# Key Metrics for Understanding Color Quality for LED Lighting

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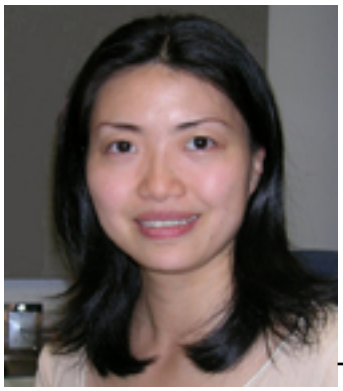

Terminology used to describe the color quality of an LED light source is often reduced to three letters: CCT and CRI, which are probably the most familiar, and CQS and GAI, which are relatively new. What do these abbreviations stand for, and how are they used?

CCT (for correlated color temperature) is the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source. A lamp's CCT value, measured in degrees Kelvin (K), is usually a good indicator of its general appearance. For example, a typical incandescent source with a CCT of 2800K has a warm, yellow look, and a fluorescent source with a CCT of 6000K or higher has a cool, white look. Phosphor-converted white LED sources typically have a high CCT and a cool, blue appearance unless special technologies are used to make them look warmer. Because they lack spectral distribution information, CCT values are not a perfect way to measure of lighting color quality. Two light sources with the same CCT value could have very different rendering effects when illuminating colored objects.

CRI (for color rendering index) is currently the only widely accepted metric for determining how well a light source renders color. It is calculated based on the average measurement of the "color shift" between test sources and reference sources illuminating eight standard test color samples (TCS), shown at the top of Figure 1. A perfect CRI score (or $R_a$) of 100 means that no color shift is observed between the test illuminant and reference illuminant. A negative CRI value means that the color shift is very large. For a typical incandescent light source, the CRI = 100. The U.S. ENERGY STAR program requires all indoor luminaires to have a CRI > 80. Because the eight test color samples for CRI are less saturated colors, $R_a$ alone inherently fails to measure how light sources render saturated color objects often found in retail lighting applications (e.g., Red Delicious apples). Therefore, in addition to $R_a$, the $R_9$ score measures the color shift when illuminating a saturated red sample (TCS9). $R_9$ is sometimes chosen by lighting manufacturers to report their product's color performance. ENERGY STAR requires all indoor lamps to have a non-negative R9 score.

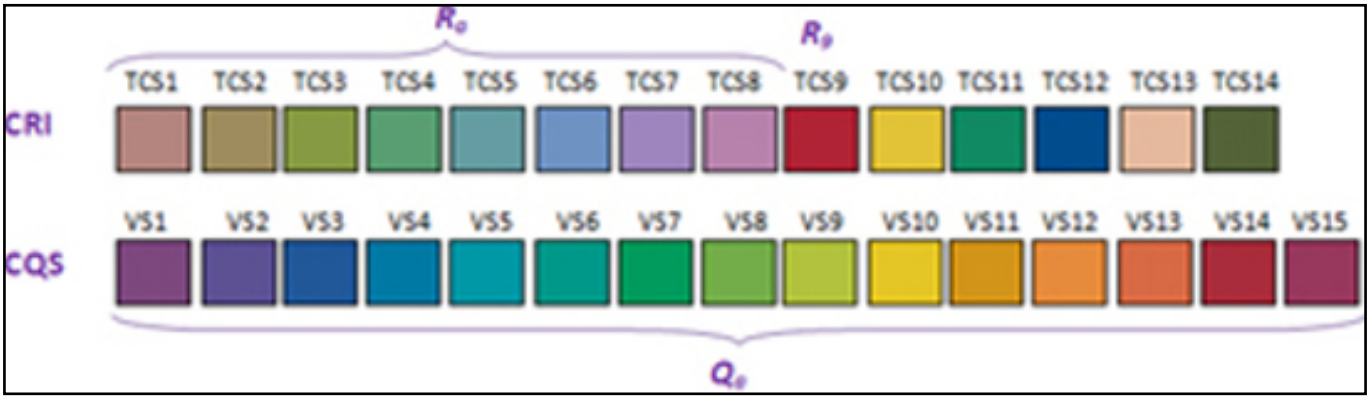


Figure 1. Test color samples for color rendering index (top) and color quality scale (bottom).

Recently, the National Institute of Standards and Technology (NIST) developed CQS (for color quality scale), a new color rendering metric that updates CRI in several respects. For CQS, 15 new test color samples were chosen, which include more saturated colors, shown at the bottom of Figure 1. All 15 test color samples are used to evaluate the general CQS score ($Q_a$) through a weighted root mean square (RMS) approach for better statistical properties. The more up-to-date CIE L*A*B* uniform color space is used to measure the color shift between the test illuminant and reference illuminant. CQS values range from 0 (very poor color) to 100 (perfect color). Since its official publication in 2010, CQS has gained increasing attention from the lighting industry. Although some manufacturers have already started to voluntarily provide CQS scores for their products, this new metric could still go through additional phases of modification, and it might still take some time before CQS could be adopted as a new CIE standard or gain acceptance as widely as CRI .

Besides the CQS approach, another notable method for evaluating color rendering performance is to use a two-metric approach that combines CRI and GAI (for gamut area index). Unlike CQS, GAI uses the same eight test color samples as CRI. The gamut area is the area of a polygon formed by eight test color samples in the CIE u’v’ color space. To calculate the GAI value, the gamut area of the test color samples is compared to that of an equal energy spectrum (EES) source. A GAI score of 100 means the gamut area is the same size as the with the EES source. A light source with a good CRI score and a good GAI score (between 80 and 100) is

considered to have good “color fidelity” and “color vividness.” A light source with a low GAI score produces poor rendering on saturated colors, whereas an overly large GAI score indicates an overly saturated rendering.

The color rendering performance discussed here applies mainly to uni-directional viewing or viewing from a local area. In addition to overall color however, color variation, both spatially and over time, also plays an important role in understanding the color quality of LED sources. ENERGY STAR (2008) requires that when viewing from different angles, the color difference measured in CIE 1976 (u’v’) be within 0.004. The color variation over the lifetime of usage needs to be no more than 0.007. Smaller color variations can often be achieved for luminaires during the design stage with the aid of illumination software.

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