Understanding Color Fidelity

What is Color Fidelity? How do we understand CRI and the new TM30 fidelity metrics and graphics?

Fidelity Myths

Many lighting people harbor misconceptions about the meaning of fidelity metrics such as CIE CRI Ra and TM30 Rf. For example:

- MYTH #1: two light sources of the same CRI will look pretty much the same
- MYTH #2: a light source with a higher CRI number will always look better than one with a lower CRI number

In other words, they believe they can directly compare two light sources by looking only at a single CRI score. This is not at all true.

Fidelity actually means Same-ness

There are two widely used standards for measuring color rendering fidelity:

- CIE Color Rendering Index (CRI), the older standard for which Ra is the fidelity index
- IES TM-30-2015, a new standard for which Rf is the fidelity index

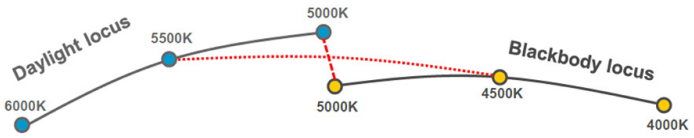
Both tests use the same spectral power distribution (SPD) data to calculate how a tested light source would compare to a reference light source in rendering the colors of test samples. The maximum possible score in both tests is 100, which would mean that the tested source renders the colors of the test samples in exactly the same degree and proportion as the reference light source. There are two important things to understand about this: (1) it only compares the rendering of the test color evaluation samples (CES), and (2) it contains the implicit assumption that the reference light source is an "ideal" source.

The same as What?

The reference source for a CRI test – at least for color temperatures up to 5000K – is a theoretical black body radiator (BBR) of the same correlated color temperature (CCT) as the test source. In the real world, the closest thing to a theoretical BBR is a tungsten incandescent or halogen lamp, but even they are not quite perfect BBRs, due to the chemical elements that are being heated.

A BBR is not necessarily ideal, or even natural. For example, the Sun is not a perfect BBR. Nor is a wood fire. In fact, sunlight replaces the BBR as the reference for higher CCT sources, which creates an awkward discontinuity in the standard CRI test.

Furthermore, there are situations when you may not want a perfect BBR. For example, the Xicato Beauty Series was developed for a major cosmetics retailer who wanted very high color rendering fidelity for skin tone comparisons, but has a side effect of making people look and feel better. Another goal may be to facilitate the observation of skin for medical diagnosis, as measured by the Cyanosis Observation Index (COI). Fortunately, you do not need to compromise traditional fidelity metrics to achieve an excellent COI score. For example, the Xicato Artist 3500K and 4000K, with CRI of 98, perform extremely well on this metric.

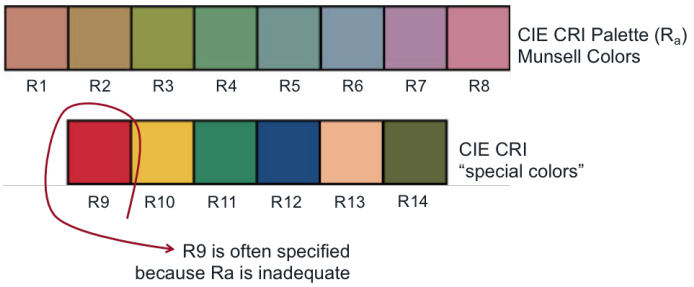


Black Body Radiator reference curves for CIE CRI and IES TM-30-2015. CRI has an abrupt discontinuity at 5000K. TM30 smooths the reference curve between 4500K and 5500K to mitigate problems with color match at points just above and below 5000K.

The Problem with Swatches

A bigger problem is with the test itself. Traditional CRI as defined by CIE only tests 8 color samples (see below), none of which test highly saturated colors, and which collectively fall far short of testing the entire gamut of visual light. In other words, even a CRI score of 100 only means that a light source is exactly like the BBR on eight muted colors!

The list of swatches (R1 through R8) was extended to 14 or 15 by some, but these are rarely incorporated into the CRI number. More commonly, R9 has emerged as an important swatch that begins to fill the gap by providing a metric for red color rendering.



CIE CRI color swatches

CRI was okay for incandescent and to a lesser extent

HID and fluorescent sources, but it failed badly when comparing LEDs. After literally decades of debate, the IES finally took the bull by the horns and created TM-30-2015, which uses 99 Color Evaluation Samples (CES) (below) specifically chosen from real objects and dyes to represent a full, balanced gamut of colors, and which made every LED manufacturer's phosphor and die bin choice relevant to the score.

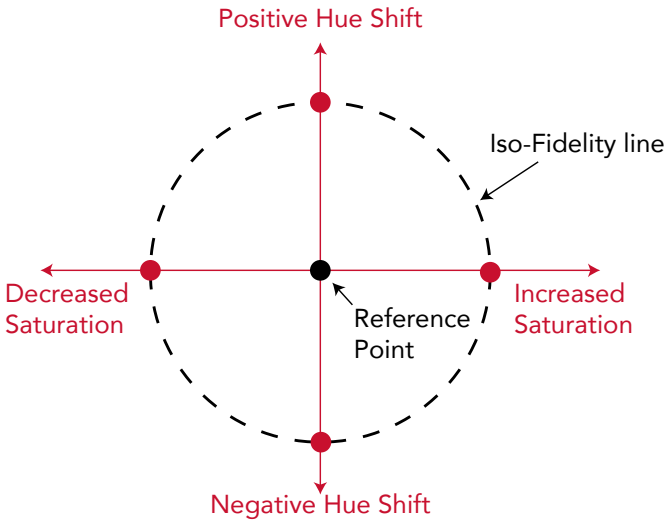
(Note: The CIE has adopted the TM-30 fidelity metric with minor revisions, and also calls it Rf, but they have not yet retired the old Ra metric, so the potential for confusion remains.)

IES TM-30-15 Color Evaluation Samples (CES)

Less than 100 Loses Meaning

What do we know about two sources that have a fidelity score below 100? Unfortunately, the further from 100 we get, the less we know. That is because the metric only tells us the average differences of the various CES from the reference, without telling us specifically how each color differs.

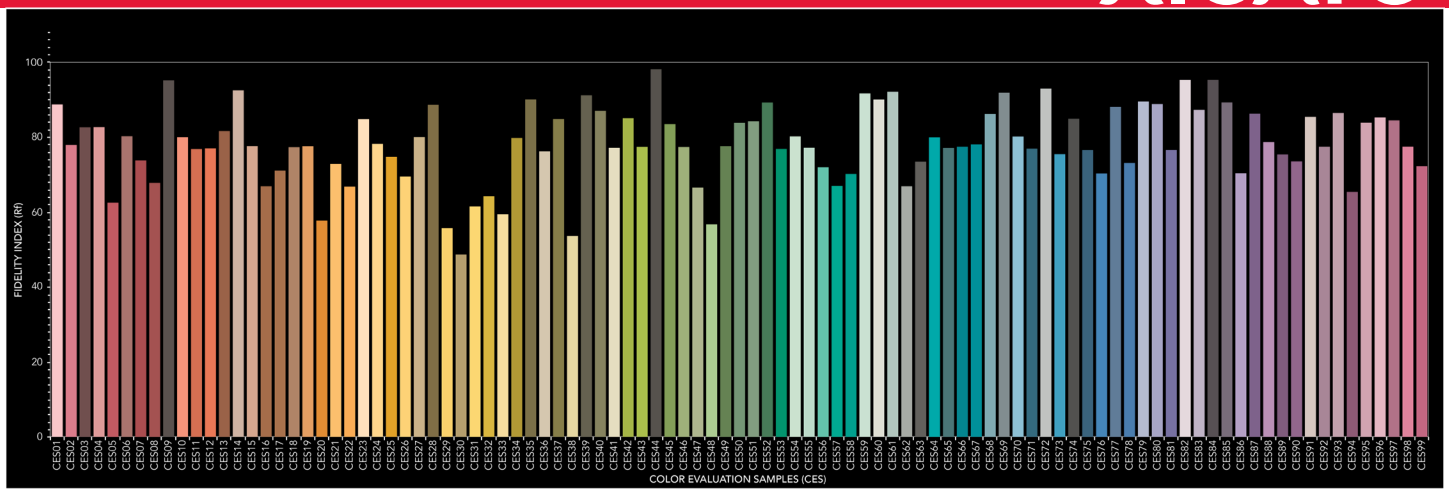
For example, a score of 85 means that, on average, the samples are 15 units different from the reference. All of the colors may be 15 units more saturated, or less saturated, or color shifted to one side or the other. More likely, a few of the colors may be very accurate, and a few others very inaccurate; some saturated, others unsaturated, others shifted. But we don't know which color is which! One 85 CRI light source may show highly saturated colors, while another shows drab, gray colors. And a source with a CRI of 70 might provide a much more pleasing effect than one with a score of 85!



This graphic shows that the same Fidelity number can be acquired by any type of deviation from the reference color rendering point. All points on the dotted line have the same fidelity score.

For example, the images below are of the same scene illuminated by two light sources with the same CRI Ra (80) and TM30 Rf (78). Yet one looks entirely different than the other, and both are very different from their appearance under a reference light source. The source on the top is highly red saturated, while the one on the bottom is obviously undersaturated. And both exhibit color shift.

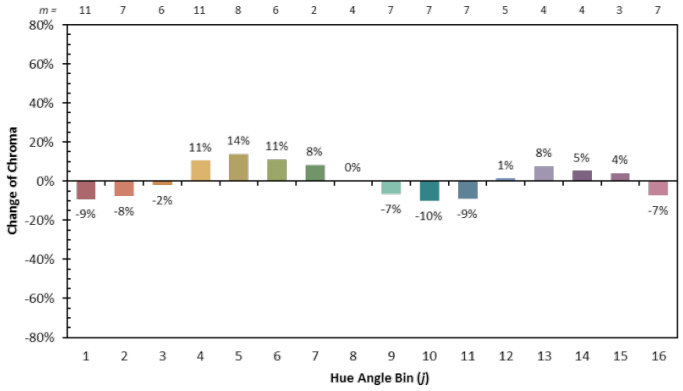
Images courtesy of Randy Burkett Lighting Design



Xicato Standard Series 3000K TM30 fidelity on all 99 color evaluation samples

Providing Meaning

To help lighting designers choose, TM30 provides several informative graphics that present Fidelity in different ways. For example, the graphic above shows the fidelity of the Xicato Standard Series (83 CRI) in 3000K CCT. A taller column represents higher color fidelity in that particular color, with a maximum of 100. The average of all of these values yields the TM30 fidelity metric, Rf, of 78.



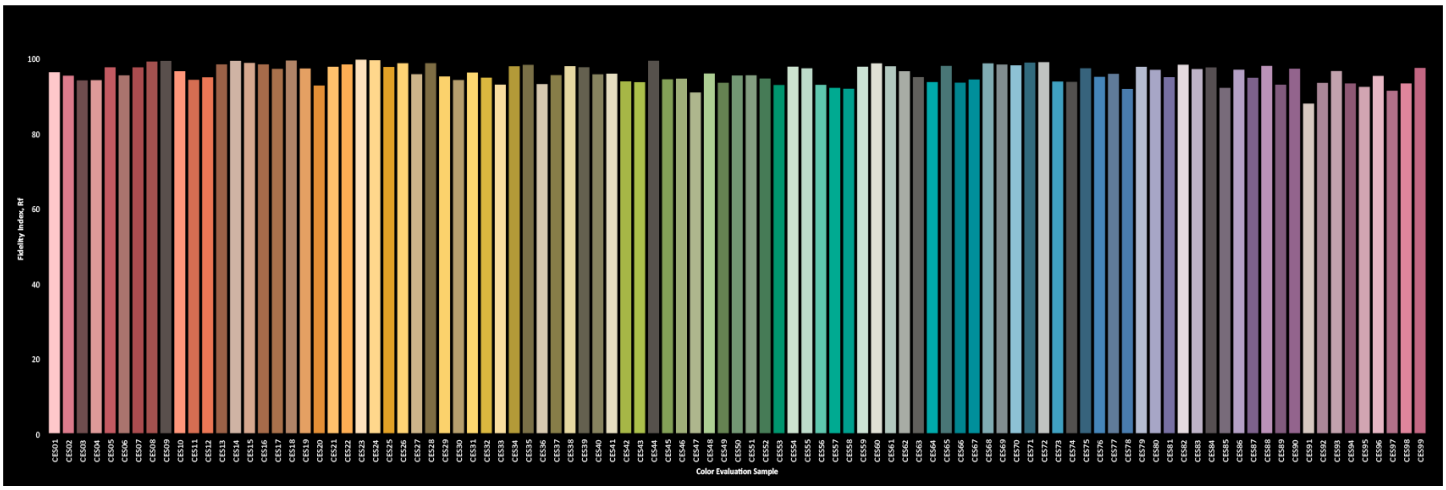
Left: Hue angle graph for Xicato Standard Series 3000K, showing color groups that are over- and under-saturated.

A casual observer might assume that the relatively short columns in yellow mean that there is less yellow in the light source. But the reality is the opposite!

To simplify presentation of color information, TM30 averages colors into 16 related groups, called "hue angles". On the left, we see a graph that shows the relative saturation of the different hue angles for Standard 3000K.

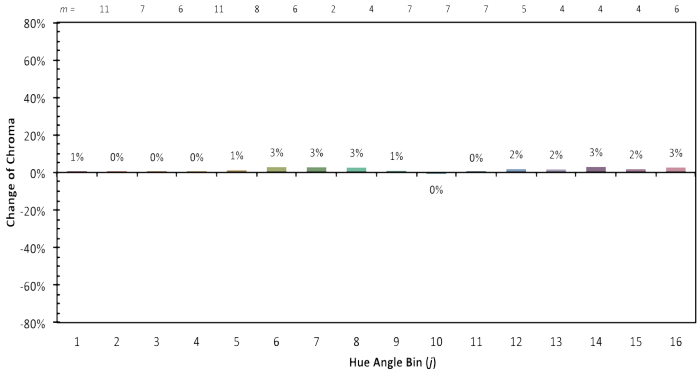
Notice that the yellow in Xicato Standard Series is lower in fidelity because yellow is OVER saturated. You can also see that greens and purples are slightly over-saturated, while reds and cyans are relatively under-saturated.

Now, let's look at a very high fidelity light source; the Xicato Artist Series® in 3000K CCT, which has a CRI of 98 and a TM30 Rf of 96 (note that TM30 is a tougher fidelity metric!). Artist Series is specifically engineered to replace halogen and incandescent lighting in color critical applications:



Notice that all of the columns are very tall, with no significant gaps.

In fact, many colors are "spot on", and no color group deviates more than 3% in saturation from the reference, as shown by the graph below.



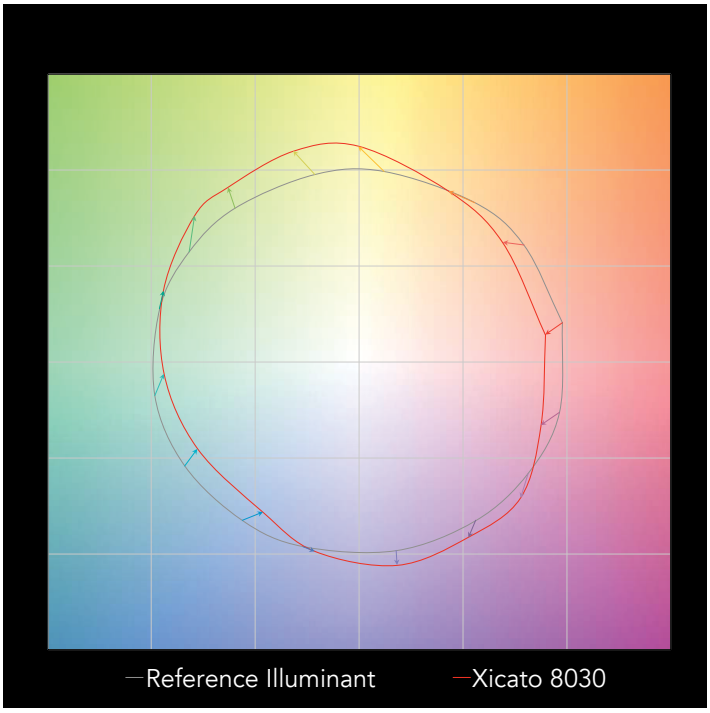
Left: Hue angle graph for Xicato Standard Series 3000K, showing color groups that are over- and under-saturated.

Color Vector Graph

So far, we have talked about how the fidelity score indicates the average deviation of a test source from the reference on a selection of CES. We have shown graphs that illustrate variation in saturation, but what about color shift, which is typically a much more objectionable variation?

TM30 has a graphic for that, too... in many ways, the best single graphic for understanding a light source lit effect.

Below is the TM30 color vector graph for the Xicato Standard Series 3000K LED light source... the same as shown above. Observe that there is a color space with a gray circle and a red, roughly elliptical shape superimposed on it. The gray circle represents the "ideal" color rendition of the 3000K reference source, and the red line represents the relative color rendition in each of the 16 hue angle bins of the tested source.



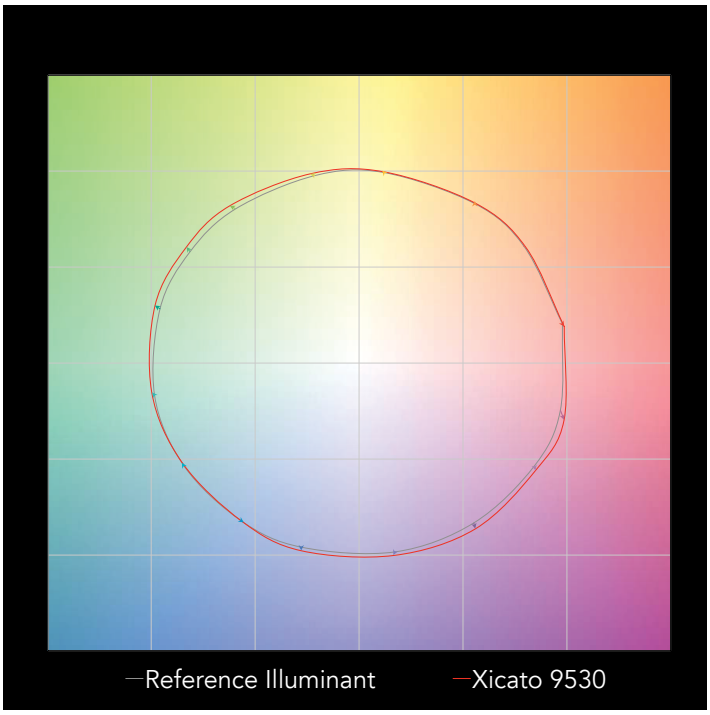
A perfect tested source would of course be superimposed directly on top of the gray circle. Like the hue angle graph above, this graphic shows you again that yellow-greens and purples are slightly oversaturated in the Standard Series product, and that blues and reds are slightly under-saturated. But it tells you even more...

Notice the tiny arrows that point in or out from the gray circle toward the red figure. The length of these arrows tells you the degree of variation from the reference, and the direction tells you in what way the hue bin differs.

- Oversaturated = radially outward
- Undersaturad = radially inward
- Hue shifted = tangential

So as is typical for most light sources, Standard is slightly hue-shifted in areas near the intersection of the two lines.

Now let's look again at Xicato Artist Series...



Notice that it is very difficult to see the tiny arrows. This is a good thing! What you see is that the red Artist line almost perfectly overlays the reference line, that the arrows are very short, and that they are all radial. In fact, Artist is ever so slightly oversaturated where it deviates, which is generally preferred, resulting in a slightly larger color gamut than the reference source.

The vector graphic for Artist 2700K, shown below, is similarly precise. This is why Xicato Artist Series is an ideal replacement for halogen lighting. The high fidelity, balanced color rendering of Artist Series has made it the preferred light source for art museums worldwide. It is used by high quality retailers and even grocers for its ability to "reveal product", bringing out the rich colors of wood, ceramics, fabrics and leather, as well as the true colors of produce and packaging.

Conclusion

You can see that simplistic fidelity metrics that present a single number – especially as the number drops further below 100 – do not provide complete information about the lit effect of a light source. Of course, the best meter is your eyes, and the best test is to compare actual sources by shining them on the objects that will actually be in your space. Absent that, TM30 is a much better tool than CIE CRI, providing much more information that enables lighting designers to make better choices for their clients.

Xicato was the first to publish full TM30 data on all of its color series, and we continue to be available to lighting designers, manufacturers and end users who want to learn more about color fidelity, gamut, quality, and metrics. Contact your Xicato representative or write to marketing@xicato.com for more information.