Special Review

Class A Color Designation for Light Sources Used in General Illumination

Jean Paul FREYSSINIER and Mark S. REA

Lighting Research Center, Rensselaer Polytechnic Institute, USA

Received April 26, 2013, Accepted July 25, 2013
This paper is based on the authors’ presentation given at the 13th International Symposium on Science and Technology of Lighting (LS-13) held June 24–29, 2012, in Troy, New York, USA.

ABSTRACT
Solid state lighting has reignited interest among lighting specialists and manufacturers in the color qualities of illumination used in architectural applications. This renewed interest has highlighted the known problems with the two currently accepted metrics used by the lighting industry to communicate the color qualities of sources of illumination, correlated color temperature (CCT) and color rendering index (CRI). These two metrics are poor predictors of viewer responses to the color characteristics of illumination and both metrics are poorly understood among consumers. The proposed “Class A color” designation serves two important purposes for helping to move the consumer market toward a broader acceptance of solid state lighting. First, the “Class A color” designation reflects bundled metrics shown to be predictive of user acceptance of color attributes from sources of illumination and, second, the designation can be readily understood by consumers as denoting light sources of high color quality.

KEYWORDS: white lighting, color rendering, gamut area, color temperature, general illumination

1. Introduction
The lighting industry relies on correlated color temperature (CCT) and color rendering index (CRI) to communicate the color qualities of electric light sources used for illumination in architectural applications. CCT is intended to characterize the apparent “tint” of the illumination, warm or cool, produced by an electric light source. A source of a given CCT designation is expected to have the same apparent “tint” as a reference light source of the same CCT, either a phase of daylight or an incandescent source on the line of blackbody radiation. Since CCT does not unambiguously characterize appearance, narrow tolerances around reference chromaticities are also part of any CCT designation for a manufactured light source. CRI is intended to represent how similar object hues appear when illuminated by an electric light source in comparison to their appearance under a reference source of the same CCT. The CIE system of colorimetry provides the interlocking logic for both metrics. Colorimetry is a measurement system based only upon the spectral compositions of light sources and of illuminated objects. Colorimetry does not consider the contextual variables that influence human color perception. Not only can individuals differ in their perception of a given spectral composition, the amount of illumination and the conditions under which that spectral composition is viewed can strongly affect color perception. For example, an orange and a chocolate bar can have the same colorimetric specification, but will appear as different colors except under very restricted viewing conditions. Since CCT and CRI are based upon colorimetry, neither metric is capable of reliably predicting human color perception. The “Class A color” designation proposed here represents a bundled set of metrics based on conventional colorimetry: however, as a set of metrics, it is a better predictor of user acceptance of color attributes from sources of illumination than CCT or CRI alone.

The two metrics used by the lighting industry to communicate color qualities, CCT and CRI, also present a non-technical problem for transforming the residential lighting market from incandescent sources to solid state lighting technologies. CCT and CRI are not understood among non-specialists, and it would be difficult and expensive to educate consumers about these metrics. This problem is exacerbated by the fact, as previously discussed, that both metrics are poor predictors of what they are trying to measure: tint of illumination and color rendering. Given the flaws in CCT and CRI and past history with other light sources intended to replace incandescent lamps, many consumers need some assurance that they will not be disappointed with the color qualities of solid state lighting systems when
they take these new technologies home. “Seals of approval” are common in industries where consumers need assurances that products will perform as expected. Rarely will consumers become involved in understanding the foundations for those industry “seals of approval.” Rather, they simply want to be assured by industry that the product purchased will not be disappointing when they install and operate the product. The “Class A color” designation proposed here is offered for consideration by the lighting industry as a “seal of approval” for color quality from manufactured sources used in general illumination applications. To meet the “Class A color” designation, a light source is expected to provide good color rendering, provide illumination with minimal tint (i.e., be white), and have an appearance consistent with other “Class A color” sources. Each of these three criteria is explained in the following sections.

2. Color rendering

Recent research shows, as articulated much earlier by Judd, that the color rendering properties of electric light sources used for illumination cannot be captured by a single metric like CRI. In an effort to develop a simple, practical and predictive color rendering measurement system, Rea and Freyssinier proposed GAI as an adjunct to the well-established and traditional color rendering metric, CRI. Rea and Freyssinier also proposed criterion values for this two-metric system of color rendering. Computational details for both GAI and CRI can be found in several references, but briefly, GAI is a simple measure of hue saturation provided by the illumination, whereas CRI is a measure of hue consistency provided by the illumination with respect to reference sources. Sources of illumination that have high values of CRI (CRI≥80) and high (but not too high) values of GAI (80≤GAI≤100) have been shown in several human factors experiments to be predictive of user acceptance (see Table 1 and Figure 1 for examples of sources that meet the two-metric criterion). Sources that score high on either metric alone are often not as well-accepted.

Whether these metrics and the associated criterion values proposed by Rea and Freyssinier are ideal representations of the color rendering properties of light sources used for illumination is still under investigation, but consensus among lighting specialists is

Table 1 Characteristics of selected commercial and laboratory light sources. Sources 3, 5, and 6 meet the color rendering and chromaticity criteria of the “Class A color” designation. Source 3 has been demonstrated in a laboratory setting but is not commercially available.

<table>
<thead>
<tr>
<th>Label</th>
<th>Light source description</th>
<th>CCT</th>
<th>CRI, Ra</th>
<th>GAI</th>
<th>CIE x</th>
<th>CIE y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Incandescent A-lamp, 60 W frosted</td>
<td>2764 K</td>
<td>100</td>
<td>49</td>
<td>0.4555</td>
<td>0.4109</td>
</tr>
<tr>
<td>2</td>
<td>Halogen</td>
<td>3277 K</td>
<td>100</td>
<td>65</td>
<td>0.4184</td>
<td>0.3969</td>
</tr>
<tr>
<td>3</td>
<td>Halogen plus blue LED (445 nm peak)</td>
<td>2921 K</td>
<td>95</td>
<td>60</td>
<td>0.4247</td>
<td>0.3703</td>
</tr>
<tr>
<td>4</td>
<td>Pulse-start metal halide, 320 W</td>
<td>4159 K</td>
<td>58</td>
<td>51</td>
<td>0.3799</td>
<td>0.3984</td>
</tr>
<tr>
<td>5</td>
<td>Ceramic metal halide, 100 W</td>
<td>4075 K</td>
<td>90</td>
<td>80</td>
<td>0.3773</td>
<td>0.3749</td>
</tr>
<tr>
<td>6</td>
<td>Fluorescent, F40T12 daylight</td>
<td>4861 K</td>
<td>90</td>
<td>84</td>
<td>0.3502</td>
<td>0.3645</td>
</tr>
<tr>
<td>7</td>
<td>Fluorescent, meat-display lamp</td>
<td>3195 K</td>
<td>61</td>
<td>128</td>
<td>0.3869</td>
<td>0.3153</td>
</tr>
</tbody>
</table>
evolving toward the belief that any useful system for characterizing the color rendering properties of sources of illumination must be based upon two uncorrelated metrics, one representing “fidelity” and one representing “saturation.” For example, Žukauskas and colleagues have shown that vividness and fidelity are important for characterizing color rendering. Similarly, Smet and colleagues have also shown the need for a system based upon two metrics. Recently, other research groups have reached similar conclusions.

Importantly, all of these dual-metric approaches are better at predicting preferences than any single metric. A systematic investigation of color rendering preferences from individuals of different countries reinforces this point. Figure 2 shows the results of experiments on color acceptance among people from several cultures. Following the same protocol used by Rea and Freyssinier, subjects were shown multicolored displays composed of fresh fruits and vegetables under light sources of only high CRI, only high GAI, and both high CRI and high GAI. In addition to rating the naturalness and vividness of the display under each source, subjects were asked to rate the overall acceptability of the source being presented. Two groups of three sources were used in the experiment, one group at ~3000 K and another group at ~5000 K. Although it seems true that different cultures can have different preferences with respect to vividness or saturation, two metrics, like CRI and GAI, are almost always needed to predict subjective judgments of “good” color rendering. Even though more research may be needed to establish which of the many two-metric proposals is ideal, the combination of CRI and GAI has many attractive features. First, CRI, the well-established and now orthodox measure of color rendering used by the industry, is preserved; GAI is simply an adjunct to CRI. Second, GAI is easy to calculate. GAI uses the same test color samples as those used in the CRI calculation, so the same exact data needed to calculate CRI are used to calculate GAI. Third, GAI is easy to understand; it is a measure of hue saturation provided by the source of illumination, which provides additional and meaningful information about color rendering. Fourth, and most importantly, the two-metric, CRI and GAI system is not a mathematical abstraction of what might be useful. Rather, the two-metric system has been validated in several human factors studies as predictive of human color preferences.

3. Tint

CCT has been used for many years to communicate the apparent tint, warm or cool, of “white” sources of illumination. Two implicit assumptions are embedded in the CCT designation. First, chromaticities along the line of blackbody radiation are perceived as “white.” Second, a CCT designation for a manufactured light source implies consistency in the chromaticities of all sources having that designation. Recent research suggests that most of the sources with chromaticities along the line of blackbody radiation do not appear “white.” An empirically established line of minimum tint in chromaticity space for CCTs between 2700 K and 6500 K is shown in Figure 3; the chromaticities of the light sources listed in Table 1 are also shown in Figure 3. Importantly too, people usually prefer sources of illumination on this “white” line more than those of the same CCT on the

![Figure 2](image_url)

Figure 2 Acceptability ratings from people of different cultures for warm white (left, WW ~3000 K) and cool white (right, CW ~5000 K) sources of illumination with different color-rendering properties. The CRI and GAI values of the light sources are, respectively, indicated in parenthesis.
All of those sources must have chromaticities that lie within the specified tolerance zone. These tolerance zones are often described in terms of MacAdam ellipses. Tolerance zones of the type illustrated in Figure 3 would be used in the “Class A color” designation proposed here. The trapezoidal tolerance zones illustrated here correspond approximately to 4-step MacAdam ellipses.

5. Summary

The “Class A color” designation has many important features that the industry should probably embrace. The proposed “seal of approval” provides consumers with assurances of good color quality for general illumination. Those assurances are based upon research where sources meeting that designation are predictive of user acceptance for general illumination. By bundling a number of color metrics together, the industry does not have to spend a lot of resources on educating consumers about the benefits provided. A “Class A color” seal of approval would help facilitate transformation of the market to higher quality, more energy efficient lighting technologies. It is important to emphasize that the “Class A color” designation described here is not offered as a prescription for light sources in all applications. It should be understood that many applications would not be well served by “Class A color” light sources when the objective is not to have a white light source of good color rendering, for example plant growth lighting and meat case display lighting.

Acknowledgements

This research was supported by Sharp Laboratories of America and the Alliance for Solid-State Illumination Systems and Technologies (ASSIST).

References


