ASSIST *recommends...*

Recommendations for Evaluating Street and Roadway Luminaires

Volume 10, Issue 1
April 2011

A publication of the Alliance for Solid-State Illumination Systems and Technologies

Lighting Research Center

Rensselaer

Published by the Lighting Research Center, Rensselaer Polytechnic Institute, 21 Union St., Troy, NY 12180, USA. Online at http://www.lrc.rpi.edu.

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Introduction

This document details a recommendation for evaluating the photometric performance of street and roadway luminaires for all light source technologies. The evaluation is based on an assessment of the effectiveness of luminaires at meeting predetermined, application-based photometric criteria. The metric described here is an extension of the work described in the publication *ASSIST recommends… Recommendations for Evaluating Parking Lot Luminaires* (Vol. 7, Iss. 3; ASSIST 2010) and is intended to be used as tool in the process of selecting and rank ordering luminaire choices for a street lighting application.

This recommendation was developed by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in collaboration with members of the Alliance for Solid-State Illumination Systems and Technologies (ASSIST). The suggested audience for this document is luminaire manufacturers, street lighting designers and specifiers, and luminaire purchase decision-makers.

Background

Well-designed, fixed street and roadway lighting is a valuable infrastructure investment because it can provide social and economic benefits to the community (Rea 2000). It is the result of careful consideration of many goals, from helping the visual tasks of drivers and pedestrians, to energy conservation and responsible environmental integration, to risk management and minimization of potential obstacles in the path of drivers. From a lighting perspective, fixed street and roadway lighting should provide sufficient light levels, uniformity, and target contrast according to the type of road, and accommodate visual needs under mesopic lighting conditions. The most common visual needs of drivers and pedestrians include the identification of objects, obstacles and individuals in both the direct field of view and in the periphery. Equally important is to minimize glare (direct and reflected) and light pollution/trespass, and to make the appearances of spaces appealing. It should have a low installation cost, consume as little electric energy as possible, and require as little maintenance as possible, so as to minimize the total cost of ownership. Thus, the effectiveness of a given lighting system should be determined by how well the lighting goals are met while considering the power and cost needed to achieve them, rather than judging only the luminous efficacy of the light source or luminaire in absence of a context.

The photometric goals of street and roadway lighting are often summarized in standards and recommended practices, among which the most common are ANSI/IES *American National Standard Practice for Roadway Lighting*, RP-08-00 (IESNA 2000); BSI *Road lighting. Performance requirements*, BS EN 13201-2:2003 (BSI 2003); and CIE *Lighting of Roads for Motor and Pedestrian Traffic*, CIE-115-2010 (CIE 2010). From the end-user's point of view, it is important that such recommendations are followed to help increase visibility. From the lighting system owner's point of view, it is important that the selected system meets the photometric requirements of the application as effectively as possible, so that the costs of operating the system are minimized. An effective system, one that meets the application's requirements with the fewest luminaires and lower total input power, can reduce initial and operating costs. Traditional metrics used to characterize light sources and luminaires in outdoor lighting applications include luminous efficacy (lm/W), coefficient of utilization (CU; Rea 2000), luminous efficacy rating (LER; NEMA 1999) and target efficacy rating (TER, NEMA 2008). However, none of these metrics accounts for whether the target photometric requirements of the specific application have been met. To provide a solution, ASSIST developed a metric (ASSIST 2010) that relates the ability of a luminaire, or a system of several luminaires, to meet the photometric requirements of specific applications. The metric, Luminaire System Application Efficacy (LSAE), builds upon the concept of *application efficacy*, which was devised to evaluate the delivery of light to where it is needed in the most energy-efficient manner. Application efficacy was defined by Rea and Bullough (2001) as the average luminous flux within a specific solid angle per unit of power. In its calculation, LSAE includes only the light output that falls on the task plane, Φ_{task}, and that meets the photometric requirements of the application's task. LSAE initially was developed and validated using criteria for parking lot applications, and different analyses demonstrated that LSAE is a good predictor of energy efficiency, whether it is used to rank individual luminaires, groups of luminaires, or a complete application (ASSIST 2010, Narendran et al. 2010).

This document shows how LSAE can be adapted to requirements typical of street and roadway lighting applications so that luminaires of different source technologies can be compared on the same basis. The requirements used in the metric presented here correspond to those in IESNA RP-8-00 and include illuminance, illuminance uniformity ratios, and glare. It is worth noting that the appropriateness of present outdoor lighting standards and recommended practices is not being questioned or endorsed here; instead, the requirements (e.g., illuminance, uniformity ratios, glare) are simply implemented into this metric in their present form as an example of how LSAE can be adapted to meet preset criteria. Similarly, it is worth emphasizing that the roadway LSAE metric presented in this document is not meant to be a substitute for complete system analysis. Other factors may influence the selection of light source and luminaire options, such as cost, availability, spectral power distribution, life, etc.

Definition of the Proposed Metric

To address the issue of performance in street and roadway lighting applications, LSAE is defined as the ratio of the luminous flux (in units of lumen) that falls on the task plane and that meets the photometric requirements of the application task, $\Phi_{task\text{-}conforming}$, to the total input electrical power (in units of watt). Equation 1 shows the definition of LSAE.

$$\text{LSAE} = \Phi_{task\text{-}conforming} \div P \quad (1)$$

By not including the light output falling beyond the task plane in the equation, the luminaires that "waste" light by sending light outside the task plane are penalized. Similarly, by not accounting for the luminous flux inside the task plane that does not yield sufficient light levels, luminaires that do not provide expected light levels throughout the task plane are also penalized. This approach leads to a more "target-oriented" evaluation system that compares luminaires on their effectiveness of delivering light for a specific application. The following sections detail how the proposed LSAE is further refined to include the characteristics of the task plane, the light level, uniformity, and glare requirements, and the characteristics of the luminaire. For purposes of this document, the lighting criteria in ANSI/IES *American National Standard Practice for Roadway Lighting*, RP-08-00 is used as an example.

Defining the task plane

To determine the LSAE for a roadway application, the task plane is defined as the area on the roadway between one luminaire cycle. The x-dimension of the task plane is the distance between luminaires in one luminaire cycle and is a function of the luminaires' intensity distribution, mounting height, luminaire overhang dimension, pavement classification, and streetlight layout, as these variables determine the maximum distance between poles so that RP-08-00 criteria are met. The y-dimension of the task plane is the travelway, encompassing the travel lanes on the roadway. Figure 1 shows an example of a staggered layout and indicates the x- and y-dimensions of the task plane.

The use of computer-based programs that optimize the pole spacing for a given set of specific conditions (i.e., luminaire intensity distribution, mounting height, overhang distance, roadway width and layout type) is highly recommended for this and the following steps of the roadway LSAE calculation.

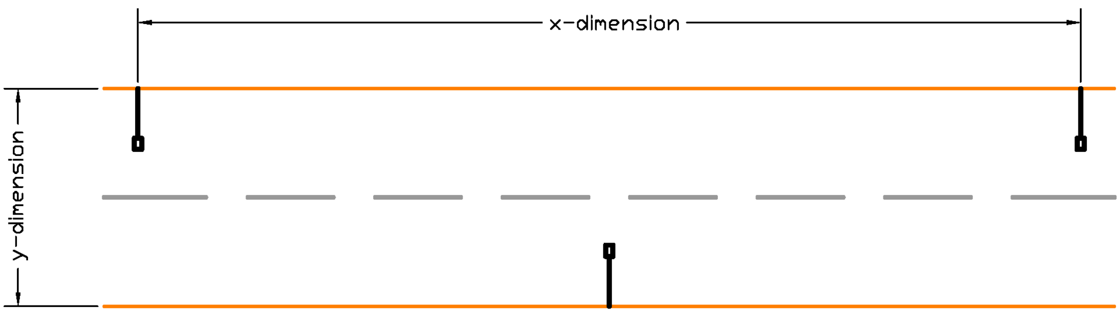

Figure 1: Task plane based on one luminaire cycle using a staggered luminaire layout. The y-dimension is the travelway (including the roadway lanes but not the shoulder(s)).

Range of Illuminance Values

The RP-08-00 publication allows either illuminance- or luminance-based design criteria to be used as a design method. Either method can be used to determine the x-dimension of the task plane area; however, the illuminance values will be used to calculate the LSAE values.

For the illuminance-based design criteria, RP-08-00 recommends a minimum maintained average horizontal illuminance value that is based on the type of road, pedestrian conflict area, and the pavement classification. The possible combinations of the three variables yield 42 maintained average illuminance criteria (Table 1). Within each of the six road classifications, there is a given average-to-minimum illuminance uniformity ratio. For example, for a collector road with medium pedestrian conflict having an "R3" asphalt surface, the recommended minimum average maintained horizontal illuminance value is 0.9 fc (9.0 lx) and the average-to-minimum uniformity ratio is 4.0, from which a minimum maintained horizontal value (E_{min}) of 0.23 fc (0.9 fc ÷ 4) can be calculated. Notice that a maximum maintained horizontal illuminance value is not given in RP-08-00. The LSAE calculation method uses the average illuminance criterion and the average-to-minimum uniformity ratio criterion as the basis to determine a luminaire's effectiveness for the selected conditions. Therefore, since a maintained average value is given, the LSAE calculation method considers as wasteful any portion of the luminaire's luminous flux that results in more than the recommended minimum average or below the recommended minimum. It is important to emphasize here that a light loss factor should be included in the calculations, as the roadway lighting criteria is based on maintained values (i.e., the lowest lighting levels on the roadway at the end of the system's service life).

Table 1. IESNA recommended maintained average horizontal illuminance levels (lx) for different types of roads, pavement, and pedestrian conditions (excerpt from IESNA 2000).

Road and Pedestrian Conflict Area		Pavement Classification			Uniformity ratio	Veiling luminance ratio
Road	Pedestrian conflict area	R1	R2 & R3	R4	E_{avg} / E_{min}	L_{vmax} / L_{avg}
Freeway Class A		6 lx	9 lx	8 lx	3.0	0.3
Freeway Class B		4 lx	6 lx	5 lx	3.0	0.3
Expressway	High	10 lx	14 lx	13 lx	3.0	0.3
	Medium	8 lx	12 lx	10 lx	3.0	0.3
	Low	6 lx	9 lx	8 lx	3.0	0.3
Major	High	12 lx	17 lx	15 lx	3.0	0.3
	Medium	9 lx	13 lx	11 lx	3.0	0.3
	Low	6 lx	9 lx	8 lx	3.0	0.3
Collector	High	8 lx	12 lx	10 lx	4.0	0.4
	Medium	6 lx	9 lx	8 lx	4.0	0.4
	Low	4 lx	6 lx	5 lx	4.0	0.4
Local	High	6 lx	9 lx	8 lx	6.0	0.4
	Medium	5 lx	7 lx	6 lx	6.0	0.4
	Low	3 lx	4 lx	4 lx	6.0	0.4

Once the task plane dimensions have been determined with the RP-08-00 lighting design criteria (either illuminance or luminance-based), a calculation grid with 2 ft by 2 ft (0.6 m by 0.6 m) cells is created for one luminaire cycle and the corresponding illuminance values are calculated (Figure 2).

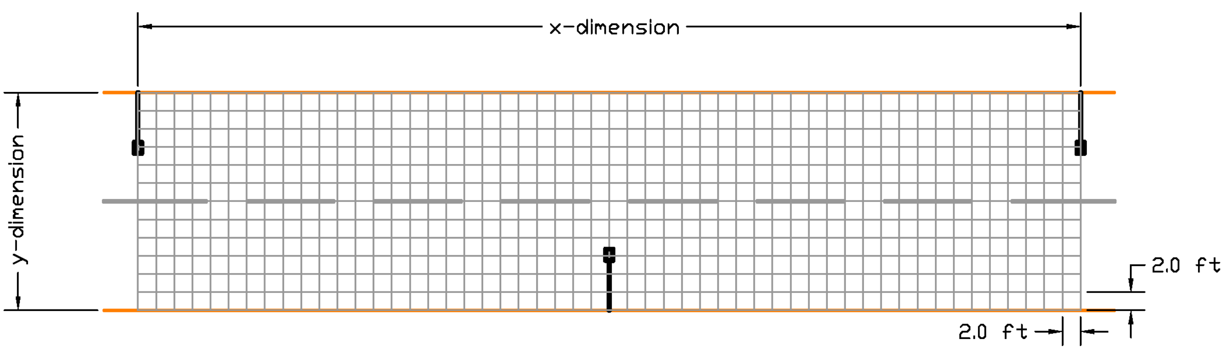

Figure 2: Calculation grid created for one luminaire cycle once the maximum pole spacing has been determined per RP-08-00 (IESNA 2000).

This grid is used to estimate the luminous flux falling within each cell of the grid by conducting a simple calculation based on the definition of illuminance, E, where E is equal to the luminous flux (Φ) divided by the area of incidence. Because the area of each grid cell ($Area_{cell}$ = 2.0 ft × 2.0 ft = 4.00 ft^2) and the illuminance at the center of each grid cell (E_{cell}) are known, it is possible to estimate the luminous flux reaching each cell (Φ_{cell}; Equation 2).

$$\Phi_{cell} = E_{cell} \times Area_{cell} \quad (2)$$

Penalizing Non-conforming Cells

Once the illuminance values are calculated in the task plane, the next step is to determine which of those values do not contribute to achieving the target illuminance and uniformity criteria because they are too low or to high. Because the target illuminance criteria in RP-08-00 are a minimum (E_{min}) and an average (E_{avg}) value, those two values are used to determine which cells should be penalized. First, all the illuminance values are sorted in ascending order. This step can be accomplished more easily by exporting the illuminance values calculated in lighting design software into a spreadsheet. Second, all illuminance values lower than E_{min} are declared non-conforming and discarded from the analysis. Third, from the remaining set of illuminance values (i.e., those that are equal to or higher than E_{min}), an average is calculated by adding one value to the calculation at a time until it equals the minimum maintained average illuminance given in RP-08-00. Once the minimum maintained average illuminance for the given roadway is met, any remaining illuminance values in the calculation grid are no longer used for the analysis. These discarded values are considered to be non-conforming because they effectively raise the average illuminance over the value required in RP-08-00 and thus can be considered wasteful. Finally, each illuminance value counted toward the minimum maintained average illuminance is converted into luminous flux using Equation 2 and is considered the only “useful” or “conforming” light reaching the task plane. Notice that the uniformity and glare criteria are already met when the pole spacing is determined following the RP-08-00 procedure (i.e., using several luminaire cycles) and that for this step only one luminaire cycle is considered and needed.

It is worth noting also that the 2 ft by 2 ft (0.6 m by 0.6 m) illuminance grid recommended for calculating LSAE is more dense than the grid specified in RP-08-00, which may lead to illuminance values closest to the curbline being lower than the minimums allowed in RP-08-00. These illuminance values are considered to be non-conforming and are not included in the calculation of “useful” luminous flux for LSAE (see step 2 in the above paragraph). Also, because of the lower illuminance values closest to the curbline, the dense 2 ft by 2 ft illuminance grid may have an average illuminance lower than the minimum maintained average illuminance given in RP-08-00. Any of these situations that may arise during the LSAE calculation should not be construed as reasons to claim that the design does not meet RP-08-00 criteria.

In cases where the streetlight layout has been designed to meet the RP-08-00 luminance-based criteria, the average illuminance may be lower than that required if the illuminance design method was selected instead. In these cases, all of the illuminance values equal or higher than E_{min} are converted to luminous flux in the LSAE calculation.

Contribution of adjacent luminaires

In cases where the roadway lighting layout is not single-sided (e.g., the lighting layout uses a staggered or opposite streetlight arrangement), the “useful” luminous flux derived from the conforming cells has to be divided in half because in each luminaire cycle, more than one streetlight is contributing light toward the task plane.

Evaluation Method

Luminaire System Application Efficacy (LSAE)

Generally speaking, the evaluation process for LSAE includes four major steps. The first step is to obtain an accurate and representative measurement of the intensity distribution of the luminaire under evaluation. The second step is to determine the task plane dimension by calculating the maximum pole spacing at which the lighting criteria are met for the desired pole layout. The third step is to create a grid on the task plane and calculate the illuminance values at each point. The fourth step is to calculate the LSAE based on the conforming illuminance values and the input power of the luminaire.

CCT, CRI, and Chromaticity

For traditional technologies (e.g., HID, fluorescent and incandescent), it is common practice to report the lamp CCT, CRI, and CIE x,y values as provided by the lamp manufacturer or testing laboratory. For LED luminaires, the IESNA LM-79-08 approved method calls for testing the photometric and colorimetric properties of the complete luminaire using the absolute photometry method (IESNA 2008).

Glare and Uplight

Light radiating at high vertical angles (approximately 75° to 80°) from a street or roadway luminaire can potentially cause glare, although in many situations it is possible to create glare from light at lower angles (e.g., 60°). Glare is a critical issue in area, street and roadway luminaire design, due to the high luminous intensity required for illuminating a large area at night. Designers may need to look at the luminous flux exiting a luminaire at a certain angle (the *glare zone*), the luminaire mounting height, and visually adjacent luminaires to evaluate the potential for glare in a particular situation (NLPIP 2004, 2007). The lighting design criteria in RP-08-00 takes into consideration glare, and this plays an important role in the calculation of pole spacing for a given set of conditions, including the luminaire’s intensity distribution, mounting height, type of pavement, etc.

Also, the uplight portion (light that extends to angles greater than 90°) from the luminaire can be considered a waste of light and can contribute to light pollution. More information can be obtained from the IESNA’s *TM-15-07 Luminaire Classification System for Outdoor Luminaires* (IESNA 2007a) and the companion document *Addendum A for IESNA TM-15-07: Backlight, Uplight and Glare (BUG) Ratings* (IESNA 2007b).

The present document does not directly address glare and light pollution because those issues are contextual; thus, specific information about the application in which the luminaire is used is needed. Additional information and evaluation tools can be found in two methods of predicting light pollution and glare from outdoor lighting installations that the Lighting Research Center has published. The first is a comprehensive method for predicting and measuring the three aspects of light pollution, called the Outdoor Site-Lighting Performance method (Brons et al. 2008). The second is a simple, quantitative model to predict discomfort glare from outdoor lighting installations (Bullough et al. 2008, ASSIST 2011).

Mesopic Characterization of Outdoor Lighting

Recent research into how the eye "sees" under mesopic conditions and the development of an alternative, unified system of photometry support the possible trade-off between light source spectrum and light level for light sources used in nighttime, outdoor applications (Rea et al. 2004). ASSIST has published step-by-step instructions for calculating the *unified luminance* of a given light source based on light level and the scotopic-to-photopic ratio of the light source. Different combinations of light sources and light levels may produce the same unified luminance, which indicates photometric equivalency. Therefore, the system can serve as a simple method for trading off light sources and light levels under mesopic conditions, and thereby aid in the selection of light sources for a given application. For more information, see *ASSIST recommends…Outdoor Lighting: Visual Efficacy* (ASSIST 2009) and IESNA's TM-12-06, *Spectral Effects of Lighting on Visual Performance at Mesopic Light Levels* (IESNA 2006).

Practicalities and Utility

Optimum Mounting Height and Pole Spacing

The roadway LSAE value is specific to the conditions used in its calculation. Most notably, the LSAE value of a luminaire is linked to the mounting height used to determine the pole spacing. Thus, for a given pole layout and roadway geometry, it is possible to calculate LSAE systematically as a function of mounting height. Generally, the optimum mounting height for a luminaire (the mounting height that yields the maximum LSAE) also yields the maximum pole spacing. With this information available, designers can narrow the selection of luminaires that most likely fit in the application at hand (e.g., if they are required to use a specific mounting height) and fine-tune their design. As an example, Figure 3 shows the LSAE values for a sample luminaire at various mounting heights. The data labels above each marker indicate the maximum pole spacing to meet RP-08-00 at that mounting height. This particular luminaire has an optimum mounting height of 25 ft for the road width used in the calculations and provides a spacing of 195 ft between luminaires and an LSAE equal to 32 lm/W.

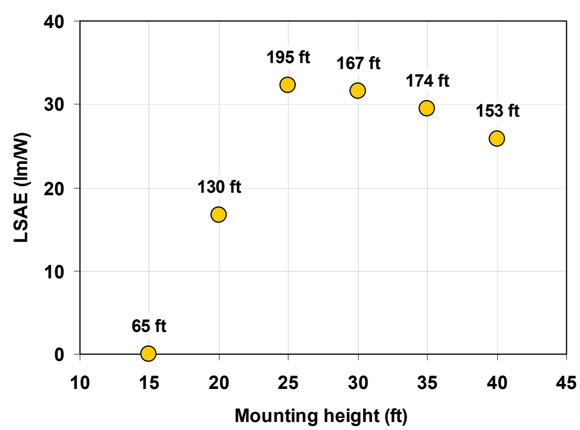

Figure 3. LSAE values and pole spacing for various mounting heights for a sample luminaire in a staggered layout.

Correlating LSAE to Energy Usage

LSAE is a useful tool to predict energy use for roadway lighting installations. Table 2 and Figure 4 show a comparison of six commercially available luminaires. The analysis shows the LSAE values for these luminaires in a staggered configuration at their optimum mounting height. This mounting height provides the maximum pole spacing possible to meet RP-08-00 for a collector road with medium pedestrian conflict that is 48-ft wide with four lanes. Using the maximum pole spacing, the number of streetlights in a staggered layout over a one-mile length of roadway was determined, and the power demand per linear mile (kW/mile) was calculated. Table 2 summarizes the characteristics of the luminaires and the results. Figure 4 shows power demand per mile as a function of LSAE. The plotted LSAE values show a high correlation between higher LSAE and lower power demand values, which means that LSAE values can be used to compare and rank order luminaires in terms of energy efficiency.

Table 2. Streetlight characteristics and LSAE results for six commercially available streetlights used to light a one-mile length of collector road to RP-08-00 (IESNA 2000) lighting criteria.

Sample	Mounting height (ft)	Pole spacing (ft)	Input power (W)	LSAE (lm/W)	# poles / mile	Power demand (kW/mile)
1	30	135	204	13.9	77	15.8
2	30	120	174	14.9	87	15.1
3	25	90	144	13.4	116	16.8
4	35	215	305	15.1	48	14.7
5	40	190	293	13.6	55	16.0
6	40	165	290	12.2	63	18.3

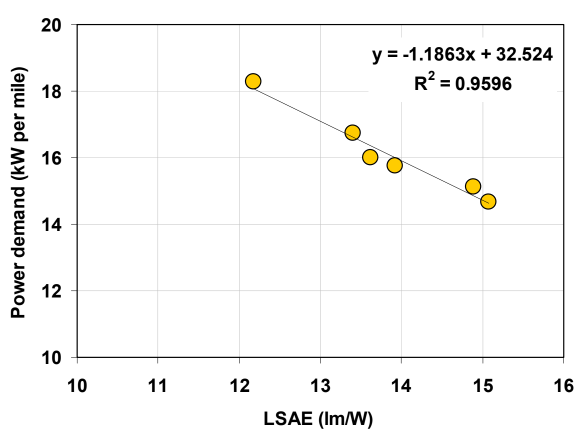

Figure 4. Power demand along a one-mile length of collector road that meets RP-08-00 (IESNA 2000) as a function of LSAE.

Summary

Luminaire System Application Efficacy (LSAE) measures luminaire efficacy for a luminaire in an application with preset criteria, including absolute illuminance values, uniformity ratios, and glare, at a given mounting height and pole spacing.

LSAE is a technology-neutral, application-specific metric that can be adapted to multiple standard recommendations.

Although the LSAE value is reported for one luminaire, its calculation includes the effects of contributing luminaires. LSAE provides a number that is specific to the mounting height, optical characteristics, and light output of a given luminaire such that designers can determine the conditions under which the luminaire will perform best at meeting the given photometric criteria. With this information, a designer can choose the best luminaire for the given application or rank order a number of products. LSAE values for a given luminaire change depending on the application, but a higher LSAE value will ensure the application has appropriate light levels to meet the application’s need with a lower power demand.

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Acknowledgments

ASSIST and the Lighting Research Center would like to thank the following for their review and feedback during the development of this publication: Philips Hadco.

About ASSIST

The Alliance for Solid-State Illumination Systems and Technologies (ASSIST) was established in 2002 by the Lighting Research Center as a collaboration between researchers, manufacturers, and government organizations. ASSIST's mission is to facilitate broad adoption of solid-state lighting by helping to reduce major technical and market barriers.