# Evaluating Light Sources with Portable Spectroradiometers – LED Case Study

**Introduction**

In museum galleries, artificial light sources used to illuminate works of art were traditionally incandescent or halogen lamps. In the last few years, light emitting diodes (LEDs) have been added, and use of diffuse natural light has returned to favor. These recent developments are partly driven by new federal and state laws requiring energy efficiency.[1] The regulations effectively render inefficient light sources such as incandescent bulbs obsolete and encourage the use of LEDs and diffuse daylight in building design.

Light sources can differ markedly in their spectral power distributions (SPDs). Typical SPDs of each type of light source are shown in Figure 1. Conservation professionals will notice immediately that most of these light sources contain ultraviolet (UV) radiation, which has enough energy to break some chemical bonds. This can lead to degradation of works of art, which can be prevented by the use of UV-blocking glazing or UV filters in light fixtures.

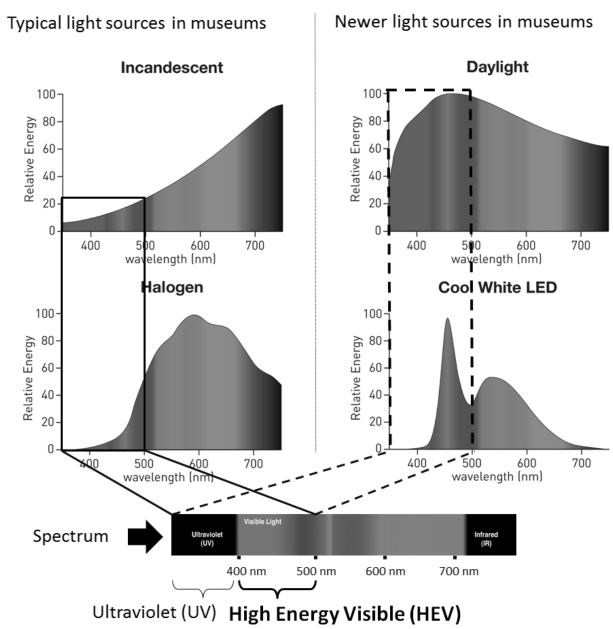


Figure 1: Spectral Power Distributions

However, UV is not the only type of radiation that can trigger damaging photochemical reactions. It has recently been reported that UV may contribute half or less of the observed light-induced fading.[2] Infrared radiation, i.e. heat, can also be deleterious, inducing physical stresses in artwork. Visible light also has the potential to cause damage, particularly if the shorter – blue – wavelengths are absorbed.

Medical research has shown that blue light can damage the eye.[3] It is well known that UV can induce formation of cataracts in the lens of the eye, but more recently it has been found that blue light, which penetrates deeper into the eye, can damage the retina. With the increased use and prolonged exposure to self-luminous electronic devices that emit blue light (e.g. cell phones, tablets), there is a growing concern regarding eye damage attributable to "high energy visible" light (HEV), a term now used in the medical field to describe light in the wavelength range from 400-500 nm. Thus, the use of sunglasses that block both UV radiation and HEV light is encouraged.[4]

In contrast to the recent recognition of the damage potential of HEV light by opthamologists, the conservation community has been aware for decades that visible light may induce damage in a variety of artists' materials [Padfield and Landi 1966, Krochmann 1986, Ishii et al.]. The wavelength dependence of damage to many materials by UV and visible light was investigated by Krochmann. He showed that some were sensitive to HEV light and that the damage function is characteristic of the material.

**Measuring Damage Function using Microfade Testing**

The Principle of Photochemical Activation states that only those wavelengths of light absorbed by a material can result in photochemical change of that material.[5] Figure 2 shows absorption spectra for textiles dyed with red and yellow Colorhue Instant-Set dyes. The yellow textile absorbs HEV light very strongly whereas the red textile has a low absorption in this region.

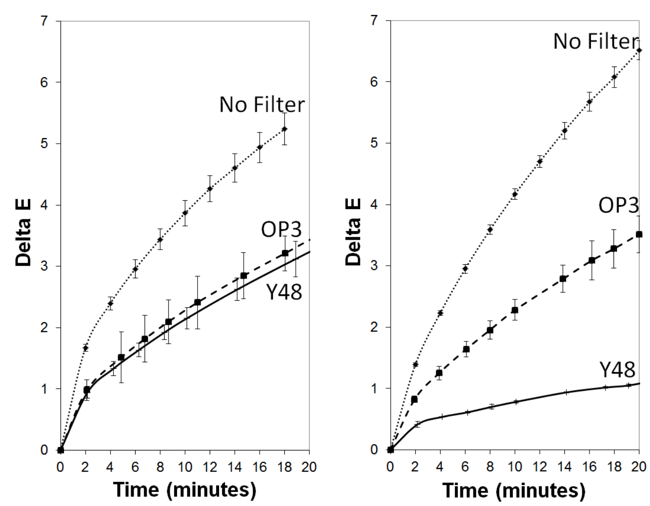


Figure: 2: MFT results for a) Colorhue Red and b) Colorhue Yellow dyed silk samples

Because the red textile does not absorb much HEV light, its removal should not have a significant effect on the appearance of the textile. In contrast, it might be expected that the greater absorbance of HEV light by the yellow textile would result in a larger appearance change.

1 energy.ca.gov/title24/ and http://www.energycodes.gov/sites/default/files/documents/Lighting_Resource_Guide.pdf

2 energy.gov/sites/prod/files/2015/01/f19/gateway_museums-report_0.pdf

3 apps1.eere.energy.gov/buildings/publications/pdfs/ssl/opticalsafety_fact-sheet.pdf

4 health.harvard.edu/staying-healthy/blue-light-has-a-dark-side

5 It should be noted that for some materials, absorbed light energy can be dissipated without causing photochemical reactions. Thus, not all absorbed light energy will result in appearance change.

**by Charlotte W. Eng, Frank D. Preusser, and Terry T. Schaeffer**

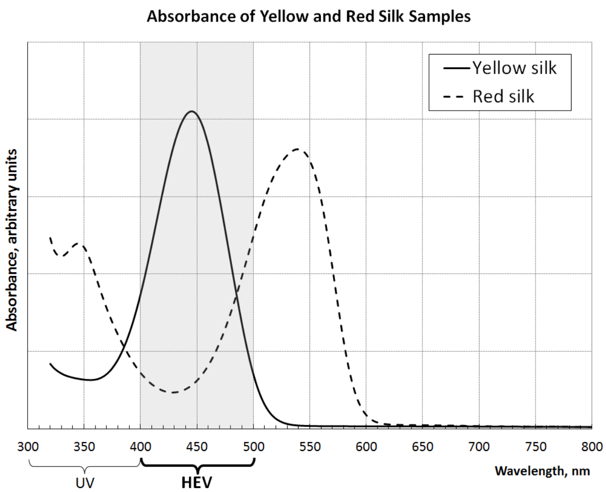


Figure 3: Absorbance spectra of yellow and red silk samples

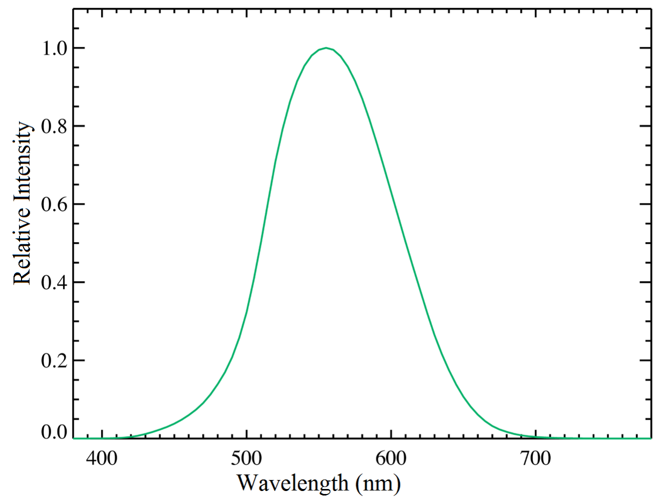


Figure 4: Photopic Curve (en.wikipedia.org/wiki/Photopic_vision)

This hypothesis was investigated by using a modified procedure for microfade testing (see Appendix). The red and yellow textiles were faded with various cut-on filters in the light path of the microfade tester: an Optivue OP-3 UV-blocking glazing, or a Hoya Y-48 filter (blocks both UV and HEV light), or no filter in the light path. The MicroFade Test (MFT) results for the red and yellow textiles are shown in Figure 3.

Not surprisingly, the appearance change of the dyed textiles was greatest (largest delta E values) when the UV and HEV radiation were both in the light source. For the red textile, the fading behavior was not significantly different whether or not HEV was removed. Because removal of HEV light did little to decrease the appearance change, UV radiation is most likely the major contributor to light damage of this sample.

This behavior contrasts with the response of the yellow textile. Removal of HEV as well as UV radiation further decreased the appearance change, indicating that UV and HEV light each have a significant role in causing photodegradation.

### Spectroradiometry vs. Photometry of Display Lighting

The MFT results demonstrate that damage to an object is dependent on the spectral absorption characteristics of its surface. If a source does not include light in the range absorbed by the material, that source will not be able to cause light damage in the material. Thus, knowledge of the SPD of light sources is equally important to understanding of photodegradation of a work of art [Schaeffer 2014].

Typical monitoring of light levels in a museum environment does not include spectral information (spectroradiometric data). Instead, measurements, either foot-candles or lux, are made photometrically using photometers. The readings would then be compared to the recommended levels.[6]

6 A standard light level for light sensitive objects such as paper and textiles is 5 foot-candles or 50 lux.

The important difference between spectroradiometric and photometric data is that the former measures light objectively in terms of absolute power across the spectrum while the latter reports the light in terms of apparent brightness to our eyes.

To generate photometric data, the spectral data detected by the photometer are modified mathematically using the photopic curve (Figure 4). This curve shows that the human eye is very sensitive to green light but not very sensitive to either ends of the visible spectrum (blue or red light).

If protection of art objects from possible light damage, rather than the sensitivity of our eyes, is the major factor in choosing appropriate display lighting, one might wonder why light levels aren't measured with spectroradiometers rather than the photometers. Spectroradiometers would clearly provide more relevant information than photometers [Cuttle 2007].

Barriers to widespread use of spectroradiometers have been cost (about $20,000), bulkiness, and complexity of use. However, portable spectroradiometers with user-friendly software that calculate photometric and colorimetric data from the spectra are now appearing on the market. In the near future, the quality, ease of use, and cost of portable spectroradiometers should make them well suited for wider adoption in the museum environment.

At LACMA, we have been evaluating the Ocean Optics Jaz spectroradiometer and its associated software for measurement of museum lighting. We are using this portable spectroradiometer not only to characterize light sources, but also to monitor a wide range of gallery lighting conditions. The instrument can quantify the amount of light energy in different regions of the spectrum (e.g. near UV, blue, and total visible) even when the overall light levels are lower than 50 lux.

## Evaluating Light Sources with Portable Spectroradiometers – LED Case Study, continued

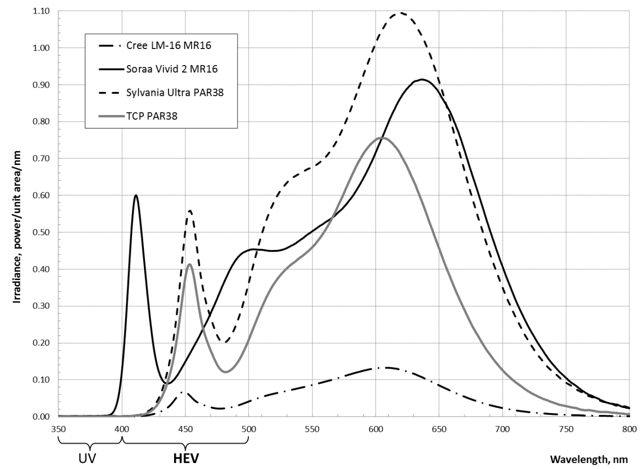


Figure 5: Spectral Power Distribution of LEDs tested in this study

### Case Study: LEDs

To demonstrate the usefulness of spectroradiometry for monitoring light sources, we measured the SPDs of five different LED lamps with our Jaz spectroradiometer. The lamps were available commercially in summer 2014. They all had a correlated color temperature (CCT) of 3000K, but their rated brightness and color rendering indices varied substantially. The SPDs of some of these LEDs are shown in Figure 5.

One of the most important features of the spectral output of LEDs is the HEV diode emission band that "pumps" the phosphors in the lamp to create white light.

The Soraa Vivid 2 MR16 LED has a violet pump, which includes a small amount of long wavelength UV. The majority of LEDs currently available, like the other LEDs we tested, are blue-pumped.

In Figure 6, the HEV regions of the spectra have been plotted. It can be seen that the blue bands vary subtly in position and intensity. The HEV band usually accounts 8 to 12 percent of the total visible output of the LED (See table in Figure 6). It should also be noted that the amount of light in the violet band can be reduced by UV-blocking glazing (dotted line in Figure 6).

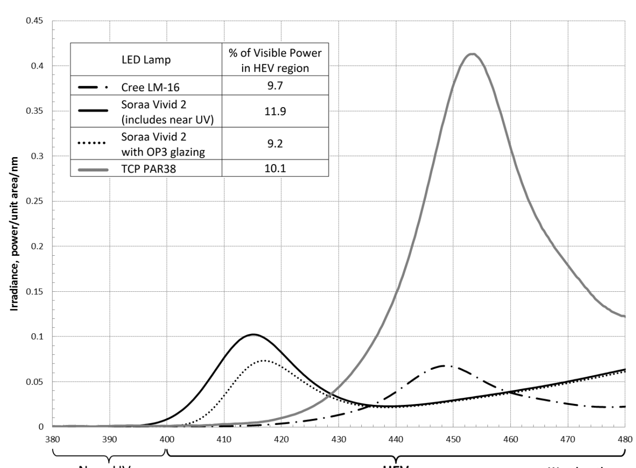


Figure 6: Spectra of LEDs in the HEV region

Table 1. Colorimetric data for LEDs tested in this study

| LED Lamp | Meas CCT | Ra (CRI) | CRI TS R9 |
|---|---|---|---|
| Cree | 2989K | 83.3 | 14.9 |
| Osram | 3137K | 82.8 | 13.7 |
| SORAA | 3007K | 93.0 | 91.0 |
| Sylvania PAR 38 | 2964K | 93.8 | 61.7 |
| TCP PAR 38 | 2980K | 83.5 | 11.3 |

Another benefit of using spectroradiometry is that photometric and colorimetric data can be calculated from the spectra (See Table 1). Lux values varied as expected based on the lumen information provided with the lamps. Four of the five lamps had CCTs within a percent of the 3000K as stated by the manufacturers; the CCT of one lamp exceeded the stated value by 5%.

The color rendering indices (CRI) calculated from the spectral data are also given in Table 1.

Neither the peak location nor the relative output of the blue or violet band appears to be directly related to the CRI.

The Sylvania Ultra PAR38 lamp had the lowest relative output in the blue band (peak at 453 nm) and an excellent CRI (93.8). Of the LEDs we evaluated, it appears that this lamp would be a better choice for illuminating works of art particularly sensitive to HEV light. During the decision making process, tradeoffs may be necessary in the selection of lamps (e.g. lower HEV output vs. better CCT or CRI).

### Conclusions

New requirements for energy efficient museum operation encourage the use of LED gallery lighting and a return to the inclusion of daylight in display spaces. LED technology is in flux, and daylight spectral quality is highly variable. The use of these light sources, combined with the wide range of wavelength dependencies of light induced appearance changes in different artists' materials, make measuring SPDs of display lighting highly advantageous.

Having both the spectral information on the light source and knowledge of the damage potential for a particular art object would provide the most complete information for selecting light sources.

Ideally, the light source would not emit much light in regions of the spectrum where the artwork has its highest absorbance, but would still provide high color rendering.

This matching of light source to each object would obviously require a larger budget, additional personnel time, and more information on the light sensitivity of most materials than are currently available.

Photometers are not designed to measure spectral outputs (SPDs) of light sources. Measuring light levels photometrically (in lux or foot candles) and knowing the color temperature of the source will not necessarily give an accurate indication of the spectral output of the lamp. Spectroradiometers overcome this problem by providing SPDs directly. In a limited survey of some LED lamps designed for use in track lighting, we have demonstrated the range of information obtainable from spectroradiometric measurements. Fortunately, portable spectroradiometers are now commercially available at prices that make them feasible for light monitoring in some institutions.

Microfade testing is one method of measuring the damage potential of light for a particular material in an art object. In this study, we demonstrated its usefulness by comparing the sensitivities of two dyed textiles to UV and HEV radiation.

In general, knowledge of the damage potential for more materials would be an improvement on the current assumption that blocking UV and limiting overall light exposure are the only available means of reducing photodegradation. In the future, we hope to have the ability to provide more specific light level recommendations for individual art objects without relying on generalized damage functions.

**Comments, Suggestions, and Practical Considerations**

- LEDs are not always UV free. Violet-pumped LEDs are likely to emit near UV radiation. LEDs are not completely IR free.
- Lamps can get hot. If they are to be used in enclosed fixtures, confirm that they are designed for this.
- If possible, personally evaluate all LEDs under consideration.
- If the SPD of an LED cannot be measured in house, request the IES LM79-09 report from the manufacturer or distributor.
- Get warranties (at least 3 years if possible).
- Consider LEDs with CCTs of 2700-3000 K. The higher the CCT, the larger the portion of total visible output that is in the HEV region.
- SPDs will change over time as LED components age at different rates. Continue to monitor the SPDs of lamps in use.
- For best color rendering, choose CRI > 90 (incandescent lamp CRIs are 99+). LEDs with CRIs in the mid or upper 80s may suffice if R9 (bright red) and R12 (bright blue) values are both high.
- Dimmable LEDs may require special track or fixtures.
- LED technology is in rapid flux; improved products are constantly being introduced.
- A paradigm shift may be occurring - to LED fixtures that eliminate replaceable bulbs by directly integrating a module with the diode and phosphors. Dedicated mounting track will likely be required for these systems, presenting additional budget needs.
- Smaller portable spectroradiometers are likely to come on the market at prices that make them competitive with high-end light monitors based on photometry.

**References**

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**Appendix**

The microfade tester consists of a xenon light source, an optical fiber bundle, and visible-range spectrometer [Whitmore 1999]. Light from the xenon source travels through one fiber down to the sample while the other fibers collect the reflected light and send it to the spectrometer.

The microfade tester can be used with or without filters in the light path. In order to record the entire visible reflectance spectra of the sample during the course of the fading with a filter in place, it had to be removed periodically for a few seconds This very small amount of exposure to UV and HEV did not affect the fading significantly. The appearance change, expressed as Delta E, is calculated from the spectra by software.