What is CCT, or Correlated Color Temperature?

CCT is a number, measured in degrees Kelvin, that helps to describe the relative warmth or coolness of a light source. Most light bulbs will range from 2700K (warm, incandescent color) to 5000K or higher (crisp, white daylight color).

For most residential applications, 2700K and 3000K are preferred color temperature options as they both create a nice, warm appearance that creates an inviting and relaxing environment.

For retail or commercial applications, 4000K is a popular color option as it provides for a crisper, more energetic shade of white. For industrial or task-oriented applications, 5000K or even 6500K is a preferred color option, as these color temperatures best match natural daylight.

LED LIGHTING

COLOR TEMPERATURE SELECTION GUIDE

Selecting the correct color temperature when searching for an LED lighting product is extremely important!

Color temperature describes how "warm" or "cool" a light source appears to us. In terms of its spectrum, we can also understand it as the relative balance between yellow/orange wavelengths vs blue wavelengths.

If you're unsure which color temperature best suits your lighting application, check out our flow chart below!

Are you looking to replicate the warm look of a traditional incandescent light bulb?

Yes, I want exactly the same look! → **2700K**

Yes, but I don't want it to be too yellow → **3000K**

NO

Is this for a residential or hospitality application?

Yes, and I want to create a relaxing and inviting atmosphere → **3000K**

Yes, but I want something with a more neutral and crisp color appearance. → **4000K**

NO

Do you want a clean, white light that doesn't appear too blue or harsh?

Yes, I want a neutral, balanced white color, similar to sunshine → **4000K**

Yes, but I want it to match natural daylight → **5000K**

NO

Are you looking to replicate natural daylight or perform visually demanding tasks?

Yes, I want a neutral, balanced white color, similar to daylight → **5000K**

Yes, but I need it to truly match north-facing daylight → **6500K**

NO

Do you need a true daylight match for art production or digital arts work?

Yes, I want a true match for north-facing daylight or D65 calibrated work → **6500K**

NO

2700K
Good For:
Living rooms
Bedrooms

3000K
Good For:
Kitchens
Dining areas
Restaurants

4000K
Good For:
Retail stores
Hotel lobbies
Office spaces
Light therapy

5000K
Good For:
Industrial
Factories
Color evaluation
Art production
Light therapy

6500K
Good For:
Art production
Digital art
Bias lighting
Photography

What is CRI, or Color Rendering Index?

The CRI value of a light source describes how accurately a light source illuminates colors of an object. It is scored on a scale with 100 being the best. Most standard bulbs have a CRI value of 80, while high CRI bulbs have a CRI value of 90 or higher.

For example, a painting shown under a 70 CRI light source may exhibit colors that don't appear correct, or accurate. When seen under a 95 CRI light source, however, the colors of the painting will likely look accurate and natural.

Part 1: Color Rendering Index (CRI) is a score with a maximum of 100

What does it mean to measure the ability of something? Like test scores, CRI is measured on a scale where a higher number represents higher ability, with 100 being the highest.

CRI is a convenient metric because it is represented as a single, quantified number.

CRI values that are 90 and above are considered excellent, while scores below 80 are generally considered poor. (More on this below).

Part 2: Color Rendering Index (CRI) is used to measure artificial, white light sources

Light sources can be grouped into either artificial or natural light sources.

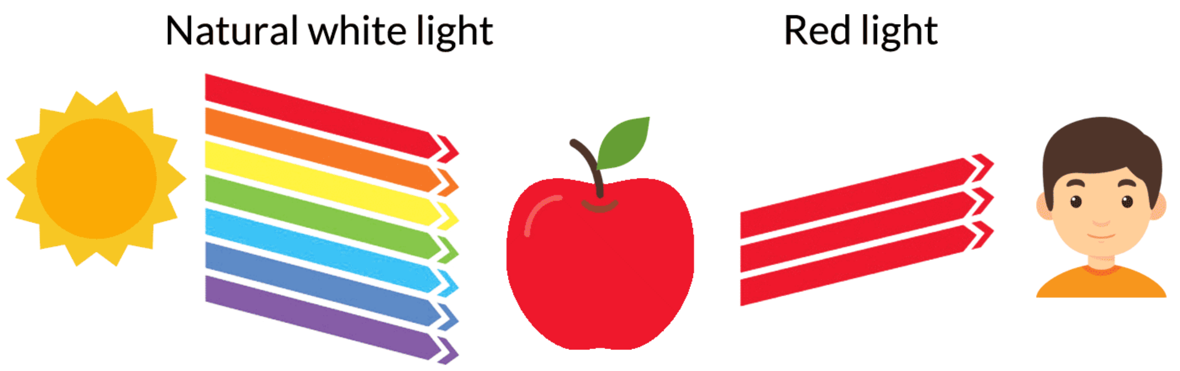
In most situations, we are concerned about the color quality of artificial forms of lighting, such as LED and fluorescent lamps.

This is compared to a daylight or sunlight - a natural light source.

Part 3: Color Rendering Index (CRI) measures and compares the reflected color of an object under artificial lighting

First, a quick refresher on how color works.

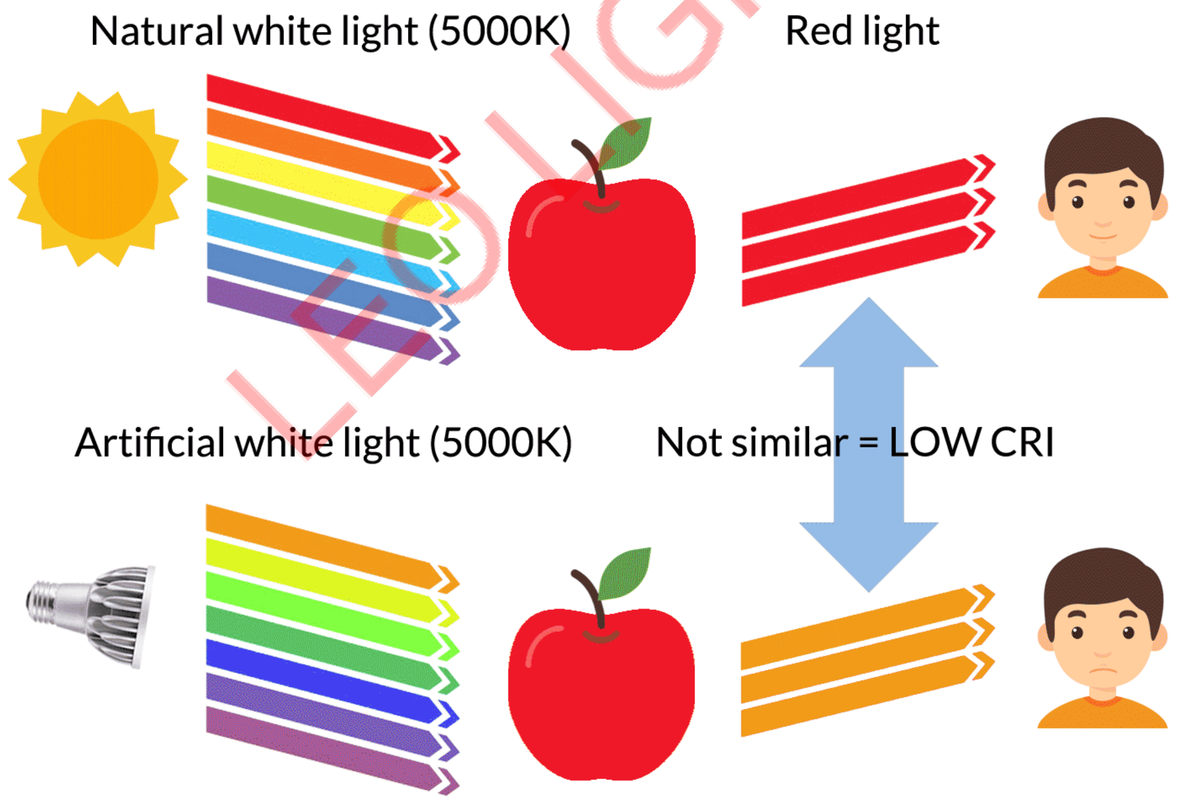
Natural light such as sunlight is a combination of all the colors of the visible spectrum. The color of sunlight itself is white, but the color of an object under the sun is determined by the colors that it reflects.



A red apple, for example, appears red because it absorbs all colors of the spectrum except red, which it reflects.

When we use an artificial light source such as an LED lamp, we are attempting to "reproduce" the colors of natural daylight such that objects appear the same as they do under natural daylight.

Sometimes, the reproduced color will appear quite similar, other times quite different. It is this similarity that CRI measures.



As you can see in our example above, our artificial light source (an LED lamp with 5000K CCT) does not reproduce the same redness in a red apple as natural daylight (also 5000K CCT).

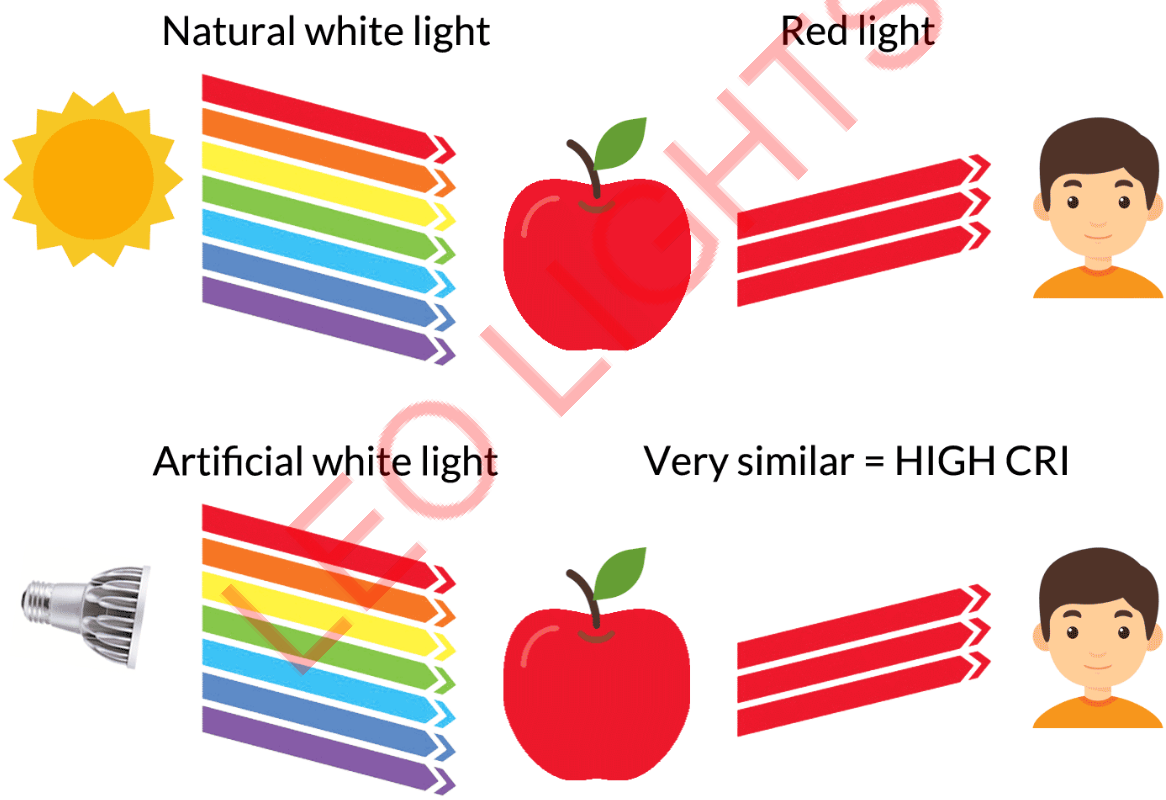
But notice that the LED lamp and natural daylight have the same 5000K color. This means that the color of light is the same, but the objects still appear different. How could this be?

If you take a look at our graphic above, you will see that our LED lamp has a different spectral composition compared to natural daylight, **even though it is the same 5000K white color.**

In particular, our LED lamp is lacking in red. When this light bounces off of the red apple, there is no red light to reflect.

As a result, the red apple no longer has the same vibrant red appearance that it had under natural daylight.

CRI attempts characterize this phenomenon by measuring the general accuracy of a variety of objects' colors when illuminated under a light source.



CRI is invisible until you shine it on an object

As we mentioned above, the same light color can have a different spectral composition.

Therefore, you cannot judge a light source's CRI by simply looking at the color of the light.

It will only become evident when you shine the light onto a variety of objects that have different color.

How is CRI measured?

The method for calculating CRI is very similar to the visual assessment example given above, but is done via algorithmic calculations once the spectrum of the light source in question is measured.

The color temperature for the light source in question must first be determined. This can be calculated from spectral measurements.

The color temperature of the light source must be determed so that we can select the appropriate daylight spectrum to use for comparison.

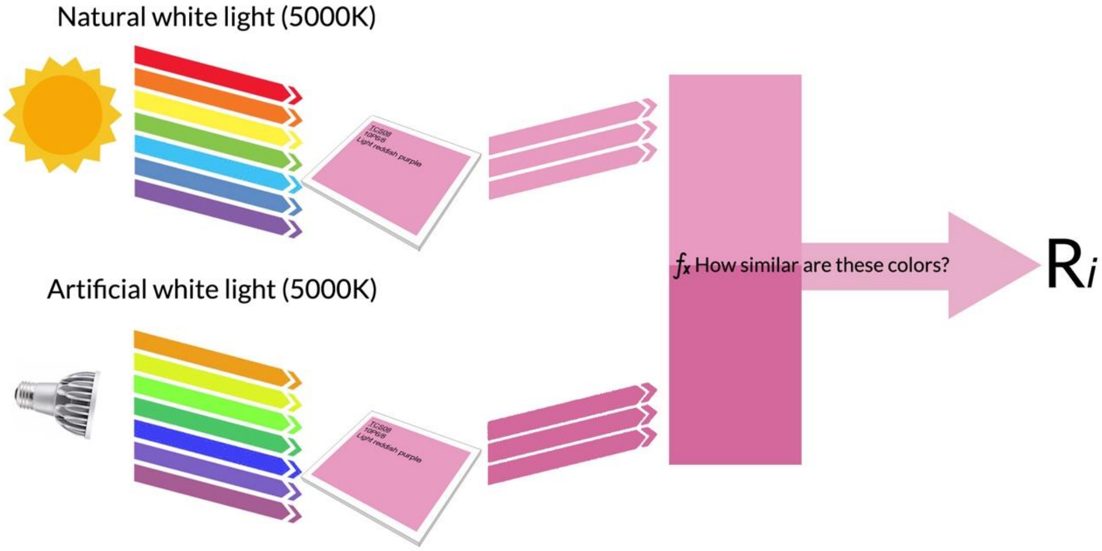
Then, the light source in question will be virtually shone onto a series of virtual color swatches called test color samples (TCS) with the reflected color measured.

There are a total of 15 color swatches:

TCS01 7.5R6/4 Light grayish red	TCS02 5Y6/4 Dark grayish yellow	TCS03 5GY6/8 Strong yellow green	TCS04 2.5G6/6 Moderate yellowish green	TCS05 10BG6/4 Light bluish green
TCS06 5PB6/8 Light blue	TCS07 2.5P6/8 Light violet	TCS08 10P6/8 Light reddish purple	TCS09 4.5R4/13 Strong red	TCS10 5Y8/10 Strong yellow
TCS11 4.5G5/8 Strong green	TCS12 3PB3/11 Strong blue	TCS13 5YR8/4 Light yellowish pink	TCS14 5GY4/4 Moderate olive green	(TCS15) 1YR6/4 Asian skin

We will also have ready the series of virtual reflected color measurements for natural daylight of the same color temperature.

Finally, we compare the reflected colors and formulaically determine the "R" score for each color swatch.



The R value for a particular color indicates the ability of a light source to faithfully render that particular color.

Therefore, to characterize the overall color rendering capability of a light source across a variety of colors, the CRI formula takes an average of the R values.

Which and how many R values are averaged will depend on which definition of CRI you are using - general CRI (Ra) or extended CRI.

What about non-daylight color temperatures?

For simplicity, we've assumed a 5000K color temperature for our examples above, and have been comparing it to a 5000K natural daylight spectrum for CRI calculations.

But what if we have a 3000K LED lamp and want to measure its CRI?

The CRI standard dictates that color temperatures 5000K and greater use a daylight spectrum, but for color temperatures less than 5000K, use the Planckian radiation spectrum.

Planckian radiation is essentially any light source that creates light by generating heat. This includes incandescent and halogen light sources.

So when we measure the CRI of a 3000K LED lamp, it is being judged against a "natural" light source that has the same spectrum as a 3000K halogen spotlight.

(That's right - despite the awful energy efficiency of halogen and incandescent bulbs, they produce a full, natural and excellent light spectrum).

What are common CRI values and what is acceptable?

For most indoor and commercial lighting applications, 80 CRI (Ra) is the general baseline for acceptable color rendering.

For applications where color appearance is important for the work being done inside, or can contribute to improved aesthetics, 90 CRI (Ra) and above can be a good starting point. Lights in this CRI range are generally considered high CRI lights.

Types of applications where 90 CRI (Ra) might be needed for professional reasons include hospitals, textile factories, printing facilities or paint shops.

Areas where improved aesthetics could be important include high end hotels and retail stores, residences and photography studios.

When comparing lighting products with CRI values above 90, it can be very helpful to compare the individual R values that make up the CRI score, particularly CRI R9.

Some of the richest, most vivid colors we see require sufficient red wavelength energy to be revealed.

Red wavelength light is plentiful in natural light, but unfortunately not the most efficient for illumination - and as a result, most LED manufacturers will reduce the amount of red light in favor of green owing to its higher efficacy.

When it comes to color rendering, however, the over-representation of green wavelengths causes a significant distortion in the way objects appear, and this is reflected in low CRI values for standard LED products.

By incorporating additional high-efficiency red phosphor in our LED manufacturing process, we are able to improve our spectral composition and create white light that more closely resembles natural light. As a result, our CRI numbers approach 100, indicating that it is almost indistinguishable from natural lighting.

The difference between CRI and CCT explained

As explained above, CCT and CRI measure two different aspects of color. CCT tells us the color of the light emitted by the light bulb, and is immediately visible to the casual observer by looking directly at the light source.

On the other hand, the CRI value does not tell us the color of the light itself. Rather, it tells us about the color appearance of objects under the light source (the light source "renders" the colors of an object, hence the term). You cannot determine a light bulb's CRI value by looking at the light itself. Instead, a light bulb's CRI can only be estimated to the naked eye by looking at the colors of an object illuminated by the light bulb. An illustrative example of this principle in action is when photographers and artists use a "color checker," which uses a palette of standardized colors to estimate the color rendering quality.

The only way to measure a light source's CRI value is by using specialized spectral measurement devices. Lighting manufacturers rely on data from these devices to publish and guarantee color rendering related metrics.

The relationship between CCT and CRI

Although CCT and CRI describe two different aspects of light color, they are nonetheless intimately related in their calculations. As mentioned above, CRI can be thought of as determining a light source's accuracy. In determining "accurate," however, we must first determine what the reference point for this "accuracy" should be. For example, when judging the color appearance of a painting, how do we know what it *should* look like? In other words, what is the reference standard?

When we refer to light accuracy, we must first determine the color temperature of a light source, so that we have a proper reference point. Each color temperature has a "reference standard" which is considered to be the light source that provides the most accurate, or natural lighting. For example, 2700K has a reference standard that is approximately equal to an incandescent light bulb. 6500K on the other hand, has a reference standard that is approximately equal to natural daylight (at noon on a midsummer day at the equator).

To continue with the painting example, if we have a light bulb whose color temperature we measure to be 2700K, we would judge the appearance of colors as compared to an incandescent bulb. We would not compare them to how they appear to natural daylight, because the color temperature of 2700K indicates that this is a warm, yellowish light source that does not come close to natural daylight.

On the other hand, if we have a light bulb whose color temperature is measured to be 6500K, we would compare the color appearance to its color appearance under natural daylight.

Why CCT is more fundamental and important than CRI

The explanation above should have made clear that CRI requires a color temperature value in order to determine what we are comparing color appearance against.

CRI is certainly an important metric that helps explain color quality, but it is almost meaningless when used alone without a color temperature value. Given a light bulb's 95 CRI rating, you might be impressed and conclude that it must be very accurate. But accurate when compared to what? Incandescent bulb light color (2700K), natural sunlight (5000K) or natural daylight (6500K)?

Think first about the color temperature requirements for your application, and then worry about CRI after. Are you looking to replicate the light of natural daylight? Pick a high color temperature value (5000K or higher), and then CRI value next. A 2700K light bulb with 95 CRI, even with a high CRI rating, will not come even close to replicating natural daylight due to its color temperature being way off.

Now, in your quest to replicate natural daylight, let's say you find a 6500K bulb but with a low CRI. In this case, the color of light emitted by the bulb might look the same as natural daylight (due to the color temperature value), but as soon as the light lands on any surface with color, you will find that the colors do not appear the same as under natural daylight (due to the low CRI value).

Next steps?

We hope this article helped to clarify any confusion between CCT and CRI values of a light source. Have you determined the color temperature needs for your application? If not, we recommend making a decision on this first. Once decided, determine if color accuracy is important for you and set appropriate requirements on the CRI value as needed. Waveform Lighting specializes in high CRI LED lighting products, and we're confident you'll find something that fits your high CRI needs.

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