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PERFORMANCE OF LED LINEAR REPLACEMENT LAMPS*

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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 LED linear replacement lamps. Above, most distributors pretend that the same visual performance and comfort will be maintained after such replacement. Optical and electrical parameters of twelve commercially available LED tubes have been measured and compared and the evolution in time of these parameters has been monitored. The performance of these lamps with distinctly different luminance distributions is investigated. 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 place. It has become clear that the impact of replacing a classical fluorescent tube by a linear LED lamp on the visual performance must not be underestimated.

Keywords: LED linear replacement lamp, fluorescent lamp

1. INTRODUCTION

Many manufacturers present a LED tube of lower power as a more energy efficient replacement for the conventional fluorescent tube. This causes a controversy in the lighting sector. Indeed, LEDs have a lot of advantages and luminaires based on LEDs will soon have a huge market share. On the other hand, the optical characteristics of LED replacement products are very different and in many cases, they suffer from an inferior quality due to the lack of standardisation and control.

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 is investigated. Distributors of LED tubes recommend their products as a superior replacement of conventional T8 fluorescent lamps. In most cases, the luminaire is not removed but retrofitted. The existing ballast has to be bypassed and the starter must be removed. Some distributors argue that retrofitted luminaires achieve equal or larger illumination levels on the task area, even though the lumen output of the LED replacement is lower, referring to the superior light output ratio (LOR) 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. Therefore, 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.

2. DISCOMFORT GLARE PREDICTION

2.1. Luminance distributions

There are many optical differences between conventional T8 fluorescent lamps and their LED lin-

* On the basis of the report presented at the 27th CIE Session in Sun City, South Africa, July 2011

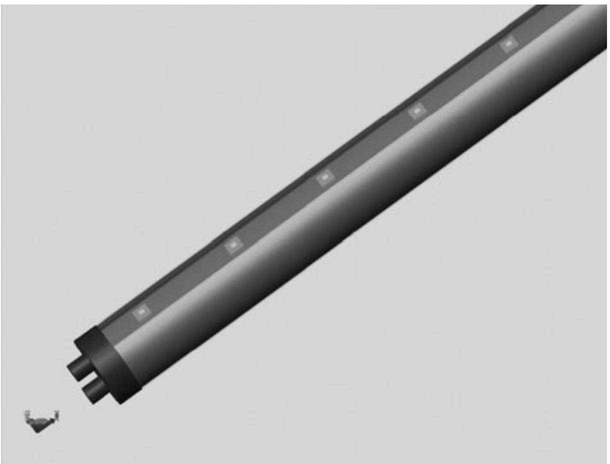

Fig. 1. Detail of the LED linear replacement lamp as modelled in the raytracing software; the distance between the centre of a LED to the next one is 37 mm, there are 32 LEDs

ear replacement lamps but the most prominent one is in the luminance distributions. The conventional lamp presents a luminous surface with a spatially constant luminance while most LED replacement lamps present a strongly fluctuating luminance distribution because of the individual LEDs.

In this section, the luminance distributions and discomfort glare estimates of a conventional T8 fluorescent tube of length 1200 mm emitting a flux of 3350 lm, and a LED linear replacement lamp with 32 SMD (surface mounted device) LEDs emitting a flux of 1500 lm are compared by means of computer simulations. Both devices are modelled in the ray tracing software package TracePro® (Fig. 1).The outer surface of the fluorescent lamp and the light emitting, 2 mm by 2 mm, square surfaces of the SMDs are modelled as Lambert emitters. A flux of 46.875 lm is assigned to each of the LEDs. By means of reverse ray tracing, luminance maps of both light sources are constructed. A lengthwise section of the luminance maps, in the plane of the long axis and through the centre of the SMDs, is shown in Fig. 2.

The fluorescent lamp has a constant luminance of 11270 cd/m² but the luminance distribution of the LED tube exhibits strong fluctuations between zero and 3.42 x10^6 cd/m². The fact that the luminance between the emitting surfaces of the SMDs is not always zero is caused by scattering in the direction of the observer of light reflected back to the SMD carrier plate by the plastic cover.

2.2. GLARE

The radiation pattern of the fluorescent lamp is accurately determined by tracing a high number of rays (5 x 10^6 rays). From these data, and by considering the light source as a luminaire, an Eulumdat file is generated. Via this file format the light source is imported in the lighting planning software Relux®. Because the Eulumdat file format is not possible for the LED tube that consists of numerous spatially separated and very small light sources, each SMD is considered as a small luminaire. So the simulation results for a single SMD are imported in Relux®.

In Relux® a simple lighting situation is set up to compare the performances. The T8 lamp is positioned against the ceiling in the centre of a 3 m by 4 m by 2.3 m room. A 1 m by 2 m table with the tabletop 0.8 m above the floor is placed directly under the luminaire. The illuminance of all surfaces is calculated in Relux® by means of radiosity. All surfaces in the room with the exception of the floor and the

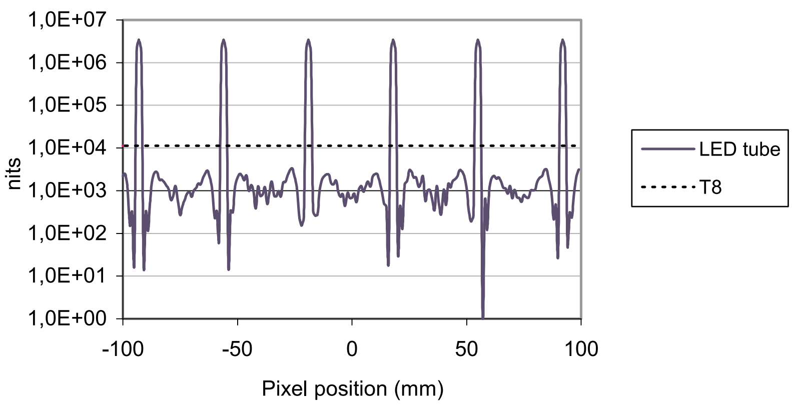

Fig. 2. Detail of a lengthwise section of the luminance distributions of the conventional T8 lamp and the LED tube. The luminance is calculated at points with 1 mm interval, zero corresponds to the centre of the LED tube. Notice the logarithmic luminance scale on the vertical axis

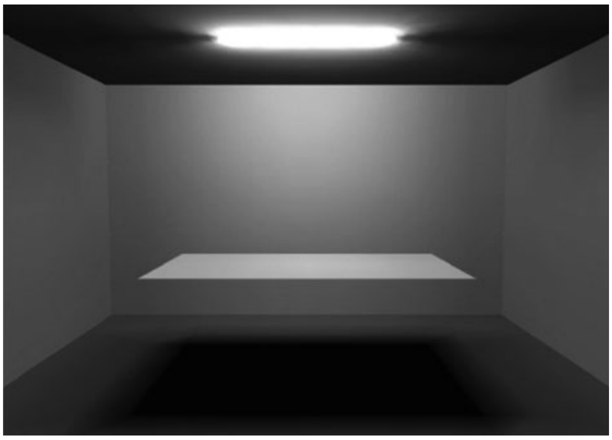

Fig. 3. Model of the room lighted with the conventional T8 fluorescent lamp

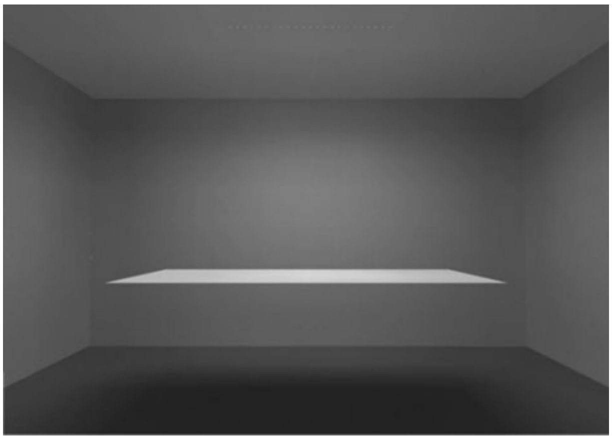

Fig. 4. Model of the room lighted with the 32 LED linear replacement lamps

ceiling are assumed to be 50 % reflective. The reflection coefficients of the ceiling and the floor are taken as 90 % and 20 %, respectively. All surfaces are assumed to be diffuse reflectors. This situation is shown in Fig. 3. In this room the bare fluorescent appears to be causing discomfort glare which can be quantified by the Unified Glare Rating (*UGR*). Because the T8 lamp has a large diffuse emitting surface the classic UGR formula can be used (CIE 1995) (Eble-Hankins 2004) (Murdoch 2003):

$$UGR = 8\log_{10}\left(\frac{0.25}{L_b}\sum_{i=1}^{n}\frac{L_i^2\omega_i}{p_i^2}\right),$$

where n is the number of luminaires in the room, L_b is the average background luminance at the observer's eye, L_i is the average luminance of the luminous parts of luminaire, i, ω_i is the solid angle of the luminous part of luminaire i as seen by the observer and p_i is the Guth position index (EN12464–1 2009) for luminaire i.

The background luminance is determined by calculating the total illuminance and the direct illuminance at the observer's eye in Relux®. The difference between these values is the indirect illuminance E_i. The background luminance is then found by (CIE 1995) (Eble-Hankins 2004):

$$L_b = \frac{E_i}{\pi}$$

We position the observer's eye at a height of 1.75 m at a horizontal distance of 0.80 m from the centre of the table, facing the centre of the opposite wall (i.e.: we consider an adult person standing in front of the table facing towards the centre of the room). We find: L_b=29.6 cd/m² and *UGR*=26. According to the European standard for workplace lighting (EN12464–1 2009) this high *UGR* implies that this simple lighting solution is only acceptable in walk through areas.

In this room model, leaving all parameters unchanged, the fluorescent tube is then replaced by the LED linear replacement lamp, which is modelled as a row of 32 SMD luminaires. In the computer constructed image of the lighting situation no obvious glare is present (Fig. 4). Because of the very small surface area of the luminous parts of the LED tube, 4 mm² per SMD and 128 mm² in total, the classic *UGR* expression can not be used. For luminous surface areas smaller than 0.005 m² a modified UGR expression, taking into account the intensity I of the light source, has to be used (Eble-Hankins 2004) (CIE 2002):

$$UGR = 8\log_{10}\left(\frac{0.25}{L_b}\sum_{i=1}^{n}200\frac{I_i^2}{r_i^2\,p_i^2}\right),$$

where r_i is the distance from the observer to luminous area i.

For the *UGR* calculation for the LED tube we consider each SMD as a separate light source (n = 32). For the same observer position and analogous as in the conventional T8 case we find: L_b =10.2 cd/m² and *UGR*=21.6. This lower *UGR* value implies that the bare LED tube is suitable for more lighting tasks than the bare T8. However, one should be careful not to judge the quality of real world lighting applications by *UGR* and illuminance values alone, e.g.: LED tubes of the type discussed here can cause ir-

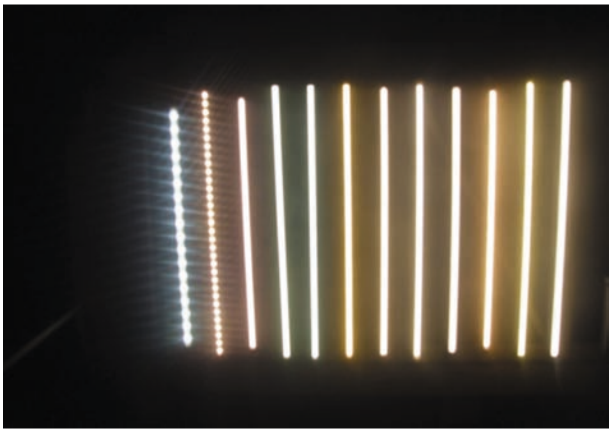

Fig. 5. Picture of the lamps – variation in CCT

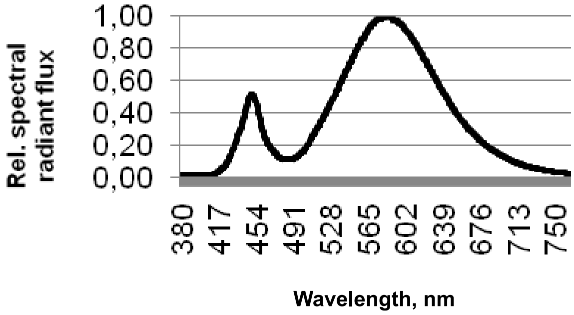

Fig. 6 Spectrum of LED tube (Brand A)

ritating multiple shadows and many people simply dislike rows of bright points as general lighting. Furthermore, in most cases a T8 lamp is used in combination with a luminaire that is designed to handle the omnidirectionality of the lamp. Simply replacing the T8 with a LED tube can change the radiation pattern of the luminaire drastically (Myer 2009).

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In September 2010, twelve LED tubes of 120 cm of brands distributed on the Belgian market were collected. These lamps are intended for replacement of conventional T8/36 W lamps. Initially, the distributors were asked to deliver a lamp with a correlated colour temperature (*CCT*) between 3500 K and 4000 K. However, control measurements revealed that the spread in *CCT* is large, as can be seen in Table 1 (3194 K – 4733 K; cold white lamp of brand B not considered). Most distributors indeed offer only 3 types (warm white – neutral white and cool white), and the stated CCT range is usually large (f.i. 3800 K- 4800 K). The visual effect of the spread in *CCT* is illustrated in Fig. 5. This spread can be an issue if the lamps are not replaced in group or if a defective lamp must be replaced.

After lamp stabilization, all relevant initial optical and electrical parameters were measured: luminous flux, radiation pattern, spectrum, colour rendering index *CRI*, memory colour rendering index *MCRI (Smet 2010)*, correlated colour temperature *CCT*, active power *P*, luminous efficacy, power factor *PF* and total harmonic distortion *THD*. A near-field goniophotometer type RIGO801 (TechnoTeam®) which utilizes an image-resolving CCD measuring technique for determining ray data and far field luminous intensity distributions was used to determine the luminous flux and radiation pattern 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* 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 (basic power accuracy of 0.02 % rdg). The sinusoidal supply voltage with an RMS value of 230 V was delivered by a power source type Agilent® 7813 B.

The results are summarised in Table 1.

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• The median value of the luminous flux is 1479 lm, which is only 44 % of the luminous flux of a new conventional T8 36 W/830 (3350 lm) fluorescent tube of the same dimensions. The spread in luminous flux is ranging from 754 lm to 1774 lm.

• There is a strong variation in lamp power going from 10,3 W to 31,6 W with a median value of 17,8 W. The lamp efficacy varies between 50.8 lm/W and 89.6 lm/W. In comparison, the efficacy of a T8 lamp/ballast combination varies between 75–95 lm/W, dependent on the power consumption of the (electromagnetic) ballast.

• It is remarkable that only two out of twelve lamps have a CRI higher than 80! According to the European standard EN-12464–1 'Light and lighting – Lighting of work places – Part 1: Indoor work places' lamps with a colour rendering index lower

Table 1. Initial lamp parameters

Brand	Lum. Flux [lm]	P [W]	Effic. [lm/W]	CCT [K]	CRI	MCRI	PF	THD
A	1650	22,8	72,4	4186	90	96	0,97	14%
B	1535	23,6	65,0	6876	72	74	0,45	192%
C	1595	17,8	89,6	3709	76	84	0,82	56%
D	1774	21,2	83,7	4016	69	74	0,66	90%
E	754	10,3	73,4	4207	76	86	0,48	55%
F	1707	20,9	81,6	3194	65	72	0,93	17%
G	1036	15,2	68,2	3307	71	78	0,51	162%
H	1437	17,7	81,1	3853	77	86	0,96	16%
I	1605	31,6	50,8	3365	88	95	0,53	135%
J	920	14,5	63,4	3678	78	89	0,84	59%
K	1479	18,3	80,8	4733	65	63	0,78	54%
L	1185	17,6	67,3	5329	73	80	0,91	22%
Median	1479	17,8	73,4	3853	76	84	0,82	55%

than 80 should not be used in interiors where people work or stay for longer periods (EN12464–1 2009). A typical phosphor white LED spectrum is shown in Fig. 6. In all lamps under study, blue LEDs with an individual phosphor layer are used.

• Up till now, there are no specific requirements for the current waveform and maximum harmonic components for LED tubes if the rated lamp power is less than or equal to 25 W [IEC 61000–3-2 2005]. However, harmonic distortion may cause problems when many fluorescent tubes are replaced by LED tubes with high harmonic content. The total harmonic distortion *THD* is a measure for the harmonic current content. For a sinusoidal supply voltage, the power factor λ is related to the *THD* as:

$$\lambda = \frac{\cos\varphi_1}{\sqrt{1+THD^2}}. \quad (1)$$

Hence, the power factor combines the phase angle φ_1 between the fundamental current and voltage component and the harmonic current distortion. The lower the power factor, the higher the losses in the electrical installation and the higher the risk for harmonic-related problems.

Four lamps have a high power factor with values greater than 0,9. On the other hand, the *THD* of three LED tubes exceeds 100%, resulting in power factors around 0,5! This implies that twice the current is needed to deliver the active power as compared to a lamp drawing a sinusoidal current in phase with the voltage for the same active power. Other lamp currents contain a lot of high frequency components which may cause electromagnetic interference. Some typical current waveforms are shown in Fig. 7.

As LEDs are Lambert light sources, the radiation pattern of the tube is also nearly lambertian, characterized with a full width at half maximum of 120 degrees. This is illustrated in Figs. 8,9.

3.2. Lamp characteristics after 2000 hours

After determination of the initial lamp characteristics in September 2010, all lamps are being operated at a burning cycle of 3 hours (2 h45 'on' – 15 minutes 'off') for a at least one year. In January, April, July and October 2011, all optical and electrical parameters are measured again. As the deadline for submitting papers was March 31, only the measurements of January are presented in this paper. In Table 2, the luminous flux variation is shown for all the lamps.

White through-hole LEDs are used in tubes of brands C, E, G, and J. It is well known that heat in a traditional through-hole LED cannot escape efficiently from the semiconductor element. This possibly explains the (strong) decrease in luminous flux.

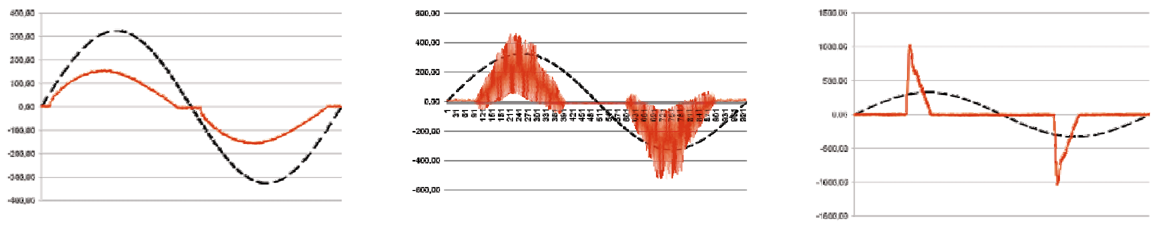


Fig. 7 Current (black line) and voltage (dashed line) waveform
(left: Brand A – middle: Brand D – right: Brand B)

Table 2. Luminous flux variation

Brand	Φ, lm Sept. 2010	Φ, lm Jan. 2011	Differ.
A	1650	1659	+0,6%
B	1535	1503	-2,1%
C	1595	978	-38,7%
D	1774	1792	+1,0%
E	754	645	-14,4%
F	1707	1711	+0,2%
G	1036	894	-13,7%
H	1437	1519	+5,7%
I	1605	1643	+2,4%
J	920	823	-10,5%
K	1479	1584	+7,1%
L	1185	1224	+3,3%

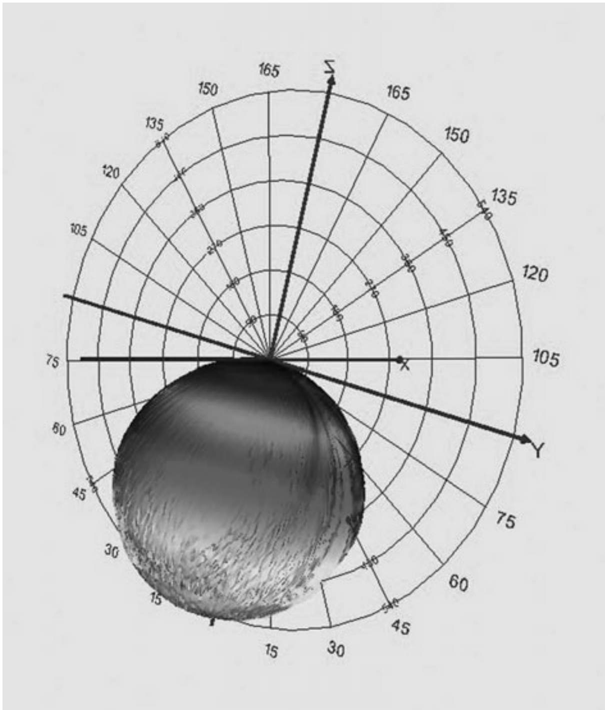


Fig. 8. Radiation pattern (3 D)

Moreover, the active power dissipated by the Brand C LED tube was also reduced by 19%, which partially explains the decrease in luminous flux. The measured active power of all other lamps remained almost constant (change between –2% and +1%), as well as all other parameters considered (*CCT*, *CRI*, *PF* and *THD*).

4. RETROFIT OF A FLUORESCENT LUMINAIRE: A CASE STUDY

In Fig. 10 a small office room used by the students' union of the Catholic University College KAHO Sint – Lieven is shown. The room is 4 m by 6 m and 2.7 m high. Three old T8 luminaires are installed, each with one T8–36 W/840 fluorescent lamp.

Replacing a conventional fluorescent lamp by a LED tube with a hemispherical, yet quite different luminance distribution, will change the luminous intensity distribution of the original luminaire and thus the illuminance on the task area.

The luminous intensity distribution of the luminaire with four different lamp types were measured under controlled conditions (25 °C, sinusoidal voltage) with a near-field goniophotometer (see § 3.1). The lamps considered are:

- A new fluorescent lamp type T8_36 W/840 – radiation pattern in Fig. 11-d. The measured active power of the luminaire is 51 *W*. Hence, the old electromagnetic ballast consumes 15 W. The measured luminaire efficiency *LOR* is 77% (*CCT*=4000 K).
- LED tube *brand A*: tube with a diffuser – radiation pattern shown in Fig. 11-a. The active power of the luminaire is 23,5 W; the *LOR* is 85% (CCT=4186 K).

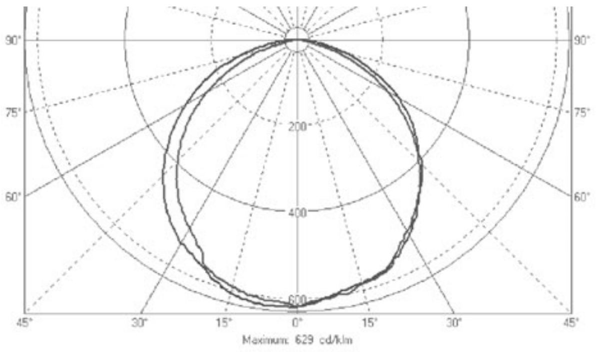


Fig. 9. Radiation pattern (C0–180 & C90–270)

Fig. 10. Small office room used by the students' union of KAHO

• LED tube *brand I*: tube with only 32, but high intensity LEDs – radiation pattern shown in Fig. 11-b. The active power of the luminaire is 32 W, the *LOR* (Light Output Ratio) is 86 % (*CCT*=3365 K).

• LED tube *brand K*: tube with 360 SMD LEDs – radiation pattern shown in Fig. 11-c. The active power of the luminaire is 19,7 W (*CCT*=4733 K).

While a fluorescent lamp emits light in all directions, a LED tube is a Lambertian directional light source emitting light in a downward-hemispherical arrangement (Fig. 8). Hence, the linear replacement lamps cannot use the luminaire reflector design in the same way as fluorescent lamps do. The hemispherical radiation of LED linear replacement lamps results in less light losses within the luminaire. Hence, the luminaire efficiency will increase after relamping (in our case, the *LOR* increases from 77 % to about 85 %). On the other hand, the radiation pattern of the luminaire can change considerably (Fig. 11).

For each luminaire – lamp combination, Eulumdat files (.ldt) were generated and imported in the lighting planning software DIALux® to simulate the light distribution in the room under consideration. The calculated mean illuminance values E_{avg} and uniformity values g_1 (i.e. the minimum divided by the mean illuminance) on the horizontal task area (0.8 m height) are given in Table 3. A wall zone of 0.3 m was used.

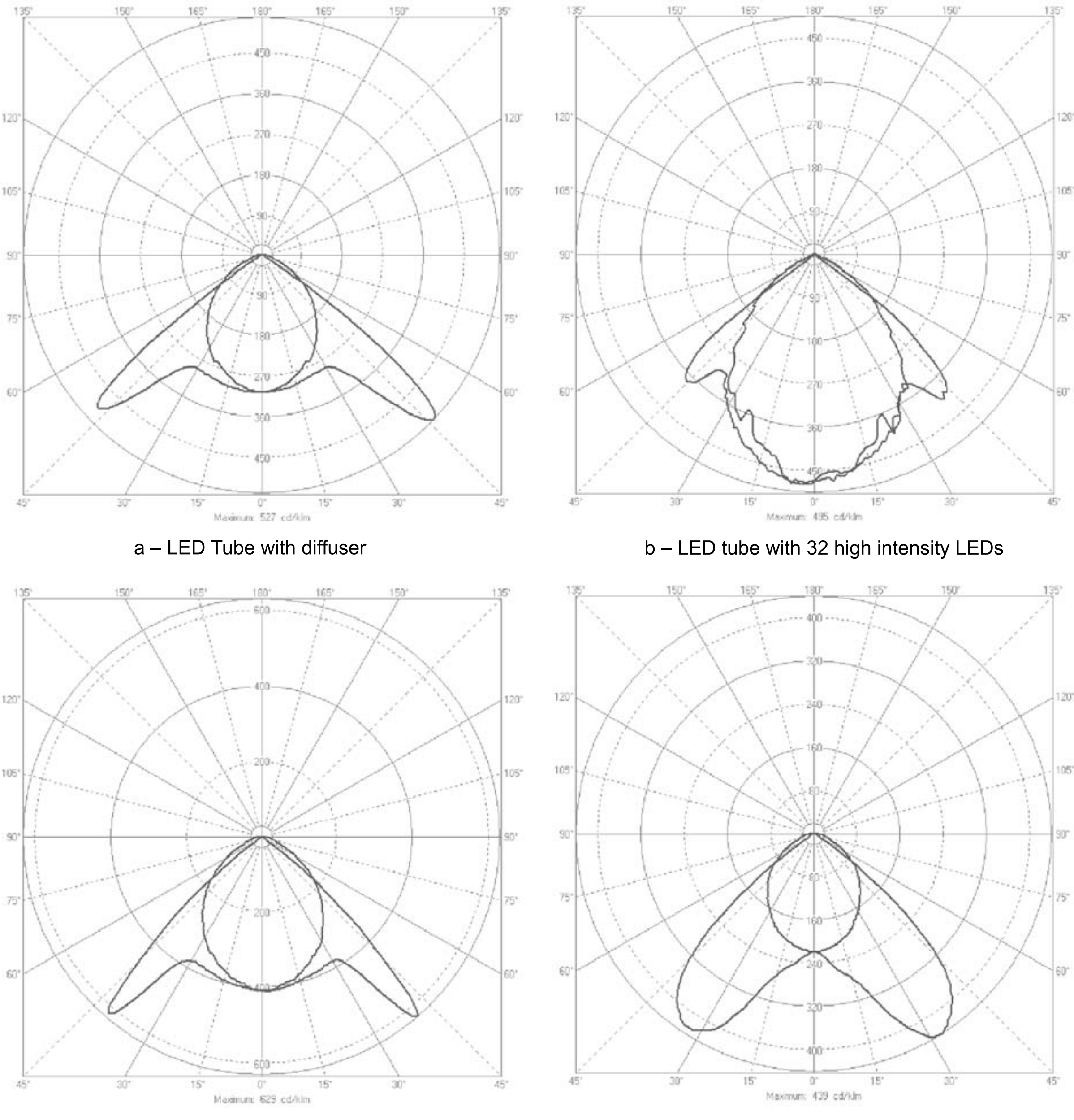
Table 3. Work plane illuminance

	$P_{installed}$, W	E_{avg}, lx	g_1
T8	153,6	278	0,21
Brand A	70,5	149	0,21
Brand I	95,7	146	0,15
Brand K	59,1	160	0,19

Replacing all fluorescent tubes by LED tubes will decrease the power consumption substantially, with energy savings up to 70 % (installation and maintenance costs not considered). However, the mean illuminance will be reduced with about 50 % to an unacceptable value! The illuminance values in Table 3 are initial values (depreciation factor equals 1) and will decrease over time, especially if through-hole LEDs have been used. The uniformity is in the same range. The light distribution on the task area is shown in Fig. 12 before and after the retrofit.

The original lighting installation should have been designed to comply with the lighting specifications [EN12464–1 2009] or legal requirements. It is clear that in most cases the modified lighting installation will not provide the same level of illuminance as the original lighting installation (Fig. 12) and the specified requirements for lighting solutions for work places will not be met anymore.

To investigate the visual appearance of the small office room (Fig. 10), 44 subjects were asked to fill out a questionnaire. The subjects, divided in groups of 4–6 persons, had to evaluate all four lamp types. During each lamp replacement, the subjects had to leave the room for several minutes. The reduced illuminance values in the room were noticed by nearly all respondents. Obviously, the room is perceived darker when the fluorescent lamps are replaced by LED tubes. Adaptation cannot compensate for those large differences in illuminance and luminance.



a – LED Tube with diffuser

b – LED tube with 32 high intensity LEDs

c – LED tube with 360 SMD LEDs

d – Fluorescent lamp T8–36 W/840

Fig. 11. Experimental radiation patterns

5. OTHER REMARKS

All commercial, economical and juridical aspects have not been considered in this study. Nevertheless, there may be safety and other concerns [Celma 2010]:

• It is known that an unsafe situation (electric shock risks) can occur when LED modules are installed;

• The lamp holders of the original luminaire may be overstressed by the weight of the LED tube;

• Probably, the converted luminaires will not comply anymore with requirements of the luminaire safety standards (EN 60598–1) and CE mark labeling. In fact, the organization modifying a luminaire should take over the full future responsibility for the luminaire with respect to all aspects (safety, EMC, photometric…);

• The lamp manufacturer's warranty will be void if the adapted luminaire does not comply with lamp safety and performance standards.

6. CONCLUSIONS

Luminaires based on LEDs are emerging into the market. Low energy consumption, long life, dimma-

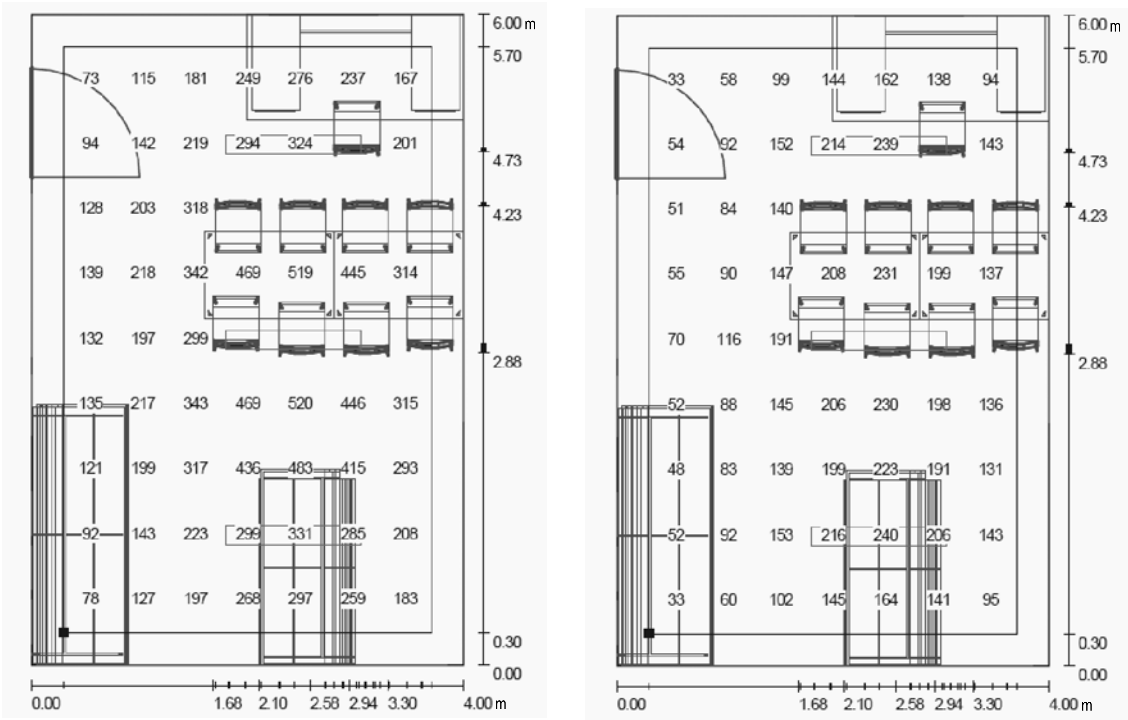


Fig. 12. Illumination distribution on the task area
Left: luminaire with T8 lamp – Right: luminaire with LED tube brand I

bility and variability, compactness and negligible heat transfer in the light beam make solid state lighting an attractive alternative to traditional light sources. On the other hand, there is a lack of standardisation to evaluate products and a lot of products have an inferior quality and/or provide confusing or false performance claims. In this study, twelve LED tubes intended as replacements for T8 fluorescent lamps were investigated. Bare lamp tests as well as performance tests in a typical luminaire with a parabolic reflector have been done. The luminous flux values of the LED tubes tested are low and could result in unacceptable low illumination levels, even though the luminaire efficiency increases slightly when replacing a T8 lamp by a LED counterpart. Furthermore, many LED tubes have a bad colour rendering. Visual tests confirm that the performance of LED tubes is still insufficient to replace fluorescent lamps, especially in office lighting. To improve the energy efficiency of a lighting installation, the most effective way is still by the installation of a new high efficient lighting installation. In that case, the lighting quality can be guaranteed and can be combined with reduced operating costs. When old-style fluorescent lamps with poor color rendering indices (50–60) were installed, a relamping with new fluorescent tubes will also improve the lighting quality and reduce the energy consumption. Nevertheless, there are applications in which the LED tubes may be the best solution, especially in case of cold-temperature conditions.

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REFERENCES

1. CELMA 2010 CELMA position paper – T5 and T8 Fluorescent Lamp and LED Lamp/ module Adaptors “Retro-fit Conversion Units” for T8, T10 & T12 Luminaires (2010).

2. CIE 1995 Commission Internationale de l’Eclairage (CIE) 117–1995, Discomfort glare in interior lighting.

3. CIE 2002 Commission Internationale de l’Eclairage (CIE) 2002, TC 3–01 Report, Glare from small, large and complex sources, Vienna.

4. Elbe-Hankins 2004 Eble-Hankins, M.L., Waters, C.E., VCP and UGR Glare Evaluation Systems: A Look Back and A Way Forward, Leukos 1 (2) (2004) 7–38.

5. EN 12464–1 2009 EN 12464–1 Light and lighting – Lighting of work places – Part 1 : Indoor work places (2009).

6. IEC 61000–3-2 2005 IEC 61000–3-2 Electromagnetic compatibility (EMC) – Part 3–2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase) (2005).

7. Murdoch 2003 Murdoch, J.B. Illuminating Engineering, From Edison's Lamp to the LED, Second Edition, 2003, Visions Communications, ISBN: 1–885750–05–6.

8. Myer 2009 Myer, M.A., Paget, M.L., Lingard, R.D., CALiPER Benckmark Report, Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps, 2009 (US Department of Energy, http://www1.eere.energy.gov/buildings/ssl/benchmark.html).

9. Smet 2010 Smet, K., Ryckaert, W., Deconinck, G., Michael, P., Hanselaer, P. Memory colours and colour quality evaluation of conventional and solid-state lamps. *Optics Express, 18* (25), 26229–26244 (2010).

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