

Beyond the G Rating: Evaluating Visual Comfort in Street and Area Lighting

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Introduction

The IES recommended practice for roadway lighting (RP8-14, annex B) divides glare into two categories: disabling glare and discomfort glare. Disabling glare results in reduced visual performance where as discomfort glare does not. RP8-14 defines veiling luminance and other metrics to address disabling glare. RP8-14 recommends that discomfort glare be evaluated separately but does not recommend a metric to do so.

However, RP8 does discuss some general practices to address discomfort glare. The metric and considerations discussed in this paper are related to these general practices. These recommendations will also potentially assist in evaluating new outdoor luminaires that are designed to address visual comfort.

New Optic Design Approaches to Address Visual Comfort

Recent optical designs used in these visual comfort luminaires are used for comparison purposes in this paper. For that reason their general characteristics are described here.

Advances in LED sources have allowed outdoor lighting manufacturers to bring innovation to optics that address visual comfort. Higher LED efficacy allows the use of secondary optics that reduce LED pixelization and increase source uniformity. Examples are shown in the top two rows. Despite the light losses of these secondary optics, these products can meet the efficacy requirements of the Design Lights Consortium (DLC). In some cases, they can meet the more stringent DLC premium levels.

The cost of high-power LED sources has come down significantly. This is one factor that has enabled commercially viable products with light guide optics. Examples are shown in the bottom two rows. Light guides use closely-spaced LEDs to pipe the light through the edges of the light guide. To keep the light emitting surface uniform, light guides require significantly more LEDs than luminaires that use discrete lenses.

Light guide optics have been used for many years in flat panel displays. The maturity of light guide technology is making it more cost effective to use them in lighting products.



Distributed LED Array with Two-piece Optics:

- Primary Lens for Directional Distribution
- Frosted Secondary Lens for Glare Control



Distributed LED Array with Multi-piece Optics:

- Primary Lens for Directional Distribution
- Diffuse Internal Reflector
- Translucent Secondary Lens with Micro-Optics for Glare Control



Light Guide with Macro Optics:

- Macro Optical Features Extracting Light
- Edge Lit Using Linear LED Array on One Side
- No Direct View of LED Array



Light Guide with Micro Optics:

- Micro Optical Features Extracting Light
- Edge Lit with LED Array on Two or More Sides
- No Direct View of LED Array

Limitations of G Rating as a Glare Metric

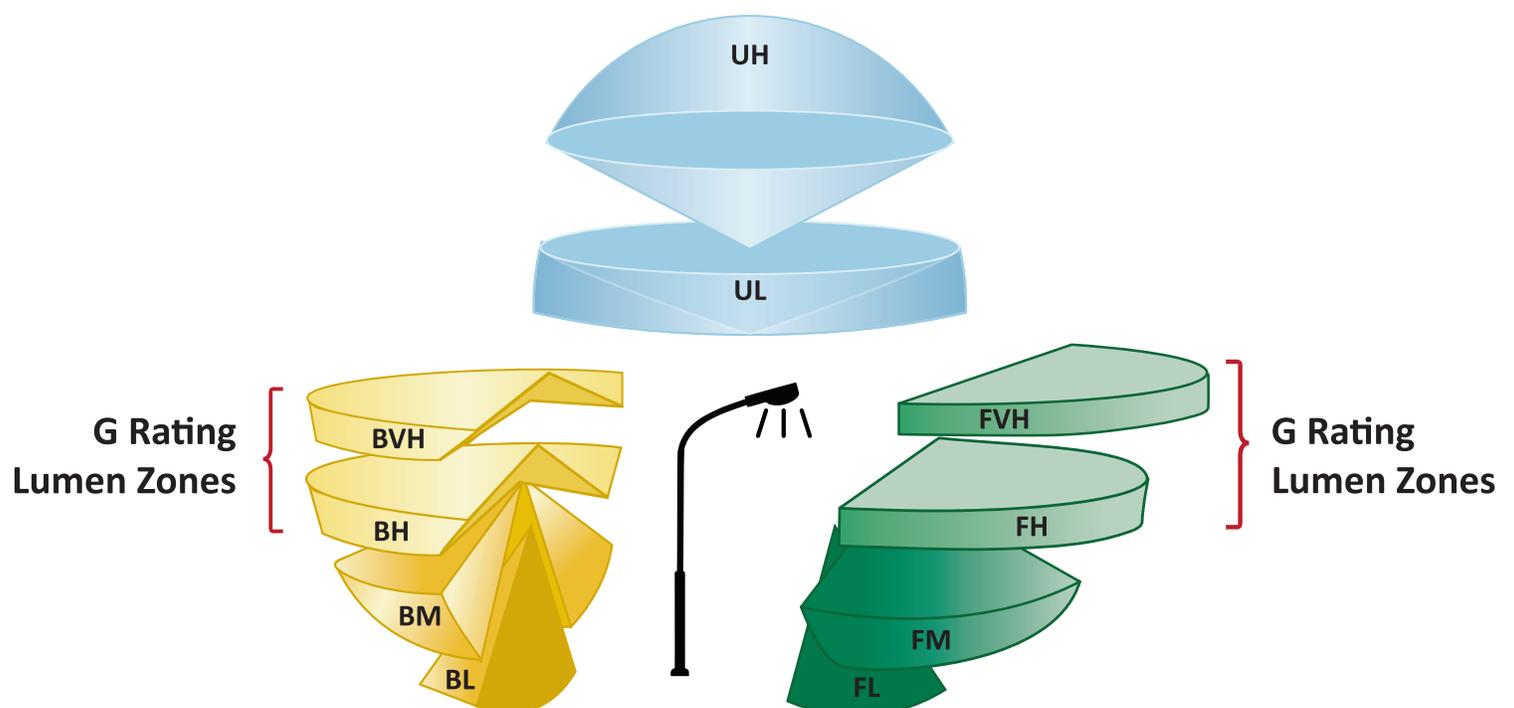
The metrics proposed in this paper discuss methods to evaluate visual comfort. These metrics are luminaire specific, similar to BUG ratings as defined by IES TM-15. The “G” portion of the BUG rating is a metric specific to glare. The G rating is an easy metric to calculate because it is based the IES file of a luminaire. However it does have some limitations as an objective metric for discomfort glare. This is especially true of new outdoor luminaire optics that are specifically designed to improve visual comfort.

The G ratings are based on the total zonal lumens in the high angle zones (FH, BH) and the very high angle zones (FVH, VBH) shown in the table and diagram below.

The luminaires shown in the table below are all residential street lights each with a G1 rating with an output of 5000 lumens.

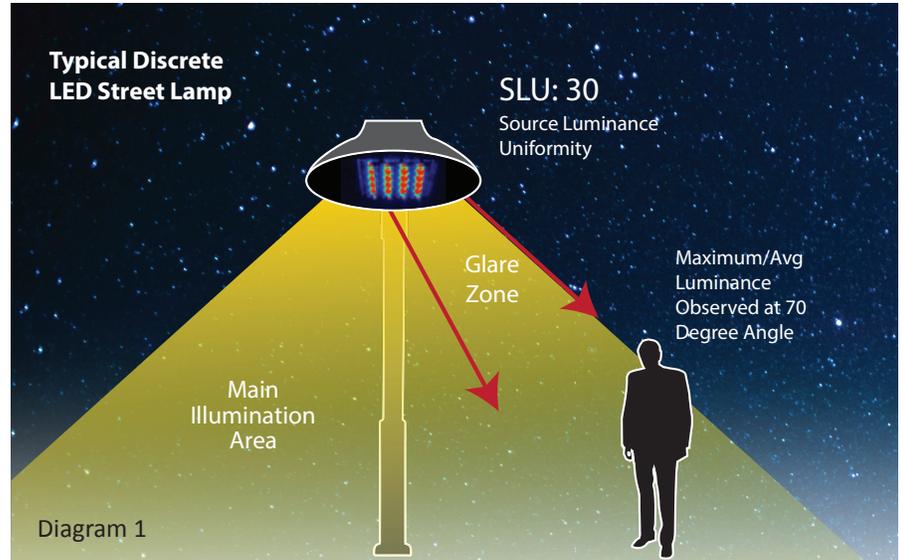
The two left columns show luminaires with optical designs that use a new approach to improve visual comfort. Qualitatively, both of those products would look distinctively different and most observers would consider them to have less discomfort glare than luminaires using the standard approach. This difference is not captured in the G rating. Because of this, the new metrics proposed here should be considered.

Lumen Zone Used for G-Rating	Maximum Zonal Lumens for G1 Rating	Conventional Approach Single Lens Over Discrete LEDs	New Approach Primary + Secondary Optics	New Approach Light Guide
FVH	100	31.8	50.6	79.6
BVH	100	13.4	13.8	46.4
FH	1800	1300.4	910.9	1005.5
BH	500	271.4	206.1	438.6



Source Luminance Uniformity: Proposed Metric to Evaluate Visual Comfort

Diagram 1 illustrates a conventional LED street light using discrete LEDs with a single lens controlling each. The image shown is a graphical representation of measured source luminance from the light emitting surface (LES). Luminance is a meaningful measurement to characterize discomfort glare because it captures the directionality of light rays reaching an observer. The source luminance was measured at a 70 degree angle from the observer in relation to the source. The angle of 70 degrees was chosen because that angle is close to maximum intensity for most optics used in outdoor luminaires and generally falls within a perceived glare zone.



Taking a closer look at the source luminance image in Diagram 1 shows red dots representing each of the brightly lit LEDs (high luminance) while navy blue area represents gaps between the LEDs (low luminance). The discontinuity in the color mapping of high and low luminance areas indicates the LES source luminance is not uniform.

A quantitative value for source luminance uniformity (SLU) can be obtained from the same data used in the source luminance image. This value can be calculated with commercially available test equipment. The process is to average the luminance values over the area of the LES, then divide the maximum luminance value by the average value to get a ratio. The lower the ratio, the more uniform the source. This resulting ratio (SLU ratio) and can be a useful metric to quantify discomfort glare. The two examples shown in Diagrams 1 and 2 illustrate this.

As mentioned earlier, Diagram 1 represents a conventional LED street light. The color map source image indicates large differences in luminance across the LES. The corresponding SLU ratio for this example is about 30. Diagram 2 represents an LED street light that uses a new optical approach to address discomfort glare. The color uniformity in this image indicates that the differences between luminance peaks and valleys now are minimized, leading to better source luminance uniformity. The corresponding SLU ratio for this example is about 10. Small, controlled surveys show the majority of observers would rate the product with an SLU ratio of 10 as more visually comfortable.

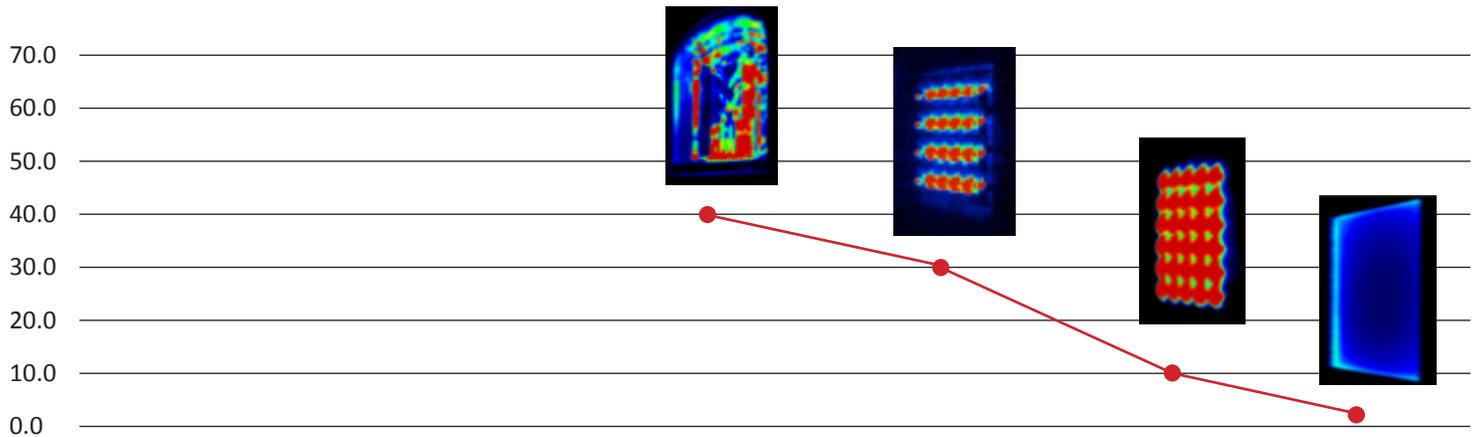


As a principle of reducing discomfort glare, RP8-14 (Annex B.3.3) recommends increasing the size of a diffusing medium around a light source. The net effect of this principal is to make the source luminance more uniform. The SLU ratio proposed here is a useful metric to quantify this.

Source Luminance Uniformity Comparison

Source Luminance Uniformity* → Max/Avg Luminance (at 70 degrees)

Uniform Color throughout = Smaller Difference Between Peaks and Valleys = Uniform Source Luminance



*New Metric: Source Uniformity at 70 degrees, Average Source Luminance, Not Absolute

Sample Light Fixtures	1	2	3	4
Uniform Source Luminance (USL) at 70 degs	40	30	10	2.1
USL % Reduction Compare to (The more reduction, the less glare appearance)	39% Over	0%	70% Reduction	92% Reduction
G Rating Using IES TM-15	G1	G1	G1	G1

The results above, from a small, controlled study, show lower SLU value correlates with perceived discomfort glare. The lower SLU value, the less discomfort glare is perceived by an observer at the 70 degree angle towards the luminaire.

1. Sample 1 -- Light guide with macro optics
2. Sample 2 – Conventional design with discrete LEDs and single lens optics
3. Sample 3 – Multi-piece optics design
4. Sample 4 -- Light guide with micro optics

Luminance Transition Zone - Complementary Feature to Address Visual Comfort



As part of the optics system, a luminance transition zone can be created to divert a small percentage of the light output to the surrounding perimeter of the light emitting surface. This transition zone creates less contrast between the lighted luminaire and the dark sky. This gradual dimming effect will be less straining in an observer's peripheral vision than a high contrast source to dark sky. Hence, the enhanced transition zone concept addresses another discomfort glare principal stated in RP-8, that is to increase the adaptation level of visual system.

Summary

Evaluation of luminaires for visual comfort should be based on these recommendations:

In small, controlled studies, source luminance uniformity (SLU) ratio correlates with perceived discomfort glare. In general, the lower the SLU ratio the higher the visual comfort. The proposed SLU ratio metric is useful for evaluating visual comfort of outdoor luminaires, whereas the G rating alone falls short.

Optical designs that utilize a luminance transition zone minimize the contrast between the lighted luminaire and dark sky background. This reduced contrast diminishes discomfort glare. When evaluating outdoor luminaires for visual comfort the inclusion of a transition zone feature should be considered.