of a halogen GU10 lamp with some compromises.

1. Introduction

The technology of LEDs has increased rapidly in the past ten years. At the beginning, the luminous efficacy of LED was nearly 30 lm/W, while now days most of commercial available types reach easily 100 lm/W (bare led) [1]. Furthermore, the European Eco Design regulations will ban low efficacy lighting sources, including halogen lamps, from the market in the next years [2]. The most characteristic type of them is the halogen PAR16 reflector lamp with GU10 base. The above mentioned type of lamp was used for years not only in professional lighting but also in households. For these reasons the penetration of a huge number of LED lighting products in the market, such as modules, lamps and luminaries is rapid. However, the compact size, the warm colour and the excellent colour rendering are the strong advantages of halogen lamps. Many lamp manufacturers around the world introduced few years ago some LED lamps in order to replace the halogen one after their future ban. The effort of the manufacturers is still to develop a LED lamp with the same characteristics of the traditional halogen, such as dimming, color rendering index except from its low luminous efficacy. So, can the switch of halogen lamps to LED to be carried out without any misapprehension? The present paper tries to focus on this issue using experimental procedures.

2. Tested lamps

The tested lamps were selected between various models of branded GU10 LED lamps. These lamps claimed to be the replacements of the traditional 50W Halogen GU10 reflector lamp. The above products were found in the market in February, 2012. The selection of the tested lamps was based on their photometric characteristics. The selected lamps are shown in Fig. 1 and their electrical and photometric characteristics are shown on Table 1. Two lamps of each type (total 12 lamps) were used in the experiments.

Philips Megaman G. Electric Toshiba Sylvania Osram Halogen

Fig. 1. Photographs of the tested LED lamps and a typical Halogen reflector lamp.

Table 1. Characteristics of the tested LED lamps according to the manufacturers

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**OSRAM**	**Halogen**
Power	***(W)***	8.5	8.0	7.0	8.0	6.5	10	50
Luminous flux	***(lm)***	275	380	310	300	380	350	350
Luminous efficacy	***(lm/W)***	32	48	44	38	58	35	7
Beam angle	***(^{o})***	35	35	40	35	35	36	35
Max luminous intensity	***(cd)***	530	900	650	600	750	950	900
Colour temperature	***(K)***	3000	2800	3000	3000	2700	3000	2700
Colour rendering R_a		>80	>80	>80	>80	>80	>80	100

3. Electrical measurements

The first step was to measure the electrical characteristics of the lamps: supply voltage, lamp current, apparent power, active and reactive power, power factor and the total harmonic distortion (THD) of the current (Table 2). The last column contains the electrical characteristics of a typical 50W halogen for a direct comparison.

Table 2. Measurement of the electrical characteristics of the tested LED lamps.

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**Osram**	**Halogen** *(typical)*
V_{rms}	*(V)*	230	230	230	230	230	230	230
I_{rms}	*(mA)*	55	49	46	42	34	44	220
P	*(W)*	8.7	7.7	7.0	8.2	6.6	9.6	50
S	*(VA)*	12.6	11.4	10.6	9.6	7.7	10.0	50
Q	*(VAr)*	-9.1	-8.4	-8.0	-5.0	-4.0	-3.0	0
PF		0.69	0.68	0.66	0.85	0.85	0.95	1.00
$THD_{current}$	*(%)*	69	69	80	53	53	30	0

A FLUKE Norma 4000 power analyzer was used for this purpose. Each lamp was fitted to a bare GU10 socket that was connected to the power analyzer. A voltage stabilizer (230V

AC) was used as power supply. The lamps did not fitted to any housing or any type of luminaire in order to avoid thermal stress of LEDs. Before the measurements, each lamp was operated for at least one hour.

4. Photometric measurements

4.1 Measurement of the luminous flux

The measurement of the luminous flux was carried out using a goniophotomer (Fig. 2). The first step was to measure the distribution of the luminous intensity of each lamp. Each measurement was performed in CIE C-planes with 15^{o} steps of C-planes and 2.5^{o} of gamma angles [3]. The lamps were left to operate until their luminous intensity stabilized. In some cases, this took more than one hour. The luminous flux was then calculated with integration of the above measurements. The result of the luminous flux measurement (averaged values from two measurements) are presented in Table 3.

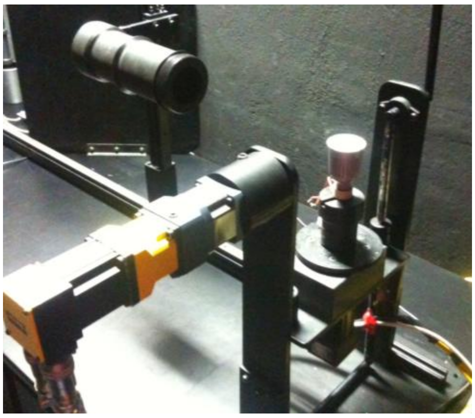


Fig. 2. The goniophotometer for the measurement of the luminous intensity distribution of the lamps.

Table 3. Measured and calculated photometric quantities of the tested LED lamps.

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**Osram**	**Halogen** *(typical)*
Luminous flux	***(lm)***	308	309	312	303	368	353	350
Luminous efficacy	***(lm/W)***	35	40	45	37	56	37	8
Max luminous intensity	***(cd)***	679	791	677	787	745	786	600

Average values from measurement of two samples of each lamp type.

4.2 Measurement of the spectral distribution

The spectral distribution was measured using the high precision spectrometer ORIEL Instruments, MS260i 74086, with 1nm step. The results are shown in Fig. 3. The curves are normalized to the maximum spectral power of each measurement. Each sub-figure contains the spectra of 2 samples from each lamp type.

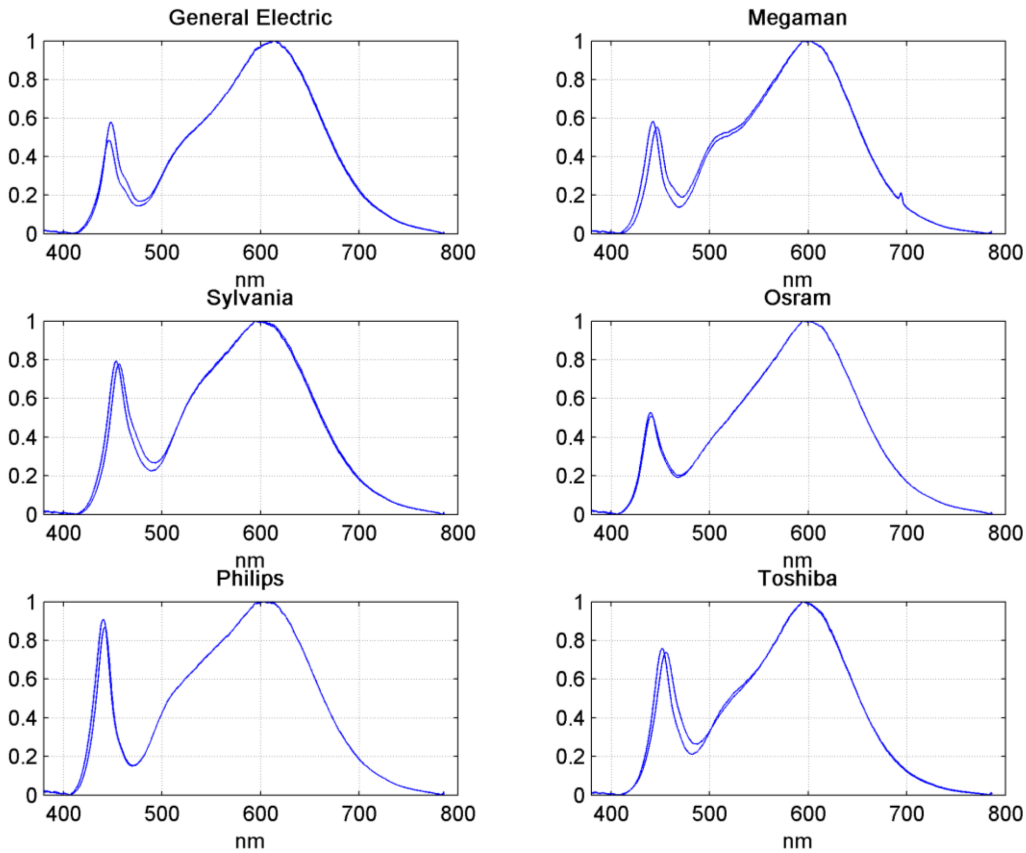


Fig. 3. Measurement of the spectrum of 2 samples from each lamp type.

4.3 Colour temperature and colour rendering index

One of the most important factors of the selection of a lamp is the colour rendering index. In other words, in some cases, is needed to have an accurate reproduction of the colours inside a room using the artificial light. The halogen lamp, as an incandescent lamp, has excellent colour rendering index (R_a=100). The issue with the LEDs as well as with other light sources is their capability to produce accurate colours. This depends on lamp's spectral distribution. The measurement of the spectral distributions was performed in order to check the capability of each lamp for colour reproduction and to calculate the R_a index.

The R_a was calculated based on the rendering score of each lamp to each of 15 standardized CIE colour targets. In other words, it was tested how accurate the light source reproduces the colour of each standard target. The spectral reflectance distributions of these colour targets are given by CIE [4]. A representation of these 15 targets is shown in Fig. 4.

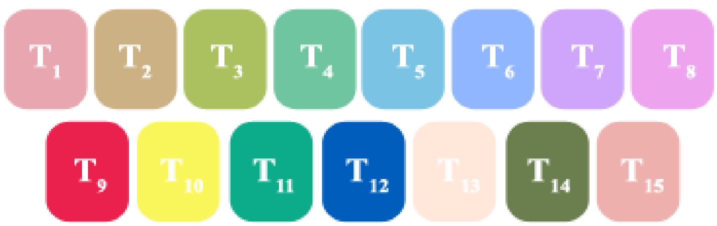


Fig. 4. Representation of the colour of the 15 standard R_a test targets

The calculation of the rendering capability was performed using a dedicated script developed in MATLAB according to CIE method [5]. The inputs were the spectral distributions of the lamps and the colour targets while the output was the rendering score on each target as well as the total colour rendering index. The results of the calculations are shown in Table 4.

The colour temperature of the selected lamps was measured using a Minolta CS-200 chroma meter. In each lamp, we measured the colour temperature in several patches of its luminous surface and calculate an average value. The results are shown in Table 5.

Table 4. Colour rendering of the tested LED lamps

Target	Toshiba	Megaman	Philips	Sylvania	Gen.Electric	Osram
T_1	80	80	84	82	85	80
T_2	91	89	89	91	91	88
T_3	95	98	92	95	96	96
T_4	78	83	85	79	86	81
T_5	80	81	84	81	85	80
T_6	87	88	86	86	89	85
T_7	81	85	86	85	87	85
T_8	58	60	70	66	70	61
T_9	3	5	27	19	31	7
T_{10}	78	77	74	75	80	73
T_{11}	76	83	87	75	86	80
T_{12}	68	75	74	62	75	73
T_{13}	83	82	85	84	87	81
T_{14}	98	99	95	97	97	98
T_{15}	74	72	79	78	80	72
R_a	**81**	**83**	**85**	**83**	**86**	**82**

Average values from measurement of two samples of each lamp type. Best score is 100

Table 5. Measured and calculated colour characteristics of the tested LED lamps.

		Toshiba	Megaman	Philips	Sylvania	General Electric	Osram	Halogen *(typical)*
Color temperature	***(K)***	2952	2954	3066	3143	2783	2958	2700
Color rendering index R_a		81	83	85	83	86	82	100

Average values from measurement of two samples of each lamp type.

4.4 Dimming

In most cases, especially in commercial use, lighting installations with halogen reflector lamps are equipped with dimming control. Thus, the tested lamps were selected in order to have the option of dimming. In case of mass replacement of halogen lamps with LED ones, it’s more likely that the dimming control will remain the same. For this reason, the selected lamps were tested in a dimming circle from 230V to 0V using a common dimming circuit. The supply voltage was reduced in 5 Volt steps. The duration in each voltage level was about 10 minutes and the luminous flux and the active power were recorded (just before next voltage step). In this case, the luminous flux variation was calculated using the variation of the illuminance reading of an integrating sphere in which each lamp was placed. The sphere was kept open except of some seconds when the measurements were taken. The results of the dimming test for each lamp are shown in Fig. 5. The abnormal behaviour of Osram samples means that these lamps require a dedicated Osram dimmer.

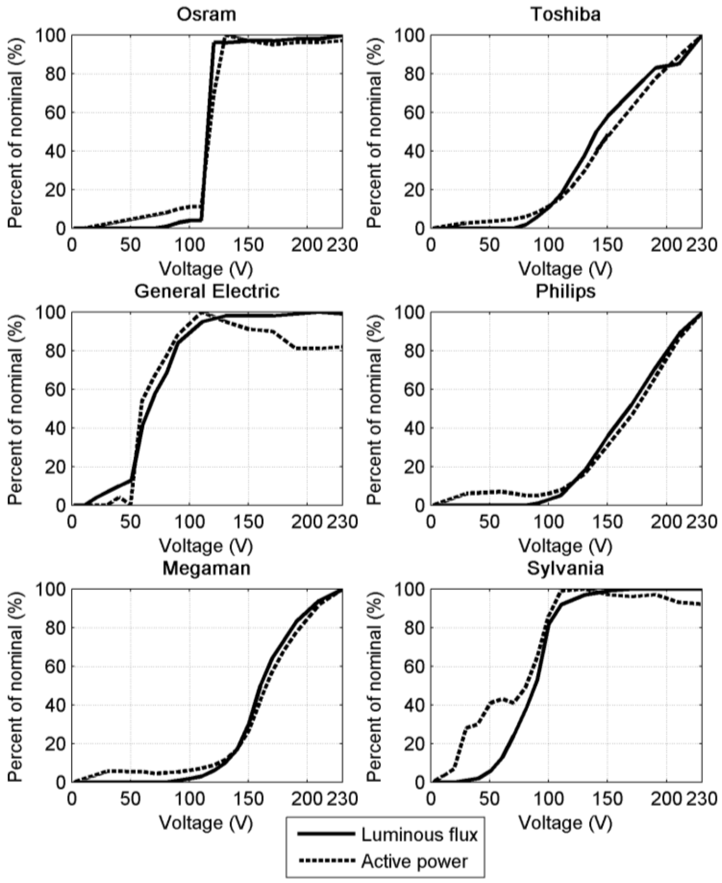


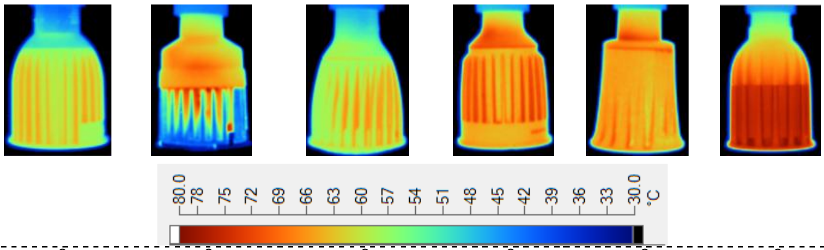
Fig. 5. Dimming test results of the tested LED lamps.

5. Thermal measurements

One important factor in both design and operation of a luminaire, is the management of the thermal load of the lamps. LEDs are producing a significant amount of heat, so a well designed cooling system is mandatory. As shown in Fig.1, all LED lamps have a kind of heatsink design in the perimeter of their body in order to dissipate the heat off the LEDs. In order to see how these heatsinks manage the heat, the thermal distribution of each lamp was measured using a thermal camera FLUKE Ti10.

The lamps were left to operate mounted on a bare GU10 base until their temperature stabilized. The temperature of the laboratory during the test was $25^{o}C \pm 3^{o}C$. The measured values of the average temperature on the surface of the lamps (in common colour scale), as well as the minimum and the maximum temperatures are shown in Table 6.

Table 6. Thermal images and key temperatures of the tested LED lamps.



	Philips	Megaman	G. Electric	Toshiba	Sylvania	Osram
Av.	58 °C	58 °C	59 °C	66 °C	65 °C	70 °C
Min	40 °C	30 °C	45 °C	51 °C	58 °C	50 °C
Max	65 °C	77 °C	67 °C	73 °C	74 °C	80 °C

6. Evaluation of test results

In terms of photometric quantities, luminous flux and maximum luminous intensities all lamps achieved similar or grater values than a common halogen 50W lamp. The differences were strongly depended on the wattage class of each lamp. There is no common wattage classification between different brands. All tested lamps produced light of colour temperature very close to the claimed value by the manufacturer. Small differences were found between the two samples of each type but this was expected. One of the noticeable point of the measurements is the span of the luminous efficacy of the tested lamps. This value varies from 35 lm/W to 56 lm/W, which is due to different types of LEDs that manufactures are using, possible different current that LEDs are driven as well as different management of heat (see Table 6).

One weak point of the tested lamps was their colour rendering capabilities. As seen in Table 5, all lamps have $R_a > 80$ (as expected) but the fact is their rendering scores on the colour targets. Fig. 6 shows the variation of colour rendering scores of all lamps on each one of the 15 colour targets.

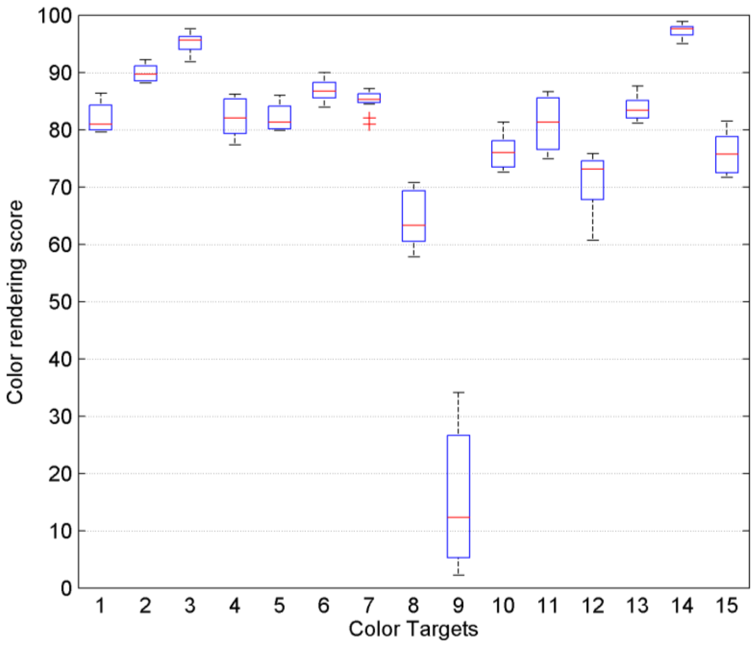


Fig. 6. Distribution of rendering scores of tested LED lamps on each of the 15 colour targets.

In this diagram, each box represents the statistic results of the colour rendering score of all lamps in each colour target. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points, and the outliers are plotted individually with red crosses. From this figure is obvious that most of the lamps are performing well (around 80) and with close scores on most of colour targets and excelled in few ones. In targets 8, 11 and 12 the variation of the rendering score is relevant big. The weakest point of these LEDs was the target T_9 which, according to Fig.4, is rich in red colour. In this colour, the scores varied from 3 to 31. This issue is not noticeable from the overall colour rendering index which in all lamps is above 80. The meaning of this score is that these lamps reproduce most types of red colours very poorly. This can be a significant disadvantage in cases where a good or better colour rendering is needed, like art galleries, clothes and vegetable stores and other. In those cases, the alternative LED lamps with greater R_a can be used but with not so better results and of course at higher cost.

The last but not least issue of the tested lamps is their size. As shown in Fig. 7, all LED lamps are at least 50% longer than the typical halogen lamp. Also, in terms of weight, the LED lamps are noticeable heavier. This could be an issue in cases where the halogen lamp fits tight inside the luminaires or in lumianaires with aiming options that cannot manage the increased lamp weight.

Fig. 7. Difference in size between LED lamps and a typical halogen lamp.

Regarding the electrical measurements (Table 2), the active power in all lamps was measured as expected. However, an average to low power factor was noticed in some types. This will have no effect in installation where the apparent power in not under consideration but will limit the reduction of the electric cost in cases of consumers whom billing scheme includes apparent power. Some lamps exhibit a quite high harmonic distortion of the current that could raise power quality issues in installations with big share of LEDs in the total load.

References

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