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Linear LED tubes versus fluorescent lamps: An evaluation

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ABSTRACT

Many manufacturers and distributors of LED tubes claim energy savings of 50% and more when replacing T8 fluorescent tubes with linear LED replacement lamps. Several distributors even pretend that the same visual comfort will be maintained after such a replacement. Optical and electrical parameters of twelve commercially available linear LED tubes have been determined and the evolution in time of these parameters has been monitored. Additionally, a case study is presented in which the fluorescent lamps in a small office room were replaced by LED linear replacement lamps in order to compare the illuminance distribution on the work plane, the glare perception and the overall visual appreciation. According to this study, it is clear that a one-to-one replacement of a classical fluorescent tube by a currently available linear LED lamp might have severe consequences on the lighting quality.

1. Introduction

LED based luminaires are emerging into the market. Properties such as long life, dimmability and variability, unlimited switching, flexible design, high luminous efficacy, compactness and negligible heat transfer in the light beam make solid state lighting an attractive alternative to traditional light sources. LED based systems are not only available for orientation and architectural lighting but more and more for general illumination applications too [1,2]. Today, LED based downlights are outcompeting the traditional compact fluorescent lamps in terms of efficiency and lighting quality [2].

On the other hand, there are many applications where the benefits of using LED products are not obvious. The use of LED tubes as replacement lamp for fluorescent lamps is a typical product causing controversy. Several distributors recommend their products as a superior replacement of conventional T8 fluorescent lamps, mainly focussing on the potential energy savings and long life of the light-emitting diode replacements. However, the lighting quality is often subordinate or ignored [3,4]. Some distributors argue that retrofitted luminaires achieve equal or even larger illumination levels on the task area, even though the luminous flux of the LED replacement is considerably lower, referring to the superior light output ratio (LOR) of the luminaire due to the directionality of LEDs. However, manufacturer data of LED tubes are often limited and incomplete and the overall light distribution of the luminaire after replacement is unknown [3–5]. Above, there is a lack of standardisation and inspection to evaluate SSL products [6], often resulting in overstated and misleading manufacturer performance claims [3] which amplifies the discussion.

In this study, the optical and electrical parameters of twelve commercially available LED linear replacement lamps have been compared and the variation over time of these parameters has been investigated. Furthermore, a case study is presented in which the fluorescent lamps in a small office room have been replaced by LED linear replacement lamps in order to compare the illuminance distribution on the task area. Finally, the performance of LED replacement lamps was investigated and compared with a standard fluorescent T8 lamp in a psychophysical experiment in terms of general lighting quality, colour quality and glare perception.

2. Optical and electrical parameters of LED linear replacement lamps: a bench test comparison of 12 LED tubes

2.1. Methodology

In September 2010, twelve LED tubes of brands distributed on the Belgian market were collected [5]. These lamps are intended for replacement of standard T8 36 W fluorescent lamps. All LED replacement lamps have an integrated driver powered directly from the ac mains power supply.

After lamp stabilization, all relevant initial optical and electrical parameters were measured: real (or active) power P, luminous efficacy, power factor PF, total harmonic current distortion THD_I,

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Table 1
Initial lamp parameters.

Brand	Φ (lm)	*P* (W)	η (lm/W)	*CCT* (K)	*CRI*	*MCRI*	CQS v7.5	PF	THD_I
A	1650	22.8	72.4	4186	90	90	88	0.97	14%
B	1535	23.6	65.0	6876	72	75	72	0.45	192%
C	1595	17.8	89.6	3709	76	83	79	0.82	56%
D	1774	21.2	83.7	4016	69	77	68	0.66	90%
E	754	10.3	73.4	4207	76	85	73	0.48	55%
F	1707	20.9	81.6	3194	65	74	68	0.93	17%
G	1036	15.2	68.2	3307	71	80	68	0.51	162%
H	1437	17.7	81.1	3853	77	85	75	0.96	16%
I	1605	31.6	50.8	3365	88	90	86	0.53	135%
J	920	14.5	63.4	3678	78	87	71	0.84	59%
K	1479	18.3	80.8	4733	65	64	68	0.78	54%
L	1185	17.6	67.3	5329	73	79	72	0.91	22%
Median	1479	17.8	73.4	3853	76	81	72	0.82	55%

luminous flux, luminous intensity distribution, spectrum, correlated colour temperature *CCT*, colour rendering index *CRI*, colour quality scale CQS and memory colour rendering index *MCRI*. The *MCRI* [7] is a new metric that assesses the colour quality of a light source with respect to the memory colours of a set of familiar objects. This metric was found to correlate significantly better at assessing the colour quality of white light sources in terms of visual appreciation than the conventional *CRI* [8]. It should be noted that, while a *CRI* score of approximately 90 is significantly lower than that of a CIE reference illuminant, it is not on the MCRI scale – CIE reference illuminants have scores around 90, while a score of 100 is reserved for a perfect 'memory colour' agreement [7,8].

The NIST CQS is another new metric which correlates better with the visual appreciation of colours compared to the traditional CIE colour rendering index. The CQS is a colour difference based metric which does not penalize chroma enhancement and even rewards chroma [9].

A near-field goniophotometer type Techno Team RIGO801® [10] equipped with an illuminance meter and an image-resolving CCD camera for determining ray data and far field luminous intensity distributions were used to determine the luminous flux and luminous intensity distribution of all lamps. The temperature and relative humidity in the room were controlled within narrow ranges (25 °C ± 1 °C and 32 ± 5% RH). The spectra and resulting *CCT*, *CRI*, CQS and *MCRI* values were determined by using a telescopic measuring head coupled to a spectroradiometer (Oriel®) with an optical fibre. A cooled CCD detector captured the spectral flux after a suitable calibration measurement with a spectral radiance standard. The electrical parameters were measured by a Yokogawa® WT3000 precision power analyser. The sinusoidal supply voltage with a root-mean-square value of 230 V was delivered by a power source type Agilent® 7813B.

2.2. Initial lamp characteristics

The initial lamp parameters as measured are summarized in Table 1. Measurements did not start before the stabilisation time was elapsed. Stable operation was reached when the relative variation of luminous flux was no more than 0.5% within 3 continuous minutes. This criterion guarantees stable thermal conditions.

With the exception of one lamp, all LED tubes draw at least 30% less real power than their fluorescent counterpart. The lamp power is going from 10.3 W to 31.6 W with a median value of 17.8 W, which is half the real power of the fluorescent lamp.

A primary objective of any (re)lighting project should be to fulfil the existing and widely accepted lighting requirements, e.g. the European standard for lighting indoor work places [11]. The luminous flux and the intensity distribution of the replacement lamp are the main factors that determine the lighting level after a relamping. The medium value of the luminous flux of the measured LED tubes is 1479 lm which is only 44% of the luminous flux of a new conventional T8 36 W/830 (about 3350 lm) fluorescent tube of the same dimensions. The spread in luminous flux is rather large, ranging from 754 lm to 1774 lm. Depending on the power consumption of the (electromagnetic) ballast, the lamp-ballast efficacy of a common T8 fluorescent lamp varies between 75–95 lm/W. The median luminous efficacy of the measured LED tubes (with integrated driver) is about 73 lm/W with 5 lamps having an efficacy of more than 80 lm/W. This is comparable with the efficacy of a T8 lamp-ballast combination. As the luminous efficacy of new LED types is still increasing, the lamp-driver efficacy of LED tubes will exceed the lamp-ballast efficacy of standard fluorescent lamps very soon.

The *CRI*, CQSv7.5 and *MCRI* values are determined from the lamp spectra. In all lamps under study, blue LEDs with an individual phosphor layer are used. A typical phosphor white LED spectrum is shown in Fig. 1. It is remarkable that only two out of twelve lamps have a *CRI* higher than 80. According to the European standard for work places [11], lamps with a *CRI* lower than 80 should not be used in indoor workplaces. The two sources, with a *CRI* score higher than 80, also scored highest on the CQS and *MCRI* scales.

If the rated real power of light sources (except for discharge lamps) is less than or equal to 25 W, there are no specific requirements for the current waveform and maximum harmonic current components [12]. As the real power of most LED replacement lamps is lower than 25 W, a non-sinusoidal current may be expected. The extra harmonic current components cause extra losses in electrical cables and transformers which is especially an issue for distribution network companies [13]. For residential electricity customers, the negative impact of harmonic currents is usually marginal. However, for non-residential customers, the harmonic distortion may cause problems when many fluorescent tubes are replaced by LED tubes with high harmonic content. Increased losses and possible

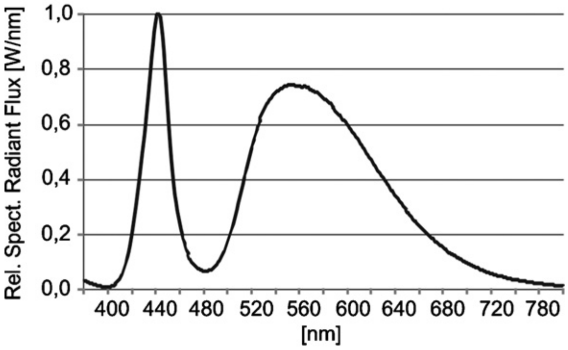

Fig. 1. Spectrum of LED tube (*Brand K*).