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Study on conservation aspects using LED technology for museum lighting

Gabriele Piccablotto[a]*, Chiara Aghemo[b], Anna Pellegrino[b], Paola Iacomussi[c], Michela Radis[c]

[a]*Department of Architecture and Design, LAMSA Laboratory,Politecnico di Torino, viale Mattioli 39, Torino, 10139 , Italy*
[b]*Department of Energy, TEBE Research Group, Politecnico di Torino, corso Duca degli Abruzzi 24, Torino, 10129 , Italy*
[c]*National Research Institute of Metrology, strada delle Cacce 91, Torino, 10135 , Italy*

Abstract

The use of LEDs in museums is becoming more and more frequent. Benefits are claimed in terms of lighting quality, conservation and maintenance. Nonetheless the impact of LED light on collections preservation is not yet completely explored. The goal of this study was to evaluate, through exposure tests, the colour degradation and fading produced by LED: several white LEDs, with different colour temperature, and a traditional halogen lamp, were used to light up light-responsive samples. The results stressed the importance of the spectral distribution with respect to effective wavelengths in causing colour degradation, and in general white LEDs resulted more suitable, in terms of fading prevention, than traditional halogen light sources.

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Keywords: Solid State Lighting; preventive conservation; light induced damage; museum lighting.

1. Introduction

Nowadays the use of Solid State Lighting (SSL) in museums is becoming more and more frequent. Several worldwide museum institutions are moving towards SSL use, for reasons mainly concerned with energy savings, ease of positioning/outfitting, improved visual appearance and safer conservation of displayed collections. Indeed, energy savings, sustainability and outfitting are recurrent topics between lighting designers and museum management staff, and these criteria seem to be potentially fulfilled by the latest LED generations. Nevertheless,

* Corresponding author. Tel.: +39 0110906679; fax: +39 0110906679
E-mail address: gabriele.piccablotto@polito.it

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SSL impact on collections preservation is not completely known, due to the recent introduction of LEDs on the market and the significant differences from traditional lamps. At present standards and guidelines on cultural heritage considering the use of SSL are few or still in progress [1, 2, 3], meanwhile recent researches have focused the attention on LED spectra, urging caution for energy peaks in narrow wavelength bands throughout the visible range or in the blue region [4, 5, 6, 7, 8, 9, 10]. The main aim of the study presented in the paper was to investigate the spectral distribution of LED sources with respect to effective wavelengths causing colour degradation on light-responsive materials. In two experimental tests white LEDs irradiate natural dyed textiles and Blue Wool swatches, for long and short time, while the spectral reflectance factor of the samples was regularly verified. The measurement results provide further information towards the benefits and drawbacks of LED technology for museum lighting.

2. Characterisation of light sources and test samples

In this study five different white LED sources (phosphor coating technology) significantly different from each other in terms of spectral emission and Correlated Colour Temperature (CCT), were tested. Focusing on CCT, three different "Warm White" LEDs were chosen (WW-LED1, WW-LED2, WW-LED3) because their spectrum was designed to mimic a halogen lamp, a source broadly used in museums for its colour rendering. The other two LEDs ranged from "Neutral White" (NW-LED) to "Cool White" (CW-LED). Besides LEDs, a low-voltage multifaceted reflector halogen lamp with cover glass (WW-MR) was also employed as reference light source. Figure 1 compares the spectral power distribution (SPD) of each light source acquired by means of a Minolta CL-500A spectrophotometer.

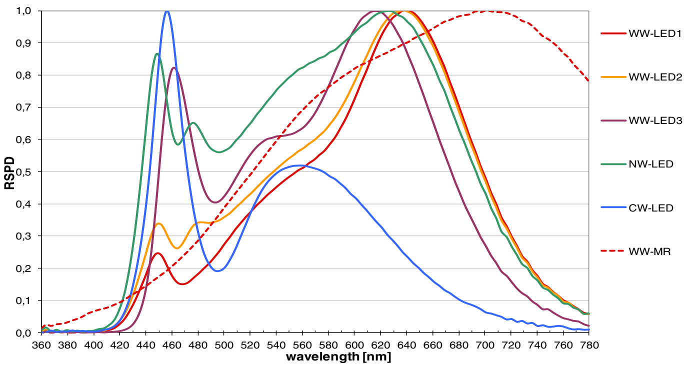

Fig. 1. Relative Spectral Power Distribution (RSPD) of the selected light sources.

Besides colorimetric information obtained from spectral data, UV-A (315÷380 nm) and VIS-NIR (380÷1000 nm) irradiance were measured using a Gigahertz-Optik P-9710 optometer. In Table 1 colorimetric and radiometric data are summarised, expressing the amount of UV-A and VIS-NIR as ratio with respect to luminous flux.

Table 1. Measurement results from laboratory characterisation of the selected light sources.

Light source	Correlated Colour Temperature, CCT	Colour rendering index, R_a	UV-A ratio	VIS-NIR ratio
	[K]	[-]	[µW/lm]	[mW/lm]
WW-LED1	2580	97	0.58	3.15
WW-LED2	2853	96	0.57	3.10
WW-LED3	3371	91	0.23	2.71
NW-LED	3892	97	0.43	2.87
CW-LED	6985	79	0.15	2.58
WW-MR	3032	93	30.27	8.60

Focusing only on UV content, its relationship with CCT seems to be inconsistent since the amount of UV-A for the cool white CW-LED is lower than in the warmer sources. This trade-off relationship may be related also to different phosphor coating ("cold phosphor" and "phosphor on chip" technology), and it is to note that the UV content of all tested LEDs is largely below the stringent limit of 10 μW/lm required for very high-responsivity objects [11], highlighting that even high CCT LED sources are less harmful than halogen lamps. Similar consideration may be drawn for the amount of VIS/NIR: the halogen lamp WW-MR almost trebles the LEDs.

According to the CIE 157 report [12], the relative damage potential of the selected LED was calculated to investigate the consistency of the relationship between damage and light sources CCT. All values are normalized to illuminant A (2856 K) and plotted against relative damage potential values of daylight illuminants and planckian sources, as in CIE 157 report and shown in Figure 2.

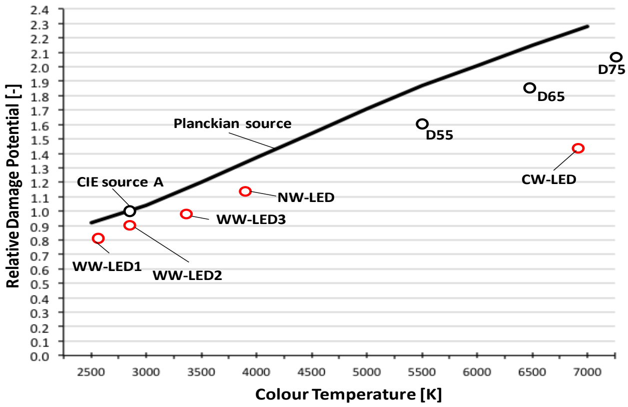

Fig. 2. Relative damage potential of the selected LED light sources (red circle) compared to planckian sources and D series illuminants (black circle). Values are normalized to illuminant A (2856 K).

In this graph the link between CCT and relative damage potential seems to be consistent also for the selected LEDs since cool white CW-LED shows the highest relative damage potential. Nevertheless, all LEDs carry less calculated relative damage potential risk than planckian sources and daylight D illuminants.

In order to verify the impact of LED light on object damage, a set of light-responsive materials were selected to be used in the exposure tests: Blue Wool Standard swatches (BWS), (ISO1, ISO2 and ISO3 grades) [13] and, eight silk fabric samples coloured with natural dyes (3 yellows, 3 reds, 1 blue and 1 violet dye) were used as representative of the most light-sensitive artefacts encountered in museum collections [14]. The apparatus for the exposure experiment consisted of enclosed booths (20x20x60 cm) equipped with the tested light source. Before the aging process, the spectral reflectance of BWS and dyed-silk samples was measured in the wavelength range 360÷830 nm (1 nm of resolution) by means of a Perkin-Elmer Lambda 900 spectrometer.

3. Methodology of the exposure tests

The first experimental part of the study consisted in a long-term exposure test: the samples were exposed to a light exposure of 64.9 Mlx·h over a period of 9 months. Three LEDs with CCT from 2600 K to 4000 K and the highest values of colour rendering index Ra (WW-LED1, WW-LED2, NW-LED) were used to irradiate BWS and dyed-silk samples. The irradiated surface of the samples was adjusted to be at 10000 lx constantly. The rationale of the exposure conditions was to accomplish a considerable light exposure to assess the fading curves possibly until no further change occurred. The fading assessment was carried out measuring, periodically, the spectral reflectance of each aging sample. The spectral information was collected from 360 to 830 mm and then transformed in CIE76 L*a*b* colour space coordinates to calculate the colour difference ΔE^*_{ab} between two consecutive spectral measurement sessions. CIE standard 2° observer and Equi-Energy Spectrum illuminant were considered.

The second experimental part (short-term exposure test) further investigated some previous results and was limited to 1.0 Mlx·h of light exposure using only BWS ISO1 and ISO2 grades. All five LED sources and an halogen lamp were used, covering a CCT range from 2600 K to 7000 K approximately. The methodology to induce and assess fading on samples was substantially the same used in the long-term exposure test.

4. Results

4.1. Long-term exposure test

This test stressed remarkable differences in terms of light-responsivity between the natural dyed silk samples, while the differences in BWS were expected and confirmed. To better clarify the differences, Figure 3 shows the comparison of fading curves, expressed in terms of ΔE^*_{ab} versus light dose, for all the samples under NW-LED.

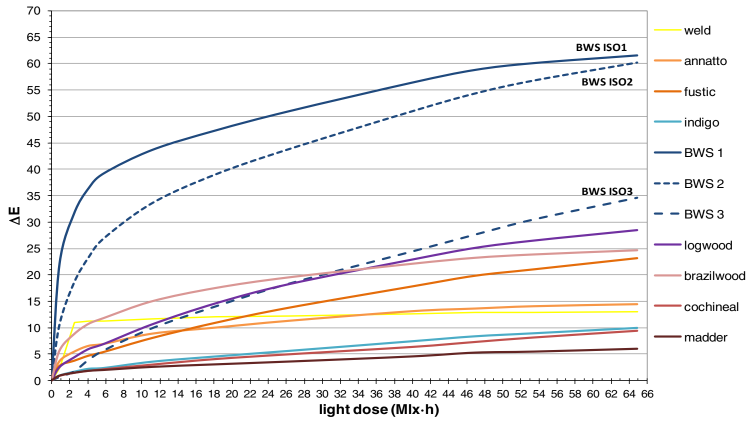

Fig. 3. Colour variation of BWS grade ISO1, ISO2, ISO3 and silk-dyed samples under NW-LED light source.

Table 2 shows the different fading induced by LEDs on the different samples, at the end of the experiment. A measurement uncertainty of ±0.5 ΔE^*_{ab}, calculated for the worst case sample, was considered precautionary valid for all samples.

Table 2. Colour variation ΔE*ab induced by NW-LED, WW-LED1, WW-LED2 at the achieved total light dose (64.9 Mlx·h).

Sample	ΔE*ab induced by each LED source			Difference of ΔE*ab Between	
	NW-LED	WW-LED1	WW-LED2	NW-LED and WW-LED1	NW-LED and WW-LED2
BWS grade ISO1	61.6	64.7	64.2	-3.2	-2.7
BWS grade ISO2	60.2	62.0	62.8	-2.6	-1.8
BWS grade ISO3	34.6	36.0	36.7	-2.2	-1.5
Weld (yellow dye)	13.1	13.4	13.4	-0.4	-0.4
Annatto (yellow dye)	14.4	12.6	13.3	+1.8	+1.1
Old fustic (yellow dye)	23.1	18.8	20.6	+4.3	+2.5
Brazilwood (red dye)	24.7	24.3	24.2	+0.4	+0.5
Cochineal (red dye)	9.4	8.2	8.6	+1.3	+0.9
Madder (red dye)	6.0	5.3	5.3	+0.7	+0.7
Indigo (blue dye)	9.9	9.0	9.0	+1.0	+0.9
Logwood (violet dye)	28.5	26.4	27.2	+2.1	+1.3

According to data in Table 2, at the achieved total light dose of 64.9 Mlx·h, some dyed silk samples (Annatto, Fustic, Logwood and less significantly Cochineal, Madder and Indigo) faded faster under the LED with the highest CCT (NW-LED). Conversely, BWS samples faded faster under the LEDs with lower CCT (WW-LED1, WW-LED2)..

4.2. Short-term exposure test

In the second test, all LEDs and the halogen lamp were used to irradiate BWS ISO1 and ISO2 grade only, for a shorter time and lighting exposure. Figure 4 shows the fading curves over a light dose up to 1.05 Mlx·h.

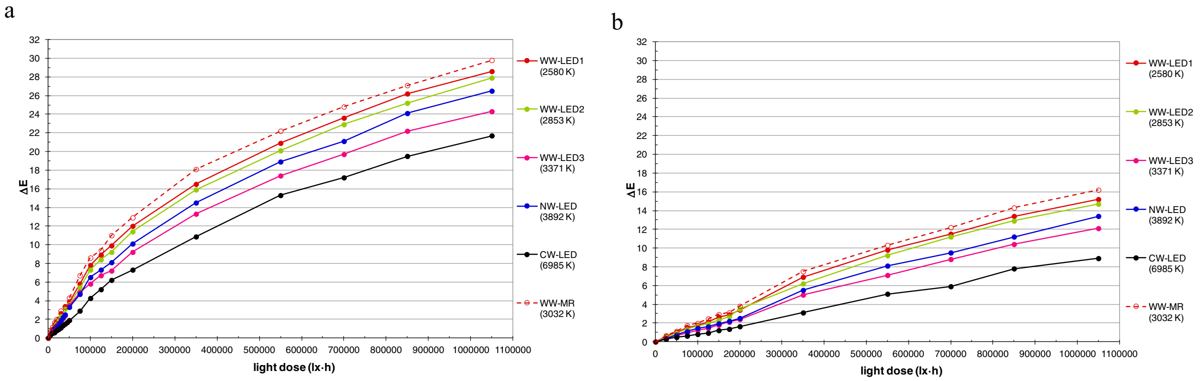

Fig. 4.(a) Colour variation of BWS ISO1 grade. (b) Colour variation of BWS ISO2 grade.

In both BWS samples, a different amount of fading occurred depending on the light source in spite of the same cumulative light exposure. Focusing on the initial part of the fading curves, the threshold light exposure to achieve $\Delta E^*_{ab} = 1$ was defined, according to the basic criterion of just noticeable fade reported in CIE 157. In Table 3 the threshold exposure values expressed in [lx·h] related to each light source are summarised.

Table 3. Threshold light dose causing just noticeable fade ($\Delta E^*_{ab} = 1$) on BWS ISO1 and ISO2 grade.

Light source	CCT	Light dose for noticeable fade on BWS	
		ISO1 grade	ISO2 grade
-	[K]	[lx·h]	[lx·h]
WW-LED1	2580	≈ 11000	≈ 50000
WW-LED2	2853	≈ 12000	≈ 55000
WW-LED3	3371	≈ 17000	≈ 80000
NW-LED	3892	≈ 14000	≈ 70000
CW-LED	6985	≈ 27000	≈ 130000
WW-MR	3032	≈ 8000	≈ 45000

The smallest amount of light exposure causing a $\Delta E^*_{ab} = 1$ colour change occurred with the WW-MR halogen lamp, whilst the largest light exposure was with CW-LED. The warm white LEDs showed threshold values around those of the halogen lamp (in particular for WW-LED1 and WW-LED2). These results partially confirm the previous findings of the long-term exposure test: BWS samples fade slower under LEDs with higher CCT, questioning if the CIE metric for damage vs CCT is still applicable to LEDs, and about the effectiveness of BWS scale as light dosimeter for LED lighting as well as for traditional light sources with a broader spectrum [15, 16].

5. Conclusions

Despite further investigation should be undertaken, from the results obtained in these tests some conclusions on SSL suitability for museum collections can be outlined.

The fading capabilities of five white LEDs with different light emission and CCT and of a halogen lamp were compared considering induced fading on Blue Wool Standard and natural dyed silk fabrics. CIE metric on CCT vs Damage potential indicates an higher risk of damage related to LED with higher CCT, but radiometric analyses showed that for LEDs higher CCT is not directly related to higher UV content, as in traditional lamps. Indeed the two light exposure experiments demonstrated that the potential damage of LEDs is not always directly related to their CCT. Blue Wool swatches faded slower under LED with the highest CCT, and faster under halogen lamp. So the use of CCT as effective predictor of material degradation is not consistent with LEDs when considering fading induced only on BWS. Because LEDs caused a slower fade than halogen lamp on BWS, it is possible to question if the use of Blue Wool swatches as light dosimeter as reported in several standards on preventive conservation is still the best choice also for SSL. Indeed more investigation must be performed on the BWS effectiveness with SSL.

In conclusion, our results showed that the selected white LEDs are suitable for museum lighting in terms of preventive conservation compared to incumbent technology. It can be said that SSL offers a tantalizing potential for museum lighting, but further research and testing are needed to assess damage metric and reference dosimeters.

Acknowledgements

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