# TM-30: A New Tool for the Lighting Design Community

Over 50 years ago, the International Commission on Illumination (CIE) introduced the "General Color Rendering Index R_a," more commonly known as CRI. Ever since, CRI has been the go-to yardstick for measuring how an electric light source renders colors compared to natural light.

There's a new challenger to this long-standing metric. Called TM-30 and developed by the Illuminating Engineering Society (IES), it aims to provide a more holistic and precise color rendering measurement that's better aligned with modern color science research and LED lighting technologies.

This FAQ addresses the primary differences between CRI and TM-30, the major elements of a TM-30 report, and how lighting professionals may benefit from incorporating TM-30 in their evaluation of luminaires.
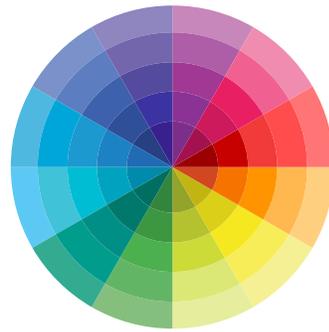
Why A New Metric?

The lighting community has struggled with the shortcomings of CRI for a long time (the CIE has been working on its own replacement on and off for more than 25 years). CRI is part of the ANSI C 78.377 standard and remains a widely used and recognized metric. But the method of measuring CRI has been largely unchanged since 1974. The same can't be said for the science and technology of lighting and color.

The advent of LED lighting has made CRI less effective for achieving desired results in real-world settings, and lighting designers and architects are finding it increasingly outdated.

What are CRI's Limitations?

CRI is calculated by comparing eight standard color samples as they appear under the electric light source being tested to how they appear under a reference light source of the same Correlated Color Temperature (CCT) – usually daylight. The coordinates for each color under both light sources are then plotted on the CIE Y-U-V color space.

Distances between these pairs of coordinates are calculated to give a difference in fidelity for each sample. When these numbers are averaged, the result is subtracted from 100 to get the CRI number. A CRI of 100 would mean that all eight colors appear to be rendered the same when viewed under the test light source and sunlight.

CRI provides a useful yardstick. For instance, we know that a CRI of 90 or higher is generally considered good enough for most color-critical applications, that a CRI of 80 is typically acceptable for general commercial and office lighting, and that a CRI of 70 may be adequate for exterior lighting and some interior spaces where color discrimination isn't essential.

So far so good. But the method's problems are well-known:

- Only eight primary color samples are tested — all pastels (7 additional samples are seldom used)
- Two artificial light sources must have equal CCT to be compared
- Two light sources with identical CRI can render colors very differently
- CRI only assigns a value to color fidelity, ignoring other spectral values that contribute to our experience of rendered color
- The CRI number is an average that can conceal hue or saturation shifts in specific colors
- CRI values are biased against oversaturated reds and undersaturated greens
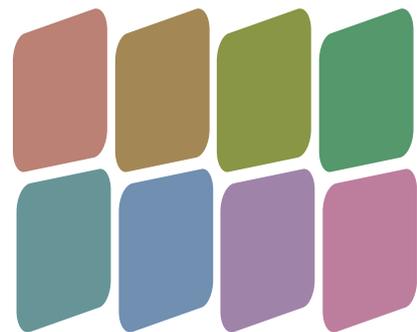
CRI's eight primary color samples are all pastels

How Was TM-30 Developed?

The IES TM-30 Color Metrics Task Group consisted of seven voting members from the lighting research, manufacturing and specification fields working collaboratively. The group started their work by amassing and reviewing decades of research into color spaces, color samples and ways of measuring color rendering. Much of this research happened after the CRI system was created, and changed our understanding of human color perception.

Color science has established three primary attributes contributing to our experience of color rendering:

> 1. **Fidelity:** how accurate colors are reproduced
>
> 2. **Discrimination:** how easily we can tell colors apart
>
> 3. **Preference:** how closely the colors match known human preferences

CRI provides a measure of average color fidelity and nothing else. The TM-30 group set out to create metrics that would correlate closely to our experience of all three factors, and could be communicated in a useful way. In addition, the group wanted a method that would use existing inputs and wouldn't require new or additional lighting tests. The group's final method was then approved by the IES Color Committee, the IES Technical Review Council and the IES Board of Directors — more than 30 gatekeepers in all.

What Are TM-30's Metrics?

The TM-30 method generates two primary numbers:

- **Fidelity Index (R_f):** How closely the observed light can render colors like daylight, using 99 color samples
- **Gamut Index (R_g):** How saturated or desaturated (how intense or rich) colors are

The calculations also generate data for several graphics. The most significant is the Color Vector Graphic, showing which colors are saturated/desaturated and which experience a hue shift.

TM-30's calculator engine also derives detailed values of particular interest:

- Fidelity by hue ($R_f\#$)
- Chroma shift by hue ($R_g\#$)
- Skin fidelity (R_f,skin)

### What Inputs Are Used to Calculate TM-30's Metrics?

Very few light sources emit equal light across every wavelength. The spectral power distribution (SPD) of a light source specifies the amount of energy emitted at each wavelength in the spectrum.

The TM-30 method uses an electric light source's SPD as its input. From that, TM-30 generates several outputs for every light source evaluated — two metrics and a series of graphic visualizations.

Between the SPD input and the method's outputs is a complex mathematical calculation engine — a mix of matrices, integrals and logarithmic transforms laid out in pages of dense formulas.

The good news for non-math majors is that this calculation engine has been incorporated into an Excel spreadsheet that anyone can use: plug in the SPD of a given light source, and the calculator tool will produce the complete set of TM-30 indices and graphics.

The spectral power distribution for an LED linear
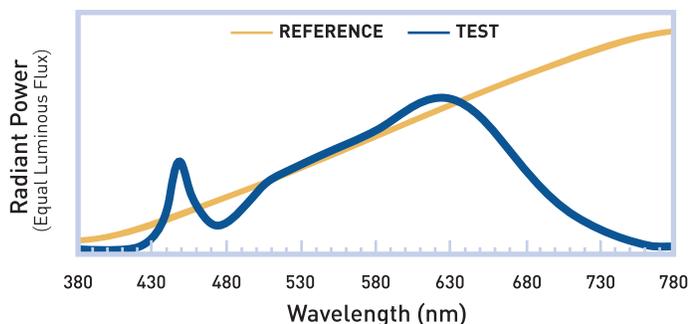
Are TM-30's Reference Light Sources Different from the CRI Reference?

The TM-30 method uses the same reference illuminants used in the CRI method. Below a color temperature of 4500K, the reference is Planckian black body radiation. Above a color temperature of 5000K, the reference is a model of daylight. What's different is that between 4500K and 5500K, the TM-30 reference is a proportional blend of Planckian radiation and daylight. Using this blended reference avoids the abrupt jump seen at 5000K in the CRI method.

DAYLIGHT LOCUS

BLACK BODY LOCUS

5000K
5500K
6000K
5000K
4500K
4000K
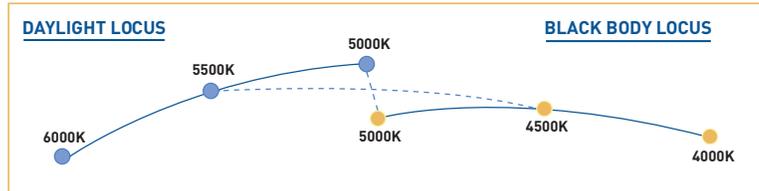
An increasing number of LED light sources on the market include a "tunable" CCT range that crosses the 5000K threshold. The CRI method can generate a jump or discontinuity in measured values for these sources. Blending the reference sources eliminates that problem.

Source: A Technical Discussion of IES TM-30-15; DOE+IES Webinar | September 22, 2015
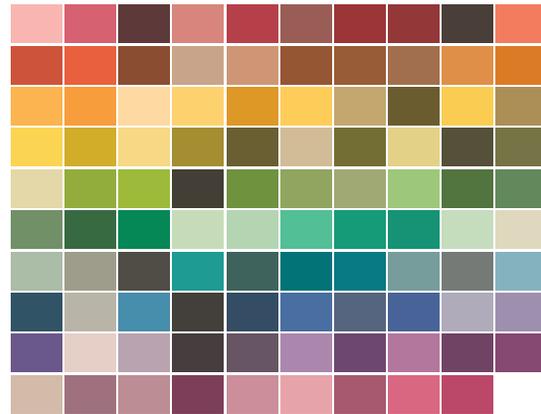
How Does TM-30's R_f Differ from CRI?

The Fidelity Index R_f is used to measure the light source's color rendering compared to that of a reference source, just as the CRI method does. However, TM-30 uses 99 color samples to create a more reliable predictor for how accurately any color in the color space will appear. The color samples display varying degrees of saturation and are pulled from real-world objects in seven categories:

- Nature (food, flowers, foliage, etc.)
- Skin color
- Textiles
- Paints
- Plastics
- Printed material
- Color systems

R_f uses a 0-100 scale to represent fidelity. For any given test light source, while you can expect to see a rough correspondence between CRI and R_f values, the numbers won't necessarily be the same.

Because of the different color spaces, color samples and calculating engines of the two methods, the CRI and TM-30 R_f scores for a given artificial light source can vary by up to 8 points in either direction. Also, light sources that have been optimized to score highly with the CRI color samples tend to have lower R_f scores, since the source's narrow spectral range can't accurately render TM-30's much broader range of color samples. Finally, light sources that increase red chroma, which is often preferred, are penalized by attributes inherent to the CRI color space.
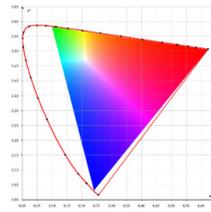
TM-30's 99 color samples used to calculate Rf (average fidelity) and Rg (average gamut)

*Source: Evaluating Color Rendition Using IES TM-30-15; US DOE Solid-State Lighting Technology Fact Sheet*

How Does TM-30's Color Space Differ from CRI's?

A color space is a representation of all the colors that a human being can see, constructed from experimentally-derived models of human color vision. When illuminated by a reference light source such as daylight, any standard color sample (and any object's color) will be a set of coordinate points somewhere in the color space. The same standard color sample or object, when illuminated under an artificial light source, will either have the same coordinates or will cause a shift of hue and/or saturation, moving the point to another set of coordinates in the color space.

When a color space is uniform, equal perceptual differences in color correspond to equal distances between points. The TM-30 group found that the older CIE U*V*W* color space used for CRI doesn't provide a uniform representation of hue and saturation. Instead, the TM-30 test method adopted the CAM02-UCS color space offering more uniform characteristics and better calculations of color differences.

The 1976 CIE U*V*W* color space used to calculate CRI
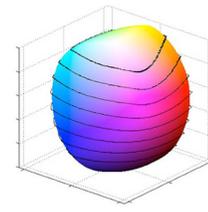
The CAM02-UCS color space used by TM-30 has been shown to be the most uniform color space created to date

### What's the reason for TM-30's hue bins?

The 99 color samples used in TM-30 are divided into 16 equally sized hue bins.

Source: Understanding and Applying TM-30-15 DOE+IES Webinar 9.15.2015

While the technical and mathematical rationale for the binning process is complex, the result is that they allow us to zero in on how a given light source will render a particular range of hues, such as reds, blues or greens. TM-30 can calculate the average fidelity for each hue bin based on the samples in it, and the resulting shape formed by connecting the average values can be compared to that of the reference.

This is helpful when you need more detailed information than the average fidelity index provides, such as when seeking to determine the fidelity of red hues or blue hues. The fidelity values for each bin can also reveal how light sources with the same average fidelity index might render colors differently. Calculating the Hue Fidelity Indices for each of the 16 hue bins allows for a straightforward comparison of two or more artificial light sources to determine how similarly they render reds, yellows, greens, etc. compared to the reference.

What's the Purpose of TM-30's Gamut (R$_g$) Index?
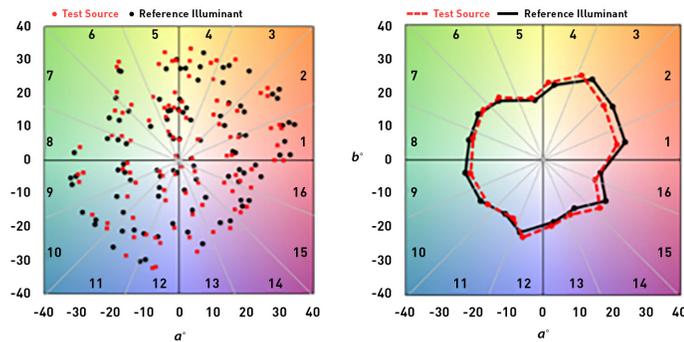
TM-30's 16 equal-sized hue bins (left) with plots for the reference light source and a test source (right).

Source: DOE "Evaluating Color Rendition Using IES TM-30-15" Fact Sheet

Repeated studies have demonstrated that our experience of both color discrimination and color preference are closely related to color saturation. TM-30 includes a measure of saturation called gamut, and symbolized R$_g$.

You've probably heard the phrase, "runs the gamut." Gamut refers to the complete range of something. In TM-30, that something is the intensity or vividness of a color.

An R$_g$ score near 100 means that color saturation under a given light source is similar to that of the reference source. Scores higher than 100 means the color will appear more saturated than under natural light; lower than 100 means it will appear more washed out.

Determining R$_g$ will give you an average value for how a light source oversaturates or desaturates colors, but not specific characteristics. One fixture may have an R$_g$ of 100 because there is very little difference in saturation from the reference.

Another fixture may have a gamut of 100 because it oversaturates and desaturates various colors by equal amounts. R_g alone won't reveal those details.

Because R_g is a measure of preference, determining the "best" R_g values will depend on the application. A retail store might want a light source that increases saturation to make products stand out without appearing too differently from how it will look at home. Saturation may be less important in an office setting than fidelity. A carpet or paint store might require precise color matching.

It's important to note that R_f and R_g are inextricably linked. If R_f equals 100 and no color shift occurs between the test light source and the reference, then R_g must also equal 100. If R_f decreases, then we know that at least some colors have shifted, and R_g will either be greater than or less than 100. In general, one point of gamut will cost about one point in fidelity: a color-boosting source with an R_g = 120 will necessarily have an R_f at or below 80, since increasing or decreasing saturation impinges on fidelity.

Why do I need graphics – aren't R_f and R_g enough?

Why average fidelity and average gamut aren't enough. The blue point represents a color sample's plot in the color space as seen under the reference light source. The four orange points represent the same color sample as perceived under four different electric light sources. The orange points are equidistant from the reference point, meaning they've shifted the color by the same distance. That means the light sources all have the same CRI — as does any point along the circle, since these are equidistant from the original color position.

Positive Hue Shift

Constant Fidelity (CRI)

Decreasing Saturation

Increasing Saturation

Negative Hue Shift
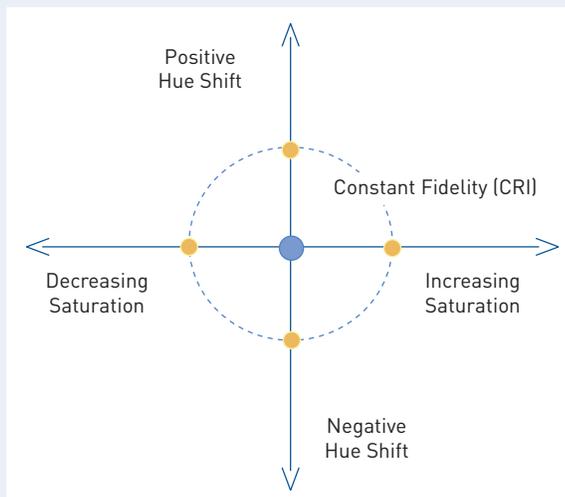
Light sources with the same CRI can render a color sample quite differently, shifting either saturation, or hue, or both. A fidelity metric only tells us the size of the shift, not its impact on individual color or hue bins.

Source: Evaluating Color Rendering With TM-30 | ENERGY STAR Webinar, March 31, 2016

R_f and R_g are both averages of 99 individual color samples scores, and average values can hide important information. Neither number tells us about the fidelity and saturation of specific colors, or how any color might be shifting in hue.

Depending on the application, you might need a light source with higher fidelity for warm colors and higher saturation for blues and greens. Or a color-critical application might require that no individual colors shift in hue. R_f and R_g can't tell us any of that. You could delve into the fidelity and gamut scores of specific colors or hue bins, but with 99 colors and 16 bins, you'll be swimming in spreadsheet tables.

TM-30's solution is simple, clean, intuitive and immediately accessible: *the Color Vector Graphic (CVG)*.

What Is the Color Vector Graphic?

In addition to the average fidelity and average gamut metrics, TM-30 generates graphics to display the size and direction of variance in saturation and hue. The single most useful element of a TM-30 report might be the Color Vector Graphic. Once you're familiar with how the graphic works, the Color Vector Graphic can quickly and easily communicate how a source will render a wide variety of colors

in an easy-to-read visual reference to use along with R_f and R_g. The graphic reveals an enormous amount of information at a glance, quickly telling you whether a given light source will make reds appear duller than under natural light, or whether green hues will "pop" more.

How to read a CVG:

① The black circle = color sample plots for the reference light

② The red shape = the plots of those same colors for the light source being tested

③ Any red line inside of the black circle means that the test light desaturates those hues compared to the reference light

④ Any red line outside of the black circle means that those hues are oversaturated compared to the reference light

⑤ When the lines overlap, the hues rendered are the same for both lights (Perfect overlap would mean the two light sources render colors exactly the same)
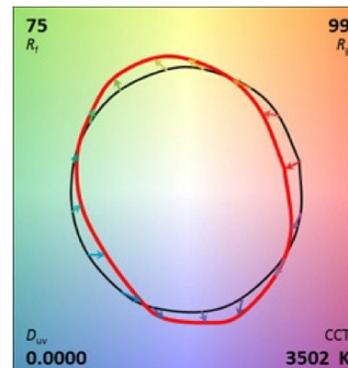
Source: TM-30 Measures and Meaning FAQs | SOLID-STATE LIGHTING, US DOE
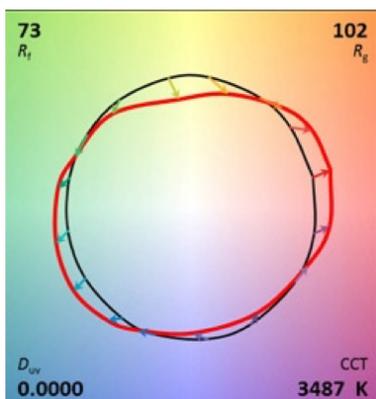
Source: TM-30 Measures and Meaning FAQs | SOLID-STATE LIGHTING, US DOE

What the arrows mean:

⑥ The *tail* of each arrow originates at the coordinates of a color under the reference light (black line)

⑦ The *point* of the arrow directs toward that same color's coordinates under the test light (red line)

⑧ Arrows pointing *outward* (toward the outside of the color space) mean colors are more saturated than the reference

⑨ Arrows pointing *inward* (toward the center) mean colors are duller or more washed out than the reference

⑩ Arrows pointing *sideways* or *angled* inward/outward tell us the color has shifted hue from its natural appearance, and in what direction

What other graphics does TM-30 create?

TM-30 can be used to generate a number of other useful color graphics as a complement to the numeric values R_f and R_g.

One of the most useful is the Color Distortion Graphic, which superimposes the color space information for the test light source on a black background, with a white circle representing the color space described by the reference source. Isolated in this way, it's easier to see how various hues are distorted by the source. Unlike the Color Vector Graphic, the Color Distortion Graphic doesn't provide information on how the test light shifts hues, only saturation.

This Color Distortion Graphic of an LED light source shows the test light desaturates red hues, as well as some green and green-blue colors, while oversaturating green-yellows, blues and blue-purples.

Source: Understanding and Applying TM-30-15 DOE+IES Webinar | September 15, 2015

Why is TM-30 Important for the Lighting Community?

Optimizing LED light fixtures for efficiency has become something of a given. As the LED lighting industry has matured, emphasis has now shifted to optimizing lighting for people's visual preferences, comfort and well-being. As the industry explores the application of specialized light sources matched to human preference and particular use cases, TM-30's metrics can be a valuable tool.

The nature of LED lighting allows manufacturers to build fixtures with specific spectral values and thus "dial in" desired lighting characteristics. Manufacturers can provide the spectral data on their fixtures that allows specifiers to calculate

TM-30 metrics, or can run the numbers themselves and provide a TM-30 report as part of the specification material for their product.

For lighting designers and specifiers, TM-30 provides a quick way to assess the spectral performance of a light source, to identify sources with particular spectral features, and to match particular applications to appropriate light sources with greater confidence.

One of the strongest potentials for TM-30: allowing lighting designers and specifiers to quantify their intuitive preferences for easier product selection. For example, if a lighting designer favors the lighting characteristics of a particular fixture, determining the TM-30 metrics for that light source would then allow the designer to identify other fixtures with the same spectral performance, expanding the design palette and helping assure successful lighting outcomes.

Will TM-30 Replace CRI?

While TM-30 is gaining ground among lighting professionals, it's got a long way to go to displace CRI as the default measure of color rendering accuracy. But TM-30 is off to a good start: it's a significant improvement over CRI and doesn't create the burden of additional testing. You can derive the TM-30 values for a given light source from existing data sources such as spectral power distribution — there's no need to conduct more measurements.

One promising sign of TM-30's eventual acceptance comes from the organization that created the CRI metric. In 2017, CIE published its own General Color Fidelity Index (R_f) based on the fidelity index (R_f in TM-30-15), but with slight differences in the calculation method. In an effort to harmonize the two metrics and gain broader acceptance for TM-30, TM-30 was revised the following year (TM-30-18) so that the two measures are now identical.

At this time, TM-30 is an IES-approved method that generates a useful report, but has yet to be adopted as an industry standard to replace or augment CRI. That's a change expected to come in time as manufacturers, specifiers and designers embrace the method's superior accuracy and explore its utility as a tool for designing, evaluating and selecting light sources.

At a Glance: CRI vs. TM-30

	CRI Calculation Engine (1974)	TM-30 Calculation Engine (2015)
Color Space	CIE 1964 U*V*W*	CAM02-UCS (CIECAM02) Modern Color Space
Color Samples	8 color samples • Medium chroma/lightness • Spectral sensitivity varies • Munsell samples only	99 color samples • Uniform color space coverage • Spectral sensitivity neutral • Variety of real objects
Outputs	Fidelity metric only	Fidelity, Gamut, Graphical, Detailed
Reference Illuminant	Step function	Continuous (Uses same reference sources, but blended between 4500K and 5500K)
Scoring	No lower limit for scores (negative scores possible)	• Fidelity (R_f) uses intuitive 0 to 100 scale where 100 is perfect fidelity • Gamut (R_g) values will exceed 100 for oversaturated colors

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