

Energy Efficiency of White LEDs

The energy efficiency of light-emitting diodes (LEDs) is expected to rival the most efficient white light sources by 2010. But how energy efficient are LEDs right now? This fact sheet discusses various aspects of lighting energy efficiency and the rapidly evolving status of white LEDs.

Luminous Efficacy

Energy efficiency of light sources is typically measured in lumens per watt (lm/W), meaning the amount of light produced for each watt of electricity consumed. This is known as luminous efficacy. DOE's long-term research and development goal calls for white-light LEDs producing 160 lm/W in cost-effective, market-ready systems by 2025. In the meantime, how does the luminous efficacy of today's white LEDs compare to traditional light sources? Currently, the most efficacious white LEDs can perform similarly to fluorescent lamps. However, there are several important caveats, as explained below.

Color Quality

The most efficacious LEDs have very high correlated color temperatures (CCTs), often above 5000K, producing a "cold" bluish light. However, warm white LEDs (2600K to 3500K) have improved significantly, now approaching the efficacy of CFLs. In addition to warmer appearance, LED color rendering is also improving: leading warm white LEDs are now available with color rendering index (CRI) of 80, equivalent to CFLs.

Driver Losses

Fluorescent and high-intensity discharge (HID) light sources cannot function without a ballast, which provides a starting voltage and limits electrical current to the lamp. LEDs also require supplementary electronics, usually called drivers. The driver converts line power to the appropriate voltage (typically between 2 and 4 volts DC for high-brightness LEDs) and current (generally 200-1000 milliamps or mA), and may also include dimming and/or color correction controls.

Currently available LED drivers are typically about 85% efficient. So LED efficacy should be discounted by 15% to account for the driver. For a rough comparison, the range of luminous efficacies for traditional and LED sources, including ballast and driver losses as applicable, are shown below.

Light Source	Typical Luminous Efficacy Range in lm/W (varies depending on wattage and lamp type)
Incandescent (no ballast)	10-18
Halogen (no ballast)	15-20
Compact fluorescent (CFL) (incl. ballast)	35-60
Linear fluorescent (incl. ballast)	50-100
Metal halide (incl. ballast)	50-90
Cool white LED 5000K (incl. driver)	47-64*
Warm white LED 3300K (incl. driver)	25-44*

*As of October 2007.

Thermal Effects

The luminous flux figures cited by LED manufacturers are based on an LED junction temperature (T_j) of 25°Celsius. LEDs are tested during manufacturing under conditions that differ from actual operation in a fixture or system. In general, luminous flux is measured under instantaneous operation (perhaps a 20 millisecond pulse) in open air. T_j will always be higher when operated under constant current in a fixture or system. LEDs in a well-designed luminaire with adequate heat sinking will produce 10%-15% less light than indicated by the "typical luminous flux" rating.



Photo credit: Cree Inc.

Terms

Lumen – the SI unit of luminous flux. The total amount of light emitted by a light source, without regard to directionality, is given in lumens.

Luminous efficacy – the total luminous flux emitted by the light source divided by the lamp wattage; expressed in lumens per watt (lm/W).

Luminaire efficacy – the total luminous flux emitted by the luminaire divided by the total power input to the luminaire, expressed in lm/W.

Application efficiency – While there is no standard definition of application efficiency, we use the term here to denote an important design consideration: that the desired illuminance level and lighting quality for a given application should be achieved with the lowest practicable energy input. Light source directionality and intensity may result in higher application efficiency even though luminous efficacy is lower relative to other light sources.

Efficiency or efficacy? – The term "efficacy" normally is used where the input and output units differ. For example in lighting, we are concerned with the amount of light (in lumens) produced by a certain amount of electricity (in watts). The term "efficiency" usually is dimensionless. For example, lighting fixture efficiency is the ratio of the total lumens exiting the fixture to the total lumens produced by the light source. "Efficiency" is also used to discuss the broader concept of using resources efficiently.



Comparing LEDs to Traditional Light Sources

Energy efficiency proponents are accustomed to comparing light sources on the basis of luminous efficacy. To compare LED sources to CFLs, for example, the most basic analysis should compare lamp-ballast efficacy to LED+driver efficacy in lumens per watt. Data sheets for white LEDs from the leading manufacturers will generally provide “typical” luminous flux in lumens, test current (mA), forward voltage (V), and junction temperature (T_j), usually 25 degrees Celsius. To calculate lm/W, divide lumens by current times voltage. As an example, assume a device with typical flux of 45 lumens, operated at 350 mA and voltage of 3.42 V. The luminous efficacy of the LED source would be:

$$45 \text{ lumens} / (.35 \text{ amps} \times 3.42 \text{ volts}) = 38 \text{ lm/W}$$

To include typical driver losses, multiply this figure by 85%, resulting in 32 lm/W. Because LED light output is sensitive to temperature, some manufacturers recommend de-rating luminous flux by 10% to account for thermal effects. In this example, accounting for this thermal factor would result in a system efficacy of approximately 29 lm/W. However, actual thermal performance depends on heat sink and fixture design, so this is only a very rough approximation. Accurate measurement can only be accomplished at the luminaire level.

Application Efficiency

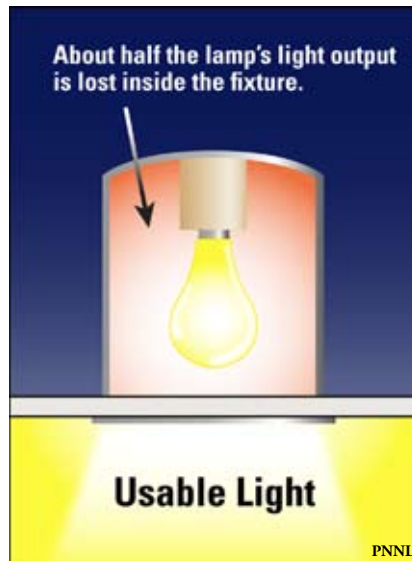
Luminous efficacy is an important indicator of energy efficiency, but it doesn't tell the whole story, particularly with regard to directional light sources.

Due to the directional nature of their light emission, LEDs potentially have higher application efficiency than other light sources in certain lighting applications. Fluorescent and standard “bulb” shaped incandescent lamps emit light in all directions. Much of the light produced by the lamp is lost within the fixture, reabsorbed by the lamp, or escapes from the fixture in a direction that is not useful for the intended application. For many fixture types, including recessed downlights, troffers, and under-cabinet fixtures, it is not uncommon for 40-50% of the total light output of the lamp(s) to be lost before it exits the fixture.

LEDs emit light in a specific direction, reducing the need for reflectors and diffusers that can trap light, so well-designed fixtures, like the undercabinet light shown below, can deliver light more efficiently to the intended location.



The low-profile design of this undercabinet light takes advantage of LED directionality to deliver light where it is needed. Available in 3W (shown), 6W, and 9W models.



*Cut-away view of recessed downlight installed in ceiling

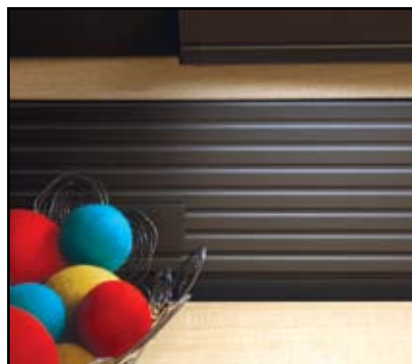


Photo credit: Finelite.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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