LIGHTING GLOBAL
Catalyzing Markets for Modern Lighting
AN INNOVATION OF WORLD BANK GROUP
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Technical Notes

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Lux & Lumens: Light Measurement Metrics

This Technical Note discusses issues related to the development of a consumer-friendly light output metric. Reporting this information in a way that end-users understand benefits the market by allowing direct comparisons of pico-powered lighting products.

This article builds on previous Technical Notes available on the Lighting Global website.

Introduction

The light output of pico-powered lighting products can be measured and reported using several different metrics. Light output (total luminous flux, or lumen output) is measured in lumens and is a good indicator of the overall 'brightness' of a product. The illuminance of that same product, measured with a photometer in units of lux, tells us how it illuminates a nearby surface like a desk, wall, or floor. Each metric can have value to the end user of a pico-powered lighting product.

For any given light source, the relationship between luminous flux and illuminance depends on the distribution of light. For the same amount of luminous flux, the illuminance experienced some distance away will be higher if the light is more narrowly focused and lower if it is distributed more widely.[1]

A standard method for reporting light output is necessary when comparing different lighting products. Lighting Global's Standardized Specifications Sheets (SSS) have listed several light output parameters that allow direct comparisons between products but are intended primarily for a technical audience (including distributors, retailers, and program managers). A consumer friendly approach with reporting requirements that fit on a consumer-facing label, would allow customers to make these same judgments at the point of purchase and add considerable value to the pico-powered lighting market.

[1] *See also Technical Notes Issue 0: Light Emitting Diode (LED) Lighting Basics; and Issue 6: Optical Control Techniques for Off-grid Lighting Products for more information on lighting metrics and light distribution*.

Lighting Global believes that the best choice for a primary consumer-facing light output metric is luminous flux. This Technical Note focuses on issues related to light measurement and the various advantages and disadvantages of using luminous flux and illuminance to report the output of a pico-powered lighting product.

Light measurement

Measuring light can be simple or complex depending on the details and requirements of the measurement. Some measurements can be made to a reasonable degree of accuracy by inexperienced personnel with inexpensive equipment; illuminance is an example of such a measurement. Hand-held illuminance meters are widely available and easy to use, though there are some nuances that influence how much information is captured during the measurement process.

Other measurements are more technically demanding and require expensive equipment; total luminous flux falls into this category. Measuring luminous flux requires an integrating sphere, a goniophotometer, or a labor-intensive procedure like that described in Lighting Global's multi-plane flux method. Calibration is accomplished with expensive lamp standards, testing software may be difficult to use, and proper test setup and execution requires experienced technical staff.

Measuring Lux

An illuminance meter measures the amount of light incident on a surface in lumens/m^2. A typical basic illuminance meter (lux meter) uses a silicon photodiode

mounted in a small cavity under a white translucent plastic cap (the meter receptor). The photodiode and support electronics provide an electrical current proportional to the amount of light falling on the active area of the diode. This signal represents the light level falling onto the plastic receptor, and, when properly calibrated, the meter will report the illuminance in either lux or foot-candles.

More advanced meters are capable of measuring spectral parameters like correlated color temperature and color rendering index, but the measurement procedure remains the same. Calibrating an illuminance meter requires comparison with a traceable instrument in a controlled, stable illuminance environment.

Measuring Lumens

Luminous flux is typically measured with either an integrating sphere or a goniophotometer. Both methods collect and measure all of the light output from the test lamp. The flux output, in lumens, is a single quantity and represents to total amount of visible radiation emitted by the source.

Integrating spheres use a process called substitution, where the measurement compares the reading of a test lamp with the reading of a standard (calibrated) lamp of known output. Integrating sphere measurements tend to drift, and spheres must be calibrated frequently with carefully handled standard lamps to preserve consistency and provide technically valid results.

Goniophotometers measure discrete portions of a test lamp output and add these individual zonal lumens to produce a total lumen output figure. Goniophotometers are relatively complex and, as with integrating spheres, require knowledgeable technical staff to produce technically valid results.

Lighting metrics in use today

Both illuminance (lux) and light output (lumens) are used to characterize the performance of lighting products and systems. Neither metric, on its own, is fully capable of conveying the appearance of light within a space and each has advantages depending on the needs of the customer and the specifics of the application for which the light is intended.

Additional lighting metrics

Luminance is used in some situations to describe the light emitted by an object in a specific direction. Luminance is most closely related to what our eyes actually 'see' in the sense that, when we look at an object, we are seeing the reflection of light from that object towards our viewing position. This takes into account the lumens falling on that surface and the surface's reflective properties. Display screens are typically rated in terms of their luminance, but luminaires and lamps are not.

Finally, **candela distribution plots** produced by a goniophotometer are common in the lighting industry. These plots show the angular distribution of light from a light source and can be displayed as polar or rectilinear graphs. They are produced by a goniophotometer and contain both distribution and total flux information. While very useful to lighting professionals, candela plots are too complex to be of use as a consumer friendly lighting metric.

Lighting design and illuminance targets

Lighting designers and architects will often have lux targets in their designs, and the lighting systems they specify will be chosen to provide enough light to meet these illuminance goals. There are some commercial standards in use that have minimum recommended illuminance targets for different types of spaces and different activities such as basic navigation, reading, cooking, etc. [2] A few program recommendations,

[2] *IESNA lighting handbook; ISO 8995-1:2002(E)/CIE S 2008/E:2001*

including those in use by Lighting Global to determine eligibility to participate in consumer awareness campaigns, point to suggested minimum illuminance levels for off-grid spaces lit by pico-powered lighting products;[3] these levels are well below those used in industrialized countries and reflect the economic challenges present in these regions (Table 1). Research by Lighting Global suggests that the cost of lighting service will remain the primary parameter that influences the amount of light purchased by customers in off-grid communities for the foreseeable future, and light levels in spaces illuminated by pico-powered products will likely remain below those typically found in more developed regions with access to grid power.

Table 1. Illumination levels

Recommended min. lux levels	Task lighting (reading, sewing)	General area lighting
IESNA	500-1000	30-100
CIE	300-500	40-150
LUTW	25-50	5-25
Lighting Global	> 50	n/a

Illuminance ratings

The use of illuminance to characterize the performance of a pico-powered lighting product requires additional information to qualify the lux measurements. The distance from the light source to the measurement surface (the task plane) and lamp orientation must be known to establish the geometric relationship between source and lux meter. Multiple illuminance measurements are also helpful to establish the overall size and shape of the task plane; illuminance maps are often used to communicate this information (Fig. 1). Measuring and reporting the total area where the illuminance exceeds a minimum value can also provide a 'single number' metric, but this approach may not distinguish between products that just meet the minimum value and those that greatly exceed it. The Lighting Global program uses a metric defined as the total surface area (m^2) with illuminance > 50 lux.

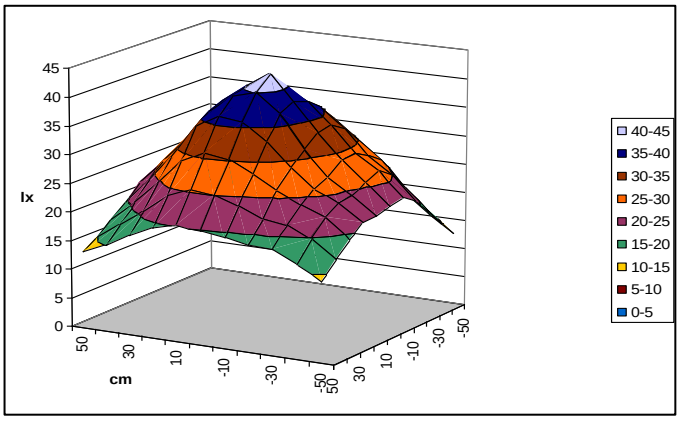

Figure 1. Illuminance map

Lumen output (luminous flux) ratings

The most common metric used to rate individual lamp light sources (i.e. light bulbs that fit into electrical light sockets) and most lighting systems is lumen output. Lumen output is a single number that does not require any additional qualifiers. Direct comparisons between products are possible if their lumen outputs are known.

Most lamps and lighting products that include consumer facing light output information will have lumen output as one of the performance numbers. Task lighting applications will occasionally include only illuminance data, although buyers and others who are considering these products would be better served if the lumen output values were also included.

The introduction of compact fluorescent and LED based replacement lamps has given rise to the use of ***equivalency*** claims whereby an LED lamp (for example) will be compared to an incandescent lamp of equivalent light output. This imperfect metric relies on the assumption that the target consumer is familiar with the comparison lamp, but it does have the advantage of providing a known reference point to the customer. A 40-watt incandescent lamp produces

[3] *Light Up the World (LUTW) Irvine-Halliday 2001*

approximately 450 lumens of light, so anyone with experience with this type of lamp will have a rough understanding of the amount of luminous flux (i.e. light output) that the light produces.

Using an incandescent lamp for equivalency claims will not, however, work in an off-grid environment where consumers may not be familiar with these lamps. Other light sources such as candles or kerosene lanterns may provide a better context for comparison, but these too present issues regarding output consistency and consumer familiarity.

Comparing lumens and lux

No single measurement of light output can provide a complete assessment of the performance of that light. Advantages and disadvantages for both illuminance and luminous flux measurements are shown in Fig. 2 and Fig. 3. There are strengths and weaknesses associated with each technique in the context of testing and also in how each metric is able to characterize a light source. Lumen output is the metric that is able to capture the most information, for both an individual product and across multiple products, with a single reported test result.

Conclusions

Based on our research and experience with the market, Lighting Global currently believes that luminous flux (lumens) is the first and best choice for a primary consumer facing metric to describe light output. This is consistent with the lighting industry at large and satisfies the need for a single metric that is simple to report and allows cross-product comparisons.

Developing the metric in the context of a consumer-friendly listing remains a challenge. Consumer education, whether at the point of purchase or in advertising and outreach campaigns, will play a key role in communicating an understanding of the metric to end users and providing value in product selection.

Lumen output (total luminous flux)

Advantages

- Lumen output is a single number describing a basic aspect of all light sources.
- Direct comparisons between products are possible.
- No additional testing information is required to understand the metric.
- Lumen output is independent of product mounting height or orientation.
- Lumens are used throughout the world to describe lamps, lighting products, and luminaires.

Disadvantages

- Lumen output does not reveal anything about light distribution.
- Lumen output can understate the performance of task lights and narrow beam lamps.
- Flux measurement equipment and lamp standards are expensive and require skilled technical staff and frequent calibration.

Fig 2. Luminous flux (lumens) as a lighting metric

Illuminance (lux measurements)

Advantages

- Illuminance measurements contain information on both the lumen output of a lamp and the light distribution.
- Illuminance is closely related to what the eye perceives.
- Illuminance can accurately describe the lighting performance of task lights and directional luminaires.
- Illuminance is relatively easy to measure.
- lux meters are inexpensive to own and calibrate.

Disadvantages

- Lux measurements require additional information: distance, lamp orientation, and task plane area.
- Illuminance can understate the performance of ambient/omnidirectional lamps.
- A single illuminance measurement is not enough to describe the performance of a source or allow comparisons between different products.

Fig 3. Illuminance (lux) as a lighting metric