

LED usage in museums and art galleries

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Introduction

LEDs provide an energy and maintenance saving alternative to halogen for museum lighting. Previously high Color Temperature single phosphor corrected (PC) white LEDs had shortcomings with gaps in the spectrum affecting accurate color discrimination and high outputs / spikes in the blue spectra affecting color fading of light sensitive materials of heritage items. Recent improvements in LED technology make their usage applicable in all areas, light sensitive and insensitive alike. This paper takes the Artist Series module from Xicato to quantify this statement.

Background: LED usage in museums and art galleries

Compared with tungsten halogen lamps, LEDs provide energy and maintenance savings. LED efficacies and useful lifetimes are higher than that of halogen lamps, eg for the Xicato Artist Series modules up to 40lm/W (depending on drive current) and 50k hours (to an expected 15% depreciation) respectively. Life is important in terms of maintenance costs, but also ruggedness is critical bearing in mind the effects of continuous luminaire repositioning as exhibitions are changed. Dependable reliability is needed for peace of mind against the tarnishing of an establishment's image that would follow failures - more of a consideration than normal if the failure is contributing not just to an ambience but to the perception of a work of art.

Additional advantages compared with halogen lamps include the lack of UV which can cause deterioration of some materials, and IR, which causes heating (which will further effect material deterioration).

The above advantages of LEDs have already led to their wide uptake in non-light sensitive areas, and for the first time also in display areas. Questions have been asked about their usage in the latter areas owing to Spectral Power Distribution (SPD) related issues^{1,2}. These questions concern impairment of human color discrimination and impairment of light sensitive materials. These issues are fundamental and will be dealt with first.

Fundamental issues: suitability of LEDs for museum lighting in terms of color discrimination and impairment of light sensitive materials

LED sources have previously been evaluated for their suitability in museum lighting by Mie ISHII et al in 2007¹. Tests for effect on color degradation of different natural dyes and different blue scale standards (the index of light color fastness for dyed fabrics) were carried out with different LED technologies and an accumulated exposure time of 150000lx.hr (a CIE standard for light fugitive materials of medium responsivity³). The main findings were that particularly single phosphor LEDs of a high CCT (over 4000K), especially if there are abrupt peaks in the spectrum around 400 – 500nm, have a greater effect on the fading of yellow dyes or blue scale grade 1 and 2 standards than that of museum fluorescent lamps (NU). UV based LEDs with Tri Phosphors were also noted to cause accelerated damage.

Another issue highlighted by Kronkright¹ involves the effect of a non-continuous spectrum on an accurate perception of a work of art.

The above observations and cautions were relevant with the phosphor corrected LEDs of the time. Advances in the light quality of LEDs and LED modules, particularly LED modules with a separated and tuned phosphor, not only overcome these shortcomings but present a solution on a par with halogen lamps. Specification points to be certain of in this respect include:

- A high CRI across all 15 CIE Test Colors (CIE 13.3-1995) to ensure accurate perception of exhibits
- Limited output between 400-500nm. From the color perspective, the blue portion of the spectrum (which is abundant in sun, moon and starlight) is needed for the proper functioning of the human eye, so there should be some light in these wavelengths, but certainly not significantly higher than halogen.

- In general a SPD that follows as closely as possible the Black Body Locus (BBL) with gradual changes and not spikes

In figures 1 to 3 the Artist Series module from Xicato, which uses their patent pending “Corrected Cold Phosphor Technology”, is compared with traditional light sources in terms of CRI and halogen and standard phosphor corrected LEDs in terms of a SPD analysis, to demonstrate how the above weaknesses are solved. Figure 4 shows an application demonstration of the Artist Series module alongside tungsten halogen.

	Ra8	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
Artist Series XSM	98	98	99	98	98	98	97	98	98	96	99	98	88	98	98	98
Typical IR coated halogen dichroic	98	98	99	99	99	98	98	99	97	92	97	98	97	98	99	97
Typical Compact Fluorescent	82	90	94	69	82	81	81	87	71	27	59	62	55	93	78	88
Typical Compact Metal Halide	87	91	93	86	91	89	90	88	70	17	76	91	81	93	92	81

Figure 1.

Xicato’s Artist Series module Color Rendering properties compared with traditional lamp types. Test Color Samples 1 to 15 are detailed, from CIE 13.3-1995. Measurements by University College London

Notes:

- High rendering properties across the visible spectrum allows fine color discernment of museum or gallery exhibits, bettering typical compact metal halide or compact fluorescent sources and on a par with halogen sources

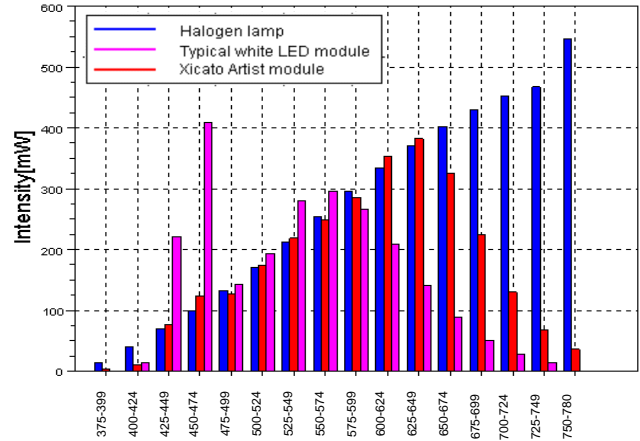
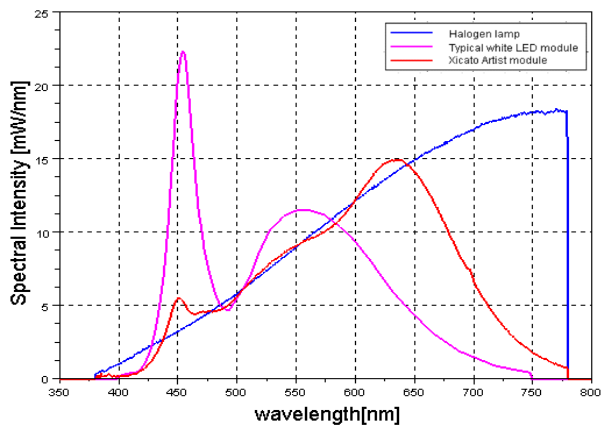


Figure 2

Comparison of SPD for Xicato's Artist Series module (3000K) with halogen and Cool White pc LED. Outputs normalised to 700lm – the output of the Xicato's Artist Series module at 700mA operation

Notes:

- Below 400nm
 - Halogen has nearly 4 times more light than Xicato's Artist Series module
- In 400-450nm region
 - Xicato's Artist Series module has less light than Halogen (87mW compared to 110mW)
 - Cool white pc LED has twice the amount of light of Halogen (236mW)
- Change in intensity from the adjacent spectral band is
 - Gradual with the Halogen lamp
 - Abrupt with the Cool White pc LED
 - Gradual change close to Halogen lamp with the Xicato's Artist Series module

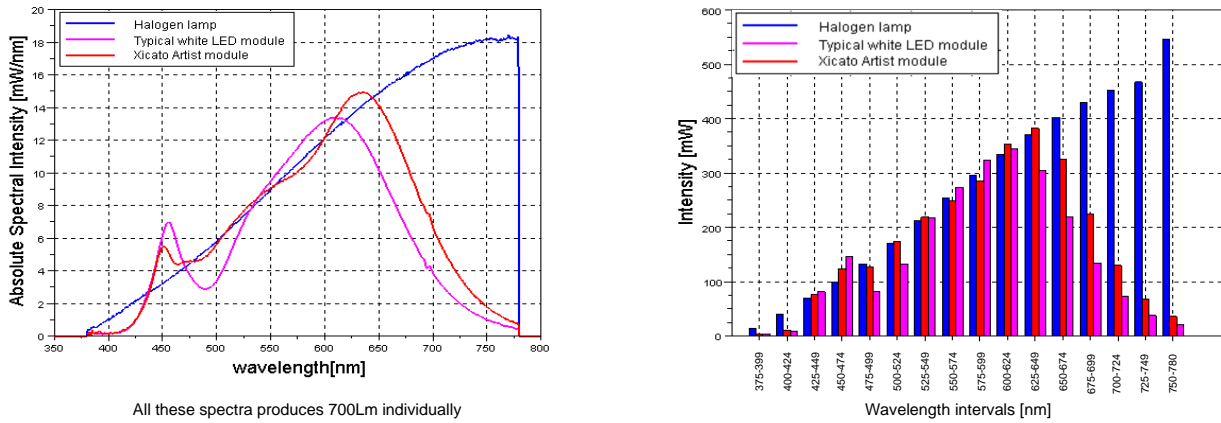


Figure 3

Comparison of SPD for Xicato's Artist Series module (3000K) with halogen and Warm White pc LED. Outputs normalised to 700lm – the output of the Xicato's Artist Series module at 700mA operation

Notes:

- Below 400nm
 - Halogen has nearly 4 times more light than Xicato Artist Series module
- In 400-450nm region
 - Xicato's Artist Series module has less light than Halogen (87mW compared to 110mW)
 - Warm white pc LED has less light than Halogen but more than Xicato's Artist Series module (91mW)
- Change in intensity from the adjacent spectral band is
 - Gradual with the Halogen lamp
 - Abrupt with the Warm White pc LED
 - Gradual change close to Halogen lamp with the Xicato's Artist Series module



Figure 4

An application demonstration of Xicato's Artist Series module alongside tungsten halogen (thanks to Mike Stoane Lighting)

LED usage for museum and gallery lighting: the wider picture

Having dealt with the above fundamentals, there are a number of other reasons why LED solutions such as the Xicato's Artist Series module are ideal for museum and gallery lighting.

- Changing exhibitions mean that dimming is normally essential to create the right viewing conditions each time – this is achievable without color shift.
- Regarding overall aesthetics, the Xicato's Artist Series' 2700K option is often needed to create a comfortable environment at low light levels (Kruithof's Law on emotional responses to light levels / Color Temperatures – see Figure 5).

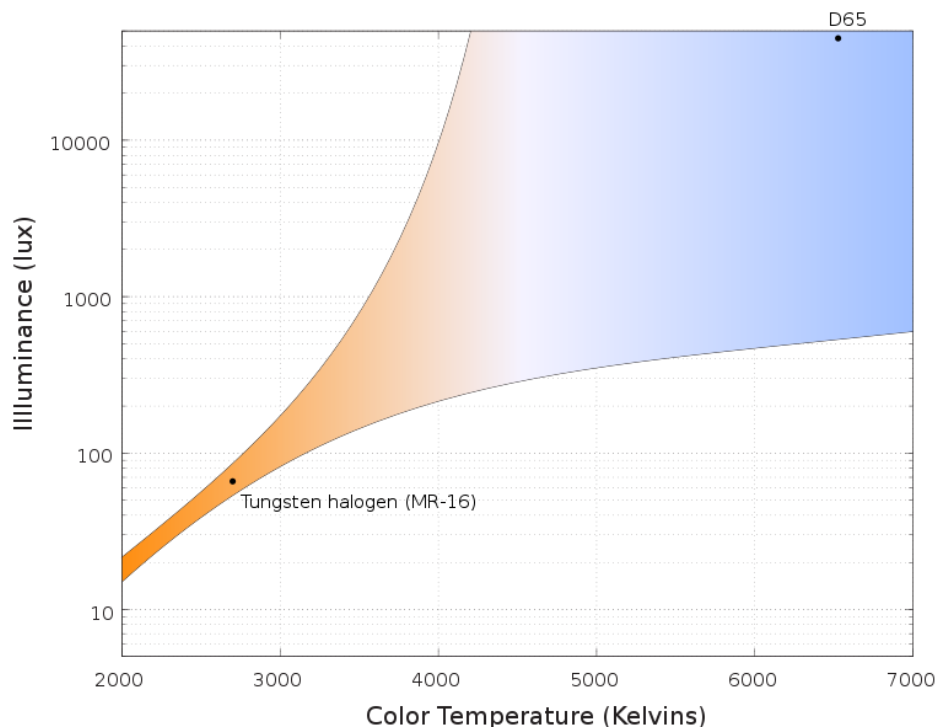


Figure 5

The Kruithof curve

- Stability of color point through life is essential for maintenance of a design. With Xicato's Artist Series module this will not deviate beyond 2 Standard Deviation Colour Matching ellipses (SDCM) of the original color point. (When traditional lamp replacements are made, even with halogen dichroic lamps if it involves a different manufacturer, there can be marked differences in color appearance).
- As accent lighting is normally track mounted in this segment, miniaturisation can contribute towards overall aesthetics. Often the architecture itself is grand or dramatic and the less obstruction from building services hardware the better.
- As with halogen lamps different beam angles are possible. Beam control for the Xicato Spot modules can be achieved by changing the reflectors, something which can be done on site. As the source is a uniform lambertian emitter it is possible to achieve a smooth beam with a sharp cut-off angle. Reflectors with 10,20,40 and 60 degree beam angles are commonly available. Because of the module's light emitting area, achieving very narrow beam distributions has an implication on reflector size. Figure 6 shows the relation between the beam angle defined by its Full Width at Half Maximum (FWHM) and the approximate diameter of the reflector for the Xicato module. Efficiency of any reflector is normally associated with size; the larger the reflector the more light can be collected and delivered to the beam. However larger sizes will create problems associated with reflection losses in the coating (the reflection factor of the commonly used aluminium or silver in the visible region is a maximum of 92%, and losses caused by this multiply with each beam reflection).

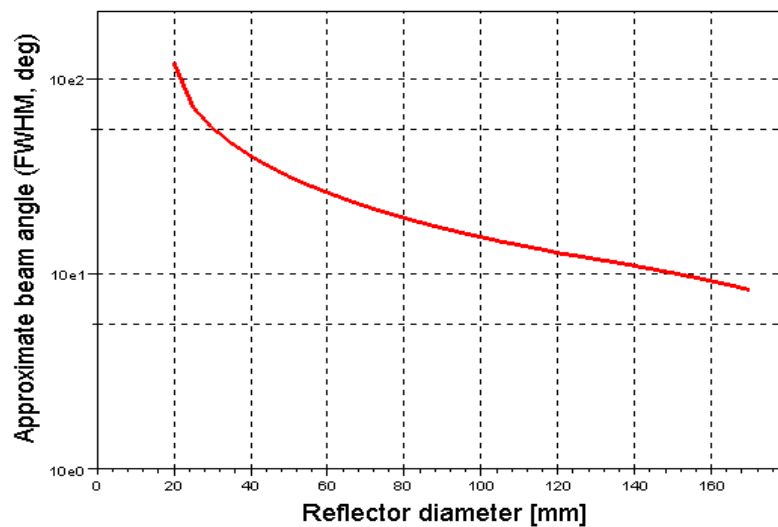


Figure 6

The relationship between beam angle and reflector diameter for a Xicato Spot module (with a 22mm diameter aperture)

Until now halogen lamps have been used predominantly in this segment. Xicato's Artist Series module provides an energy saving, long life alternative with no light quality compromises.

Figures 7 to 9 show a number of recent museum and gallery installations using Xicato's Artist Series modules.



Figure 7

The Sunderland Museum and Winter Garden.

Notes:

- Over 380 'Quartet' Uno track spots and 'Quartet' RG recessed gimbal downlights from High Technology Lighting are installed, replacing the previously used AR111 and MR16 halogen.



Figure 8

Brooker Gallery at the Chicago Field Museum

Notes:

- Here Lighting Services Inc's LumeLEX™ 2040 luminaires using Xicato's Standard (80 CRI) Series modules are installed. 26 LumeLEX™ luminaires replaced 32 Halogen PAR38 lamps and reduced the wattage from 900W to 400W - a 500W energy savings. In addition, the luminaires were dimmed approximately 40% to achieve the same light levels required for the space by the museum.



Figure 9

San Francisco MOMA (Museum Of Modern Art).

Notes:

- Lighting Services Inc. replaced 25 Halogen PAR38 lamps with 17 LumeLEX™ 2040 luminaires, using the 2700K Artist Series module in the The Djerassi Gallery. The energy savings amounted to 61%. 2700K Artist Series modules were used, creating a "human" environment according to their head curator for photography.

References

1. Open letter from Mr Dale Kronkright, Head of Conservation at the Georgia O’Keeffe Museum to the Green Task Force of the American Institute for Conservation of Artistic and Historic Works, 30th March 2010 (<http://cool.conservation-us.org/byform/mailling-lists/cdl/2010/0361.html>)
2. “Colour Degradation of Textiles with Natural Dyes and of Blue Scale Standards Exposed to White LED Lamps: Evaluation of White LED Lamps for Effectiveness as Museum Lighting” by Mie ISHII et al, J. Light & Vis. Env. Vol 32, No 4, 2008
3. CIE: Control of damage to museum objects by optical radiation (CIE 157:2004), CIE, (2004) – from which:

Category	Illuminance (Lux)	Exposure (Lux-hours)
Irresponsive	no limit*	no limit*
Low responsivity	200	600,000
Med responsivity	50	150,000
High responsivity	50	15,000

* No conservation limit but there may be adaptation, visibility or heat effects if high light levels are used on irresponsible items.

Acknowledgements

To Kevan Shaw of KSLD, Prof. Dr.-Ing. Heinrich Kramer, FPLDA of LICHTDESIGN- Ingenieurges.m.b.H. and Dale Kronkright of The Georgia O’Keeffe Museum and Research Centre for pre-publication reviews of this paper.

Afterword 1

Dale Kronkright, Head of Conservation at The Georgia O’Keeffe Museum and Research Centre

As a result of some 30 years of published experimental results in the field of art conservation, conservators concerned with the preservation of light sensitive materials know several that have long proved consistently reliable. Among these are two important points.

- Light-sensitive materials are so named because they undergo color changes (fading, yellowing, color loss or darkening) even when all ultra-violet radiation is removed from the light source. That is that they fade as a result of their exposure to the human-visual portion of the electro-magnetic spectrum.
- The earliest color shifts in light-sensitive materials, up-to and including several delta E values or “just noticeable difference” are a result of exposure to the absorption spectra of those sensitive colors. The reflected wavelengths – the colors we see - do no damage initially. It is the colors or wavelengths of light that we do not see that are being absorbed by the most sensitive colors, which are initiating light damage in light sensitive materials.

Conservators have learned to manage the damage to light sensitive materials as a result of the extensive testing done measuring the predictive relative fade rates of the ISO Blue Wool fade cards and relatively continuous-output incandescent light sources. For the last 10 years, conservators have had reason to be reasonably certain about the number of exhibition lux*hours a given object can undergo before its most sensitive colors just noticeably change. In the case of the Georgia O’Keeffe Museum, we manage that “light-lifetime” to ensure that each work lasts a minimum of 120 years before just noticeably changing. But when a light source has a spectral distribution that is different than the incandescent source upon which all

our predictive management strategies are based – a fluorescent, HID or LED light source for example, the equations that conservators have used for nearly 30 years no longer apply.

Xicato 3000K Artist Series solid state LED light sources appear to be rather remarkable among LED sources. The changes in spectral intensity very closely resemble the gradual spectral distribution of our relatively predictable incandescent sources. While museum's long ago learned how to effectively remove the small amount of ultraviolet energy emitted by halogen incandescent sources below 400nm using commonly available filters, the Xicato 3000K Artist Series virtually no UV to begin with – a considerably safety measure for even non-light sensitive museum collections. Moreover, despite the fact that the spectral distribution curve for the source shows a nearly 30% intensity drop-off at the "red" 675 nm range, the CRI for red colors is an astonishingly high 96.

The spectral quality of solid state LED light sources is clearly changing rapidly and it may be safe to assume that in 5 years time most warm-white Led sources will have spectral distributions similar to that provided by the current generation of Xicato 3000K Artist Series sources. But to think that the Xicato Artist Series spectral distributions are typical of the present LED commercial supply, in any way is not borne out by my experience. To say that there is even a "typical" spectral distribution for warm white LEDs, generally, seems to me like saying that there is a "typical horse". All horses have a similar general appearance but some kick harder than others.

In studying the spectral distribution curves of many "warm-white" LED sources (2700K - 3000K) using the US Department of Energy's CALiPER website, few reliable trends appear. A large number of sources have outputs that I find to be considerably higher than the continuous incandescent model. There are frequently excessive peaks in the blue, 450nm – 475nm region, the 575nm – 580nm yellow-green region and the 620nm – 640nm orange light region. If a museum's light-sensitive yellow, violet or red watercolor pigments, textile or photographic dyes or natural history specimens absorb strongly in these regions, many contemporary warm-white LED sources could affect damage to these materials at a faster rate than contemporary conservation models predict.

For these reasons I remain resistant to any implication that warm-white LED light sources, generally are safe, let alone ideal, for the illumination of light sensitive museum collections. The Xicato 3000K Artist Series appears to have successfully met this goal. But its properties are, as yet, far from common in the solid state LED commercial supply chain.

Afterword 2

Prof. Dr.-Ing. Heinrich Kramer, FPLDA, LICHTDESIGN-Ingenieures.m.b.H.

My office having completed over 30 museums in different countries, I am very much convinced by the Xicato Artist Series module.

Three points on the article:

1. There is much less belief nowadays in the Kruithof curve. The preferences for the Color Temperature of artificial light are influenced by our experience with daylight and artificial light sources. Thus museum directors all over the world prefer in art galleries with paintings of the old Dutch masters the PAR 38 lamp (Color Temperature of 2500K), because they know these paintings are painted under gas or candle light. So maybe Xicato should also develop a LED with a lower Color Temperature.
2. The deep red parts of the spectrum effect also dark browns (you can see it also in the CRI of the Color sheet R9). Maybe you can add a bit more long wave red. The overall CRI is fantastic, but this is what museum directors require.
3. There is a trend away from scallops over exposed paintings and towards usage of projectors or wallwashers.