LIGHTING AFRICA

Catalyzing Markets for Modern Lighting

Lighting Education and Technical Support (LETS) for Off-Grid LED Lighting

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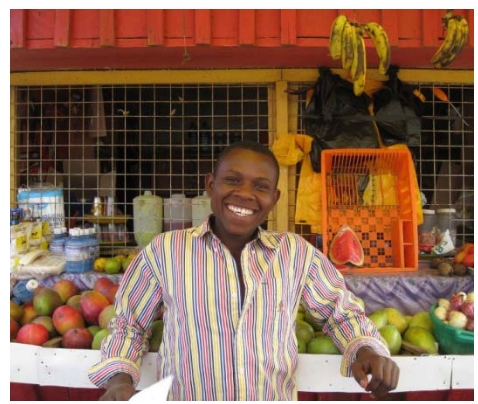
THE WORLD BANK

Lighting Africa's
Quality Assurance Strategy

- **Quality Assurance Strategy Key Elements**
- Performance evaluation test methods
- Product Reviews & Information Dissemination
- Products of the Year Awards
- Lighting Education and Technical Support






LETS Overview

Lighting Africa plans to produce **a series of documents** intended to help the production and procurement of high-quality off-grid lighting systems

- Focus on topics that:
  1. Have a strong connection to product quality
  2. Address issues that are shared by many manufacturers and/or buyers
  3. Can be addressed with relevant education and information
- Two types of documents planned:
  1. "Best Practices"
  2. "Component Reviews"

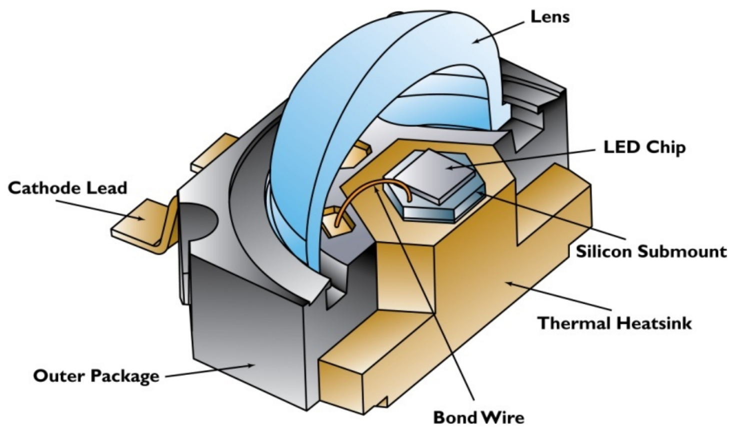
Dual Audience

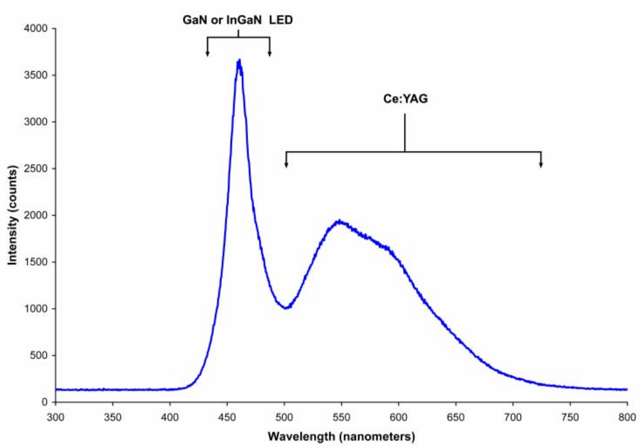
- Manufacturers & Importers:
  - Technical resources to assist in addressing common engineering areas affecting quality
  - No-cost or low-cost methods to consider
  - “Component Reviews” for key components

- Wholesale Buyers and Distributors:
  - Accessible background information to evaluate product quality
  - Key questions to ask when evaluating products

"Best Practices" Overview

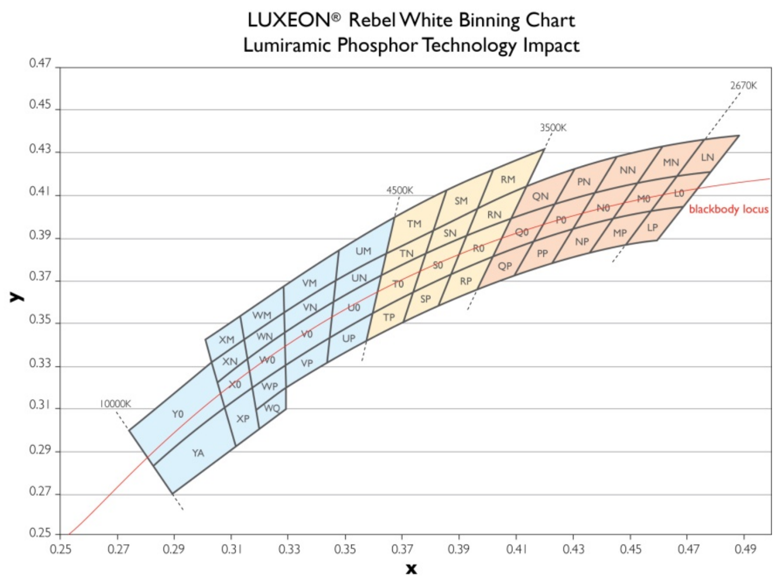
- Provide basic technology information necessary to design, produce and/or evaluate quality systems
- Address areas that are common quality failure points
- Focus on design and engineering methods that can improve quality with minimal cost implications





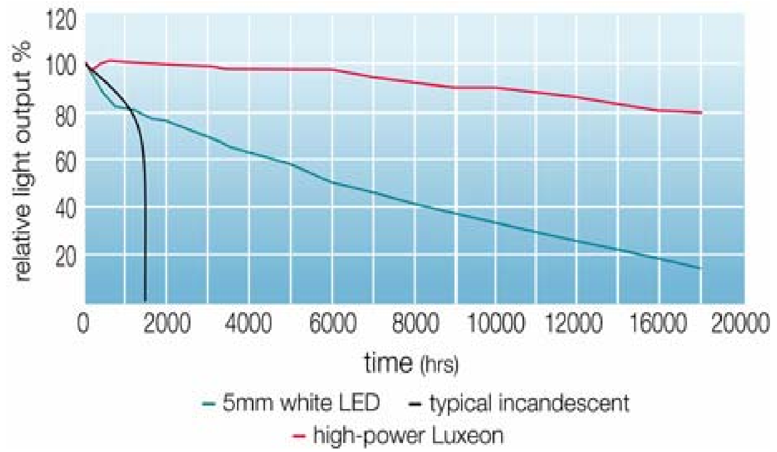
Potential "Best Practices" Topics

- **LED Primer: An overview of LED technologies and system design**
- **Basic photometric terms for LED lighting**
- **LED package considerations**
  - Through hole and surface mount LED package types, solder joint integrity, lead frame structure, mechanical durability
- **LED lifetimes and reliability**
- **Optical control techniques and glare mitigation**
- **Sourcing LEDs**
  - Types of LEDs, binning, performance parameters, key questions to ask suppliers, etc
- **LED electronic system integration**
  - Driver design approaches, LED array configurations, dimming and power management
- **Thermal management techniques for LEDs**
- **Performance of solar modules**
- **Performance of batteries**
- **Battery charges control**



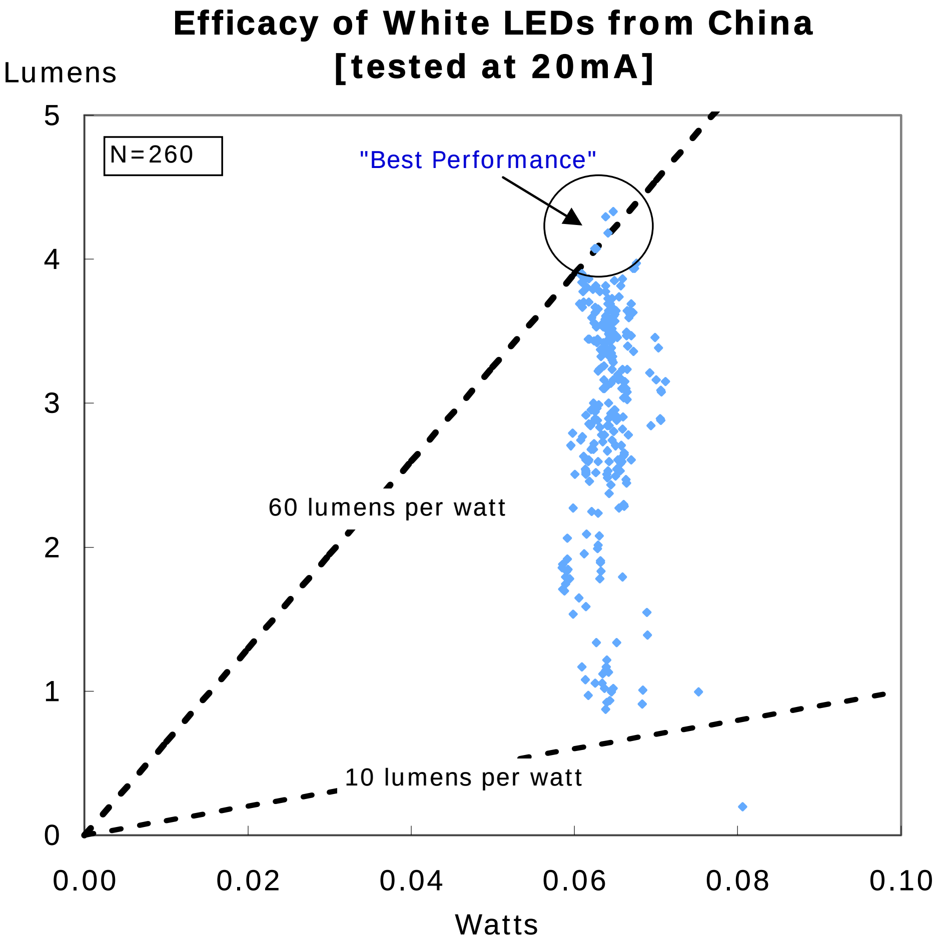
“Component Review” Overview

- Much like Lighting Africa’s Product Reviews, but for reviewing *key components* for manufacturers rather than reviewing whole lighting systems for buyers
- Consumer Reports model of testing and reviewing
- Cost will be a consideration
  - **Focus wherever possible in identifying high preference components that are low or no-cost adders to “standard” components**



Component Review Example

The quality of the individual LEDs used in many off-grid lighting products varies widely.



Mills, 2007

Potential "Component Reviews" Topics

- LEDs
- LED drivers
- Solar Modules
- Batteries

Basic Photometric Terms for LED Lighting

This technical brief reviews several important photometric terms and concepts. It addresses some common misconceptions in lighting and is intended to give the reader a basic understanding of the information that is included on an LED datasheet.

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Lighting Education and Technical Support
Basic Photometric Terms for LED Lighting

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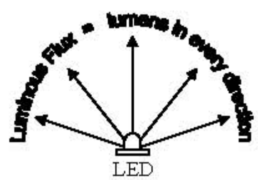
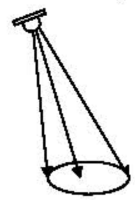
This technical brief reviews several important photometric terms and concepts. It addresses some common misconceptions in lighting and is intended to give the reader a basic understanding of the information that is included on an LED datasheet.

Luminous Flux and Illuminance

The basic unit of visible light is the **lumen** (lm). A lumen represents a quantity of light and takes into account the sensitivity of the human eye. The total amount of light emitted by an LED, in every direction, is referred to as 'luminous flux'. A 60 watt incandescent light bulb produces about 900 lumens.



Illuminance is the amount of light incident on a surface, measured in lumens per meter^2 (lm/m^2). The unit of illuminance is lux; 1 lux = 1 lm/m^2. A typical handheld illuminance meter measures lux (or footcandles in English units).



Illuminance = light incident on a surface
(this is what you measure with an illuminance meter; this is NOT luminous flux)

Flux vs Illuminance

The difference between lumens and lux is important. A focused LED can concentrate light onto a small area, and the illuminance at this point can be very high. But the total lumen output (luminous flux) for the device can still be very low because the light is only emitted in a narrow angle.

Photometric Units

Photometric Term	SI unit	Basic units
Luminous flux	Lumen	lm = cd □ sr
Illuminance	Lux	Lx = lm/m^2
Luminance	Nits	Nits = cd/m^2
Luminous intensity	Candela	Cd = lm/sr

Another way to characterize the light from an LED is to measure its **luminous intensity**. Luminous intensity, measured in candelas (cd), is lumens emitted by an LED in a specific direction (imagine a narrow cone). LED datasheets often list candelas (or millicandelas) as a measure of 'brightness'. Again, this is not a measure of its luminous flux and primarily reveals how tightly the LED focuses its light output.

Color (Chromaticity)

The human eye can see wavelengths between about 400 nm (deep purple) to 700 nm (deep red); this is the visible spectrum. To make a white LED, a blue LED chip is covered with a phosphor that converts some of the blue light into other wavelengths. The resulting mixture is perceived as white light. The chemical composition of the phosphor determines the specific mixture, and white light of many different 'shades', or color temperatures, can be produced.

The color temperature of a white light source is defined by the different colors of light given off by a heated 'black body' emitter (think of a heated filament in a light bulb). At lower temperatures, the filament will glow red, then orange, yellow, and white. Heat the filament further, and the white glow will start to take on a bright bluish color. These different 'colors' of white light are referred to as color temperature or correlated color temperature (CCT). Color temperature is expressed in degrees Kelvin (K)

White LED light with a strong blue component will appear cool or bluish in color. This is said to have a high color temperature (corresponding to a very hot filament). If the phosphor has more red component added, the LED can appear much warmer and therefore

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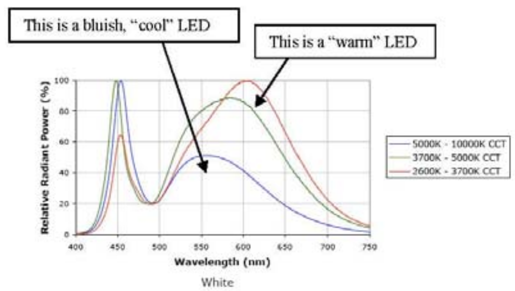
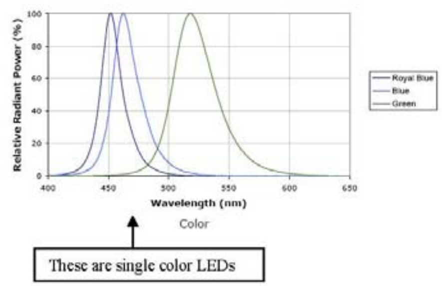
has a low color temperature (the filament not glowing very far past the red)

The first white LEDs were high color temperature (bluish). Recent advances have produced LEDs with lower color temperatures because some people prefer the warmer feel of the light. Very warm LEDs, similar to incandescent lights, have CCTs in the 2700K range, while cooler LEDs have CCTs of 5000K, 6000K, or higher.

LEDs are sorted by color temperature into bins. Different LED manufacturers have different bins, but all manufacturers offer their LEDs within ranges, and all LED bins have minimum and maximum CCT values

Spectral power distributions of white LEDs:





Efficacy

Efficacy is a specific term used to describe the efficiency of an LED, and LED array, or an LED system. Efficacy is measured as lumens (total luminous flux) per watt, lm/w.

Efficacy measurements can be taken at several points in a system. An LED manufacturer usually makes efficacy measurements of individual LEDs as they come off of the assembly line, and lists the results with the LED bin. The tests are quick (~25 milliseconds) and use the standard forward voltage and current for that LED type. These are ideal conditions, as the LED chip has not had time to heat up, and the efficacy measurement will not include other losses that will be included in a complete (real world) LED system.

To get a true picture of the efficacy of an LED system, the entire system must be tested after the LEDs have had time to warm up. The power measurement should be the input power to the system, and all lenses or diffusers should be in place.

Efficacy values are sometimes included on the datasheet for an LED product. This will often be the efficacy value for the bare LED, taken from the LED manufacturer's datasheet, and will not include many of the losses that are part of the completed product.

Glare

Glare can be a problem with LED systems. Glare results from a concentration of light coming from a small area, and is likely to occur any time an LED can be seen directly or reflections from an LED bounce off of specular (mirrored) surfaces.

LEDs emit light from a small area, which is perceived as being very bright. As discussed earlier, however, perceived brightness does not necessarily mean a high lumen output. Glare, in addition to being distracting or annoying, can actually make it harder for people to see the illuminated area.

LED systems should be designed so that direct viewing of the LED sources is avoided. This can be accomplished by using diffusers in front of the LEDs to spread out the light (increase the luminous surface area) or by shielding the light with reflectors. Keep in mind, though, that diffusers and reflectors will absorb some light and thus decrease the efficacy. A balance should be struck between efficiency and visual comfort.

Thermal Management for LEDs

This technical brief discusses thermal management techniques and concepts for LEDs and is intended to give engineers and product managers some basic tools for LED thermal system design.

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Thermal Management for LEDs

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Good thermal management design is essential to the operation of any LED system. Light output, color shift, lumen maintenance, and lifetime are all adversely affected by high LED temperatures during operation. This technical brief discusses thermal management techniques and concepts for LEDs and is intended to give engineers and product managers some basic tools for LED thermal system design.

Thermal Resistance and Heat Flow

Light from an LED comes from the LED chip (or die) within the LED package. In addition to emitting light, the LED chip also becomes hot, and this thermal energy must be conducted away from the LED chip and dissipated to the surrounding environment. The critical temperature of the LED chip is called the LED Junction Temperature (Tj). Good thermal design can ensure that the LED Tj will stay acceptably low and the performance of the LED will live up to expectations.

Thermal energy (heat) flows from a hot object to a cool object when the two come in contact with each other. This is called *thermal conduction* and in this case both objects will eventually become warm (and equal in temperature) if no more heat is added to the system. If the warm objects are then allowed to come in contact with air, and the air is free to flow around them, the objects will transfer their thermal energy to the air by a process called *convection*. With both of these processes (convection and conduction), the amount of heat transferred from hot to cold is limited by the surface area of contact between the hot object and the cold object (or the cold air). This limit in heat transfer can be thought of as a bottleneck and is mathematically represented by a thermal resistance (much like a resistor limits the flow of electricity in an electric circuit). One general rule of thumb is important to remember: ***Increasing surface area increases the flow of heat and lowers the thermal resistance.***

Each thermal resistance step is given in degrees Celsius per watt (°C/W) and means the *rise in temperature per watt of power dissipated.*

The flow of heat from an LED chip to the ambient environment can be modeled as a series of thermal resistances between the chip (at Tj) and the ambient environment (Ta). The sum of these resistances is the total thermal resistance for the system, and each thermal step needs to be optimized to keep the overall resistance as low as possible.

The first step in thermal resistance occurs between the LED chip junction Tj and the LED case Tc. Since the LED chip junction is not accessible (touching it with a thermocouple would destroy the LED), another location must be chosen for temperature measurements. The LED case temperature location is defined by the manufacturer and is typically the heat slug of the LED package (for surface mount devices), or one of the leads of a 5mm epoxy LED. The LED manufacturer is responsible for listing the thermal resistance of the LED package, and this resistance value can be used to calculate the LED junction temperature Tj ***if*** the LED case temperature Tc is known.

Example: The LED Tc = 50 °C. The thermal resistance for the LED is 10 °C/W, and the LED is being driven at .5 watts. A quick calculation (.5 °C/W x 10 W = 5 °C) shows that Tj is 5°C higher than Tc and so Tj = 55°C.

One popular method for thermal resistance (R) notation is to use subscripts to describe the beginning and end points of a thermal path. For the entire path from LED junction to ambient environment, this would be

$R_{j\text{-}a}$ and would be the thermal resistance from ***juntion to ambient.*** If we include the smaller individual steps along the way we will get the general equation for the thermal resistance of the system. We already have described the resistance from LED junction to LED case as $R_{j\text{-}c}$, and can also include a few more:

$R_{c\text{-}hs}$ = resistance from case to heatsink

$R_{hs\text{-}a}$ = heatsink to ambient

So now our equation for the full thermal path is:

$$R_{j\text{-}a} = R_{j\text{-}c} + R_{c\text{-}hs} + R_{hs\text{-}a}$$

Thermal Management for LEDs

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The goal of good thermal design for LED systems is to keep the LED case temperatures, and therefore the LED junction temperatures, as low as possible. This means that each thermal transfer area beyond the LED case location should be carefully configured to lower its thermal resistance. In general the following rules will apply to most LED systems:

1) Make contact areas between mated parts as large as possible along the thermal path. An increase in area will allow heat to conduct more easily between parts. Use heat transfer grease and thermal pads where possible to eliminate microscopic air gaps between surfaces.
2) Shorten the length of the thermal path and maximize conductor cross sections. The farther heat has to travel from one side of a material to the other, the greater the resistance. When heat does need to be transported a long distance, use thick conductor cross sections. As with electrical conductors, heat flows better in short runs with large cross section conductors.
3) Use high thermal conductivity materials. Copper is a very good thermal conductor, followed by aluminum. ***Steel, particularly stainless steel, and plastics are poor thermal conductors*** and should be avoided in the thermal path.
4) The final step in the heat transfer path will be the transfer of heat to the ambient air. This is a critical step and often misunderstood. The best, biggest heatsink will not perform well if it is insulated or isolated from ambient airflow. For heatsinks that are contained **inside** an outer plastic enclosure (the plastic case of the luminaire), the pocket of air around the heatsink will serve as the "ambient" environment. This pocket should be designed to be as large as possible and not be cut off from other adjacent pockets. In many ways this is not the true "ambient" but just another step in the thermal path that includes the resistance from heatsink to the inner air pocket, the resistance from the air pocket to the outer plastic case, and finally the resistance between the outer case and the outside ambient air.

Measuring LED Case Temperatures

Thermocouples are most frequently used to measure the LED case Tc. The measurement location is specified by the LED manufacturer, and should be as close to the LED chip junction as possible. For 5mm and lamp type, leaded LEDs, the thermocouple measurements will be taken on the lead that attaches directly to the LED die (this is most often the cathode of the LED). This is often visible from the outside. The other lead attaches to the wire bond that connects (usually) to the anode of the LED and is not used for thermal measurements.

Good thermal measurement results are very important. Care must be taken when making measurements because mistakes will yield temperature readings that are lower than the actual temperatures.

Obey the following guidelines when making thermocouple measurements:

1) Check thermocouples for accuracy. Use boiling water and ice water to make sure the thermocouple measures 0 °C and 100 °C.
2) Use thin gauge thermocouple wire (30 gauge or higher). The thermocouple mass should not be large enough to conduct significant heat away from the measurement point. This is particularly true of (5 mm) leaded thru-hole LEDs.

Next Steps

- First 2 final tech notes (LED Photometrics, Thermal Management) available July 1, 2009
- Targeting 2 tech notes/month
- Initial focus on "Best Practices", followed later by "Component Reviews"

Key Questions

- Will manufacturers find these notes usefully and utilize the provided recommendations? What can we do to make them most useful?
- Will buyers find these notes useful and utilized them to evaluate products? What can we do to make them most useful?
- How technical is too technical? How technical is not technical enough? What if the answer is different for different audiences?
- Which topics are in most need of notes? Where should we start?
- Others Questions?

Thank You!

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