Understanding Light and Color

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While 80 percent of our impressions of the world are visual, 100 percent of those impressions are dependent on light and, therefore, lighting. This is especially true when considering color. The most detailed and powerful color scheme can be produced, but if the wrong light source is chosen, a dramatically different scene could result. It therefore pays to understand how light affects color in order to securely achieve the overall design goals.

The first of a series, this article describes the fundamentals of light and color, then describes the tools used to determine the color characteristics of various lamps; in future articles, we will discuss selection criteria, performance based on lamp type, color marketing trends and more sophisticated concepts.

LIGHT AND COLOR

Light is radiant energy that travels in waves composed of vibrating electric and magnetic fields. Light waves have both a frequency and length (measured in nanometers); the ranges of frequency and wavelength differentiate light from other forms of radiant energy expressed on the electromagnetic spectrum, such as heat and radio waves. Certain light waves comprise a portion of the spectrum called the visible light spectrum. This energy is capable of exciting the eye's retina, producing a visual sensation.

Visible light, however, is not really visible. It must strike an object first, then be reflected into our eyes. Even a beam of light reaching into the night sky from a powerful flashlight is not visible to us - - we are actually seeing light reflected from a multitude of tiny dust particles floating in the air.

The visible light spectrum is composed of different colors/wavelengths, from violet (380 nanometers) to red (about 620 to 760 nanometers). An even balance of these wavelengths composes pure white visible light. This can be physically demonstrated by shining a beam of white light through a glass prism; the light will be refracted into a rainbow of colors appearing from the other side.

We see objects because light strikes them, and the light is reflected back to our eyes. This is also how we see color. The surfaces of objects are chemically oriented to absorb all wavelengths of light except their "own color," which they reflect, and so we see the object as a shade of that color.

When electric lighting is employed, the color spectrum of the light 0may not be evenly balanced. For example, it may be saturated in blue and green wavelengths, and low in red, yellow and orange. As a result, if the object is blue or green, it will appear a rich blue or green; if it is red, it will appear darker and duller if the light source is low in red, black if red is non-existent.

For those who believe that perception is reality, therefore, the lighting designer has a lot of power over how the space is viewed by choosing the right light source. To choose the right light source, three standard tools are available: color temperature, color rendering and the spectral power distribution curve.

COLOR TEMPERATURE (CT)

Color temperature is a numerical measurement that describes the color appearance of the light produced by the lamp and the color appearance of the lamp itself, expressed on the Kelvin scale (K). It appears in the lamp catalog.

For incandescent lamps, the color temperature is a true value; for gaseous discharge lamps, the value is approximate and results in a value called correlated color temperature (CCT). The difference is subtle enough that the two terms are often used interchangeably.

The science behind determining color temperature values starts with a theoretical blackbody radiator, a block of black metal through which electric current is passed (performed as a computer model). As we heat the metal, it turns red-yellow, then white, then blue; as we measure the temperature of the metal at any given color produced, we then match the color to that temperature and produce a color temperature value.

In application, we use the color temperature of lamps to categorize them as warm, neutral or cool sources. The terms are not directly related to temperature; instead, they describe how the light source appears visually. Warm sources actually have a lower color temperature (3500K or less), producing a red-yellow appearance. Neutral sources (between 3500K and 4000K) have a white appearance, and cool sources (4000K and higher) have a bluish-white appearance. Daylight (summer sunlight), with a color temperature of about 5500K, is a very cool light.

These three photos simulate the effects of color temperatures on objects. (Left) a warm light source is used, enhancing reds and oranges while dulling blues and greens; (Middle) a neutral source is used; (Right) a cool source is used enhancing blues and greens while dulling reds and oranges. Courtesy of Osram Sylvania

In design, the color temperature of the lamp will affect the visual appearance not only of the lamp itself, but more importantly, objects in the room. Lamps with a warm color temperature, for example, produce light that is saturated with red and orange wavelengths, producing a richer appearance of red and orange objects and lending a reddish tint to whites, while darkening blues and greens.

Warm light sources are traditionally used for applications where warm colors or earth tones dominate the scene, and where we want to impart a feeling of comfort, coziness and relaxation. Applications include the home, restaurants, lobbies and private offices. Neutral light sources are traditionally used for applications where we want to enhance all colors equally, such as supermarkets and stores. Cool light sources are traditionally used for applications where we want to enhance blues or stimulate the occupant to alertness and activity, such as offices and hospitals.

Note that HID lamps may experience a phenomenon known as color shift, a change in the color appearance of the light source that can negatively impact color uniformity in a space. It is most noticeable in uplighting and wall-wash application. Depending on the lamp type, it may be caused by operational age, operating phenomenon such as voltage variations, or dimming using a dimming ballast (usually 50-60 percent of light output). To account for color shift due to operational aging, group relamping may be desirable. Ask the lamp manufacturer for more information about color shift and how its products perform.

COLOR RENDERING

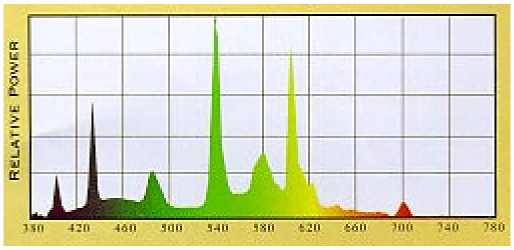
Color rendition describes how a light source makes the color of an object appear to our eyes, and how well subtle variations in color shades are revealed. A lamp's color rendering ability is measured on the Color Rendering Index (CRI), a scale from 0 to 100 (although negative values are possible). Incandescent lamps have a CRI rating of 100. The higher the CRI rating, the better the lamp's color rendering ability is. The rating is provided in the lamp catalog. CRI ratings are only useful when comparing lamps with the same color temperature.

CRI ratings are developed via computer analysis. First, a lamp with a given color temperature lights eight standard color samples, which is compared to a blackbody radiator at the same temperature. If the samples show no color shift between the two, the CRI rating is 100; if there are changes, a lower rating is given based on the degree of color shift. Note that a high CRI rating means that the range of eight colors will be rendered well, but it does not guarantee that any specific color will appear natural.

In application, lamps with a CRI rating of 80 or higher are considered to have "good" color rendering properties, causing objects to look "natural." Thanks to improvements in lamp phosphor technology, CRI ratings for fluorescent lamps have steadily increased, now offering a range from 48 up to 95 depending on the lamp.

In design, high-CRI lamps are ideal for color critical applications where color rendering and matching is important, such as clothing stores, groceries, graphic design studios and similar applications.

Color rendering is sometimes confused with color temperature. First, we must understand that color rendering is a comparative tool between lamps with the same color temperature as a base. If we choose a lamp with a cool color temperature, for example, we can effect richer blues and greens in the space; however, if we then choose a high CRI rating for that lamp, we can effect color enhancing for the weaker colors, rescuing in a sense the reds, yellows and oranges from distortion and darkening.



A spectral power distribution curve for a 4000K lamp with a triphosphor (red, blue, green) coating to improve color rendering. Courtesy of Osram Sylvania

SPECTRAL POWER DISTRIBUTION

Although color temperature and color rendering are useful tools in determining the color behavior of lamps, a more precise picture is provided by the lamp manufacturer in the form of a spectral power distribution curve (SPD). In a typical curve, we are essentially seeing the visible light portion of the electromagnetic spectrum. Incandescent lamps produce a smooth curve, low in blue and green and heavily saturated in red and orange. Gaseous discharge lamps are characterized by spikes, which are generated by the arc, and low points provided by the fluorescence of the phosphor coating. Lamps with improved phosphor coatings show a more continuous spectrum of energy, resulting in better color rendering. On the curve, therefore, we can see, to an extent, both color temperature and color rendering in action; we see what colors the lamp is saturated in, which are very low in energy or non-existent, and we see the effect of the phosphors at improving color performance. Because the SPD is somewhat complex, it is most useful when combined in analysis with color temperature and color rendering.