

Optibin

Technology
Overview

Color
Consistency
for Color
and White-
Light LEDs

PHILIPS



Optibin: Color Consistency for Color and White-Light LEDs

Color consistency is an index of light quality for both color and white-light LEDs. Where white light is concerned, *correlated color temperature*, or CCT, describes whether white light appears warm (reddish), neutral, or cool (bluish). The standard definitions of CCT allow a range of variation in chromaticity that can be readily discerned by viewers even when the CCT value is the same. Ensuring color consistency, therefore, is a major concern of LED manufacturers, who devise methods to keep color variations under tight control.

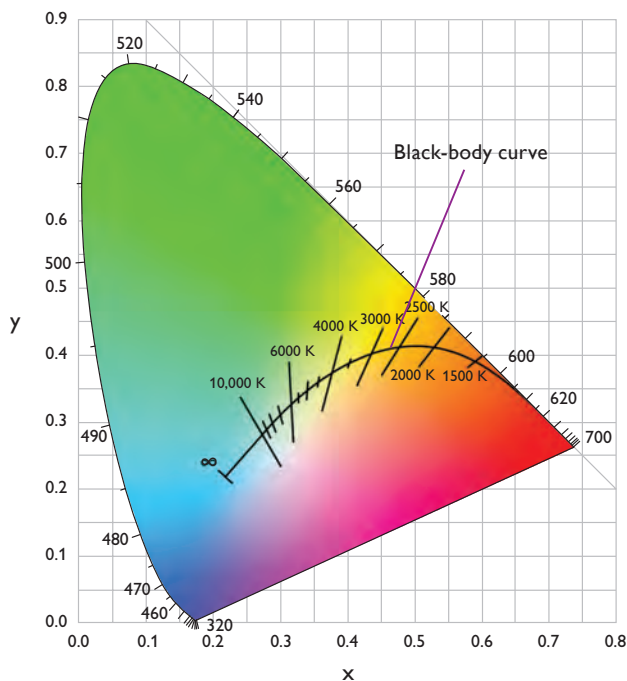
OPTIBIN[®]
CK TECHNOLOGY

Optibin[®] is a proprietary binning optimization process developed by Philips Color Kinetics. Optibin uses an advanced bin selection formula that exceeds industry standards for chromaticity to guarantee uniformity and consistency of hue and color temperature for Philips lighting products.

Understanding Correlated Color Temperature

✿ A black body is an object that absorbs all electromagnetic radiation falling on it. Because it reflects no light, a black body appears black. No perfect black bodies exist, but certain metals offer good approximations.

Technically speaking, the “temperature” in correlated color temperature refers to *black-body radiation* — the light emitted by a solid object with certain properties, heated to the point of incandescence — and is expressed in degrees K (Kelvin), a standard measurement of absolute temperature. As a black body gets hotter, the light it emits progresses through a sequence of colors, from red to orange to yellow to white to blue. This is very similar to what happens to a piece of iron heated in a blacksmith’s forge. The sequence of colors describes a curve within a color space. The diagram below shows the CIE 1931 color space, created by the International Commission on Illumination (CIE) to define the entire range of colors visible to the average viewer, with the black-body curve superimposed on it.



The black-body curve defines the range of color temperatures, from warm (reddish) to cool (bluish), within the CIE 1931 color space.

An incandescent lamp emits light with a color of roughly 2700 K, which is toward the warm or reddish end of the scale. Because an incandescent bulb uses a filament that is heated until it emits light, the temperature of the filament is also the color temperature of the light.

Spectral analysis of visible light makes it possible to define color temperatures for non-incandescent white light sources, such as fluorescent tubes and LEDs. The actual temperature of a 2700 K LED source is typically around 80° C, even though the LED source emits light of the same color as a filament heated to a temperature of 2700 K.

The American National Standards Institute (ANSI) has produced a series of standards that define the chromaticity of different types of light sources. For LED light sources, chromaticity standard C78.377A, published in 2008, defines 8 nominal CCTs ranging

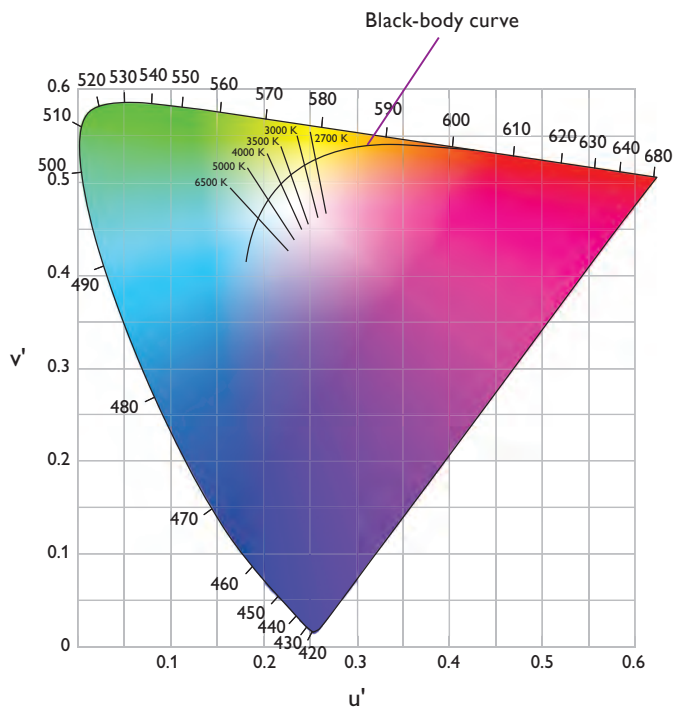
from 2700 K (warm) to 6500 K (daylight). For consistency across light source types, six of these CCTs correspond to the chromaticity specifications for compact fluorescent lamps (defined in the ANSI C78.376 standard, published in 2001). Since LED sources can be manufactured to produce any color temperature within the range, ANSI C78.277 defines two additional CCTs (4500 K and 5700 K) to fill in gaps along the black-body curve which are not accounted for by the CFL chromaticity standard.

Allowable Variations in CCT

Each nominal CCT has an allowable range of variation, or *tolerance*, both along the black-body curve and perpendicular to it. Variations that lie along the black-body curve make a light source appear more reddish or bluish. Variations above and below the black-body curve make a light source appear more greenish or pinkish.

Variations along the black-body curve are measured in degrees K, while variations perpendicular to the black-body curve are notated as Duv. Duv ranges are defined on the CIE 1976 color space, rather than the 1931 color space, because the 1976 color space (also known as the CIELUV color space) is better suited for evaluating color differences of light sources: It uses a uniform scale in which a distance measured anywhere on the color space represents the same degree of difference in color.

The axes of the CIE 1976 color space are u' and v' , instead of x and y . Duv measures the distance from the black-body curve, and therefore the degree of color change (its delta). Positive Duv values are above the curve, while negative Duv values are below the curve.



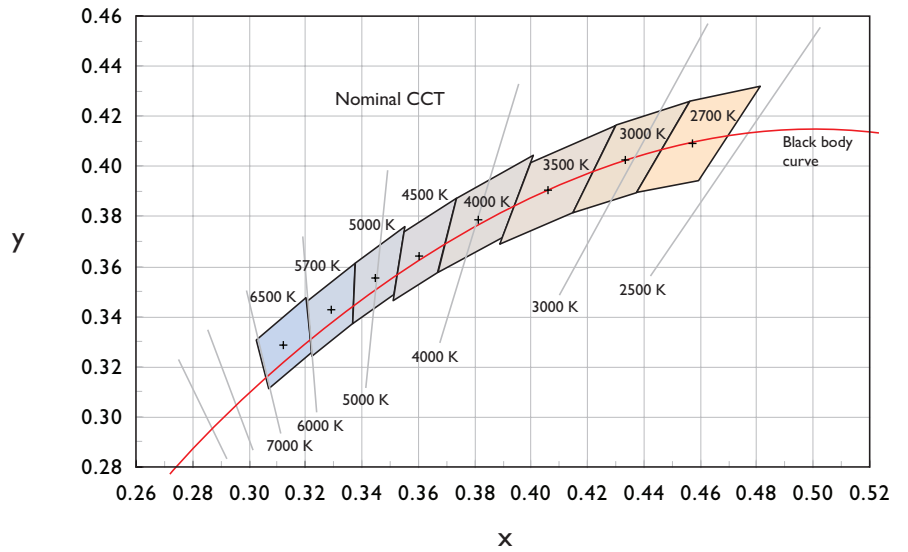
The black-body curve drawn on the CIE 1976 (CIELUV) color space. Because this color space uses a uniform scale, it is better suited to calculating Duv of light sources. Positive Duv values are above the black-body curve, while negative Duv values are below it.



Photography: John Brandon Miller

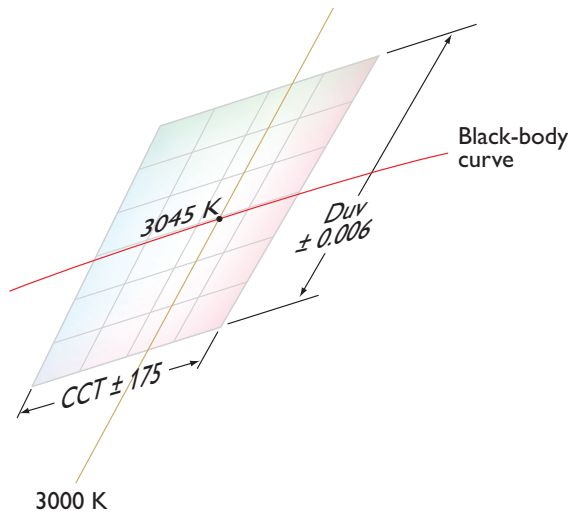
Because of advances in color quality and energy-efficiency, white-light LEDs have come into their own for general illumination. LED cove lighting gives an elegant and inviting look to historic Old North Church in Boston, Massachusetts.

As the diagram below shows, allowable variations both along and perpendicular to the black-body curve define a quadrangle within the color space for each color temperature.



Nominal CCT (ANSI C78.377A)		
CCT	CCT Range	Duv Range
2700 K	2725 K \pm 145	0.000 \pm 0.006
3000 K	3045 K \pm 175	0.000 \pm 0.006
3500 K	3465 K \pm 245	0.000 \pm 0.006
4000 K	3985 K \pm 275	0.001 \pm 0.006
4500 K	4503 K \pm 243	0.001 \pm 0.006
5000 K	5028 K \pm 283	0.002 \pm 0.006
5700 K	5665 K \pm 355	0.002 \pm 0.006
6500 K	6530 K \pm 510	0.003 \pm 0.006

The size of each quadrangle is determined by the CCT and Duv ranges for each color temperature, as specified in the ANSI standard. For example, the quadrangle for nominal CCT of 3000 K is centered on 3045 K, with a tolerance of plus or minus 175. The 3000 K quadrangle, therefore, covers from 2870 K to 3220 K along the black-body curve. In the other dimension, the quadrangle extends 0.006 Duv above and below the curve.

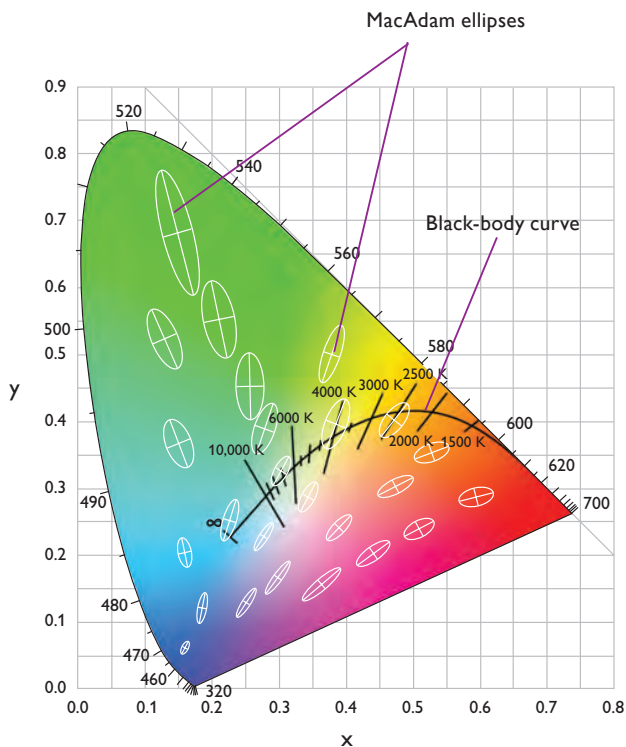


In practice, this means that the measured CCT and Duv of LED light sources can vary considerably and still be described as having a nominal CCT of 3000 K.

How Much Can the Color of Nominal CCT Vary?

The threshold at which a color difference becomes perceptible is defined by a *MacAdam ellipse*. A MacAdam ellipse is drawn over the color space in such a way that the color at its center point deviates by a certain amount from colors at any point along its edge. The scale of a MacAdam ellipse is determined by the *standard deviation of color matching* (SDCM). A color difference of 1 SDCM “step” is not visible; 2 to 4 steps is barely visible; and 5 or more steps is readily noticeable.

As the illustration below shows, the size and orientation of MacAdam ellipses differ depending on their position within the CIE 1931 color space, even when each ellipse defines the same degree of deviation between the color at its center and any color along its edge.

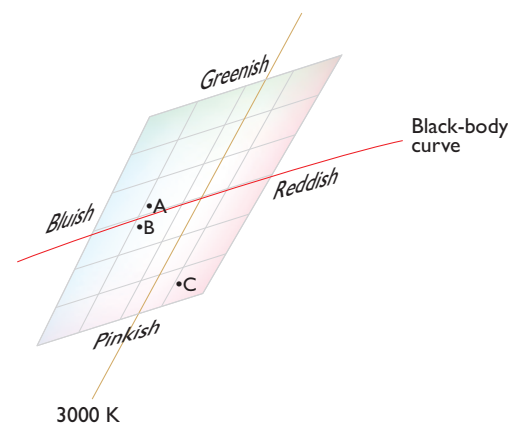


* Note that, for clarity, the MacAdam ellipses shown in this and other diagrams are 10 times larger than actual size.

The quadrangles that define the color ranges of the eight nominal CCTs described in the ANSI C78.377A standard are roughly equivalent in size to 7-step MacAdam ellipses. Any LED light source whose measured color point falls within one of these quadrangles is considered to have that nominal CCT. But since color differences of 7 SDCM steps are readily visible, light sources with the same nominal CCT can display fairly large — and noticeable — differences in hue.

For example, the chart to the right shows three hypothetical LED light sources, A, B, and C. Even though A and B are on either side of the black-body curve, the color difference between them is negligible. The color variation between A and C, on the other hand, is four times as great as the color variation between A and B. Nevertheless, all three light sources conform to the ANSI specification for nominal CCT of 3000 K.

One important goal for lighting fixture manufacturers is to ensure that color differences between fixtures are small, if not imperceptible. Since nominal CCT does not ensure this degree of color uniformity, LED fixture manufacturers devise various *binning schemes* to tightly manage color variations in the LED sources that they purchase and use in their fixtures

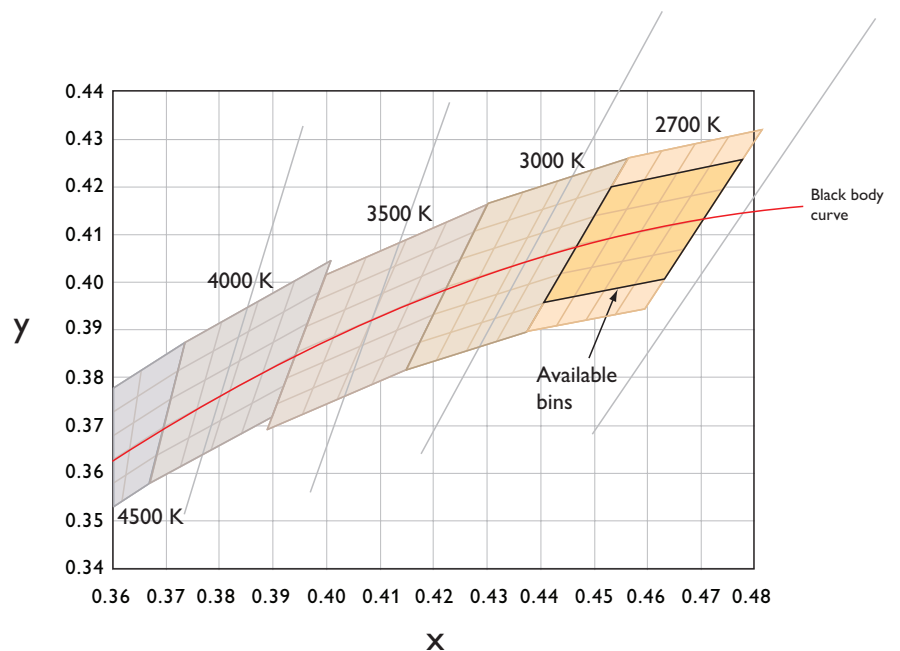


Achieving Consistent Color with Binning

During production, LEDs vary in color, luminous flux, and forward voltage. Since the differences are significant, LEDs are measured and delivered to the market in subclasses, or *bins*. Binning makes it possible to select LEDs that conform to stated specifications — for instance, to select LEDs for traffic signals with the specific color required to meet the European standard.

Lighting fixture manufacturers devise methods of selecting bins of LEDs in such a way as to minimize differences in color that might be visible from fixture to fixture or from production run to production run. To understand how a bin is defined, we return to the diagram of the CIE 1931 color space, and zoom in on the black-body curve.

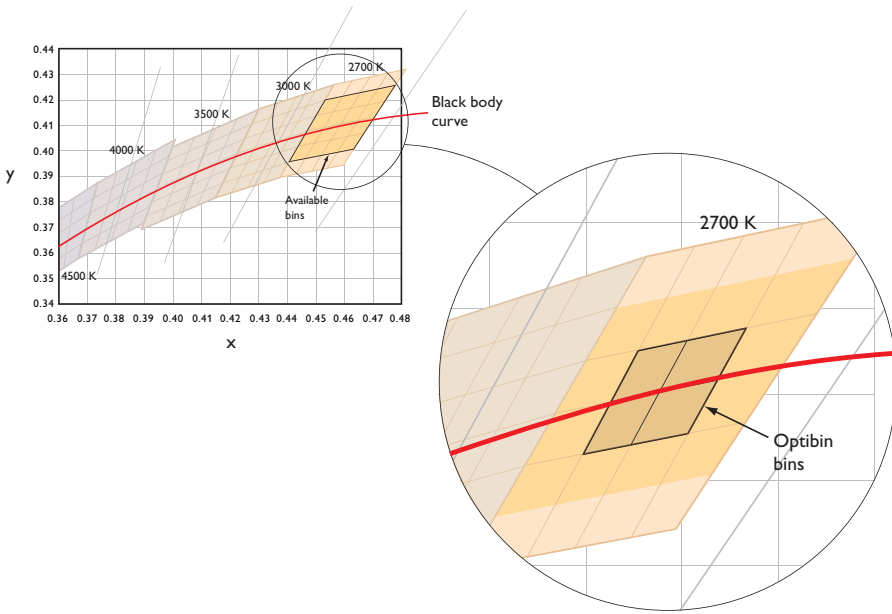
Because each ANSI-defined nominal CCT quadrangle allows for readily perceptible color variations, LED manufacturers subdivide each quadrangle into multiple smaller areas. These smaller areas are the available bins for LEDs of a given nominal CCT. A leading LED manufacturer, for example, sells a certain number of bins for a color temperature, each of which falls within the area that conforms to the ANSI standard for that nominal CCT. The diagram below shows an example binning plan for the manufacturer's white-light LEDs at 2700 K.



Even though all 16 bins that the manufacturer offers conform to ANSI C78.377A for a nominal CCT of 2700 K, there will be some variation in degrees K and Duv from bin to bin.

Since ANSI C78.377A only goes part of the way toward ensuring color consistency, some LED lighting manufacturers are adopting standards for LED source purchase and use that exceed the standard. For instance, Philips Color Kinetics has developed a mathematical model for sorting, called Optibin[®], that guarantees color uniformity across fixtures and production runs.

Optibin's CCT and hue tolerances for LED fixtures fall within a 4-step MacAdam ellipse, rather than within the 7-step ellipse dictated by the ANSI standard. To ensure that variations in color will be barely noticeable, Optibin dictates the use of LEDs from bins which lie as close as possible to the black-body curve within a 4-step ellipse.



Optibin uses proprietary algorithms to ensure color consistency from fixture to fixture, as well as from manufacturing run to manufacturing run. Ensuring reliable color consistency over time is especially important for phased installations where fixtures are purchased and installed at different times, for expansion and multi-site installations, and for color-matching replacement fixtures in case of fixture failure.



Photography: Dariusz Kuzmickas

The multi-layered atrium of the World Market Center in Las Vegas features an extensive labyrinth of coves. Thousands of linear feet of eW[®] Cove Powercore, an LED cove fixture from Philips Color Kinetics, provide seamless blending of light in runs of up to 50 feet. Color consistency from fixture to fixture and across individual fixtures' beam spread (color spatial uniformity) is especially important in high-profile, angle-dependent lighting installations such as this one.

The Optibin process is applied each time Philips Color Kinetics selects bins of LED sources for purchase from its suppliers. The Optibin process is also applied each time manufacturing builds a run of fixtures, to determine the placement of LED sources within those fixtures to maintain optimal color consistency. By purchasing and intelligently combining tightly specified LED sources from a range of manufacturing bins, Optibin guarantees the availability of LED sources with the correct color attributes, as well as their proper deployment, throughout the lifecycle of the lighting fixtures that use them.

Optibin and Philips Color Kinetics LED Fixtures

Philips Color Kinetics white-light LED lighting fixtures achieve industry-leading color consistency and uniformity using Optibin. For instance, the new line of white LED cove lights from Philips Color Kinetics — eW Cove MX Powercore, eW Cove QLX Powercore, and eW Cove EC Powercore — exceed both ANSI and ENERGY STAR standards for color uniformity in interior general illumination.

Achieving consistency of color temperature and hue in cove lighting applications is particularly challenging for lighting designers and installers. In cove lighting applications, light sources are positioned very close to the illuminated surfaces — usually white walls or ceilings — so there is very little room for mixing, and the appearance of the light is strongly angle-dependent. Viewed from a distance, even small variations in color temperature and hue are clearly visible.

Linear fluorescent light sources are fairly uniform, but cove applications that use them can suffer from socket shadowing — areas of low luminance toward the ends of the fluorescent tubes — and hot spots, creating an uneven distribution of light along the illuminated surfaces. Fluorescent fixtures at the same nominal color temperature are also known to vary greatly in hue from manufacturer to manufacturer.

Linear LED cove lights pose their own challenges to consistency and uniformity of light distribution. The beam produced by an LED cove light is a series of adjacent point sources, each with a certain degree of hue and color temperature variation. Unless these variations are tightly managed with an advanced binning scheme, unwanted color striations can result.

eW Cove MX Powercore, eW Cove QLX Powercore, and eW Cove EC Powercore use Optibin to ensure virtually imperceptible differences in output from LED to LED and fixture to fixture. eW Cove MX Powercore, for example, allows significantly smaller variations in CCT Duv than ANSI Chromaticity Standard C78.377A.

	ANSI Chromaticity Standard†		eW Cove MX Powercore‡	
	CCT Range	Allowed Variation	Measured CCT	Actual Variation
2700 K	2725 K ± 145 K	5.3%	2775 K +50 K	1.8%
3000 K	3045 K ± 175 K	5.7%	3006 K -39 K	1.3%
3500 K	3465 K ± 245 K	7.1%	3345 K -120 K	3.5%
4000 K	3985 K ± 275 K	6.9%	3955 K -30 K	0.8%

† ANSI Chromaticity Standard C78.377A

‡ eW Cove MX Powercore color reports

White LED cove lights from Philips Color Kinetics also feature extremely high color spatial uniformity (CSU). Unlike CCT and Duv, which measure the color quality of the light from an LED lighting fixture as a point source, CSU measures the color quality of light across a lighting fixture's beam — that is, it measures color variations in an individual fixture with changes in viewing angle, an especially important consideration for strongly angle-dependent applications.

eW Cove MX Powercore, for example, features extremely high color spatial uniformity, exceeding even the ENERGY STAR standard, which calls for Duv of no more than 0.0040 at any angle. As a result, there are no visible color variations across the beam from center to edge, or at different viewing angles.

eW Cove MX Powercore / 2700 K‡		
Vertical Angle	Measured Duv	ENERGY STAR Standard
0	0.0028	< 0.0040
10	0.0021	< 0.0040
20	0.0016	< 0.0040
30	0.0005	< 0.0040
40	0.0004	< 0.0040
50	0.0013	< 0.0040
60	0.0012	< 0.0040
70	0.0010	< 0.0040
80	0.0012	< 0.0040

† DOE's ENERGY STAR LED Lighting Program at www.energystar.gov/index.cfm?c=ssl_res.pt_ssl_program

‡ eW Cove MX Powercore 2700 K color report. Measurements at 0 degree lateral angle.

With Optibin, Philips Color Kinetics white-light LED cove lights deliver extremely uniform and consistent color in linear cove applications, with no socket shadowing, hot spots, color shifting, tiger-stripping, or unwanted edge effects. They offer quality of light as good as if not better than comparable fluorescent fixtures. Additionally, they offer superior energy efficiency and an average useful life 10 to 20 times longer than the rated life of many fluorescent sources.



Photography: John Brandon Miller

iW® Cove Powercore, tunable white-light LED fixtures with channels of warm and cool LEDs, allow the staff of Boston's Rustic Kitchen to dial in the exact shade of white light they desire — cooler for daytime (above), warmer for night (below).

Choosing the Right White

LEDs can be made in a wide range of color temperatures that approximate the color temperatures of many non-LED lighting sources, daylight, and skylight. To select the right color temperature for an application, you must consider a number of factors.

Particular color temperatures, from warm to neutral to cool, are associated with certain light sources and environments. Color temperature also alters the emotional effect of a space, and can dramatically affect the appearance of objects on display in stores, galleries, and museums. Selecting the right color temperature matches light source to environment, and can positively influence buyer behavior or increase productivity in the workplace.

White-light LED fixtures with fixed color temperatures can easily replace most conventional light sources. Tunable white-light LED fixtures offer a range of color temperatures that can be varied on the fly with lighting controllers. Tunable white light is ideal for illuminating changing retail displays, for altering the mood of a public space (with different morning, evening, and overnight lighting schemes, for example), and for theatrical or studio applications that call for varying levels and shades of white light.

Warm Color Temperature



Cool Color Temperature



Effect, Mood, and Application by Color Temperature

Color Temperature	Warm 2700 K	White 3000 K	Neutral 3500 K	Cool 4100 K	Daylight 5000 K – 6500 K
Effects and Moods	Warm Cozy Open	Friendly Intimate Personal Exclusive	Friendly Inviting Non-threatening	Neat Clean Efficient	Bright Alert Exacting coloration
Applications	Restaurants Hotel lobbies Boutiques Homes	Libraries Office areas Retail stores	Showrooms Bookstores Office areas	Office areas Classrooms Mass merchandisers Hospitals	Galleries Museums Jewelry stores Medical exam areas

Delivering the Whole Range of Color Temperatures

Like fluorescent sources, LEDs can deliver the whole range of color temperatures from warm to neutral to cool to daylight. Although mixing light source types in a single installation is not usually recommended, LEDs can replace fluorescent, halogen, incandescent, or metal halide sources in retrofit applications.

Tunable white light fixtures, such as the line of IntelliWhite® fixtures from Philips Color Kinetics, offer a range of color temperatures in a single fixture.

Light Sources and Their Color Temperatures

Color Temperature	Fluorescent	Halogen	Incandescent	LED	Metal Halide
Warm 2700 K	✓		✓	✓	
White 3000 K	✓	✓		✓	✓
Neutral 3500 K	✓			✓	
Cool 4100 K	✓			✓	✓
Daylight 5000 K – 6500 K	✓			✓	

References

NEMA / ANSI ANSLG C78.377-2008: *Specifications for the Chromaticity of Solid State Lighting Products for Electric Lamps*. American National Standards Institute, 2008.

“DOE’s ENERGY STAR LED Lighting Program,” www.energystar.gov/index.cfm?c=ssl_res.pt_ssl_program. Accessed June 7, 2010.



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