BENCHMARK TEST ON LED REPLACEMENTS OF DIRECTIONAL HALOGEN LAMPS

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ABSTRACT

This paper presents the results of the evaluation of various LED in terms of their photometric and electric performance. These lamps are promoted as retrofit replacements of halogen reflector lamps with GU10 base. This type of lamp is widely used in commercial lighting. The tests and corresponding calculations were carried out according to the European Standards in the Lighting Laboratory of National Technical University of Athens. The paper describes the methodology and the procedures of the applied tests. The tests were divided into two categories, photometric and electric. The photometric part consists of measurements of luminous intensity, colour temperature and colour rendering index of each lamp. The electric part consists of power quality measurements. Concluding, the paper presents the results of the photometric and the electrical performance, the corresponding calculations and some remarks on the results.

Keywords: LED, retrofit, GU10, halogen, replacement, benchmark

1. INTRODUCTION

LED products gradually replace luminaires with conventional light sources. 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 most of the commercial available types can easily reach, in bare led, efficacies higher than 100 lm/W (DoE, 2011). Furthermore, the European Eco Design regulations will ban low efficacy light sources, including halogen lamps, from the market in the next years (EC, 2005). One characteristic type of the lamps that will also be banned in next years is halogen PAR16 reflector lamp with GU10 base. The above-mentioned type 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, colour rendering index except from its low luminous efficacy. So, could the switch of halogen lamps to LED be carried out without any misapprehension? Thus, the paper tries to focus on this issue using experimental procedures.

2. TESTED LAMPS

The tested lamps were selected between various models of branded and private label GU10 LED lamps. These lamps are sold as replacements of the traditional 35W and 50W Halogen GU10 reflector lamps. The types of the tested lamps are shown on Table 1. Two lamps of each type (total 46 samples) were used in the experiments.

3. ELECTRICAL MEASUREMENTS

The first step was to measure the electrical characteristics of the lamps. 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 were not fitted to any housing or any type of luminaire in order to avoid thermal stress of LEDs.

Table 1 –Tested LED lamps

Lamp type	Brand	Model	Rated power (W)
1	GENERAL ELECTRIC	Energy Smart 4.5W 170lm 2700K	4.5
2	GENERAL ELECTRIC	Energy Smart 5W 240lm 3000K	5
3	PRIVATE LABEL	GU10 5W Warm White	5
4	PRIVATE LABEL	GU10 5W Warm White	5
5	PRIVATE LABEL	GU10 5W Warm White	5
6	PRIVATE LABEL	3XP1 GU10 WW 4.5W	4.5
7	PRIVATE LABEL	3XP1 GU10 NW 4.5W	4.5
8	LIGHTING SCIENCE	GU10 SoL MR16 WW FL	6.5
9	OSRAM	Parathom PAR16 35 35^o Advanced	5.5
10	MEGAMAN	LR1506-35H36D	6
11	MEGAMAN	LR0408-50H35D	8
12	OSRAM	Parathom PRO PAR16 50 35^o Adv.	9
13	OSRAM	Parathom PRO PAR16 50 Adv. R	10
14	OSRAM	Parathom PRO PAR16 35 Adv. R	8
15	OSRAM	Parathom PRO PAR16 50 35^o Adv.	9
16	SYLVANIA	Hi-Spot RefLED Par16	8
17	GENERAL ELECTRIC	Energy Smart 6.5W 380lm 3000K	6.5
18	PHILIPS	MASTER LEDSPOT MV	7
19	TOSHIBA	E-Core LED LDRC0930WU1EUD	8.5
20	PRIVATE LABEL	GU10 6W Warm White	6
21	PRIVATE LABEL	GU10 6.5W Warm White	6.5
22	MEGAMAN	LR1108d-50H35D (10W43)	8
23	MEGAMAN	LR1108d-50H35D (12W28)	8
24	35W Halogen GU10 lamp		35
25	50W Halogen GU10 lamp		50

Prior to measurements, each lamp was operated for at least one hour. The measured electrical quantities were: supply voltage, lamp current, apparent power, active and reactive power as well as the power factor. Table 2 shows the results of the measurements.

4. PHOTOMETRIC MEASUREMENTS

4.1. Luminous intensity distribution and luminous flux

The measurement of the luminous intensity distribution was carried out using a two axis goniophotometer. Each measurement was performed in CIE C-planes with 15^o steps of C-planes and 2.5^o of gamma angles (CIE, 1996). The lamps were left to operate until their luminous intensity stabilized. The luminous flux was then calculated with integration of the above measurements.

Table 2 – Measured electrical characteristics of the tested LED lamps

Lamp type	Voltage (v)	Current (mA)	Active power (W)	Apparent power (VA)	Reactive power (Var)	Power factor
1	230.0	37.34	4.48	8.59	7.33 cap	0.52
2	230.0	24.16	4.66	5.74	3.03 cap	0.84
3	230.0	39.23	4.82	9.02	7.63 cap	0.53
4	230.9	40.88	4.90	9.44	8.07 cap	0.52
5	230.1	39.89	4.80	9.18	7.82 cap	0.52
6	230.0	22.40	3.65	5.15	3.63 cap	0.71
7	230.0	22.29	3.62	5.13	3.63 cap	0.71
8	229.8	49.62	6.26	11.40	9.53 cap	0.55
9	230.1	42.81	5.03	9.85	8.47 cap	0.51
10	230.0	31.41	5.08	7.22	5.14 cap	0.70
11	230.0	58.42	7.12	13.44	11.40 cap	0.53
12	230.0	39.39	8.59	9.06	2.88 cap	0.95
13	230.0	43.65	9.57	10.04	3.02 cap	0.95
14	230.0	33.80	7.35	7.77	2.52 cap	0.95
15	230.0	38.17	8.31	8.78	2.83 cap	0.95
16	230.0	41.69	8.17	9.59	5.01 cap	0.85
17	230.0	32.60	6.31	7.50	4.04 cap	0.84
18	230.0	46.01	6.97	10.59	7.97 cap	0.66
19	230.1	54.63	8.71	12.57	9.07 cap	0.69
20	230.0	58.91	5.49	13.55	12.39 cap	0.40
21	230.0	39.33	6.66	9.05	6.12 cap	0.74
22	230.0	49.39	7.68	11.36	8.38 cap	0.68
23	230.0	44.92	7.15	10.33	7.46 cap	0.69
24	229.7	152.70	35.08	35.08	0.62 cap	1.00
25	229.7	212.22	48.75	48.75	0.64 cap	1.00

Regarding the light distribution, all LED lamps performed well by producing a light cone of 35^o. Figure 1 shows the luminous intensity distribution of three typical lamps (low, intermediate and high intensities). Figure 2 shows the calculated luminous flux and maximum luminous intensity of LED lamps. The corresponding values of 35W and 50W halogen are also shown in these figures.

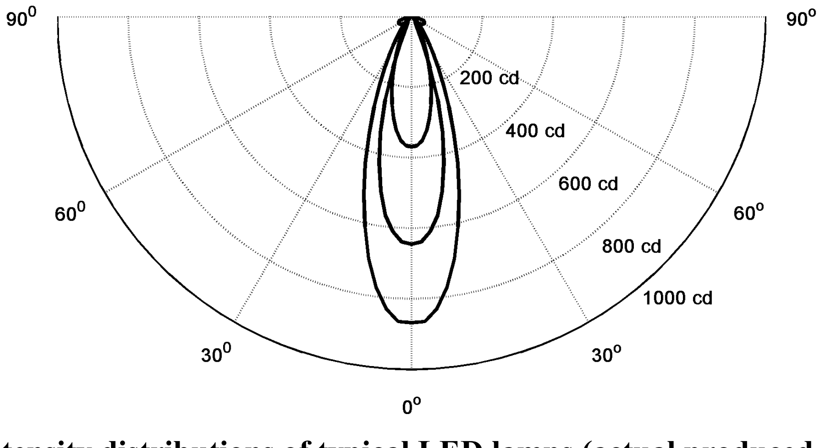


Figure 1 –Intensity distributions of typical LED lamps (actual produced candelas).

4.2. Light spectrum, colour rendering and colour temperature

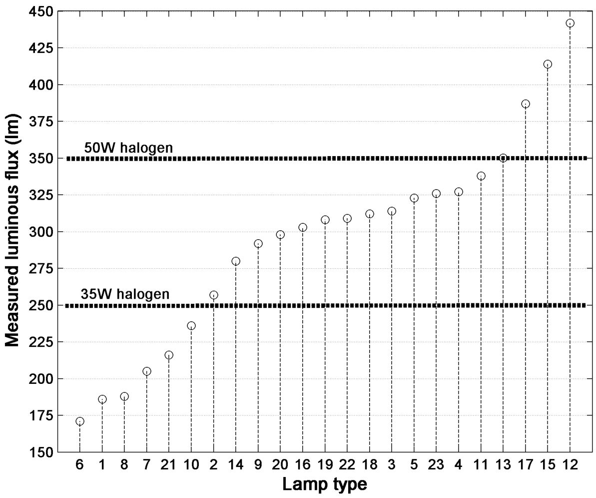
The spectral distribution of each lamp was measured using a spectrometer. Using these measurements, the colour rendering, as well as the colour temperature of the emitted light were calculated. For the colour rendering, 15 standard colour targets (CIE, 1995) were used. The R_a index was calculated using the scores from targets 1 to 8, while the extended colour rendering was calculated using all 15 colour targets scores. The individual rendering scores as well as the rendering indices are shown in Table 3.

Table 3 –Summary of photometric results

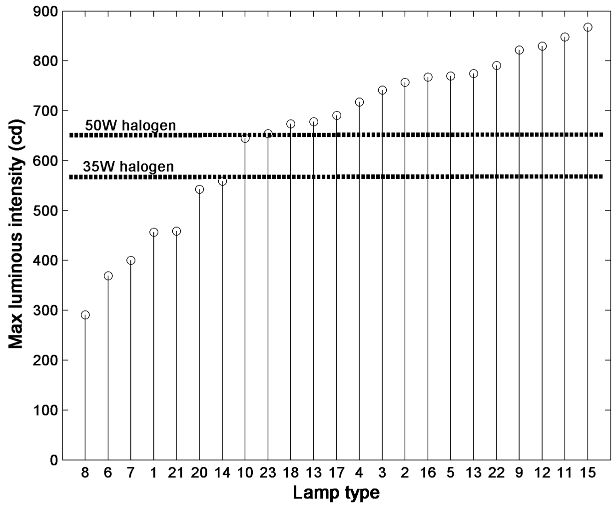
Lamp type*	Luminous flux (lm)	Max luminous intensity (cd)	Luminous efficacy (lm/W)	Colour temp. (K)	Colour rendering	
					8 targets (Ra)	15 targets
1	186	457	41	2602	83	77
2	257	757	55	3015	84	79
3	314	742	65	3452	84	78
4	327	718	67	3437	83	76
5	323	770	67	3470	83	77
6	171	369	47	3043	81	74
7	205	400	57	2821	83	78
8	188	291	30	2724	81	74
9	292	822	58	3275	84	79
10	236	645	46	2974	84	78
11	338	848	47	2895	85	80
12	442	830	51	2842	91	88
13	350	775	37	2585	82	76
14	280	559	38	3094	83	78
15	414	868	50	3141	91	87
16	303	768	37	2746	83	77
17	387	691	61	3100	87	82
18	312	674	45	2679	85	80
19	308	678	35	2579	81	75
20	298	543	54	2991	84	79
21	216	459	33	2890	78	70
22	309	791	40	2581	83	77
23	326	654	46	2880	85	80

*2 samples per type. The results express the average values of the 2 samples

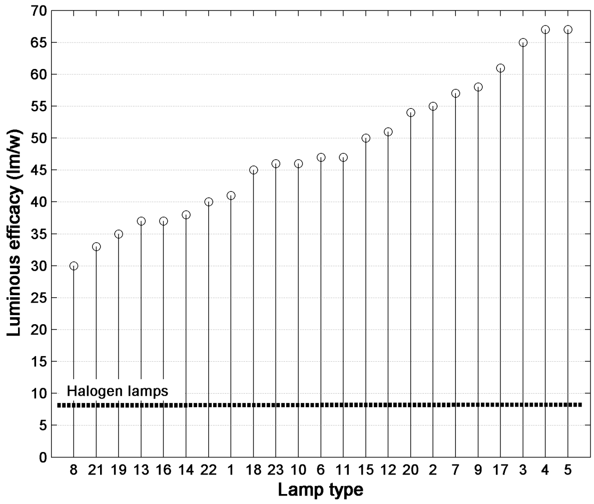
Figure 3a illustrates the variation of the colour rendering scores between different lamps as well as between two rendering indices of the same lamp. Figure 3b illustrates the distribution of the rendering scores on each colour target produced by all lamps. On each box, the central mark is the median, the edges of the box are 25th and 75th percentiles, the whiskers extend to the most extreme data points, and the outliers are plotted individually with crosses. Figure 4 shows the spectral distribution of four selected LED lamps. Two of them have the lowest and the highest colour temperature of the 23 types respectively and the other two achieved the worst and the best rendering index (in both 8 and 15 targets).



(a) Luminous flux

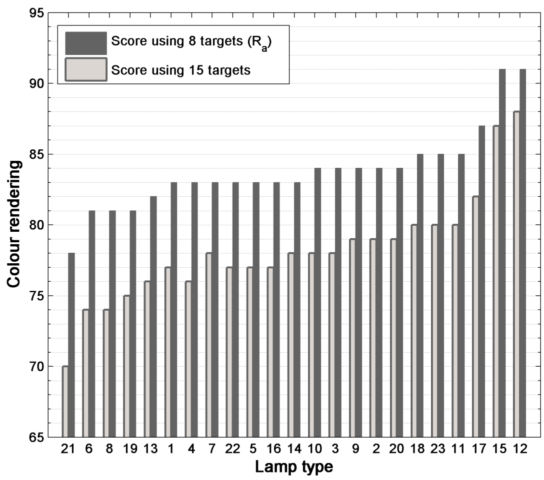


(b) Maximum luminous intensity

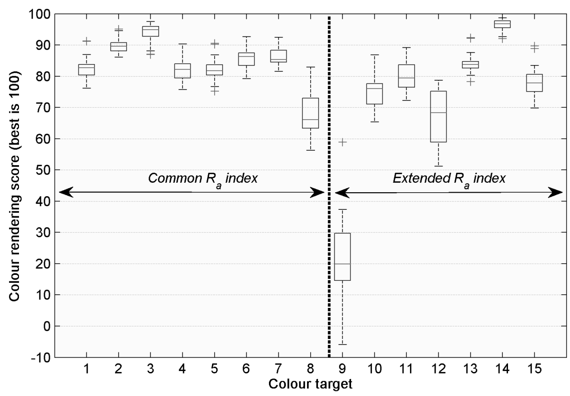


(c) Luminous efficacy

Figure 2 –Luminous flux, max luminous intensity and luminous efficacy of LED versus halogen lamps



(a) Colour rendering scores



(b) Rendering scores in 15 targets

Figure 3 – Colour rendering calculations for the tested LED lamps

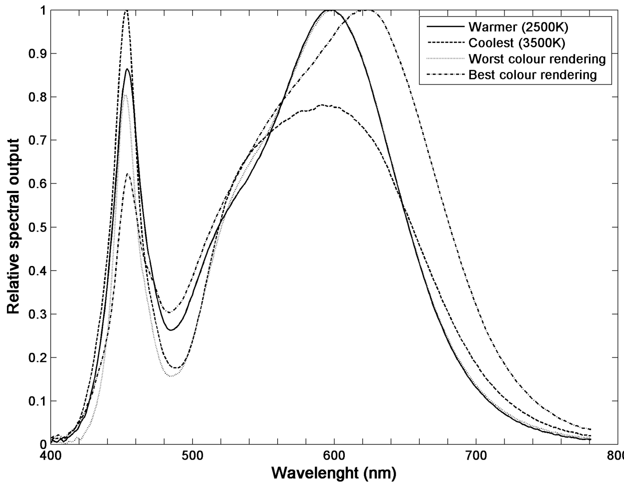


Figure 4 – Spectral distribution of key LED lamps

5. CONCLUSIONS

In case of replacement of a halogen lamp the produced luminous flux combined with the corresponding luminous efficacy and maximum luminous intensity must be considered. In most cases, a good result regarding one factor doesn't mean that the other two factors meet the requirements of the replacement. One of the noticeable points of the measurements was the span of the luminous efficacy of the tested lamps (30 to 70 lm/W), which leads to different wattage classification between different brands. The difference is due to different types of LEDs that manufactures are using, possible different current that drives the LEDs as well as different heat dissipation. All tested lamps produce light with colour temperature very close to the claimed value by the manufacturer. Regarding colour rendering capabilities, most lamps achieved R_a index over 80, but not with the extended rendering index. As shown in Figure 3, the colour rendering index drops dramatically when all targets are calculated. This issue mainly depends on the 9th target (Strong Red) where the scores are commonly low (Figure 3b). The electrical measurements meet the rated values. Noticeable, however, was the low power factor of some lamp types. Finally, the oversized and overweighed LED replacements may cause retrofitting problems in cases where luminaires are designed for the size and weight of halogen lamps.

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REFERENCES

CIE, *The photometry and goniophotometry of luminaires*, Pub. No 121, Paris, 1996, Commission Internationale de l' Eclairage

CIE, *Method of Measuring and Specifying Colour Rendering Properties of Light Sources*, Pub. No 13.3, Paris, 1995, Commission Internationale de l' Eclairage

DoE, *Commercially Available LED Product Evaluation and Reporting (CALiPER)*, Round table report of 2011, USA, 2011, Department of energy USA

EC. *Eco design for energy-using products*, Directive 2005/32/EC, 2005, E.C.