Thermal Management of White LEDs

LEDs won't burn your hand like some light sources, but they do produce heat. In fact, thermal management is arguably the most important aspect of successful LED system design. This fact sheet reviews the role of heat in LED performance and methods for managing it.

All light sources convert electric power into radiant energy and heat in various proportions. Incandescent lamps emit primarily infrared (IR), with a small amount of visible light. Fluorescent and metal halide sources convert a higher proportion of the energy into visible light, but also emit IR, ultraviolet (UV), and heat. LEDs generate little or no IR or UV, but convert only 20%-30% of the power into visible light; the remainder is converted to heat that must be conducted from the LED die to the underlying circuit board and heat sinks, housings, or luminaire frame elements. The table below shows the approximate proportions in which each watt of input power is converted to heat and radiant energy (including visible light) for various white light sources.

Relative Power Conversion for "White" Light Sources

	Incandescent† (60W)	Fluorescent† (Typical linear CW)	Metal Halide‡	LED*
Visible Light	8%	21%	27%	20-30%
IR	73%	37%	17%	~ 0%
UV	0%	0%	19%	0%
Total Radiant Energy	81%	58%	63%	20-30%
Heat (Conduction + Convection)	19%	42%	37%	70-80%
Total	100%	100%	100%	100%

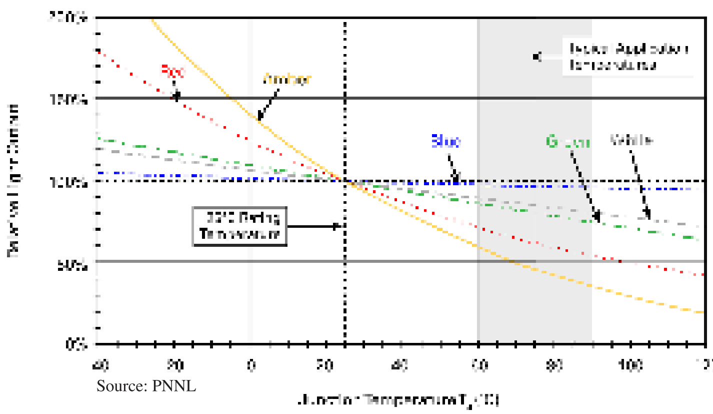
† IESNA Handbook ‡ OSRAM SYLVANIA

* Varies depending on LED efficacy. This range represents best currently available technology in color termperatures from warm to cool. DOE's SSL Multi-Year Program Plan (Mar 2009) calls for increasing extraction efficiency to more than 50% by 2025.

Why does thermal management matter?

Excess heat directly affects both short-term and long-term LED performance. The short-term (reversible) effects are color shift and reduced light output while the long-term effect is accelerated lumen depreciation and thus shortened useful life.

The light output of different colored LEDs responds differently to temperature changes, with amber and red the most sensitive, and blue the least. (See graph at right.) These unique temperature response rates can result in noticeable color shifts in RGB-based white light systems if operating T_j differs from the design parameters. LED manufacturers test and sort (or "bin") their products for luminous flux and color based on a 25 millisecond power pulse, at a fixed T_j of 25°C (77°F). Under constant current operation at room temperatures and with engineered heat mitigation mechanisms, T_j is typically 60°C or greater. Therefore white LEDs will provide at least 10% less light than the manufacturer's rating, and the reduction in light output for products with inadequate thermal design can be significantly higher.



Source: PNNL


Photo credit: Philips Lumileds® Rebel

Terms

Conduction – transfer of heat through matter by communication of kinetic energy from particle to particle. An example is the use of a conductive metal such as copper to transfer heat.

Convection – heat transfer through the circulatory motion in a fluid (liquid or gas) at a non-uniform temperature. Liquid or gas surrounding a heat source provides cooling by convection, such as air flow over a car radiator.

Radiation – energy transmitted through electromagnetic waves. Examples are the heat radiated by the sun and by incandescent lamps.

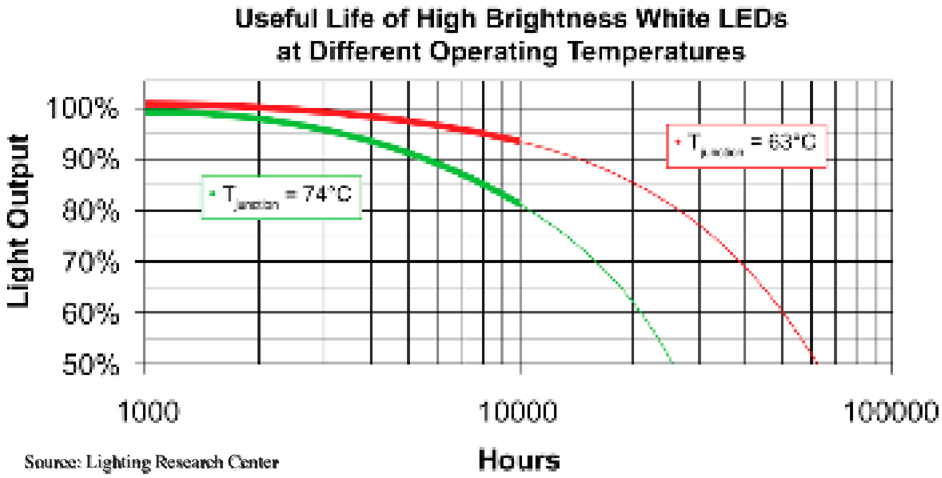
Junction temperature (T_j) – temperature within the LED device. Direct measurement of T_j is impractical but can be calculated based on a known case or board temperature and the materials' thermal resistance.

Heat sink – thermally conductive material attached to the printed circuit board on which the LED is mounted. Myriad heat sink designs are possible; often a "finned" design is used to increase the surface area available for heat transfer. For general illumination applications, heat sinks are often incorporated into the functional and aesthetic design of the luminaire, effectively using the luminaire chassis as a heat management device.


Source: Enlux

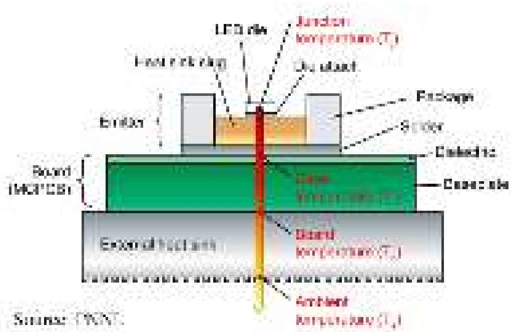
Continuous operation at elevated temperature dramatically accelerates lumen depreciation resulting in shortened useful life. The chart below shows the light output over time (experimental data to 10,000 hours and extrapolation beyond) for two identical LEDs driven at the same current but with an 11°C difference in T_j. Estimated useful life (defined as 70% lumen maintenance) decreased from ~37,000 hours to ~16,000 hours, a 57% reduction, with the 11°C temperature increase.

However, the industry continues to improve the durability of LEDs at higher operating temperatures. For example, manufacturers of high-power white LEDs typically estimate a lifetime of around 50,000 hours to the 70% lumen maintenance level, assuming operation at 700 milliamps (mA) constant current or higher, at maintained junction temperatures above 100°C.



What determines junction temperature?

Three things affect the junction temperature of an LED: drive current, thermal path, and ambient temperature. In general, the higher the drive current, the greater the heat generated at the die. Heat must be moved away from the die in order to maintain expected light output, life, and color. The amount of heat that can be removed depends upon the ambient temperature and the design of the thermal path from the die to the surroundings.



The typical high-flux LED system is comprised of an emitter, metal-core printed circuit board (MCPCB), and some form of external heat sink. The emitter houses the die, optics, encapsulant, and heat sink slug (used to draw heat away from the die) and is soldered to the MCPCB. The MCPCB is a special form of circuit board with a dielectric layer (non-conductor of current) bonded to a metal substrate (usually aluminum). The MCPCB is then mechanically attached to an external heat sink which can be a dedicated device integrated into the design of the luminaire or, in some cases, the chassis of the luminaire itself. The size of the heat sink is dependent upon the amount of heat to be dissipated and the material's thermal properties.

Heat management and an awareness of the operating environment are critical considerations to the design and application of LED luminaires for general illumination. Successful products will use superior heat sink designs to dissipate heat, and minimize T_j. Keeping the T_j as low as possible and within manufacturer specifications is necessary in order to maximize the performance potential of LEDs.

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