California Leadership Ensures High-Quality LED Lamps are Available to Consumers

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> *"How do I ensure that I am buying the **right light** for **my home?**"*

How do I ensure that I am buying the right light for my home? This will be a common question that California homeowners will be asking in the coming year given that the new lamp quality and efficiency regulations went into effect January 1, 2018. California is demonstrating leadership as the first state in the country to set regulations that ensure both lighting quality and efficiency for common lamps purchased for residential applications.

The new regulations ensure Californians can enjoy the full color fidelity potential of new, solid-state LED technology as well as the opportunity for greatly increased energy savings. This supports the state's long-term commitment to smart energy use and the environment.

One of the key drivers behind the new regulations is that the use of energy-efficient lamps need not involve sacrifices in color, quality or the visual experience in today's homes. Without these regulations, poor quality products often flood the market, resulting in consumer dissatisfaction with new lighting technology.

Given the wide range of choices confronting homeowners at the store, this introduction and attached Pocket Guide provide background and a series of considerations that should be examined when making a lamp purchase. Unfortunately, most of the key quality issues that consumers need to understand are not adequately or properly presented by manufacturers or appliance labeling agencies, both of which often present consumer information based on a narrow view of energy efficiency only.

When consumers purchase lamps for their homes, they are principally interested in visual service or the work that the light is intended to do. Overall, there are four key metrics that homeowners should consider in order to make good, long-term purchase decisions.

1. Amount of light
2. Directionality
3. Color quality
4. Cost

Amount of Light

Most homes require a range of lamp types depending upon the amount of light needed for a task. Historically, residential consumers have selected lamps with the "right" amount of light based on the lamp's wattage. A 60-Watt incandescent lamp, the most common lamps used in homes, represented a standard metric for consumers to estimate the amount of light needed. For higher demands, consumers moved to 75 W or 100 W incandescent lamps. Conversely, for lower light levels people often used a 40 W lamp.

These rules of thumb have changed given the advent of LED light sources that have significantly higher efficacies (lumens per watt) than their incandescent counterparts. Now, consumers should adjust their purchasing approach and estimate the amount of light they need based on **lumens**. Lumens describe the total amount of light output and is the number that tells us how much light will come from a light source, akin to the flow of water from a garden hose.

The term **brightness** is often used today and incorrectly equated to total luminous output (total lumens). Brightness is a measure of light that we "see" and can vary from person to person as well as vary based on the person's location relative to the light source. It is a very different metric than the lumen.

Most utilities and appliance labeling agencies will provide simple charts and diagrams to show approximate lumen equivalents to common historic incandescent lamp wattages in an effort to help consumers make the right choice. For example, a 10 W, 800 lumen, LED will closely match a common 60 W incandescent. Consumers can use the comparative charts supplied by the manufacturer or the utility to become more familiar with lumen equivalents. The Pocket Guide also includes a table showing historic incandescent lamps matched to today's high-efficiency LEDs, compared using equivalent lumens.

Directionality

Lamps for residential applications typically come in two types. The first is the **omnidirectional** lamp, like the common screw base light bulb used in table lamps. Omnidirectional lamps distribute light uniformly in all directions. The second is the **directional** lamp designed for either track lighting or down lighting where the light is directed in a specific direction. An example of a typical application for a directional light source, such as a recessed downlight, is a kitchen where the light is focused on the kitchen counter or cooking surface. These applications have historically used 65 W incandescent reflector (R or BR) lamps. There are numerous high quality LED replacement lamps now available that come with high CRI and lumen output that closely emulates the traditional incandescent products.

Some residential applications call for other types of directional lamps such as MR-16 or PAR lamps, which are used specifically for accent lighting and displays. MR-16 and PAR lamps are typically assigned a specific beam angle that describes the relative angle of light directed at a specific target. Today's new LED PAR lamps and MR-16 lamps are available in a range of beam angles.

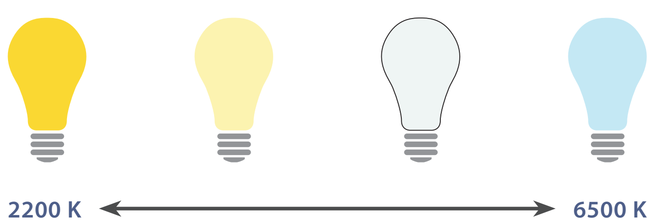
Color Characteristics

There are two main color characteristics that consumers need to consider when purchasing light sources: correlated color temperature and color fidelity.

Correlated Color Temperature

Correlated color temperature (CCT) describes the apparent coolness or warmness of a light source relative to a reference temperature. The higher the CCT, measured in Kelvin (K), the cooler the lamp will appear. Lamps with CCT greater than 4500 K are considered cool and may appear to have "blueish" white light. Conversely, the lower the color temperature, the warmer the light will appear. Incandescent lamps typically have a very warm CCT of approximately 2700 K (warm yellow-red similar to a late evening sunset). Lamps with warm CCT are typically preferred in most residential applications in the evening hours. Higher CCT such as 4000 K and above is typically reserved for commercial and office applications, where people usually prefer a cooler appearance.

The color temperature you select for the home is largely based on personal preference, however, there's a long cultural and historical experience with warmer color temperature sources in residential applications (2700–3000 K). There is also a growing body of evidence that indicates that cooler color temperatures (4000–5000 K), which often have higher blue content, can lead to circadian disruption—a disruption in our body's normal hormone production cycles. Unless there's a specialty application in need of cooler CCT, the general CCT recommendation for residential applications is 2700 to 3000 K. This will satisfy the majority of needs in the home.



Color Fidelity

The second color characteristic to consider is color fidelity, which is typically described by its **color rendering index (CRI)**. CRI tells us how well a light source renders a series of reference colors relative to daylight or incandescent. In a sense, CRI tells you how natural objects will appear when lit by the light source where 100 is equivalent to daylight. Many high efficacy lamps with excellent color are available in California. Utilities will rebate only high quality lamps. The following ranges of CRI are commonly available in today's lamps:

- **95–100 CRI**—Excellent color, similar to incandescent or daylight. All colors will look natural with high color fidelity.
- **90–95 CRI**—Very good color rendering and most materials will look very natural and well rendered. Good for home use.
- **80–85 CRI**—Poor to average color and typically will not render colors in the home faithfully. Color distortion and inaccuracy will occur particularly for red-biased materials. People, food, material and textures may look unnatural.

Energy efficiency advocates have historically said that no one can see the difference between an 82 CRI lamp and a 95 CRI lamp. However, current research shows that when people are shown an 80 CRI and 90 CRI lamp side-by–side, they can see a difference, and that when given the option, prefer the higher CRI lamp. Further experimental studies have shown that people performing simple color sorting tasks perform better under 95 CRI than 82 CRI. An 80 CRI light source is appropriate for outdoor applications or in the garage; however, it is recommended to use a 90+ CRI light source inside the home.

Why 90 or higher CRI only in the home?

Our visual system has evolved under a light source (daylight) that has a very broad, rich color spectrum allowing all colors to be rendered (or seen) exceedingly well. Additionally, our historical and cultural experience with lighting in homes has evolved under the incandescent light source that also renders color exceedingly well.

Unfortunately, our color experience with new, energy efficient light sources over the last few decades has not been up to par. This is mainly an issue stemming from limited color spectrum common to many energy efficient lamp technologies. When a lamp is missing key color components from its emitted visible spectrum, it leads to reduced color rendering capabilities as well as a skewed appearance of the light emitted from the lamp. Many linear fluorescent lamps, compact fluorescent lamps and LED lamps typically have this deficient spectrum—meaning that not all colors are well-represented. These light sources are usually deficient in multiple colors and very weak in the red wavelengths.

Even today, LED and CFL products that meet the minimum ENERGY STAR® requirements can have especially low red spectral content and render common materials found in the home poorly relative to daylight or incandescent. Red spectral content is extremely important in a light source, because most of our day-to-day materials and colors encountered in the home are heavily red-biased. Skin tones have a strong red-biased color and people typically look more natural under light sources with good red spectral content—which often translates to a higher CRI. Furthermore, other common materials in the home such as woods, fabrics, meat, fruit and other natural surfaces usually have a very high red color component. In order for these materials to appear true and natural, the light source must have 'good red' spectral content. In the CRI metric, this red content is described as R9. 'Good red' spectral content is typically defined as an R9 value of at least 50 on a scale of 0–100.

Why have we migrated away from good color?

The erosion in color quality for common light sources started in the early days of compact fluorescents (circa 1990). These products were marketed to consumers to replace incandescent lamps based on an efficiency-only perspective. In parallel, lamp standards during this same period were based narrowly on efficacy, lumens per watt, and not on visual service or color quality. At that time, the focus was on achieving a similar amount of light (lumen matching) with minimal energy consumption. This approach unintentionally sacrificed color appearance to achieve efficiency. Those early technologies produced white light by combining relatively narrow red, green and blue (RGB) spectra.

This approach delivered sufficient light output (lumens) but did not deliver a broad rich color experience—falling well short of the incandescent or daylight-type color consumers expected.

Most home owners have experienced this dullness or unnatural color perception due to the poor color composition delivered by fluorescent sources. Even LED lamps designed to meet minimum ENERGY STAR® requirements often limit the spectrum by reducing red-orange components in order to boost the yellow-green. This yellow-green portion of the visible spectrum takes less energy to produce and while these light sources claim to deliver "white" light they do not provide an equivalent high-CRI experience like daylight or incandescent.

Energy efficiency advocates expected consumers to not notice the reduction in color fidelity and appearance relative to incandescent, with the "hope" that they would transition quietly to use of lighting products with reduced color rendering. However, consumers did notice and market transformation efforts focused on replacing incandescents with CFLs stalled. Americans actually were very sensitive to color quality and, by and large, rejected early CFL technology for home applications.

In addition, utility rebates and other financial incentives attached to consumer lighting products were based on efficiency only, not color or visual service. Subsequently, there's been a steady migration away from satisfying consumer needs as products are more directed at satisfying advocates and utilities that "scored" for energy savings.

California has recognized this steady erosion of lighting quality and has proactively developed quality metrics for lighting that recognize that efficiency should be coupled to other performance attributes that support consumer needs including color quality, uniformity, dimming and longevity. With these additional attributes, consumers are much more likely to purchase and maintain LED light sources for the home based on preference, not tolerance, which will deliver sustained, persistent energy savings. By valuing quality and efficiency, California believes it will avoid a rollback to less efficient sources were consumers to find the LED sources sub-standard in terms of color and lighting quality.

Today, California utilities are rebating lamps that meet the Voluntary California Quality Light-Emitting Diode (LED) Lamp Standard, which ensures that lamps with high color quality are promoted. Furthermore, new homes built in California after January 1, 2017 require high quality lighting fixtures and lamps throughout the home. California's residential energy standards require use of high-efficacy, high-CRI lamps. Finally, effective January 1, 2018, LED lamps manufactured and sold at retailers must meet requirements pertaining to efficacy and color performance.

Cost

With incandescent lamps, consumers enjoyed high color quality at very low initial cost. However, incandescent lamps also came with a very high operating cost due to high energy use. In addition, incandescent lamps have a very short life, which translates to more replacements and increased costs. LED replacement lamps offer the potential for greatly reduced operational costs due to increased efficacy and long life; however, with LED technology there is a very wide range of quality among commercially available products.

The current marketplace is suffering from the age-old "race to the bottom" process—meaning that cost factors are leading to a significant compromise on product quality. While many of these products save energy, they also significantly compromise color and quality. Higher color-quality lamps can be more expensive, adding perhaps a dollar or two to the lamp cost. If consumers consider that these lamps will last five or more years under normal operating conditions, this is an insignificant amount of additional investment for greatly increased user experience and color appreciation. Additionally, in California, the higher-quality LED lamps are eligible for utility rebates and incentives—which may, overall, make them less expensive than a lower-quality LED lamp.

Additional Purchase Considerations

Dimming

Many consumers enjoy and require dimming capability in the home, typically in dining and kitchen applications. Most high-quality LED light sources are dimmable; however, it is important to pair system components (dimmers and light sources) that are compatible with each other. Compatibility information is provided by the component manufacturer and should be taken seriously. California lamp requirements ensure that high-quality, rebated lamps are dimmable.

Other Lamp Types

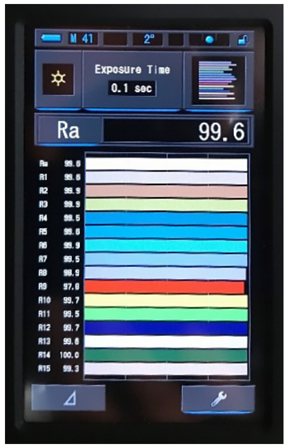
Specialty lamps, such as candelabra and MR-16 lamps, are also available with both high-quality and energy efficient LED light sources. Directional MR-16 lamps are often used for artwork and sculpture, which absolutely require high color rendering capabilities. Similarly, candelabra lamps used in dining room chandeliers should utilize light sources that have high color rendering.

Measuring Color Rendering and R9 (Red) Content

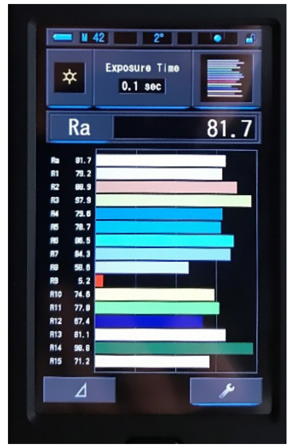
The red content in a lamp's spectrum is one of the key factors determining its color fidelity, naturalness and color rendering. It is usually the one key factor that separates low-quality energy-efficient lamps from high-quality energy-efficient lamps. When manufacturers measure quality, they sample how different colors look (or are rendered) under their lamp relative to sunlight or incandescent.

The following images (also enlarged on next page) illustrate the wide range of measured color rendering for three commercially available lamps:

- **Lamp 1**—Incandescent Lamp (99–100 CRI)
- **Lamp 2**—ENERGY STAR® Lamp (82 CRI with low R9)
- **Lamp 3**—California Quality Lamp (93 CRI with high R9)



Lamp 1



Lamp 2

Lamp 3

The color bars on each meter in the photographs show the relative ability of each light source to render color accurately as compared to daylight or incandescent. The CRI for the three lamps is measured with the color meter that samples 15 different colors across a broad spectral distribution and represents it as individual color bars R1 through R15. Measuring or sampling these discrete colors allows one to better understand the color rendering capabilities for any particular light source.

Deficiencies for each particular color sample can be seen by the relative height of the bar for each color sample. These individual color bars tell us how well this light source renders that particular color sample. Ideally, these bars should be at 100 for each color sample. Significant deficiencies in one or more of the bars will indicate that this lamp will not render some color well. Historically, incandescent and daylight provide near 100 in each one of the sample colors, R1 through R15.

The first photograph shows a common incandescent lamp with excellent color rendering. This can be seen clearly from the full color bars in each one of the sample colors. Incandescent light sources will render all colors in the home with high fidelity making materials look natural and true.

The middle photograph shows a commercially available LED replacement lamp designed to meet minimum ENERGY STAR® requirements. The variability and reduction in color rendering can be seen by the shortening of the color bars in many of the color samples. The largest reductions in color fidelity occurs at the value of R9 corresponding to a saturated red. This low level of red may result in poor color appearance in the home particularly with many common materials and surfaces (people, skin and faces and many other natural surfaces).

The right-hand photograph shows an LED replacement lamp with high-color quality. This particular lamp has high color rendering of all the color samples particularly in the R9. This type of lamp will render all colors found in the home well and with high fidelity.

The best recommendation for any consumer is to first know the lighting facts, which go beyond a lighting facts label, by educating yourself on color, dimming, warranty and other non-energy benefits. In general, finding a high color-quality lamp that is dimmable with a 5-year or longer warranty will be an appropriate lamp for most residential applications.

Measuring Color Rendering and R9 (Red)

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Incandescent Lamp (99–100 CRI)

Lamp 2
ENERGY STAR® Lamp (82 CRI with low R9)

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