Color Rendering Index and LEDs

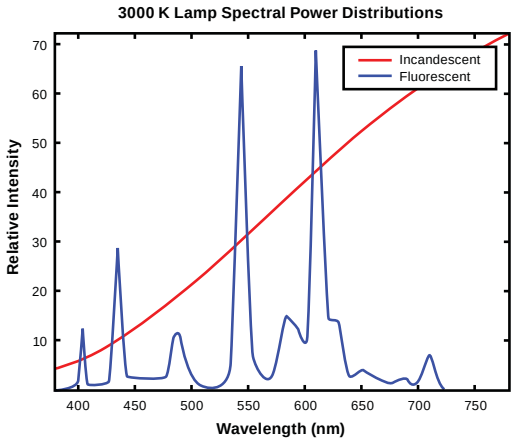
The CIE Color Rendering Index (CRI) specifies the color rendering properties of white light sources. It has been successfully used to compare fluorescent and high-intensity discharge (HID) lamps for over forty years, but the International Commission on Illumination (CIE) does not recommend its use with white light LEDs.

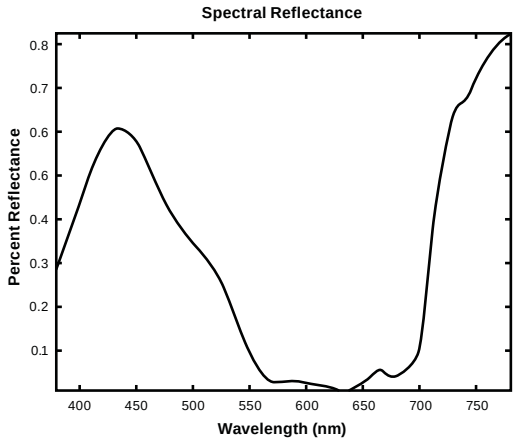
The CRI of a light source is a mathematical measure of how much test colors perceptually shift when viewed under the light source in comparison to a reference light source with the same color temperature. As an example, imagine a blue material with the spectral reflectance shown below that is illuminated by an incandescent lamp and a fluorescent lamp. Both lamps have a correlated color temperature (CCT) of 3000 K, but their spectral power distributions (SPDs) are very different.

When we view an illuminated surface, the color we perceive is determined by the spectral power distribution (SPD) of the light source and the spectral reflectance of the surface. The two different lamp SPDs therefore result in our perceiving two different colors:

Perceived color when illuminated by 3,000 K incandescent lamp

Perceived color when illuminated by 3,000 K fluorescent lamp





The resulting measurements are averaged to obtain the General Color Rendering Index R_a, which is the CRI value of the test lamp (or more generally, the "illuminant").

Two important points must be kept in mind when comparing the CRI values of two or more lamps:

1. The correlated color temperatures (CCTs) of the lamps must be the same. Our perception of color shifts with changing color temperature. This is why we often notice differences in the color appearance of paint samples and textiles viewed under incandescent light and daylight, even though the CRI values are nominally 100 in both situations.
2. Differences in CRI values of less than five points are not significant. For example, lamps with the same CCT (say 4000 K) and CRI values of 82 and 85 respectively should be considered equivalent in terms of color rendering properties.

Color Rendering Properties of White Light LEDs

As stated in CIE Technical Report 177:2007, *Colour Rendering of White LED Light Sources*, "The conclusion of the Technical Committee is that the CIE CRI is generally not applicable to predict the colour rendering rank order of a set of light sources when white LED light sources are involved in this set."

Different amounts of color shift occur for different colors, so the CRI is calculated by determining the specific color shifts for eight test colors:

Approximation of CIE CRI Test Colors

Terms

General Color Rendering – Color rendering is defined as the "effect of an illuminant on the colour appearance of objects by conscious or unconscious comparison with their colour appearance under a reference illuminant" (CIE 17.4, International Lighting Vocabulary).

Color Rendering Indices – The General Color Rendering Index R_a is calculated in accordance with CIE 13.3-1995, "Method of Measuring and Specifying Colour Rendering Properties of Light Sources." It is the arithmetic mean (i.e., average) of the Specific Color Rendering Indices for each test color and is usually referred to simply as the CRI value of a test illuminant.

Test Colors – Eight pastel test colors are used to determine the color shifts and hence the Specific Color Rendering Indices for a test illuminant. Six additional colors are sometimes used for special purposes, but they are not used for calculating R_a.

Color Shifts – The perceived color shifts seen when viewing test colors under the test and reference illuminants are calculated using mathematical models of human color vision. They may not however correspond with what we actually perceive under real-world circumstances.

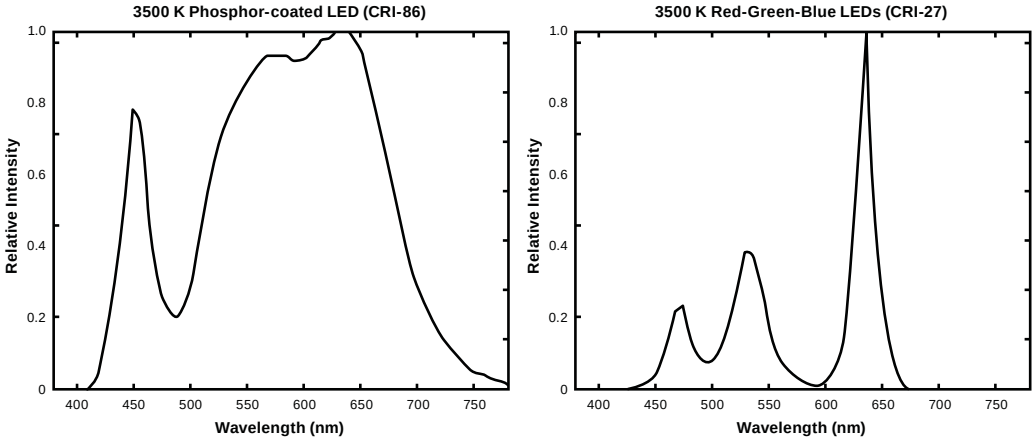
This recommendation is based on a survey of numerous academic studies that considered both phosphor-coated white light LEDs and red-green-blue (RGB) LED clusters. Most of these studies involved visual experiments where observers ranked the appearance of illuminated scenes using lamps with different CRIs. In general, there was poor correlation between these rankings and the calculated CRI values.

Commercial phosphor-coated white light LEDs usually exhibit high R_a values (70 to 90). However, these values have been found to be poorly coordinated with their subjective rankings in terms of perceived color shifts.

Commercial RGB LED clusters typically exhibit R_a values ranging from 25 to 70, depending on the CCT and LED dominant wavelengths. There may in addition be substantial color shifts for some saturated colors. These shifts are due to the narrow spectral bands generated by the color LEDs and also the lack of yellow light in the region of 580 nm.

Regardless of their low R_a values, the white light generated by commercial RGB LED clusters is usually visually appealing. One possible reason is that they typically tend to increase the perceived saturation (chroma) of most colors without producing objectionable hue shifts.

A similar situation occurs with neodymium incandescent lamps (GE Reveal, Philips Natural Light, Sylvania Daylight, etc.) that block yellow light. These lamps have low CRIs and produce noticeable color shifts, but objects illuminated with them appear brighter and livelier when compared with unfiltered incandescent lamps.



Color Rendering versus Color Appearance

Color *fidelity* – that is, freedom from color shifts – is important when visually comparing the colors of paints and textiles. However, we are often more interested in the subjective color *appearance* of illuminated objects. This is a complex topic that involves the visual relationship between groups of colors, the direction of color shifts in hue and chroma, the appearance of skin tones, our ability to distinguish colors, chromatic adaptation, and color constancy effects.

The CIE Color Rendering Index is based on the idea that any color shifts between the test and reference illuminants are undesirable. While this is true for applications requiring critical color comparisons, it does not consider whether the color shifts are visually appealing.

CIE Technical Committee 1.69, Colour Rendering with White Light Sources, is currently investigating this issue with the goal of developing new color metrics that will supplement and eventually replace the current Color Rendering Index. Given the complexity of the task, this effort may take several years.

In the meantime, while CRI values are still useful for comparing fluorescent and HID lamps, they should be applied to white light LEDs with considerable caution.

Recommendations

A long-term research and development process is underway to develop a better color quality metric that would be applicable to all light sources. In the meantime, CRI can be considered as one data point in evaluating white LED products and systems. It should not be used to make product selections in the absence of in-person and on-site evaluation.

1. Identify the visual tasks to be performed under the light source. If color fidelity under different light sources is critically important (such as paint and fabric selection), CRI values may be a useful metric for rating solid state lighting products.
2. If color appearance is more important than color fidelity, do not exclude white light LEDs solely on the basis of relatively low CRI values. Solid state lighting products with CRIs as low as 25 still produce visually pleasing white light.
3. Evaluate solid state lighting systems in person and, if possible, on-site when color fidelity or color appearance are important issues.

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For Information on the Next Generation Lighting Industry Alliance:

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