Understanding Photometric Reports for SSL Products

In 2008, IESNA released its *Approved Method for Electrical and Photometric Measurements of Solid-State Lighting Products*, designated as IES LM-79-08. When evaluating SSL photometric reports, which features are useful? Which data are essential? With some basic orientation, understanding LM-79 test reports may be easier than you think.

Given the complex functional relationship between light-emitting diode (LED) light sources and luminaire or replacement lamp components, solid-state lighting (SSL) products do not lend themselves to traditional photometric methods, which were developed separately for lamps and luminaires (i.e., *relative* photometry). Consequently, the Illuminating Engineering Society of North America (IESNA) developed an SSL product testing method based on *absolute* photometry, which characterizes a luminaire or replacement lamp as a whole—and acknowledges the unique thermal, optical and electrical properties of these integral products.

The LM-79 Report

IESNA has developed test methods for a broad range of light sources and luminaire types, each providing test protocols specific to the unique attributes of the tested lighting products. For SSL products, LM-79 testing addresses the following key measurements: **electrical characteristics, light output, luminous intensity distribution**, and **color characteristics**. Another important measure of SSL performance, lumen maintenance, is addressed in a separate IESNA test method (IES LM-80-08). LM-79 does not prescribe a specific testing report format or contents, but instead makes the general requirement that the report "… shall list all significant data for each SSL product tested together with performance data."[1] LM-79 results are critical for evaluating SSL products against application requirements, comparing with other lighting products—and qualifying for the ENERGY STAR® voluntary labeling program.[2]

Electrical Characteristics

LM-79 prescribes the power supply characteristics and electrical instrumentation setup for SSL product testing, and requires that the tested product be operated at its rated voltage (AC or DC). Measurements are typically collected for **input voltage** (in volts, V), **input current** (in amperes, A), and **input power** (in watts, W). These data are used to calculate luminaire efficacy (expressed in lumens per watt, lm/W)—a core indicator of SSL product performance. It is important that separate electrical measurements are taken for each type of photometric test included in the LM-79 report (i.e., integrating sphere and distribution methods discussed below), so that luminaire efficacy is calculated using light output and power measurements from the same test.

Light Output (Luminous Flux)

Essential Data

Total light output (i.e., luminous flux, expressed in lumens, lm) can provide a general indication of how a lighting product stacks up against application needs and/or products it is intended to replace. By extension, **luminaire efficacy** (lm/W) indicates how efficiently

[1] Section 14.0 of LM-79-08 also includes a list of "typical items reported."

[2] ENERGY STAR for SSL program details available at: www.ssl.energy.gov/energy_star.html.

Photo credit: Labsphere, Inc.

Test Method Quick Reference

IES LM-79-08: *IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*. Describes the method of absolute photometry for LED luminaires and integral replacement lamps, and associated electrical measurements. Provides performance data (i.e., light output and efficacy, light distribution, and color characteristics) for the entire, integrated product—versus separate results for the light source ("lamp") and luminaire provided by traditional relative photometry.

IES LM-80-08: *IES Approved Method for Measuring Lumen Maintenance of LED Light Sources*. Describes the measurement of lumen maintenance—the amount of light output maintained over time—for LED packages, arrays or modules (i.e., devices). LED devices are operated for at least 6,000 hours at representative operating temperatures, with photometric data collected at a minimum of every 1,000 hours. Using modeling guidance from a proposed companion test method, IES TM-21 (see below), this "device-level" data can be applied to the integrated LED product to predict useful operating life and light output over time.

IES TM-21 (IN DEVELOPMENT): *Lumen Depreciation Lifetime Estimation Method for LED Light Sources*. Will provide a method for determining an LED luminaire or integral replacement lamp's expected operating life, based on initial performance data collected per IES-LM-80. IES TM-21 is currently in development, with multiple models being considered to address the potential degradation paths seen with different LED technologies.

IES LM-79 performance testing is typically conducted by independent testing labs on behalf of manufacturers or testing programs like DOE CALiPER.* Given its duration and space requirements, long-term testing under IES LM-80 is generally performed by LED device manufacturers.

* More information on DOE's Commercially Available LED Product Evaluation and Reporting (CALiPER) Program can be found at: www.ssl.energy.gov/caliper.html.

the product generates its light output. Both total light output and luminaire efficacy are major criteria for ENERGY STAR qualification. LM-79 allows two different methods for measuring total luminous flux, one or both of which may be referenced in a test report. The *integrating sphere* method, as the name suggests, integrates the total light output of a tested source to produce a single measurement. In contrast, the *distribution (i.e., goniophotometer)* method collects multiple luminous intensity measurements around the source's horizontal and vertical axes, which are converted and summed as total luminous flux.

Zone	Lumens	%FIXT
0-30	702	68.69
0-40	971	95.06
0-60	1021	99.98
0-90	1022	100.00
90-180	0	0.00
0-180	1022	100.00

Figure 1. Detail from Typical Zonal Lumen Summary Table

Total light output measurements may be presented as a single value, or as the summed values in zonal lumen summary tables. The sample zonal lumen summary in Figure 1 shows the cumulative lumen totals for different vertical angle "zones," with the 0° – 180° zone (highlighted) representing the total light output (in the case of this recessed downlight, no light is emitted above 90° vertical). If both integrating sphere and goniophotometry have been performed, then two sets of total light output and luminaire efficacy values may be provided—these values may differ by 3% due to typical measurement uncertainties. ENERGY STAR for SSL also establishes zonal lumen requirements for many applications, to help ensure that SSL products perform similarly to the traditional lighting products they replace.

Calculating Luminaire Efficacy

Although input power and light output values may be presented in multiple locations and formats within an LM-79 report, a luminaire efficacy value might not be included in the document. Calculating this value is straightforward, following a few simple steps:

Step #1 Note the tested product's total light output—either a single value from an integrating sphere test, or a summed zonal lumen value from a goniophotometer test. For example, the total lumen output value from the zonal lumen summary table in Figure 1 is **1,022 lm**.

Step #2 Note the measured input power *from the same photometric test as the total light output*. For this example, assume a value of **23.3 W**.

Step #3 Divide the total light output by input power to obtain the tested product's luminaire efficacy. Completing the example:
1,022 lm / 23.3 W = **43.9 lm/W**

Luminous Intensity Distribution

Essential Data

In addition to how much light an SSL product produces, it is important to understand where the product directs its light output. LM-79 reports typically present **luminous intensity distribution** data in both tabular and polar graph formats. A **polar graph** allows the reader to quickly assess whether the luminaire or replacement lamp has a "narrow" or "broad" distribution, and gauge its symmetry. For example, Figure 2 illustrates an SSL downlight that produces its highest luminous intensity directly below the fixture (i.e., 0° or nadir), tapering off with essentially no light output above 45° vertical. The solid and dashed lines represent two vertical "slices" made along and across the fixture (i.e., at 0° and 90° horizontal, respectively). The two distributions are nearly identical, suggesting that the light distribution ("beam") is essentially symmetrical about the vertical axis.

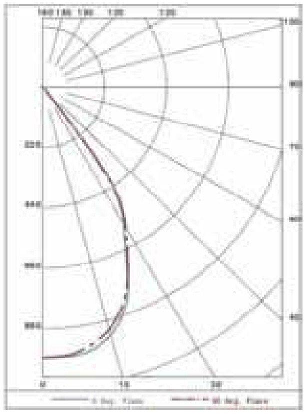

Figure 2. Sample Polar Luminous Intensity Distribution Graph. *Image credit: Luminaire Testing Laboratory, Inc.*

The polar graphs correspond with tabular intensity data for different vertical and horizontal angles (expressed in candelas, cd), and may be referred to as a "candela distribution" or "candlepower summary." Luminous intensity values are a key component of illuminance calculations, and distribution data can be provided by the testing laboratory in standardized "IES file" electronic format, compatible with lighting calculation and visualization software.[3]

Useful Features

Luminous intensity distribution data inform a range of other lighting metrics used to characterize visual comfort and SSL product performance. Directional lamps, such as halogen MR16 and PAR lamps, are typically characterized by their **center beam candlepower (CBCP)** and **beam angle,** and these measures are useful when comparing LED replacement lamps with their traditional counterparts. Although CBCP and beam angle are often not included in LM-79 reports, they can be approximated from tabular intensity data (see "Comparing Directional Lamps").

[3] Electronic file format specified in IESNA LM-63-02.

Comparing Directional Lamps

If not presented in the LM-79 report, CBCP and beam angle for directional LED replacement lamps can be derived from tabular intensity data. Figure 3 presents the candela (intensity) distribution data for an LED PAR38 replacement lamp, and a corresponding polar intensity graph. The important features of the table are the **vertical angles** (left column) and **intensity data** for each vertical angle (right column). Vertical angles describe the location of data points relative to the center beam (or axis) of the lamp, as illustrated in the polar intensity graph. As is common for directional lamps, only one set (plane) of intensity data is provided, and the beam is assumed to be symmetrical around its central axis.

With the lamp pointed downward, a vertical angle of 0° describes the center of a directional lamp's beam, the single point at which the CBCP is determined—in this case, **1855 cd** (yellow highlight). **Beam angle** is defined as **two times the vertical angle** at which the intensity is **50% of the maximum**. In this example, the maximum intensity is the CBCP (1855 cd) and 50% maximum occurs at approximately 15° (green highlight). Because this vertical angle describes only one-half of the beam, the beam angle would be approximately **30°**.

The CBCP and beam angle data should be used to verify the claimed values from the LED replacement lamp's packaging and/or catalog listing. The data can also be compared with that for halogen MR16 lamps to determine if the LED product will provide the "punch" and distribution needed for the lighting application.

DEG	CANDELA
0	1855
5	1742
15	954
25	291
35	68
45	22
55	15
65	10
75	5
85	2
90	1

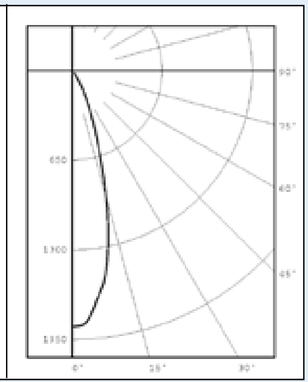

Figure 3. Sample Tabular Intensity Data and Polar Intensity Plot for an LED PAR38 replacement lamp. *Image credit: Independent Testing Laboratories, Inc.*

Luminance summaries (expressed in candelas per square meter, cd/m^2) are structured similarly to luminous intensity tables, with data that roughly correlates with perceived "brightness" of a light source from different observer positions. As an example, excessive luminance—particularly at higher vertical angles—could potentially result in visual discomfort from glare.[4]

Many test reports also provide an isoilluminance plot, an illustration of a tested product's predicted illuminance pattern and resulting initial light levels (expressed in footcandles, fc). As shown in Figure 4, the diagram (also called an "isofootcandle plot") uses contour lines to delineate the light pattern and horizontal illuminance levels below the tested product, with a conversion chart included for different mounting heights. The scale of the x and y axes is expressed in multiples of the mounting height, so it is important to convert to actual distances and use the same mounting heights when comparing with other products.

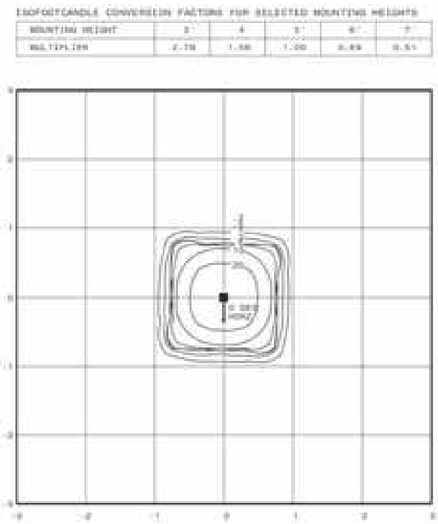

Figure 4. Sample Isoilluminance Plot with Mounting Height Conversion Factors. *Image credit: Luminaire Testing Laboratory, Inc.*

Color Characteristics

Essential Data

SSL luminaires and lamps may be used to replace and/or integrate with other traditional "white light" products. Consequently, it is important to measure and describe SSL **color characteristics**. LM-79 prescribes methods for measuring the total radiant power (spectral content) of SSL products, from which **chromaticity coordinates, correlated color temperature (CCT)**, and **color rendering index (CRI)** can be derived. ENERGY STAR for SSL also establishes application-specific limits for these measures.

Typically, a product's **spectral power distribution (SPD)** is presented in a graph format (Figure 5), which allows the reader to evaluate the relative amount of radiant power (expressed in milliwatts per nanometer, mW/nm) across the range of wavelengths in the visible spectrum (expressed in nanometers, nm), or approximately 380 – 780 nm. Some reports may provide spectral radiant power measurements in tabular format, in 10 nm increments.

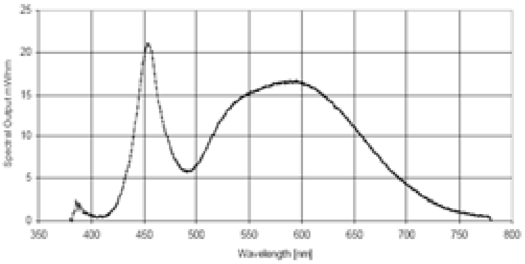

Figure 5. Sample Spectral Power Distribution (SPD) Graph. *Image credit: Lighting Sciences Inc.*

[4] ***Note***: Given the complex and dynamic interactions between lighting systems, the lighted environment, and observer, it is difficult to characterize glare based on photometric data alone.

Useful Features

Test reports provide chromaticity coordinates (x, y; u, v; and/or u', v'), and typically plot these values on the corresponding **CIE chromaticity diagram** (Figure 6), giving a visual indication of where the tested product falls on the "black-body locus," along which "white light" is defined for lighting products.[5] The *Duv* value, i.e., the plotted distance of chromaticity coordinates from the blackbody locus, describes the relative "whiteness" of light for a given CCT.[6] Products with excessive *Duv* values can appear off-white (e.g., pinkish or greenish). *Duv* can be calculated, or requested if not available on reports.

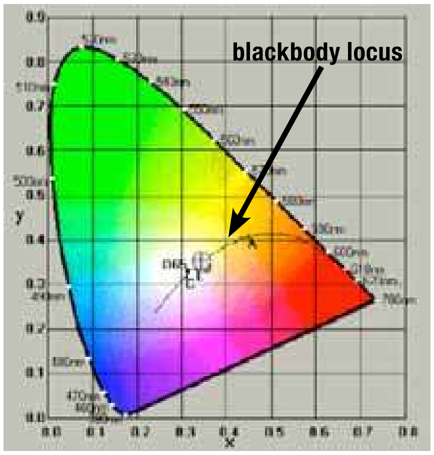

Figure 6. Sample CIE 1931 x, y Chromaticity Diagram, illustrating a tested product's coordinates (indicated by "⌖") on the blackbody locus. *Image credit: OnSpeX*

Additional Information

Thermal Measurements

LED performance and service life are closely tied to the LED's operating temperature, which can be extrapolated from readings at a designated **temperature measurement point** (TMP, also known as a "hot spot") on the SSL luminaire or replacement lamp. LM-79 does not address product operating temperature or its measurement; however, TMP data is required separately under LM-80 for LED lumen maintenance life testing. Having surface temperature measurements also allows the reader to determine if a sample product was operating at similar temperatures in different photometric tests, as different operating temperatures could affect light output and efficacy.

Sample and Testing Description

Test reports should identify the **testing laboratory** and clearly indicate that **LM-79 was used**, as well as identify the **photometric methods used** (integrating sphere and/or goniophotometer) and a listing of the **testing equipment used**. Some reports may also provide equipment calibration dates and/or descriptions of reference standards and their traceability. Because SSL product performance is closely linked to its components, physical construction and thermal characteristics, it is important that the report explicitly identify the particular **version of the product tested**. Attention should also be paid to secondary optics and other accessories (e.g., lenses, diffusers, trimrings, etc.) that can affect product performance, and whether these items were in place during testing.

Conclusions

Photometric reports for SSL products under LM-79 present basic measures—electrical, light output and efficacy, light distribution, and color characteristics—that inform a number of other useful report features. For example, luminous intensity distribution data form the basis of polar intensity graphs, fixture luminance tables, and isoilluminance plots. Spectral radiant flux measurements are used to generate SPD graphs and tables, as well as determine chromaticity coordinates, CCT and CRI. Even if not included in a particular lab report, the data and information discussed here is typically collected by and available from the testing laboratory at their customer's request. Additional educational materials about SSL product performance and measurements are available from the DOE Solid-State Lighting program website.[7]

[5] Figure 6 illustrates the Commission Internationale de l'Écalairage (CIE) 1931 x, y Chromaticity Diagram. Chromaticity definitions for nominal CCT values in SSL products are presented in Table A1 of American National Standard ANSI_NEMA_ANSLG C78.377-2008.

[6] To meet ANSI specifications, measured chromaticity coordinates for an SSL product must plot not only within established CCT boundaries but also within prescribed distances of the blackbody locus on the CIE 1976 u', v' Chromaticity Diagram. The *Duv* chromaticity targets and tolerances are presented in Table 1 of ANSI_NEMA_ANSLG C78.377-2008.

[7] Information resources available at: www1.eere.energy.gov/buildings/ssl/factsheets.html.

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