The problem with natural daylight is that its appearance and spectral characteristics can change dramatically from day to day, season to season and even during a single day.

Macbeth Lighting
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Tech Brief

Demystifying Daylight:

Four myths and misconceptions about daylight simulation that everyone evaluating color should know.

It's commonly known that natural daylight is the only light source that will not distort our ability to evaluate color. Any well-managed color program specifies a form of daylight as the light source of choice for making accurate color evaluations.

The problem with natural daylight is that its appearance and spectral characteristics can change dramatically from day to day, season to season and even during a single day. Morning sunrise tends to have a red hue. An overcast day appears gray and drab, and a crystal clear bright sky appears blue. Changes in daylight quality are affected by atmospheric conditions, the change of seasons, time of day, pollution, altitude and even your location – city versus country. All of these factors affect our ability to accurately evaluate the color quality of a product, hence the need for daylight simulation.

This paper dispels the common myths and misconceptions about daylight simulators. It reviews technologies, industry standards and practices, and issues relative to simulating daylight in color evaluation applications.

Top Four Myths about Daylight Simulation

Myth #1 *All daylight simulators are the same.*

FALSE! Natural daylight has been thoroughly defined by the CIE, International Commission on Illumination, as having three specific attributes: (1) spectral power distribution (SPD); (2) chromaticities and (3) correlated color temperature. The ability to simulate all three characteristics is critical for accurate daylight simulation. There are some simulators that meet the criteria based on one or two of these attributes. Without meeting the criteria for all three attributes, the simulator will be deficient in rendering color.

The facts about spectral power distribution (SPD)...

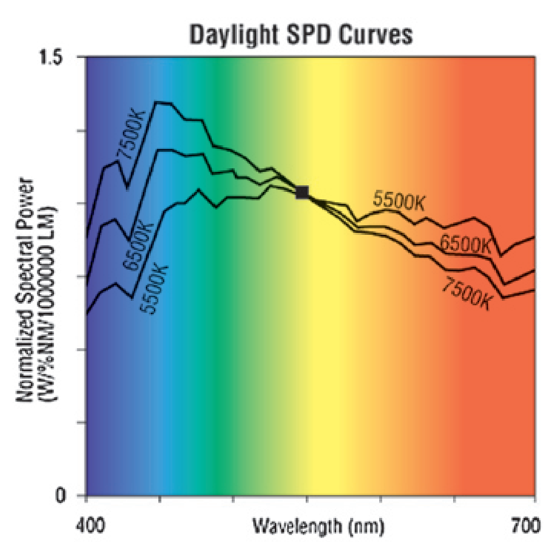
The following graphic displays the relative energies found in different phases of daylight. The energy content of a light source determines its ability to render colors accurately. This energy is known as spectral power distribution and is determined by measuring the lamp output with a spectroradiometer. It should be noted that the human eye is sensitive to light energy that falls within the 400 to 700 nanometer wavelength range, which is why the X axis on each graph displays that wavelength range.

The graphic shows ideal curves for three standard daylight illuminants: D55 or noon sky daylight, D65 or average daylight and D75 or north sky daylight. Although the curves are uneven, all colors of the spectrum are present in relatively equal proportions. Therefore, all three phases of daylight have similar curves, indicating similar spectral content. Thus, colors that match under one phase of daylight will also match under the other phases of daylight.

Why all daylight simulators are not the same...

Simulated daylight can be achieved through several different lighting methods, including wide band fluorescent (commercial daylight) seven-phosphor wide band fluorescent (patented GretagMacbeth technology) and filtered tungsten halogen (patented GretagMacbeth technology). All produce light energy with a correlated color temperature and chromaticities equal to the phase of daylight that they simulate. However, closer evaluation of their energy content reveals more obvious differences in the quality of the simulators as shown in the following graphs.

The spectral power distribution curves represent typical simulations for D65 daylight at 6500 degrees Kelvin. The target is labeled "CIE D65." It's obvious from the curves that the graphic labeled "SpectraLight D65" most closely replicates the spectral power distribution curve of CIE D65. However, as mentioned above, spectral power distribution is only one of the three attributes of daylight as defined by the CIE. Accurate daylight simulation must also meet criteria for two other



This discrepancy between color temperature and spectral power distribution uncovers a fundamental flaw in using color temperature alone to specify a light source.

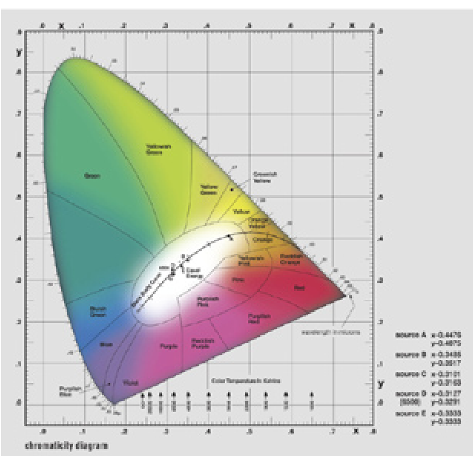
attributes – chromaticity and correlated color temperature. The next myths reveal the truth about these two attributes.

Myth #2 *As long as the light source is D65, it's a good daylight simulator.*

FALSE! Let's take another look at the spectral power distribution curves in the previous chart. All the sources have the same apparent or correlated color temperature of 6500 degrees Kelvin, yet different spectral power distribution curves. This discrepancy between color temperature and spectral power distribution uncovers a fundamental flaw in using color temperature alone to specify a light source.
To further explain, let's take a look at the relationship between chromaticity and correlated color temperature. This relationship reveals just how widely the spectral power distribution can vary based on color temperature alone.

Why two light sources can have the same color temperature, but different color rendering quality...

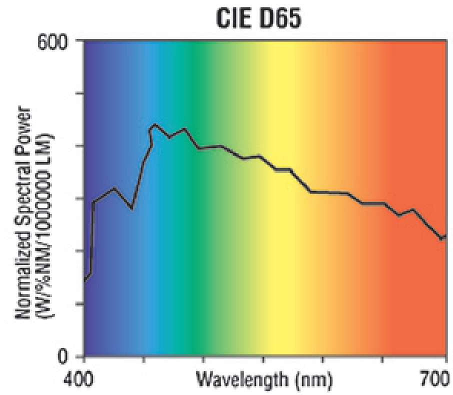
The color temperature designation for a light source identifies the appearance of the light source as compared to the 1931 CIE Chromaticity Diagram (see the following figure). The chromaticities are

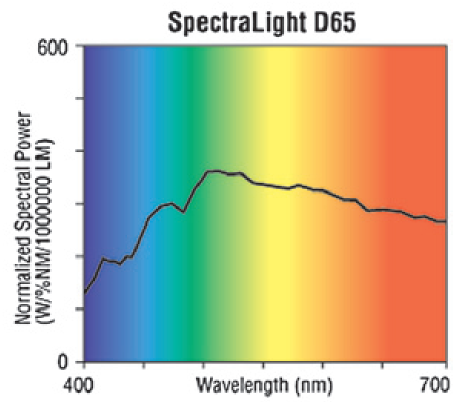


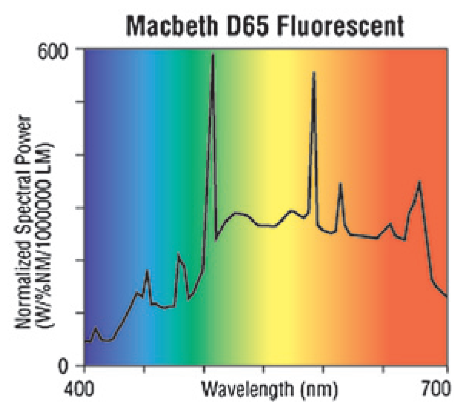
the x and y coordinates for a light source. These coordinates are plotted and correlated to a tolerance acceptable for a specific color temperature. Herein lies the flaw... using the correlated color temperatures provides an infinite number of chromaticity coordinates – all with the same color temperature! So lamps that match the correlated color temperature can vary widely in their ability to simulate CIE D65 daylight as well as their ability to render color accurately or consistently.

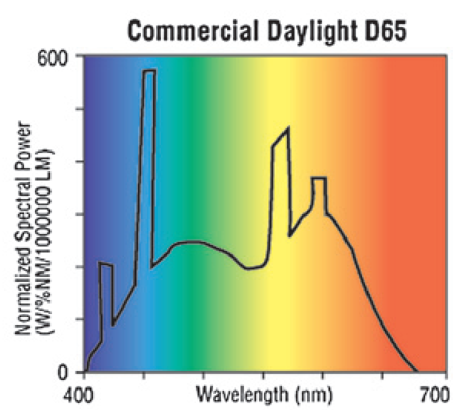
Myth #3 *CRI is the best way to determine the quality of a daylight simulator.*

FALSE! Color rendering index, primarily used for fluorescent lamps, represents a light source's ability to render color. It was developed by the lamp manufacturers themselves as a means to illustrate the color rendering performance of their fluorescent lamps – theoretically, the









The color rendering of any light booth is a function of the entire system – not just the lamps.

higher the index, the better the color rendering. However, a little known distinction in the way the index works can be misleading.

Why some fluorescent light sources can have excellent color rendering indexes, yet poorly render color...

The color rendering index is a relative index, meaning the lamp performance is relative to a reference light source, which is assigned the highest rating of 100. The reference light source for lamps below 5000 degrees Kelvin (most commercially available fluorescent light sources) is incandescent or tungsten. It's a well-known fact that incandescent light has very little blue energy and an overabundance of yellow, orange and red energy – certainly not a good choice for accurate color evaluation. Yet this light source has a CRI of 100. Caveat... the CRI index is not an absolute indicator of lamp performance. CRI tells you that lamp performance is only as good as the reference source, which may not be good at rendering color at all.

For an absolute indication of how well a lamp renders colors, consult the CIE Assessment Method, Publication 53. The following is a summary.

CIE Assessment Method (Publication 53)

- Tests spectral quality of daylight simulators for visual appraisals and instrumental measurements.
- Includes test methods for D50, D55, D65 and D75.
- Uses 5 virtual metamer sets for visible and 3 for ultraviolet.
- Quality grades are based on delta E or total color difference of the metameric sets.
- More accurate than CRI for evaluating the quality of daylight simulation.

Quality Grade	Metamerism Index	
	CIELAB	CIELUV
A	<0.25	<0.32
B	0.25 to 0.50	0.32 to 0.65
C	0.50 to 1.00	0.65 to 1.30
D	1.00 to 2.00	1.30 to 2.60
E	>2.00	>2.60

Standards:

The use of good quality daylight simulation is not only a good idea, but in many industries, it is an absolute requirement. This is further evidenced by the number of corporate, national and international visual color standards requiring accurate daylight simulation including ASTM D1729, SAE J 361, BS950, ISO 3664 and AATCC Procedure 9.

The following illustrates the daylight rating requirements of several industry standards:

- ASTM D1729 "Visual Evaluation of Color Differences of Opaque Materials" (BC required)
- SAE J361 2000 "Visual Evaluation of Interior and Exterior Trim" (rating of B and should be A)
- ISO 3664 - 2000 "Viewing conditions for Graphic Technologies and Photography" (C or better and should be B)
- BS 950 Part 1 (BD required)
- AATCC Evaluation Procedure 9 "Visual

Assessment of Color Difference of Textiles" (BC or Better)

Myth #4 *Fluorescent technology is more advanced and works as well as the leading filtered tungsten halogen technology at a lower price.*

FALSE! The upfront investment of filtered tungsten halogen technology is certainly more than fluorescent technology. However cost issues aside, the performance of filtered tungsten halogen technology is unparalleled by any fluorescent technology, including a lower cost yet highly accurate specialized seven-phosphor daylight simulation technology. One must consider the total cost of ownership plus

Longer lamp life does not mean more hours of reliable consistent color rendering.

consistent quality of color rendering over the life of the product. Let's take a look at the facts about fluorescent versus filtered tungsten halogen technology.

Why simply changing the lamps is not enough to ensure accurate color rendering...

It's fact that the color rendering of any light booth is a function of the entire system – not just the lamps. To ensure optimum system performance, certification is required by every quality system such as ISO, Six Sigma, etc. The certification process involves a comprehensive system check. All light sources are measured with a spectroradiometer for light levels, color temperature, spectral power distribution and chromaticity coordinates. The system is thoroughly cleaned and operating voltages measured with a true RMS meter and set for proper operation. While all lighting systems are shipped with the correct color temperature, many environmental factors can shift the spectral characteristics of the system including cleanliness of the walls and filters and performance of the ballast and power supply. Simply changing the lamps is analogous to the Department of Motor Vehicles sending you an inspection sticker for your car without your having the emissions, brakes, tires and lights checked.

Why lamp stability is not an issue with either technology...

Lamp stability, whether fluorescent or tungsten, is a function of the

Critical color decisions, on which millions in profit and loss are at stake, require careful consideration and a clear understanding of the advantages and limitations of simulated daylight technology.

current supplied to the lamp. In fluorescent fixtures, the use of a ballast, commonly known as a constant wattage auto transformer, is required to start the lamps at voltages in excess of 800 volts. Once the arc is struck, the ballast maintains the proper operating voltages to the lamp. Every time the fluorescent lamp is turned on and off, the same process occurs. This is why it is better to leave fluorescent lamps on rather than turn them on and off.

Typical household tungsten or incandescent lamps are dependent on a constant current to maintain their color temperature and light output. A reduction in the voltage to a tungsten lamp will decrease light output, color temperature and increase lamp life. The opposite is also true. That's why tungsten halogen color viewing technology employs a highly engineered regulating power supply. Once calibrated at the factory, this system not only maintains constant power to the lamps, but also automatically corrects for high or low voltage based on the electrical load in a factory or office environment. These "smart" systems literally check for proper line voltage on start-up and notify operators if the voltage supply falls below acceptable limits at any time during operation. Thus, voltage fluctuations are eliminated from affecting color judgment over the life of the system.

Why lamp life can be misleading...

The objective of color viewing is to have a reliable consistent daylight source. Longer lamp life does not mean more hours of reliable consistent color rendering. On the contrary, most fluorescent lamps have a much longer lamp life than the 400 hours of tungsten halogen. However, approximately 75% of the lamp life is not usable for color viewing. Here's why...

Studies show that fluorescent lamps experience as much as a 30% reduction in light output and color shifts as high as 400 degrees Kelvin over the life of the lamp. In addition, the phosphors within the lamp degrade over time. This degradation reduces the lamps efficiency and changes the spectrum produced. The first change affects the red and orange regions of the spectrum. Red content is reduced, light output is reduced and the ultraviolet content is increased. The change occurs gradually over time and is not apparent to the naked eye. However, it can unknowingly have a profound affect on color judgment. It is recommended that fluorescent lamps be changed every 3000 to 5000 hours to meet the light level, color temperature and spectral output for accurate color rendering.

Why ultraviolet energy is most accurately and safely reproduced with filtered tungsten halogen...

Ultraviolet energy is found in natural daylight. Shorter wavelength UV like UV A and B are harmful to human observers. Through the use of filtered long wavelength UV lamps, we can simulate the amount of Near UV found in real daylight. Additionally, the filtered tungsten daylight systems include filtered UV lamps that provide five times the near UV content found in natural daylight. This feature allows operators to easily detect the presence of optical brighteners, whitening agents and fluorescent dyes and pigments.

It is important to note that these are filtered lamps and only provide long wave, near UV commonly know as black light blue energy. This energy is found in the spectrum at 325 nm and higher. The coatings on these lamps eliminate harmful short wave radiation, which can cause retina damage, sunburn and skin cancer.

Adding a UV component to a fluorescent lamp is not only impractical, but also very dangerous, as fluorescent lamps degrade rapidly over time. As the phosphors degrade, they allow more UV to pass through the envelope of the lamp. Without filters, this short wave radiation will flood the viewing area becoming potentially harmful to the operator.

Why filter solarization is virtually impossible...

Despite a number of recent claims, the daylight filters in filtered tungsten halogen simulators are not subject to solarization. These daylight filters require very little maintenance and will provide accurate daylight simulation for 20 years or more. There are many first generation SpectraLight® products in use for over 20 years. Mild soap and water are all that is required to remove dust build-up and other environmental particulate, which can bake onto the filters and cause temporary discoloration.

Solarization, on the other hand, is a phenomenon that occurs only when glass contains iron or manganese oxide and is exposed to high intensity, short wave UV and or x-ray radiation for long periods of time – years or decades. The manganese becomes photo oxidized and imparts a pink or violet color to the glass.

Solarization is virtually impossible with filtered tungsten halogen technology because a tungsten halogen light source does not contain a large amount of UV. In fact, research shows that many filtered tungsten halogen lighting products, originally manufactured in the mid seventies, are still in service today and maintain their original calibration and certification performance nearly 30 years later!

Summary

Filtered tungsten halogen technology is the closest simulation of natural daylight available. Moreover, it also maintains consistent, stable light output and color quality over the life of the product.

Additionally, filtered tungsten halogen technology offers more flexibility for evaluating a wider variety of samples. It provides directional illumination making it better-suited for evaluating directional samples such as precious gems and metals; metallic, pearlescent or glossy paint, and plastic samples; and high sheen fabrics or directional textiles. Fluorescent technology, on the other hand, provides diffuse illumination and is not recommended for these applications.

There's a lot more to daylight than meets the eye. Critical color decisions, on which millions in profit and loss are at stake, require careful consideration and a clear understanding of the advantages and limitations of simulated daylight technology.

That's why numerous corporate and industry standards worldwide specify filtered tungsten halogen technology for reliable daylight simulation and the most confidence in accurate color evaluation.

X-RITE WORLD HEADQUARTERS

Grand Rapids, Michigan USA • (800) 248-9748 • +1 616 803 2100