# COLOR QUALITY OF INTELLIGENT SOLID-STATE LIGHTING SYSTEMS

## What is Color Quality and the Color Rendering Index?

### Color Quality

When we view objects under different types of light sources such as incandescent light or fluorescent light we notice differences in the light and in the way surfaces and objects are rendered under these different light sources. Color quality can be a very subjective measure and there are measures of color quality that allow the designer to compare and evaluate light sources. How do we compare these light sources and what do we compare them to? One way of specifying and comparing light sources is the color rendering index (CRI).

### Color Rendering Index (CRI)

All light sources are not equal even when, at first appearance, they look the same. For example, two white light sources can illuminate a white surface and the resultant light may appear identical but when illuminating colorful surfaces and objects will render colors differently. So which is correct? How should we judge colors? This is why there is a need for a color metric; a means to judge the quality of a white light source. But of course even nominally white light can be of different tones and colors. The Color Rendering Index or CRI was created in 1965 and later updated to compare different light sources and how they render colors. However, CRI does have limitations and should not be used exclusively to evaluate light quality.

CRI is a specification to assist designers in making a comparison between two lamp sources. CRI is a relative comparison between a lamp source and a reference source. Light sources are compared to the color temperature equivalent of the light source and a score based on the color shift of a palette of eight colors is used to determine the CRI value. CRI can be used only to compare to sources of the same type. CRI cannot be used to compare the CRI of two sources of dissimilar color temperatures. To compare CRI of two lamp sources, the color temperature of the two light sources should be within 100K.

### How is it measured?

CRI measures the color shift of objects when first illuminated by the light source and then compared when the object is illuminated by a reference illuminant of comparable color temperature. In the Color Rendering Index, a palette of specific colors is used to measure the color difference between a reference source and the source under test. This is termed the General Color Rendering Test and represents a calculation using color sample numbers $R_1$ through $R_8$. Additional colors $R_9$-$R_{15}$ were later added to CRI and can be used for calculations of the Special Color Rendering Indices. The specification for measuring CRI is given in CIE publication 13.3-1995.[1]

The calculation is the difference between each color sample illuminated by the light source under test and the reference source. The group of samples is then averaged and a score between 0 and 100 is calculated. 100 is the best match between illuminants.

In general CRI values of 80 to 100 are considered good for visual inspection tasks such as in printing or fabrics industries.

[1] CIE Publication No. 13-3, Method of Measuring and Specifying Color Rendering Properties of Light Source (1995).

**What are the limitations of CRI?**

There are several limitations to CRI. First, it is a simple scalar value, but light is a rich space of hue, saturation and brightness. No single measure can reveal everything about the quality of a light source. Even light sources with dramatically different spectral power distributions can have identical CRI values yet render colors in very different ways.

Specifically the color space that CRI uses is obsolete and no longer used for standards except for CRI calculations and determination of correlated color temperature (CCT). The Color Space, termed W*U*V*, is obsolete due to substantial distortion, especially in the red region. The set of colors used for the reference for calculating CRI are pastel colors and lack the richer saturated colors. But, ironically, the most dramatic color shifts are in the more saturated colors! Additionally, with only eight colors used for CRI calculations it provides a sparse set of colors given the breadth of the visible spectrum.

Another common misunderstanding is that high CRI means that the light source will render all colors well. But this is not the case. CRI is measured only with respect to a reference source which is either the blackbody curve below 5000K or a CIE Daylight source above 5000K. The reference must be the closest in chromaticity (color) to the source being tested. Otherwise the comparison makes little sense. Comparing the CRI of two very different color temperature sources is meaningless but in general, higher CRI's mean less deviation from the reference source.

Here is a simple test: Use an incandescent source to discriminate between dark navy blue and black materials. Although the incandescent source is, by definition, a black body source, it has little output in the blue region. Conversely, a beautiful northern blue sky may have a color temperature of 7500K or greater and have a CRI of 100, yet not render reds effectively.

Even with all the perceived accuracy of a calculation, many designers put their hand in front of the light to see the effect on their skin. This is often a good, though subjective, measure of the quality of a light source.

Another mistaken impression is that a higher CRI value comes closest to approximating natural daylight, but this is incorrect. There is no single measure of natural daylight as the color of the sky and the light from it can vary significantly over the course of a day and viewer location.

In some sense the CRI measurement method attempts to quantify a subjective measure. However, because the CRI score is affected by the spectrum, it is possible to manipulate the spectrum and produce a higher CRI value. Fluorescent lamp manufacturers have been known to 'game' the CRI metric by shifting the emission points within their lamp spectra. This can shift CRI by several points. In general though, differences of 5 points in the CRI value do not matter.

To further support the subjective nature of CRI, in one study LED light sources were compared to reference light sources and the LED light sources were preferred over halogen and incandescent light sources for overall color appearance and that CRI had no correlation to people's color preference.[2]

There are several efforts to improve CRI and several organizations, including the CIE, are working

[2] N. Narendran, L. Deng, *Color Rendering Properties of LED Light Sources*, Solid State Lighting II, SPIE. 2002

at improving the measure. This will take some time and until a new and accepted measure is developed, CRI is a just one way to compare the color quality of light sources. However, given the limitations of CRI, the lighting designer who must make his or her own judgments and comparisons, it is a generally accepted measure of comparing color rendering properties of illuminants and, until a new measure is developed and accepted, will be the default metric.