Achieve U.S. Department of Energy ENERGY STAR® Results for Your Solid-State Lighting Design

Contributed by the Arrow Electronics Lighting Group

Achieve U.S. Department of Energy ENERGY STAR® Results for Your Solid-State Lighting Design
The process is complex, but here's some information to help you realize real results.

Contributed by the Arrow Electronics Lighting Group

To achieve a U.S. Department of Energy **(**US-DOE) CALiPER-quality LED fixture, design engineers require an efficient LED array, a well-designed electronic driver, an effective heat sink, and an optimized optical lens solution, if necessary. The proper combination of these key items directly determines the effectiveness, light output, and lifetime of these fixtures. US-DOE CALiPER testing has clearly indicated that first-rate components cannot simply be cobbled together to produce a quality product. This article will discuss how customers can get results with a combination of world-class components and the appropriate design and engineering support.

Design Challenges
In order to meet the Group A DOE ENERGY STAR® guidelines, luminaire designers need to keep in mind the following US-DOE CALiPER minimums: 20 to 35 lm/watt per fixture (rating is dependent upon the fixture application type). This will change to 70 lm/watt in 2011. The current benchmark today is the T8 (100 lm/watt) FL fixtures that deliver 70%+ efficacy. The US-DOE CALiPER tests for six items: total luminous flux, luminaire efficacy, correlated color temperature, color rendering index, steady state module/array temperature, and maximum power supply case/TMP temperature.

The designer must also factor in the following luminaire requirements:

LED Light Source
- CCT (IESNA LM-79, LM-58, LM-16, and CIE 15-2004)
- The eight ANSI defined MacAdam ellipses (2700k, 3000k, 3500k, 4000k, 4500k, 5000k, 5700k, and 6500k)
- Lumen depreciation (IESNA LM-80): 70% of initial lm to 35,000 hours (commercial) or 25,000 hours (residential)
- Color spatial uniformity (IESNA LM-79, LM-58, LM-16, and CIE 15-2004)
- Color maintenance (ANSI C78.377A, IESNA LM-79, LM-58, and CIE 13.3-1995)
- 75 CRI minimum (indoor)
- Thermal management: meet component suppliers' guidelines

Power Supply
- Off-state power: zero, except with integral controls (i.e., occupancy, motion, photo, and networked) 0.5 watts
- Key items for the LED driver/power supply/ballast power supply efficiency: 90%+
- FCC EMI/RFI: 47 CFR part 15/18 (consumer and non-consumer)
- Transient protection (voltage spikes)
- Frequency: 120 Hz or above
- Noise: Class A, 24 dB maximum
- Power factor (ANSI C82.77): 0.90+ (commercial), 0.70+ (residential)
- Temperature range: -20°C to maximum rating by power supply manufacturer
- Safety (ANSI/UL 153, UL 1598)
- Thermal management: meet component suppliers' guidelines

Four of the six US-DOE CALiPER tests are thermally related, and this article will focus mainly on how thermal design impacts LED performance and luminaire efficacy.

The following four key items help maximize luminaire efficacy:

LED Selection: impacts total luminous flux, luminaire efficacy, correlated color temperature, and color rendering index

Thermal Management: impacts steady state module/array temperature, maximum power supply case/TMP temperature, and luminaire efficacy, as well as lumen depreciation, color maintenance, and CRI

Power Supplies: impact steady state module/array temperature, maximum power supply case/TMP temperature, and luminaire efficacy as well as FCC, transient protection, noise, off-state power, and power factor

Optics: impact total luminous flux and luminaire efficacy

Two industry measurement references are used for fixture efficiency. The first is the coefficient of utilization (CU), which is an indication of a fixture's efficiency for delivering incandescent lamp lumens onto the horizontal surface to be illuminated. Highly efficient lighting fixtures have CU values above 0.9.

The second is fluorescent luminaire efficacy (LER), which is the luminaire's light output divided by the input power. The formula is:

LER = [luminaire efficiency (EFF) x total rated lamp lumens (TLL) x ballast factor (BF)] divided by [luminaire watts input]

Note that the effects of all components of the luminaire system are included in the LER. "LER gets to the core of what energy efficiency is all about—to get more energy service using less energy," stated Francis Rubenstein, staff scientist, Lawrence Berkeley Laboratory. (http://www.lightsearch.com/reference/nlc.html).

To estimate LED luminaire efficacy (LLE), here is a “rule of thumb” formula to help luminaire designers determine if their initial design will approach the DOE CALiPER requirements:

LLE = ([LED lumens/watt)] x [LED junction temperature derating %]) x [power supply efficiency %] x [optical efficiency %]

Using a 100 lm/watt LED, a 90% derating value, an 85% power supply efficiency, and a 90% optical efficiency

LLE = ([100] x [90%]) x [85%] x [90%]

LLE = 68.85 lumens/watt

This result is on par with the current top efficacy of fluorescent fixtures at 70%+ efficiency when using 100 lm/watt T8 FL lamps.

LED output degrades as the junction temperature increases. The LED junction temperature is impacted by the ambient temperature; current through the LED; forward voltage drop; internal losses; LED junction to ambient losses, and air convection thermal transfers. Even the highest lumen output LEDs will be tremendously derated by poor thermal design. [1]

When using a power LED, the relationship between its junction temperature and its thermal resistance (resistance to the conductivity of heat, measured as °C/W), is very important. If the LED's power consumption is constant, a smaller thermal resistance makes for a smaller rise in temperature at the junction. This allows the LED to operate within a higher ambient temperature environment.

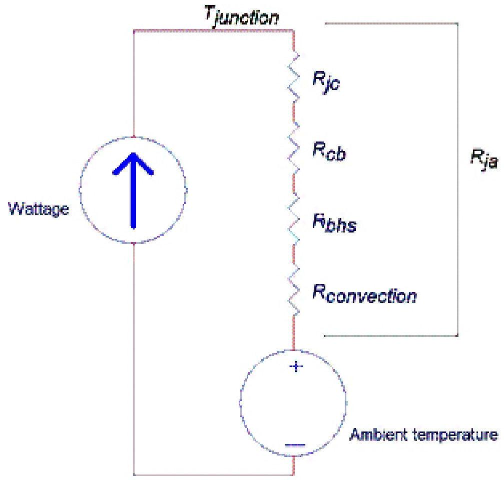

Figure 1
A typical thermal model for an LED package; the LED power dissipation is modeled as a current source, thermal resistance is modeled as resistors, and the ambient temperature is modeled as a voltage source.[2]

A common engineering design problem involves the selection of an appropriate sized heat sink for a given heat source. Working in units of thermal resistance greatly simplifies the design calculation. When thermal resistances occur in series, they are additive, i.e., when heat flows through two components each with a thermal resistance of 1°C/W, the total resistance is 2°C/W.

The thermal resistance between two points is defined as the ratio of the difference in temperature to the power dissipated; the unit is °C/W. From the LED junction to the thermal contact at the bottom of a package, the thermal resistance is governed by the package design. It is referred to as the thermal resistance between the junction and the solder point (R_{JC}). Different components in the heat conduction path can be modeled as different thermal resistances. By "thermic Ohm's law," we have the equation as follows:
TJ = TA + (RJA × PLED), and $R_{ja} = R_{jc} + R_{cb} + R_{bhs} + R_{convection}$

The junction temperature will be lower if the thermal impedance is smaller, as well as with a lower ambient temperature. To maximize the useful ambient temperature range for a given power dissipation, the total thermal resistance from junction to ambient must be minimized.[2]

The maximum forward current is determined by the thermal resistance between the LED junction and the ambient temperature. Given an existing thermal resistance of 8°C/W between the junction and the solder point, it is crucial for the luminaire to be designed in a manner that minimizes the thermal resistance from the solder point to ambient in order to optimize lamp life and lumen output. A key component of good thermal design is minimizing the number of thermal path interfaces. Each one adds more thermal resistance to the total. An LED with an internal heat sink that does not require external electrical isolation will have a lower total system thermal resistance since it does not need the extra layer of electrical isolation that interrupts the thermal path.

The thermal impact is highlighted per the Maximum Allowable Current vs. Temperature Chart (Chart #1) (maximum current vs. ambient temperature) and the relative Luminous Flux vs. Current Chart (Chart #2). The LED lumen output at 125 °C ambient would be reduced to ~ 38% if the total thermal resistance Rj-a was 35 °C/W instead of 10 °C/W.

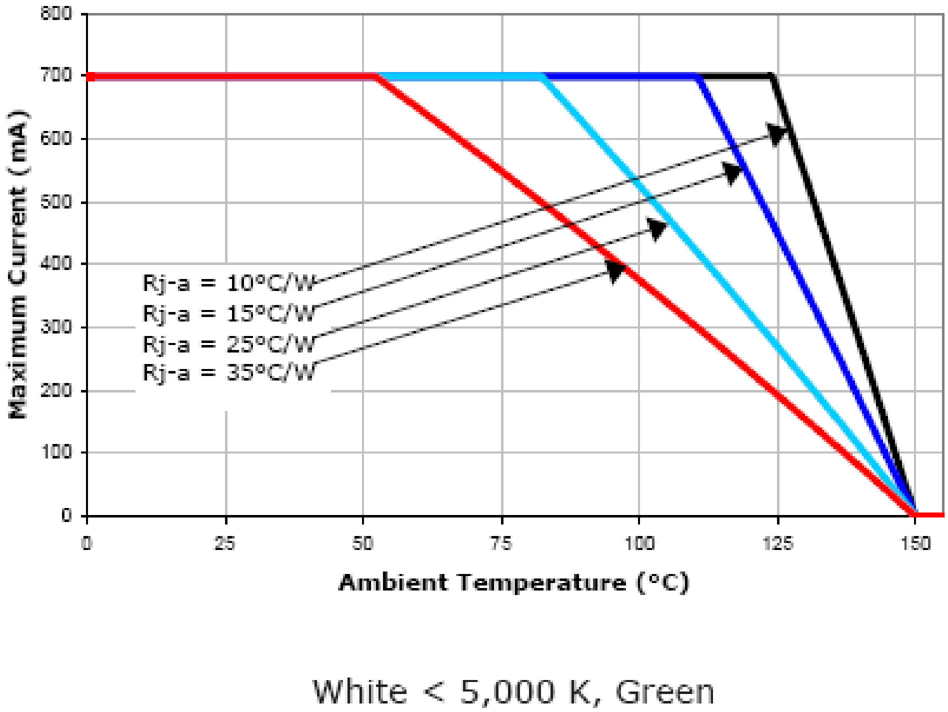

Chart 1 Maximum Allowable Current vs. Temperature

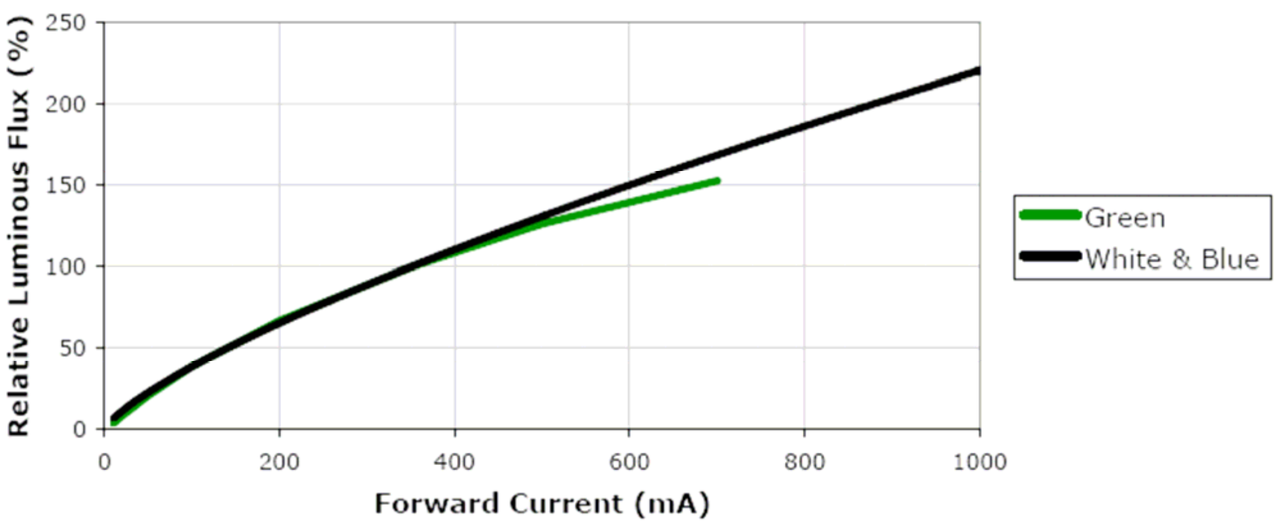

Chart 2 Luminous Flux vs. Current

Junction temperature has a second significant impact on LED lifetime (ANSI L70 rating). As the LED junction temperature increases, the L70 operating life decreases, as seen in the Operating Life vs. Junction Temperature Chart (Chart #3). Heat sinks play a very valuable role in keeping high-power LEDs cool. It is important to know that not just any piece of metal will do a good job. While many lighting fixtures use sheet steel in their fabrication, steel is not nearly as effective as aluminum or copper as a heat sink. While any heat sink may be better than none, an effective heat sink design can reduce overall product weight, increase heat dissipation, and can become an aesthetic part of the product's design.

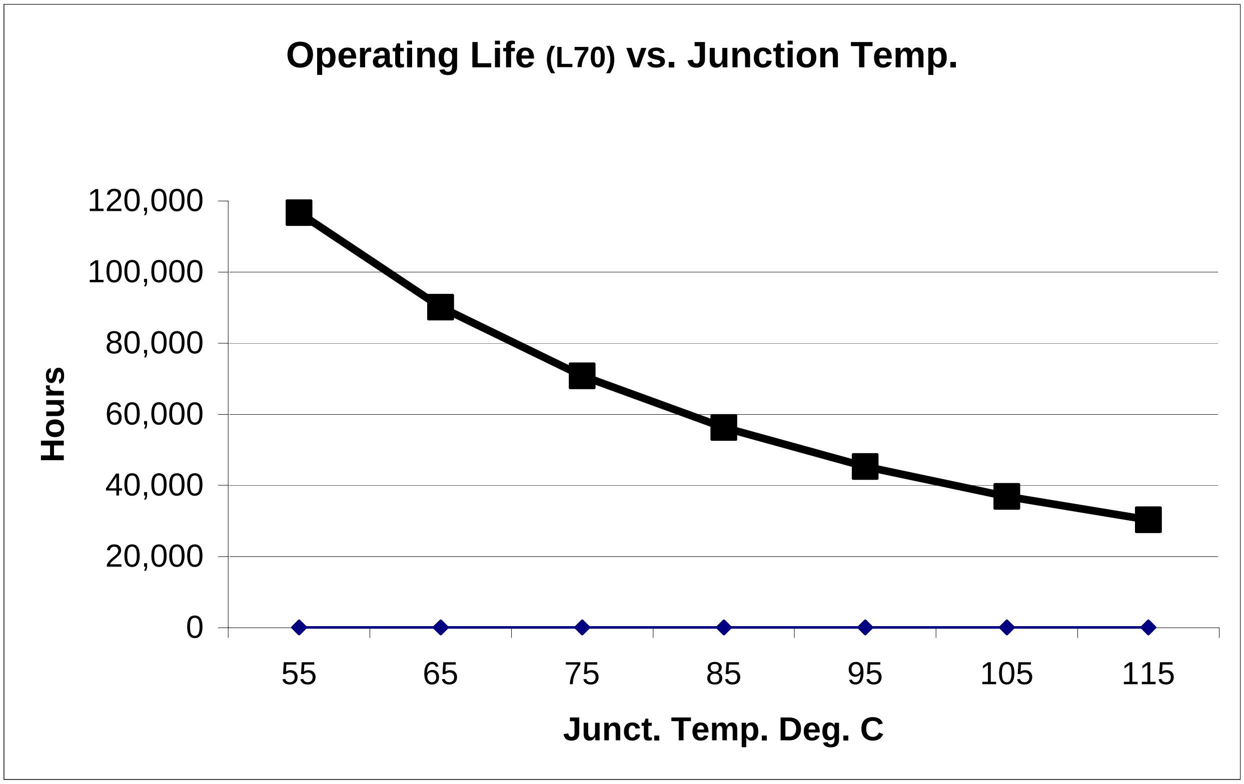

Chart 3 Operating Life vs. Junction Temperature

The next biggest impact for an LED fixture is the optical design. The best optical TIR lenses and the best reflectors for LEDs may approach 90% efficacy. Matching up the right lens or reflector is critical in maximizing lumen output. Just as with thermal interfaces, optical interfaces create losses. The proper mounting of the lens and LEDs is critical to a good optical interface. Keeping the number of interfaces to a minimum is also crucial. Photons do not like to go through multiple optical materials and those losses quickly multiply with each additional interface. Optical manufacturers produce lenses and reflectors that are matched to a specific LED's optical output. Do not swap the lens from one LED with another model or brand. You will get much less optical output than you planned for!

The last key item is power supply efficiency. In seven rounds of CALiPER testing, this has ranged from a low of 51% to a high of 95%. As mentioned above, the current benchmark is a T8 (100 lm/watt) FL fixture at 70%+ total efficacy. A fixture using 100 lumen LEDs with a 90% value for thermal, lumen, and optical efficiency would only reach 73% efficiency. If your power supply is working at 51% efficiency, the fixture system total would then be reduced to 41% efficiency. While many off-the-shelf LED driver options are available, it is important to match the LED circuit load to the power supply as closely as possible. Tweaking the LED array to get a best match with an existing LED driver power supply can be very time consuming and may result in too many or too few lumens to work with.

An optimal solution is to design your power supply to meet your fixture's requirements in order to get your efficiency as high as possible. This task is not to be taken lightly and is not for the novice. However, design help is available from many of the IC suppliers that make the components used within power supplies. The downside is that you will have to undergo UL testing of your custom power supply vs. buying one that is already UL recognized from a ballast/driver manufacturer.

Component manufacturers have developed considerable infrastructure (R&D, manufacturing, purchasing, quality assurance, sales and marketing, shipping, customer service, etc.) that allows them to provide the best products for their target markets. This allows them to be very efficient in developing and processing their products. This incredible storehouse of technical knowledge can also produce a "silo" side effect.

Where Can You Turn for Help?

You can call dozens of component manufacturers and hope for the best, or you can call your local electronics distributor that has a lighting team deployed, to help you attain maximum fixture efficiency with a minimum of headaches.

One of the key reasons it's good to work with an electronics components distributor: faster time-to-market solutions. Distributors offer a one-stop solution for the numerous electronic technologies needed to develop an LED luminaire solution that meets your requirements. Other reasons: distributors provide global engineering and manufacturing support; product design/development expertise; and access to emerging technologies in LED light sources, optics, LED drivers, thermal management, and controls. Distributors also offer a number of centralized and local field applications engineers who are a quick phone call or e-mail away from helping you develop an efficient luminaire solution.

Electronics distribution allows customers to source the right technology at the right time, for the right price. It's not just where to find parts, it's where the solutions are waiting for you!

References:

1- http://www.necel.com/en/faq/f_therma.html
2 - http://en.wikipedia.org/wiki/Thermal_management_of_high_power_LED