UNDERSTANDING LM-79 REPORTS

In 2008, the Illuminating Engineering Society of North America (IES) published LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*. Why are special test procedures required for this technology, and what kind of information is gleaned from testing conducted using this new method?

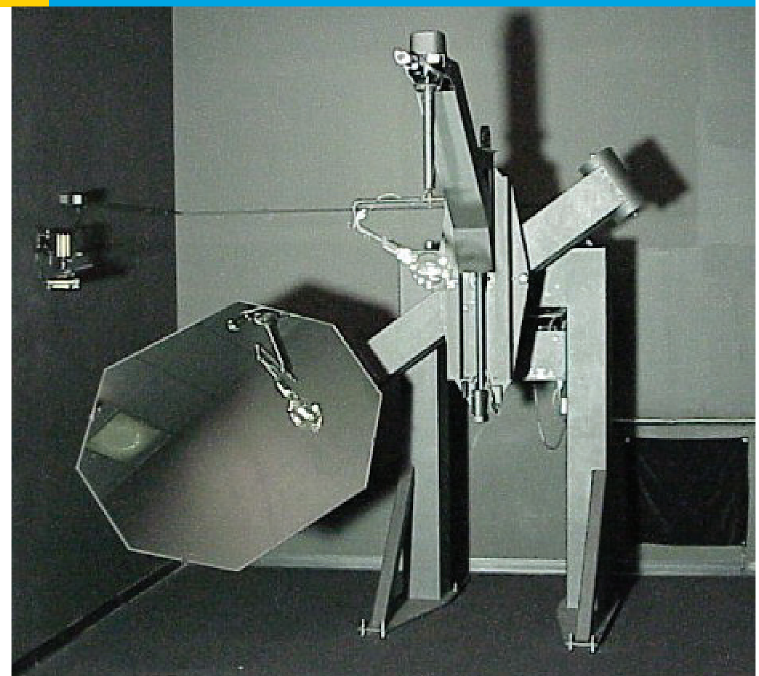
LM-79 testing captures performance characteristics of products that feature solid-state lighting (SSL) technology, including light-emitting diodes (LEDs). This testing provides a snapshot of performance under specified operating conditions at some point in the life of a product, usually at the beginning of operation—these are referred to as initial measurements. It does not address lifetime ratings, changing performance over time (e.g., lumen maintenance), or LED case temperature.[1] The LM-79 method is applicable to integrated LED products, such as luminaires and replacement lamps. It is not applicable to LED packages, modules, or arrays (herein collectively referred to as LED light sources).[2]

LM-79 data enables objective product comparisons, allows for evaluation relative to performance requirements, and is required by voluntary labeling programs such as LED Lighting Facts and ENERGY STAR®.[3] Although LM-79 does not prescribe a report format or the minimum content, a substantial list of "typical items reported" is provided. Key types of measurements addressed in the document include electrical characteristics, lumen output, spatial distribution of light, and color attributes. The DOE fact sheet, "LED Color Characteristics," (which is available online at *www.ssl.energy.gov/factsheets.html*) is dedicated to a discussion of color-related metrics that may be included in LM-79 reports.

Electrical Characteristics

A variety of electrical measurements may be conducted as part of LM-79 testing, including but not limited to:

- Input voltage, expressed in volts (V). Testing is performed with the SSL product operated at its rated input voltage.
- Input current, expressed in amperes (A). Input current can be either direct current (DC) or alternating current (AC), depending on product design. Note that this metric is not equivalent to the current supplied to a given LED light source (i.e., LED drive current), which often cannot be measured directly without damaging the product.[4]
- Input power, expressed in watts (W). Input power is essential for determining energy savings.
- Power factor (PF), is a power quality metric reported as a unitless decimal value between zero and one. PF is calculated by dividing input power by the product of input voltage and input current.



A goniophotometer is used to characterize spatial distribution of light. A mirror travels around a light source and reflects light to a detector, providing intensity measurements over a range of angles. (Photo credit: ITL Boulder)

Lumen Output and Luminous Efficacy

Light output—more formally referred to as luminous flux—is expressed in lumens (lm).[5] Lumen output is a more meaningful metric than input power when establishing product equivalency because the ratio of total lumen output to input power can differ from product to product.[6] This quotient is termed luminous *efficacy* and is expressed in lumens per watt (lm/W).

Relative vs. Absolute Photometry

Non-SSL products are typically measured using *relative* photometry, for which lamps and ballasts are tested separately from luminaires. Luminaire *efficiency* is calculated by dividing the total lumen output of the luminaire by the product of the rated

1 Long-term performance is discussed in the DOE fact sheet, "Lifetime of White LEDs," which is available at www.ssl.energy.gov/factsheets.html.

2 The term LED light source is defined in IES LM-80-08. See IES RP-16-10 for formal definitions of related terms.

3 For more information on these programs, please visit www.lightingfacts.com and www.energystar.gov.

4 LED drive current is nominal (i.e., reported by manufacturer); this metric is discussed in the DOE fact sheet, "Lifetime of White LEDs."

5 Photometric quantities are based on photopic visual adaptation. For more on this topic and the use of scotopic/photopic (S/P) ratios, see IES TM-12 and the 10th edition IES Lighting Handbook.

6 See the DOE fact sheet, "Establishing LED Equivalency," for more on this topic.

output of the lamp(s) and the ballast factor (BF). Once determined, this value is assumed to be unaffected by the choice of lamp or ballast. By contrast, due to their unique thermal and electrical characteristics, no standard test method has been developed to measure the lumen output of LED light sources; thus, relative photometry is inapplicable. To remedy this situation, the LM-79 test method uses *absolute* photometry to directly measure total lumen output for a particular configuration of an integrated LED lamp or luminaire with LED light sources operated in situ; consequently, the efficiency of an integrated LED luminaire cannot be calculated in a standard manner. However, luminous efficacy can be used to compare integrated LED luminaires or lamps with non-SSL technologies.[7]

It should be noted that when using relative photometry for a non-SSL luminaire, a single test can be adjusted in a straightforward manner to estimate performance with a variety of different lamp-ballast systems. Lacking a recognized method for similar adjustment of absolute photometric data, and given the frequent release of next-generation LED light sources, the test burden for manufacturers of LED luminaires and lamps may be greater than for other technologies.

Spatial Distribution of Light

Once the total lumen output of an SSL product has been determined, it is important to understand where the light is directed. More light is not necessarily of benefit if it is not delivered where it is needed; thus, total lumen output should only be used to compare products which distribute light in a similar manner. Luminous intensity, expressed in candelas (cd), is measured at a variety of angles to enable characterization of the spatial distribution of light. This intensity data is then used to calculate a variety of metrics and to generate diagrams that might be found in photometric reports, depending on the type of product and the intended application. Common examples of such metrics and diagrams include polar plots of luminous intensity, zonal lumens and BUG ratings, luminance of lamp or luminaire, beam and field angles, spacing criteria, and isoilluminance plots.

Polar Plots of Luminous Intensity

Luminous intensity data is most directly communicated using polar plots and tables. The polar plot in Figure 1 is essentially a cross-sectional side view of the light emitted by a 10,000 lumen source with an intensity distribution that is proportional to the cosine of the angle from nadir (i.e., straight down). A downward-directed LED light source lacking any form of optical control could be expected to emit light in this manner. The blue curve shows luminous intensity in a vertical plane passing through the center of the luminous opening (the primary light-emitting portion of the lamp or luminaire). If for a given product the intensity plots in all possible cross-section planes are identical, then the intensity distribution can be said to exhibit rotational symmetry. In this example, it can be inferred from one plot that luminous intensity is zero in all directions at or above 90° from nadir (i.e., no light is directed upward). Polar plots are usually given for the vertical plane in the direction of maximum luminous intensity and/or for two orthogonal vertical planes.

Figure 2 shows a similar plot for a streetlight of equal output (10,000 lumens), but featuring specialized optics to produce a luminous intensity distribution that is only symmetric about a single vertical plane (bilaterally symmetric). The two blue curves show intensity in vertical planes—the dark blue curve shows the plane containing the direction of maximum intensity, and the light blue curve shows the plane of symmetry. By contrast, the red curve presents a kind of birds-eye plan view, illustrating intensity around the base of a cone that originates at the center of the luminous opening and has an angle from nadir equal to the angle of maximum intensity. It can be inferred from this diagram that the maximum intensity occurs at an angle of approximately 68° from nadir and 75° from the vertical plane of symmetry.

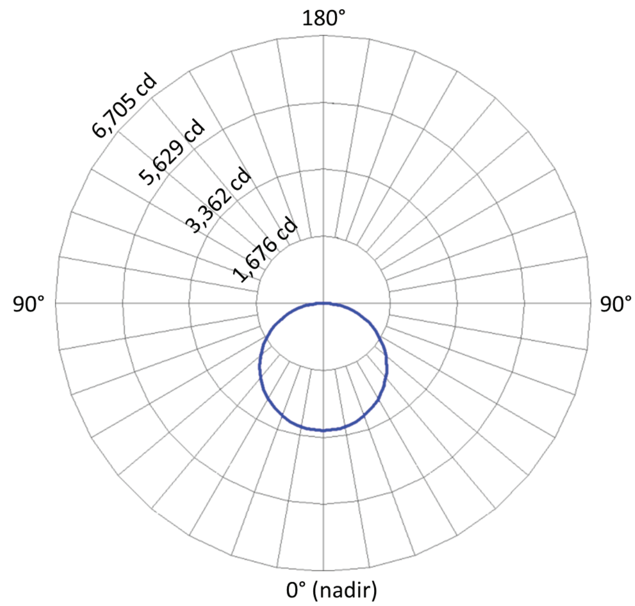


Figure 1. *Polar plot of the luminous intensity for a light source with a cosine distribution.*

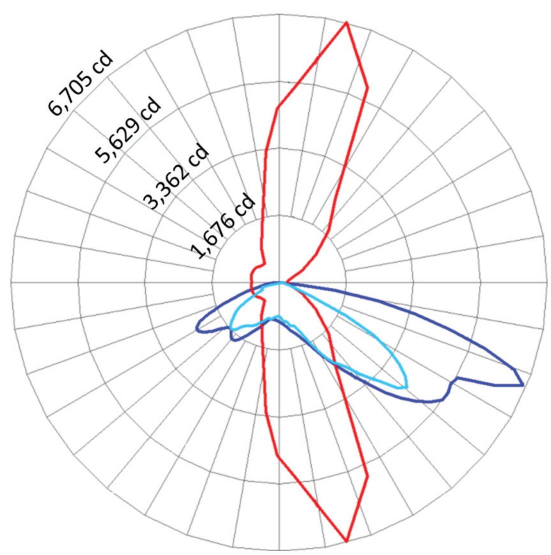


Figure 2. *Polar plot of the luminous intensity for a light source with a bilaterally symmetric distribution.*

7 *See the DOE fact sheet, "Luminaire Efficacy," for more on this topic.*

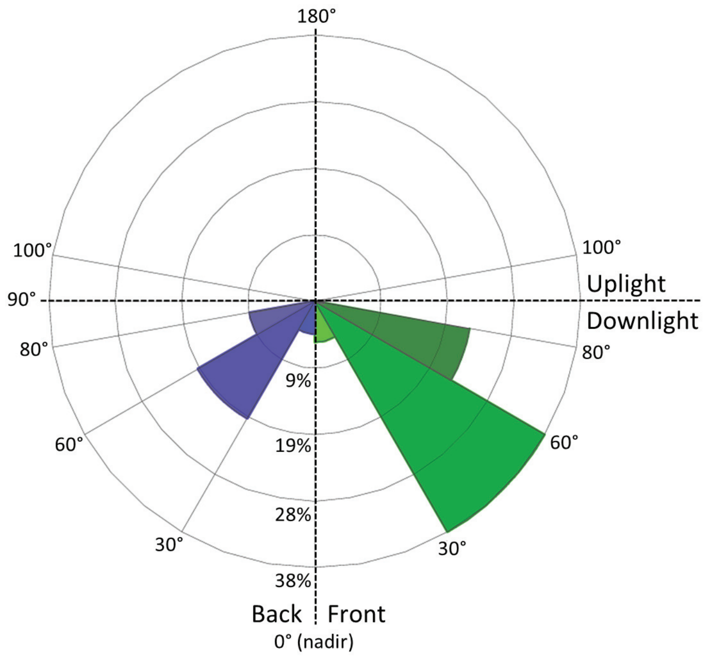


Figure 3. *Zonal lumen diagram showing the percentage of luminaire lumens emitted in each of the LCS zones for the same bilaterally symmetric distribution shown in Figure 2.*

Zonal Lumens and BUG Ratings

Spatial distribution of light can also be characterized by the amount of luminous flux in various zones, which are defined by vertical planes and/or angles from nadir. Figure 3 illustrates zonal lumen densities for the bilaterally-symmetric intensity distribution shown in Figure 2. This angular breakdown corresponds to the IES Luminaire Classification System (LCS), which is used to determine Backlight-Uplight-Glare (BUG) ratings for outdoor lighting products.[8]

Luminance of Lamp or Luminaire

Luminance, expressed in cd/m^2, is often reported for a variety of viewing angles and acts as a surrogate for the perceived brightness of the lamp or luminaire. However, these values are averaged across the luminous opening and interpretations of what might constitute the luminous opening may vary.[9] Consequently, this metric may not provide a meaningful characterization for products exhibiting non-uniform aperture luminance (e.g., high-intensity discharge (HID) or LED luminaires used to light parking lots).[10]

Beam and Field Angles

Directional lamps (e.g., PAR or MR lamps) are typically characterized on the basis of beam angle and center beam intensity, due to the rotational symmetry of the luminous intensity distribution about the center beam axis. In other words, the projected pattern of light—which is circular if directed perpendicular to the surface—does not change as the lamp is rotated about its axis.[11] Similarly, floodlight luminaires featuring luminous intensity distributions that exhibit quadrilateral symmetry (elliptical pattern) are often classified on the basis of field angles measured in the two orthogonal planes of symmetry.[12] Beam angle and field angle are calculated as twice the angle (from center beam) where intensity is 50% or 10% of the maximum value, respectively.[13] For example, the cosine distribution in Figure 1 would yield relatively wide beam and field angles of 120° and 169°, respectively.

Spacing Criteria

For indoor applications, spacing criterion (SC) is used to approximate the area covered by recessed downlights and troffers as a function of the height above the workplane. For example, a luminaire with a cosine intensity distribution would have a SC of 1.3, meaning that it would be expected to produce adequate workplane uniformity when arranged on a square grid spaced along either axis at a distance of up to 1.3 times the height above the workplane.

Isoilluminance Plots

Many photometric reports include a diagram plotting isolines of equal horizontal illuminance, expressed in footcandles (fc) or lux (lx), as shown in Figure 4. These isoilluminance plots, which

8 See the DOE fact sheet, "Outdoor Area Lighting," for details.

9 See ANSI/IESNA LM-63-02 for a discussion of luminous openings. This document also provides a standard file format (IES-format) for the electronic transfer of luminous intensity data, commonly referred to as IES files.

10 This also applies to many louvered troffers; IES RP-1-04 recommends evaluation of intensity in lieu of luminance for mitigation of reflected glare from video displays.

11 The term candlepower, which is synonymous with intensity, has been deprecated by the IES but remains in common use.

12 A field angle classification system for floodlights can be found in IES RP-6-01.

13 Note that ANSI/IES RP-16-10 uses the maximum intensity, whereas ANSI C78.379-2006 uses the center-beam intensity.

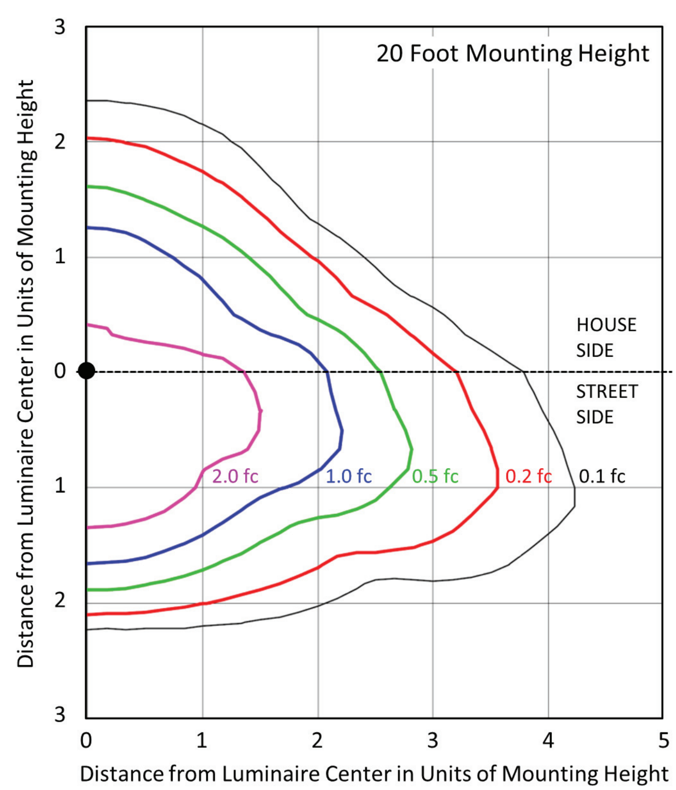


Figure 4. *Isoilluminance plot for the bilaterally symmetric distribution shown in Figures 2 and 3. For a cosine distribution, the isolines would be circles.*

are analogous to the contour plots used to indicate elevation on topographic maps, can serve as simple templates for preliminary design in applications where inter-reflection of light from building surfaces is expected to be negligible. Horizontal distances are either fixed or given as a multiple of luminaire mounting height. In the latter scenario, instructions are typically provided to enable adjustment of isoline values for different mounting heights and total lumen output levels.

Additional Considerations

Test Method and Apparatus

The content of a given LM-79 report depends in part on the apparatus used for measurement. Using an integrating sphere, the total lumen output of a tested source is captured in a single measurement (see Figure 5). An integrating sphere is also the most common apparatus for capturing colorimetric data. By contrast, using a goniophotometer, luminous intensity measurements are recorded at a series of locations surrounding the test sample and then total luminous flux is calculated. Some goniophotometers may have the capability, but most do not measure colorimetric performance.

Given the different capabilities of the two methods, both of which are documented in LM-79, the content of photometric reports may vary. For example, if only the integrating sphere method was used, the report will not characterize the spatial distribution of light. Similarly, if only the goniophotometry method was used, the report is unlikely to include color metrics. Notably, if both the integrating sphere and goniophotometry methods have been used, then two sets of values may be provided. In some cases, the same metrics will be included for both methods (e.g., lumen output or luminous efficacy), and the values may differ somewhat due to measurement uncertainties.

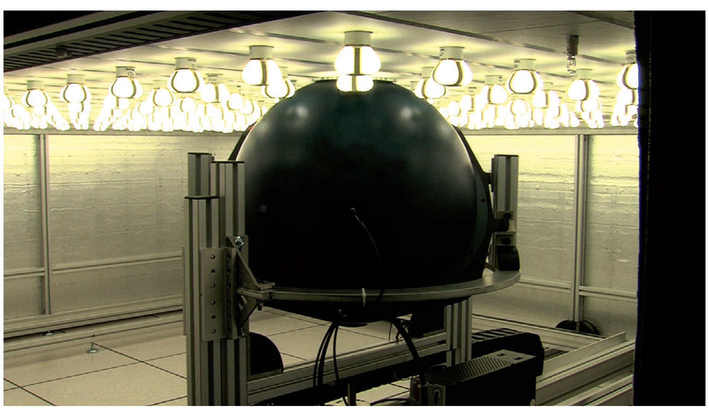


Figure 5. *A small, mechanized integrating sphere used for testing L Prize product samples (www.lightingprize.org).*

Beyond Performance Metrics

Aside from the performance of the product itself, several important elements should be included in LM-79 reports. For all photometric reports, the test laboratory—which should be accredited for the specific tests performed—should be clearly identified.[14] Further, reports should clearly indicate that the LM-79 test method was followed, list the apparatus(s) used, and describe the specifics of all test equipment. It is also important that the report explicitly identify the particular configuration and version of the product tested, along with the test date. Additionally, complete information should be provided for LED light sources, power supplies, and other components, such as those used for optical control and thermal management. Finally, product photographs can reveal items that may otherwise be overlooked or difficult to adequately describe. These items should be compared to product specification sheets to ensure manufacturers are accurately using the test results.

Using LM-79 Test Data

The metrics and diagrams included in LM-79 reports can be useful for preliminary product screening. An experienced user may be able identify products that have an appropriate distribution for a specific application, or detect potential problems in terms of uniformity, glare, or obtrusive light. For example, it should be clear that a product with a cosine intensity distribution would direct a greater proportion of its output (50%) behind the luminaire than would the product with the bilaterally-symmetric intensity distribution shown in Figure 2 (33%). In addition, a series of products with a cosine distribution would be less likely to meet uniformity requirements—they might create pools of light directly under luminaires, with relatively dark areas in between—in scenarios such as street lighting, where the distance between luminaires often greatly exceeds the mounting height.

Simple metrics and diagrams, however, are easily misinterpreted. A given product cannot be simply characterized as low or high performance—it may perform well in one scenario and poorly in another. Lighting software can be used to overcome this gap by incorporating LM-79 test data (typically using IES-format electronic files), geometric parameters, reflectance characteristics of illuminated surfaces, and the combined contribution of all luminaires in the lighting system. Although LM-79 reports may be somewhat limited in utility, the data gleaned from LM-79 testing enables complete photometric analysis to ensure requirements are satisfied.

14 The CALiPER program only uses independent testing laboratories with LM-79 accreditation which includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP). Please visit www.ssl.energy.gov/test_labs.html for details.

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