Reducing the exposure levels of highly light-responsive objects without turning down the light level

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Abstract

This paper reports on progress in a series of research investigations aimed at reducing the exposure of museum objects to damaging radiation while maintaining illumination levels. Not all wavelengths of light are equally important for colour rendering, and by concentrating radiant power into the wavebands that are most important it is possible to generate spectral power distributions (SPDs) that can provide a given illuminance with good colour rendering, while subjecting the receiving surface to relatively low irradiance. This research seeks to address the questions: What are the critical wavebands? What SPDs offer the greatest potential for reduced irradiance? How do viewers respond to museum displays illuminated with this type of lighting? To what extent can the potential for reduced exposure be achieved in practice?

Introduction

For the most light-responsive objects in museum displays it is to be expected that UV exposure will be effectively eliminated, excessive IR exposure will be avoided and light exposure will be restricted to not more than 50 lux. It is generally understood that these precautions do not prevent light-exposure damage from occurring, so it may be asked whether there is anything more that could be done for conservation of the displayed objects?

During the past ten years the author has pursued the notion that it may be possible (and even practical) to illuminate an object to a prescribed illuminance (such as 50 lux) with satisfactory object appearance (including colour rendering) and to do this with significantly reduced irradiance (incident W/m^2 of radiant energy) than would occur with a conventional light source (such as a tungsten halogen lamp).

A pilot study

The author has reported an experimental study that successfully tested the hypothesis that an art object illuminated by a light source comprising three narrow wavebands of light can match the level of viewing satisfaction given by a conventional tungsten halogen display lamp providing the same illuminance (Cuttle 2000). The advantage of the three-band approach lies in the fact that the irradiance due to this source was 30–40% less than for the tungsten halogen lamp.

The procedure was that two identical and adjacent viewing rooms were constructed at the Lighting Research Center, Rensselaer Polytechnic Institute, Troy, New York, in which identical art reproductions were displayed (Figure 1). In the first room, the artwork was illuminated by a tungsten halogen MR spotlight that was slightly under-run to operate at a correlated colour

Figure 1. One of the experimental viewing rooms at the Lighting Research Center.

temperature (CCT) of 2850 K, and which provided an illuminance of 50 lux. The spectral power distribution of this light source is shown in Figure 2. In the second room, the illuminance was adjustable, and sometimes was provided by a halogen lamp identical to that in the first room, and sometimes by overlapping the beams from separate halogen lamps, each with a 40-nanometre-wide bandpass filter, to give a spectral power distribution (SPD) comprising three distinct spectral bands (Figure 3). The radiant power in each of the three bands had been carefully adjusted to match the chromaticity of the halogen lamps, which means that the appearance of a neutral surface (i.e. white, light grey, dark grey) would appear identical when lit to the same illuminance by either type of light source.

Subjects were brought into the first room and asked to examine carefully the appearance of the artwork. Then they were led into the second room and asked to adjust the light level so that the appearance of the identical artwork matched as closely as possible the appearance in the first room. Three artworks were used:

Achromatic: an Escher woodcut reproduction.
Prime colours: a screen print of a Mondrian painting.
Multiple hues: a lithographic reproduction of a Renoir painting.

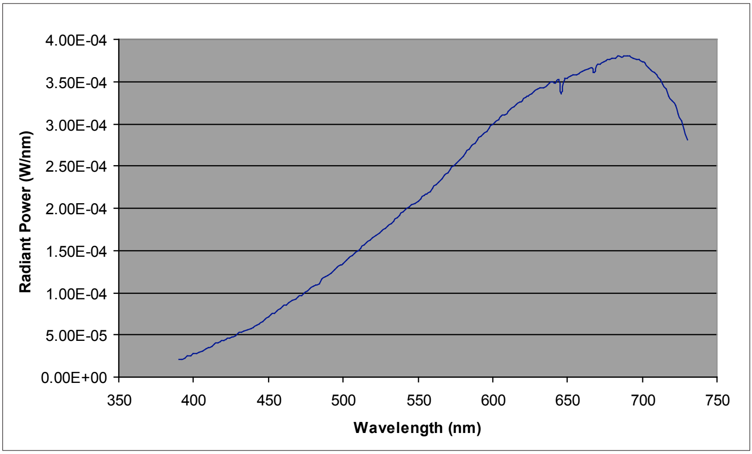

Figure 2. Relative spectral power distribution for tungsten halogen light source at 2850 K.

The subjects could return to the first room as many times as they wished, but were not able to see the two artworks side by side. When a setting had been made, the experimenter recorded the illuminance in the second room and asked the subject whether they could see any differences between the two situations, using a seven-point magnitude scale and five categories of perceived difference. Sixteen subjects completed the experiment, first with the 2850 K halogen lamp as reference, and again with a halogen with a special dichroic reflector to give a CCT of 4200 K.

To summarise the main outcomes of the experiment:

- When subjects set for equality of appearance, they set for equality of illuminance. For this condition, the irradiance of the artwork for the three-band illumination, compared with the halogen source, was less by 41% at 2850 K, and less by 30% at 4200 K.
- While subjects were more likely to report differences of appearance after matching with the 3-band source than with the identical halogen source, they generally rated any differences as small and they were as likely to prefer the three-band source as the halogen source.

This study was funded by the National Center for Preservation Technology and Training, Natchitoches, Louisiana, USA.

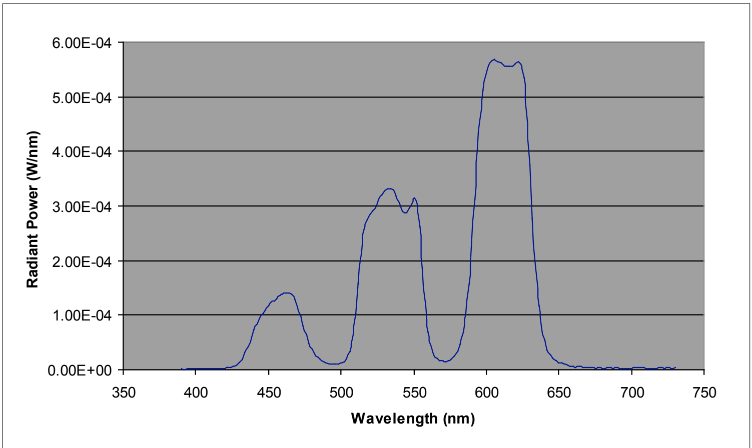

Figure 3. Relative spectral power distribution for three-band experimental light source at 2850 K.

The Spectra Project

The author was invited to give a presentation on this work at a seminar organised by the Getty Conservation Institute, Santa Monica, California, in October 2002. The Paul Getty Trust has a notable collection of Old Masters' drawings, and the purpose of this seminar was to bring together experts from around the world who could assist the trust to implement display conditions that would minimise deterioration of these artworks. An outcome of the seminar was that three study groups were formed, each with the aim of coordinating research in a specific field towards developing practical means for minimising the deterioration of displayed museum objects in general, and of the Getty's Old Masters' drawings in particular. One of these was the Spectra Group, which comprises:

James Druzik, Coordinator, Getty Conservation Institute.
Christopher Cuttle, Principal Investigator, The University of Auckland.
Dr. David Saunders, British Museum, London.
Stefan Michalski, Canadian Conservation Institute, Ottawa.
Dr. Terry Schaeffer, Los Angeles County Museum.

The crux of the issue is to achieve good colour rendering with high luminous efficacy. *Colour rendering* is concerned with how illumination affects the appearance of coloured materials. In 1959 the International Commission on Illumination defined a Colour Rendering Index (CRI), which scores nominally white light sources out of 100. This gives the misleading impression that a CRI value of 100 indicates perfect colour rendering, whereas it actually means that the colour rendering of the source exactly matches that due to a 'reference source' of the same colour temperature. It needs to be understood that two lamps having CRI equal to 100 but different colour temperatures would render colours differently. While CRI has proved useful for distinguishing between the various light sources used in everyday lighting practice, it does not provide a reliable basis for selecting sources to meet the demanding colour rendering requirements of museums. Ultimately, the human observer is the arbiter of colour rendering, and, for artworks, it may be argued that the observer should be an art expert. A fully convincing experimental programme that compares alternative light sources would need to include assessments of real artworks in a museum setting.

Luminous efficacy is concerned with the human visual response to radiant power, measured in lumens per watt (lm/W). Figure 4 shows the Relative Luminous Efficiency Function (RLEF) which defines the typical human visual response to equal quantities of radiant power at different wavelengths. RLEF has a value of 1.0 at 555 nanometres, which is in the yellow-green part of the spectrum. By definition, one watt of radiant power at this wavelength equals 683 lumens, the lumen being the international unit of light. At 610 nanometres, RLEF drops to 0.5, meaning that one watt of radiant power at this wavelength would equal only 341.5 lumens, and would appear correspondingly less bright. Beyond 760 nanometres is the infra red region of the spectrum, and below 380 nanometres is the ultra violet region, both totally lacking visual effect. To determine the lumen output of a lamp, its radiant power output (watts) is measured at small wavelength intervals throughout the visible spectrum (380–760 nanometres), and the power at each wavelength is evaluated according to RLEF in order to determine the total lumens. It may be noted that when the two vastly different forms of illumination used in the previously

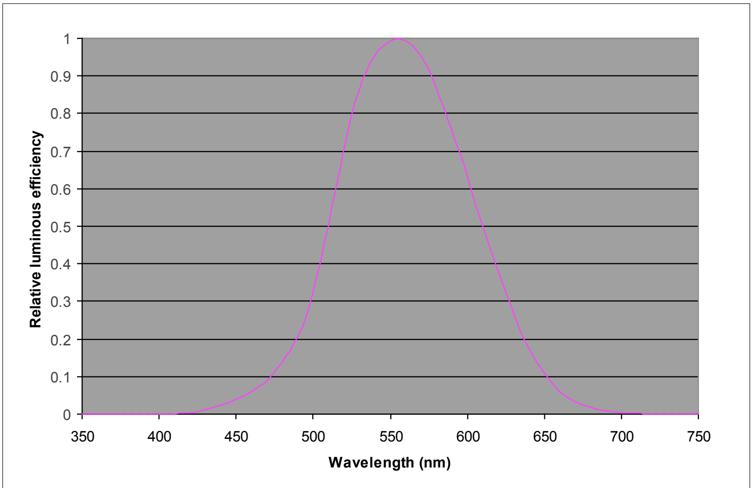

Figure 4. The Relative Luminous Efficiency Function, V(λ).

described experimental programme were judged to match, the measured illuminance values were also found to match.

The irradiance of a surface is a measure of the density of incident radiant power in watts per square metre (W/m^2). The illuminance of a surface is a measure of the density of incident light in lux, where 1 lux = 1 lm/m^2. If, therefore, the incident illumination has a luminous efficacy of 50 lm/W, when we illuminate the surface to 50 lux we are irradiating it to 1 W/m^2. If we can double the efficacy to 100 lm/W, we halve the irradiance to 0.5 W/m^2 for the same illuminance, which means that we would be halving the exposure to radiant power without reducing the visual effect. The crucial research question for the Spectra Project is: how far can we raise luminous efficacy while maintaining colour rendering that would be judged satisfactory in the visually demanding situation of an art museum?

Spectra Project objectives

Three stages of objectives have been drawn up:

Stage One is a computer-based study to identify SPDs that achieve various colour rendering index values with maximal luminous efficacy.

Stage Two is visual assessment of artworks illuminated by the SPDs identified in Stage One.

Stage Three is the development of a practical museum light source (or sources) that provides satisfactory colour rendering with minimal exposure to radiation.

Stage One: Computer-based study

Stage One has been completed. The author has written and run a computer program for which the operator enters a colour temperature, and the program generates a reference source SPD, which is actually the SPD of a hypothetical 'black body', and by definition has a CRI of 100. Then the program progressively modifies this SPD by an iterative process, minimally reducing the CRI while maximally increasing the luminous efficacy. An example of the output from the program is shown in Figure 5, where the optimal three spectral bands are shown for CCT 3500 K. Small shifts in the peak wavelengths occur for different

CCTs. It is a fact of human vision that not all wavelengths are equally important for colour rendering, and by concentrating power into the wavebands that are critical for discriminating colour differences, the luminous efficacy of illumination can be increased with minimal loss of colour rendering. Note that although CRI has been criticised as being insufficient for choosing between good colour rendering light sources for application in a gallery, it has been usefully applied in this exercise to identifying underlying characteristics of the human process of colour discrimination.

From these studies a relationship between CRI and colour temperature has been identified. In Figure 6, CRI 100 refers to the reference sources, and it can be seen that the low CCT sources have relatively low efficacy values. For the SPDs derived in Stage One, efficacy increases as CRI reduces, and some changes of relativities occur. In particular, the 3500 K curve rises to approach a luminous efficacy of 300 lm/W as CRI reduces to a value of 80. From a conservation point of view an efficacy of 300 lm/W is good, but would the colour rendering of this SPD be judged satisfactory?

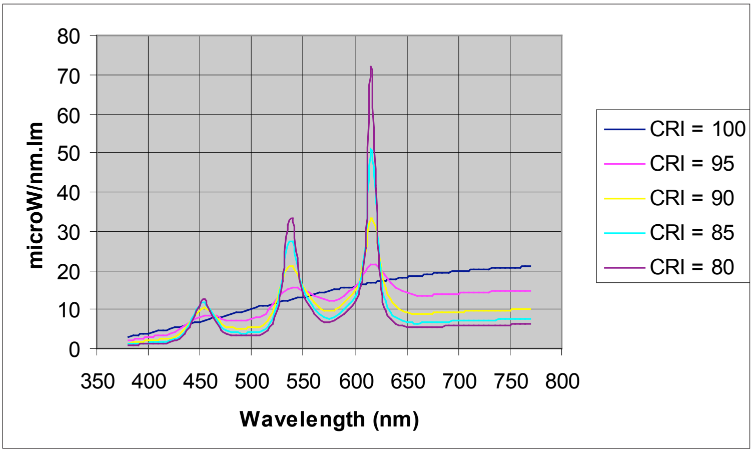

Figure 5. Relative SPDs for CCT 3500 K derived in Stage One of the Spectra Project for various levels of CRI and normalised for equal lumens.

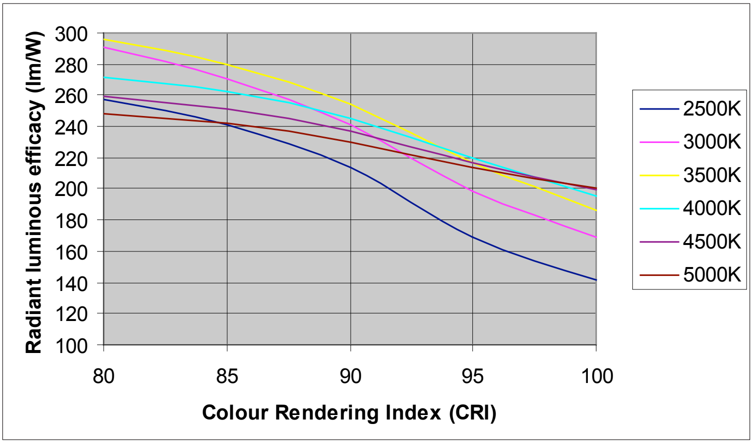

Figure 6. Relationship between relative luminous efficacy, CRI and CCT for the relative SPDs derived in Stage One.

Figure 7. Display cases for the Old Masters' drawings at the Getty Center.

Stage Two: Visual assessment

Work is in progress to enable Stage Two to proceed. The Getty Center has one gallery devoted to its Old Masters' drawings, which are displayed in cases illuminated by fibre-optic lighting (Figure 7). Two short cases matching those in this gallery are being constructed in a separate space to enable a research programme of experimental observations. The fibre-optic illuminators for these cases will be fitted with tungsten halogen lamps, but there will be facility to replace one of the illuminators with a special 'Spectra' illuminator that will enable a very high level of control over the SPD of the illumination within that display case.

Figure 8 illustrates the principle of the illuminator, which comprises a spectrograph modified by the addition of a template. Light input is through the entrance slit, from an external light source, which is spectrally dispersed by a diffraction grating. A template in the light path modifies the wavelength distribution of the light, which is recombined and focused onto the input terminal of the fibre optic harness. In this way, the experimenter will be able to exercise control over the SPD in one of the

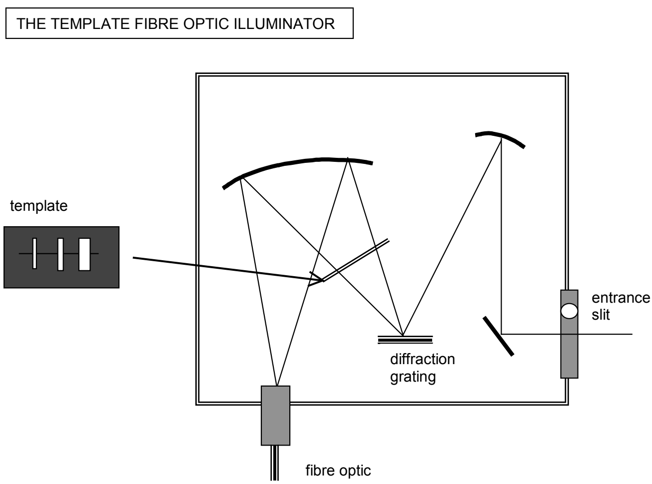

Figure 8. The principle of the 'Spectra' illuminator, which enables the spectrum of light to the fibre optic to be controlled by inserting a template.

experimental display cases. This will enable comparative observations of displayed objects in a simulated museum setting.

In 2004 the Getty Conservation Institute provided funding to develop the 'Spectra' illuminator, and a task group was formed. For this project the author is working with Dr Andrew Chalmers and Roger Vanryn, both of the Manukau Institute of Technology. Figure 9 shows the components of the illuminator undergoing evaluation. This work has not been without problems, but hopes remain high that the required performance will be achieved, and that the Stage Two programme of comparative observations will be able to proceed.

Concluding comments

This paper describes research work in progress. While it includes discussion of expected outcomes, these may change as the work progresses.

Neither the three-source experimental lighting nor the 'Spectra' illuminator are practical sources for museum lighting. Both are means of controlling spectral power distributions in experimental facilities, and the development of practical means of providing prescribed SPDs in museums will be addressed in Stage Three of the project.

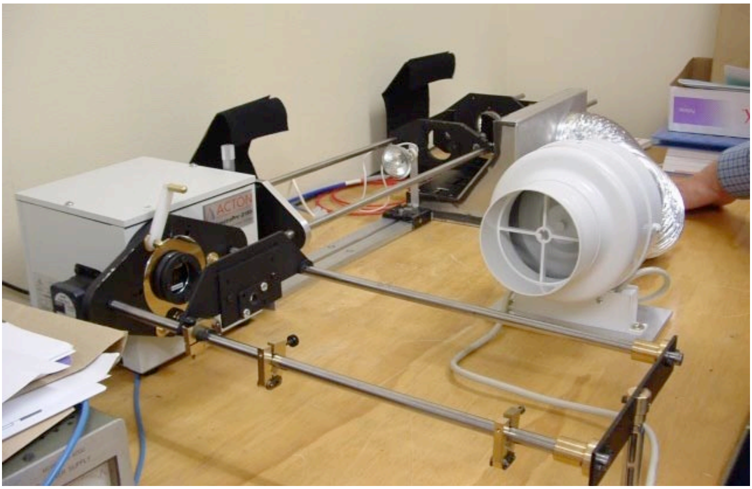

Figure 9. Components of the 'Spectra' illuminator assembled for evaluation.

The Stage Two visual assessments are crucial to the outcome of the project. At present it is quite unknown how far the SPD for an actual museum display can depart from a continuous distribution before the appearance of the display becomes unacceptable, and how this may be affected by the chromatic content of the displayed material.

Reference

Cuttle, C. 2000. A proposal to reduce the exposure to light of museum objects without reducing illuminance or the levels of satisfaction of museum visitors. *JAIC* 39: 229–244

Author biography

Professor Christopher Cuttle is a senior lecturer in Architectural Technology at the School of Architecture, University of Auckland. He has carried out extensive research in the area of museum lighting, including the measurement and monitoring of exhibition lighting and the performance of skylight materials.

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