Classifying Outdoor Luminaires: The Limits of BUG

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Abstract

The IES BUG rating system is useful for classifying outdoor luminaires when considering light trespass, sky glow, and glare in accordance with the Joint IDA-IES Model Lighting Ordinance (MLO). However, there are limits to what can be measured in the laboratory. Luminaires with uplight ratings of U0 or U1 or a glare rating of G0 may require further analysis when comparing manufacturers' products.

Introduction

Light pollution, including light trespass, nighttime sky glow, and visual glare, has been a topic of concern since the 1970s. To address this issue, the International Dark-Sky Association (IDA) and Illuminating Engineering Society of North America (IESNA) recently issued the Joint IDA-IES *Model Lighting Ordinance* (MLO) [IDA-IES 2011]. Written for lighting designers, city officials, engineers, citizen groups, and other interested parties, this document is a template for municipalities interested in developing outdoor lighting regulations.

Recognizing that municipalities will have varying levels of expertise in lighting design, the MLO provides two methods for determining compliance. The *prescriptive method* "contains precise and easily verifiable requirements for luminaire light output and fixture design that limit glare, uplight, light trespass and the amount of light that can be used," while the *performance method* is mostly intended for lighting designers and professional engineers using lighting simulation software.

Both methods rely on the Backlight, Uplight, and Glare (BUG) rating system as described in IES TM-15-11, *Luminaire Classification System for Outdoor Luminaires* [IESNA 2011]. In particular, luminaires intended for use in the five MLO lighting zones (LZ-0 to LZ-4) must have the appropriate BUG ratings to ensure that sufficient shielding is used to limit light pollution.

The BUG system is quite elegant in that the backlight, uplight, and glare ratings are easily calculated from the luminaire manufacturer's photometric data reports. Equally important, lighting professionals can easily verify these ratings using commercial lighting design software. If an outdoor luminaire manufacturer provides BUG ratings, everyone from lighting designers and specifiers to municipal engineers and homeowners can be confident that the products will meet the appropriate MLO requirements.

Or can they? It may be easy to verify a BUG rating based on the luminaire's photometric data report, but this leaves open the question of whether the photometric data report itself is sufficiently accurate or even correct.

The MLO prohibits any uplight whatsoever (an uplight rating of U0) and glare ratings of 10 lumens or fewer above 60 degrees vertical (a glare rating of G0) for lighting zones LZ-0 and LZ-1. As the MLO notes, 10 lumens is roughly equivalent to the light output of a 5-watt incandescent lamp. At the same time, the downlight may be on the order of tens of thousands of lumens from high-wattage lamps. It is therefore appropriate to ask how this light is measured in the photometric laboratory.

Stray Light

Quoting Addendum A of TM-15-11, "The zonal lumen thresholds listed in the following three tables are based on data from photometric testing procedures approved by the Illuminating Engineering Society for outdoor luminaires (LM-31 or LM-35)."

Without going into detail, both IES LM-31-95 [IESNA 1995] and LM-35-02 [IESNA 2002] specify the measurement of luminous intensity distribution using a goniophotometer that is mounted in a large room with black surfaces. The key issue here is *stray light*. When a luminaire is mounted on the goniophotometer (FIG. 1), its emitted light will illuminate the room floor, walls, and ceiling. The light reflected from these surfaces will be seen and measured as stray light by the wall-mounted photosensor as the goniophotometer mirror rotates about the horizontal axis of its support arm.

FIG. 1 Rotating mirror goniophotometer (image courtesy LightLab International)

This stray light is not insignificant. According to a study by Texas A&M University [Williams undated], generic black paint has a total (diffuse and specular) reflectance of 4 percent. Black felt has a total reflectance of 2 percent, and even the best optical flocking material has a reflectance of 1 percent. TM-15-11 presents an example 250-watt metal halide luminaire that emits 13,553 lumens. Of this, some 100 to 500 lumens will be reflected back into the room as stray light.

Unfortunately, LM-31-95 has little to say on the topic:

> 3.2.5 **Stray Light.** Precautions shall be taken to eliminate stray or extraneous light from the test setup by use of adequate shielding and baffling.

and LM-35-02 is little better:

> 3.1 **Stray Light.** Precautions should be taken to eliminate stray light from the test environment by the use of adequate shielding and baffling. For moving photodetector photometers, the light incident on the photodetector must be only that which is directly transmitted from the floodlight. For a moving mirror goniophotometer, only light reflected directly from the floodlight via the mirror to the photodetector should be measured.

By way of comparison, corresponding CIE documents are equally vague. CIE 121-1996 [CIE 1996], for example, simply says:

> 4.2.1 **Test room.** The luminaire shall be measured in surroundings so arranged that the photometer head receives only light from the luminaire direct or with intended reflection.

Measurements versus Data

Given this, it is interesting to look at the reported uplight lumens for the TM-15-11 example luminaire: zero. That is zero lumens for the entire upper hemisphere. The reported resolution of the zonal lumen data is one lumen. In terms of measurements, this would require the room surface reflectances to be less than 0.01 percent.

The explanation is that photometric laboratories simply subtract the stray light from the measured data. Measuring this stray light involves a bit of black magic. To illustrate this, FIG. 2 shows a fisheye view of a simulated photometric laboratory measuring a roadway luminaire with an IES Type II distribution. The wall-mounted photosensor is provided with a crescent-shaped shield such that it only "sees" the rotating mirror and stray light within its field of view over the vertical angles 0 to 180 degrees. To measure the stray light, the mirror is rotated to its 270 degrees position (i.e., out of the sensor's field of view) and one or more readings are taken through the shield for each vertical scan. The average reading is the amount of stray light that is to be subtracted from the measured data for the given luminaire horizontal angle.

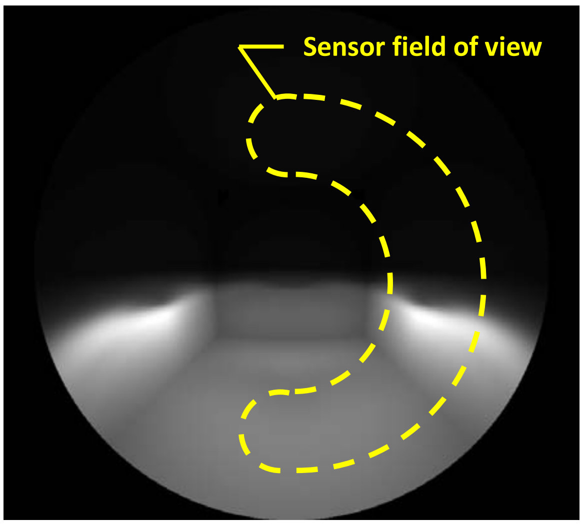

FIG. 2 Simulated photometric laboratory with IES Type II distribution roadway luminaire

The problem with this approach is that it assumes that the stray light as seen by the photosensor is constant throughout the vertical scan. Unfortunately, this may be a risky assumption. In the example shown (and one that is common for many roadway and area luminaires), positioning the mirror at 80 degrees will block most of the stray light, while positioning it above 100 degrees will not block any. In other words, the amount of stray light seen by the photosensor is dependent on the mirror position.

It must also be emphasized that this is but one of several approaches to luminaire goniophotometry. Some laboratories perform a full 360-degree vertical scan with the rotating mirror, in which case it is not possible to measure the average stray light. CIE 84-1989 [CIE 1989] describes a two-step method where a black shade that "just covers the light source completely" rotates in synchrony with the mirror to perform stray light measurements, but there is no requirement for the laboratory to use this complicated and time-consuming technique.

This issue aside, subtracting the average stray light measurement from the measured data will result in readings for vertical angles greater than 90 degrees that may be greater or less than zero. The lab technician then has to examine the physical luminaire and decide which readings should be set to zero, and whether an additional "fudge factor" should be applied to account for any residual stray light. (Alternatively, the measured data may be reported as is without any modification.)

This manual modification of the measured data is justifiable in that there is no other practical means of accounting for stray light. However, the process is entirely dependent on the expertise and experience of the lab technician, and also the photometric laboratory policies. There is no guidance whatsoever offered by LM-31-95 or LM-35-02 on this matter.

This applies even if a photometric laboratory is accredited under NIST's National Voluntary Laboratory Accreditation Program (NVLAP). The NIST Handbook [NIST 2010] used for accreditation purposes simply references IES and CIE publications, with no further guidance on stray light issues.

Photometric Test Reports

For most photometric test reports, this approach makes perfect sense. Whether it presents relative or absolute photometry, it is acknowledged that the report is for a particular test luminaire. Luminaire manufacturing tolerances alone will limit the expected accuracy of the luminous intensity data to at best a few percent when applied to production luminaires. Stray light considerations have not previously been an issue because stray light is mostly insignificant in terms of the overall luminous intensity distribution.

The BUG rating system, however, is different. In order to achieve a U1 or G0 rating (for vertical angles between 80 and 90 degrees), the measured data must be shown to be 10 lumens or fewer. Given only a photometric data report, it is impossible to know how reported zonal lumens of fewer than 10 lumens (and the luminous intensity values they were based on) were derived from the measured luminous intensity data.

The U0 uplight rating requirement for MLO compliance is particularly insidious. If any luminaire has a U0 rating, it can only be because the photometric laboratory technician made a decision to either not measure the upper hemisphere or simply ignore the measurements. Somewhat surprisingly, this is explicitly permitted by TM-15-11, which reads in Appendix A:

> To determine BUG ratings, the photometric test data must include data in the upper hemisphere unless no light is emitted above 90 degrees vertical (for example if the luminaire has a flat lens and opaque sides) per the IES Testing Procedures Committee recommendations.

Simply put, U0 ratings are not based on the measured photometric data. Rather, they are achieved by fiat.

The problem is that it is possible for the same luminaire to be measured by two independent photometric laboratories and as a result be assigned two completely different BUG ratings. Given that there are no IESNA or CIE requirements to subtract stray light from the photometric measurements, the same luminaire could be assigned an uplight rating of U0, U1, or even U2, and a glare rating of G0 or G1.

Summary

To be clear, this is not a critique of any photometric laboratory or even the luminaire testing industry. The procedures currently in place, even if not formally documented, are perfectly adequate for most applications of luminous intensity distribution data.

What is important is the recognition that BUG uplight ratings of U0 or U1 and a glare rating of G0 for high viewing angles are in most cases not based on measured data. They are instead based on a physical examination of the luminaire by a laboratory technician.

Equally important is the recognition that even if a luminaire does not have a BUG uplight rating of U0, this may be due to the photometric laboratory not subtracting the stray light from the measured data, or subtracting the average stray light and zeroing only the negative residual values.

Looking beyond the voluntary MLO with its focus on municipal bylaws, the US Green Building Council's forthcoming LEED v4 (formerly LEED 2012) rating system has adopted the MLO and IES TM-15-11 as the basis for its Sustainable Sites (SS) Light Pollution Reduction credit [USGBC 2012]. Once LEED v4 is released and adopted, the BUG rating system will be part of an international green building standard.

This then becomes a significant issue for the lighting industry. If a photometric laboratory measures and reports stray light, the luminaire manufacturer will not be able to market its products as being MLO-compliant. If, on the other hand, the laboratory simply truncates uplight measurements or does not perform them, there will inevitably be occasions where these decisions are called into question. For example, a mounting flange or bracket might reflect more than 10 lumens upwards – was this considered? Either way, it undermines confidence in the BUG rating system.

The underlying issue is that TM-15-11 requires that the zonal lumen thresholds for the BUG ratings be "based on data from [approved] photometric testing procedures." It is impossible to measure zero lumens, and measuring 10 or fewer lumens pushes the limits of what can be achieved in any laboratory. As a result, the all-important U0 rating for MLO compliance is entirely dependent on a visual inspection of the test luminaire. Contrary to the intent of NVLAP accreditation [NIST 2010], there is no paperwork required to document such decisions.

This raises the question of why the U0 rating is required. Quoting from the MLO User's Guide (page 6):

> The limits for light distribution established in Table C (for the BUG rating system) prevent or severely limit all direct upward light. A small amount of uplight reflected by snow, light-colored pavement or a luminaire's supporting arms is inevitable and is not limited by the prescriptive method of this ordinance.

The diffuse reflectance of snow and light-colored pavement varies between approximately 70 and 90 percent. If we take the TM-15-11 example of a 250-watt metal halide luminaire that emits over ten thousand lumens into the lower hemisphere, between seven and nine thousand of those lumens will be reflected into the night sky. This is hardly a "small amount of uplight." It makes the requirement of zero lumens of directly emitted upward light rather puzzling[1].

Puzzlement aside, the IESNA and CIE technical committees will hopefully address the stray light issue and publish recommended procedures for post-processing the measured data as a means of stray light compensation. Such work however typically takes years to complete, and does not address the problem of existing photometric data reports.

[1] To be fair, IES TM-15-11 references an astronomical paper [Cizano and Castro 1998] that explains that the effects of uplight emitted at low angles (i.e., between 90 and 100 degrees) dominate for observing locations outside of urban centers, while uplight emitted at higher angles contributes more to light pollution within city limits. To be precise, a "small amount of uplight" (less than two percent) is diffusely reflected from the ground *at low angles*. This is still however on the order of several hundred lumens.

More usefully, the Joint IDA-IES Model Lighting Ordinance Task Force should revise the MLO User's Guide to explain that U0 ratings are not based on photometric measurements. If a particular luminaire has a U1 or even U2 rating, there should be a procedure within the ordinance text whereby an exception is allowed if a visual inspection of the physical luminaire shows that there is no significant uplight.

This simple proposal offers three advantages. First, it benefits luminaire manufacturers in that they would not have to redo their photometric tests with stray light compensation solely for the benefit of achieving U0 ratings. Second, it removes the uncertainty of whether a given photometric data report is accurate. Even if the luminaire has a published U0 rating, the visual inspection offers the municipal engineer or planning official to the ability to reject the luminaire upon visual inspection.

Third and best of all, this proposal is fully within the scope and intent of both the MLO and TM-15-11. As the MLO User's Guide notes, "… the MLO, like all other modern codes, is designed to evolve over time." This is an instance where a significant problem can be addressed by a minor but equally significant change to the MLO text.

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