Guide for Parking Lot Lighting:

Maximizing Illuminance Uniformity to Promote Perceptions of Safety While Reducing Power Demand

LIGHTING ENERGY ALLIANCE

Natural Resources Canada / Ressources naturelles Canada

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Introduction

Exterior lighting in parking lots should support the visibility of hazards so that drivers and pedestrians can safely move through them. Parking lot lighting should also reinforce perceptions of safety so that people are not afraid to use the space at night.

Illuminance and Safety

Multiple research studies (Fotios and Cheal 2009; Bullough 2010; Bhagavathula and Gibbons 2020) indicate that a minimum horizontal illuminance of 2 lux is sufficient for visual performance tasks such as detecting a potential tripping hazard on the ground, and in North America the Illuminating Engineering Society (IES 2020) has specified a minimum horizontal illuminance of 2 lux in parking lots. However, lighting that provides for adequate visibility may not be perceived as safe by people walking through a parking lot, another important criterion for parking lot lighting (Boyce et al. 2000).

Brightness Perception, CCT, and Safety

Additional studies have demonstrated that perceptions of safety are correlated with perceptions of how bright the overall lighted scene appeared. Perception of scene brightness is influenced by short-wavelength (blueish-white) light; light sources with a higher correlated color temperature (CCT) will tend to have greater short-wavelength output. Spectral sensitivity for scene brightness has been successfully modeled in the laboratory (Rea et al. 2011), and validated in the field (Rea et al. 2017). Parking lots illuminated with higher CCT sources are judged to be brighter and safer than those with lower CCT sources.

Uniformity and Safety

Other research has shown the importance of uniformity on perceptions of safety in parking lots. Narendran et al. (2016) showed that when the average illuminance was the same, a more uniformly lighted parking lot (3:1 maximum-to-minimum illuminance uniformity ratio) looked substantially safer than a parking lot with lower uniformity (10:1).

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Contributors include Jennifer Brons, John Bullough, Leora Radetsky, Jeremy Snyder, Kaela Kiefer, Katherine Snively, and Rebekah Mullaney.

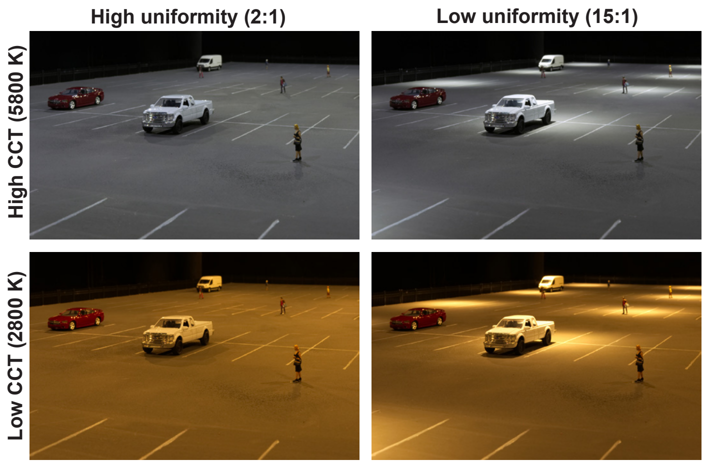
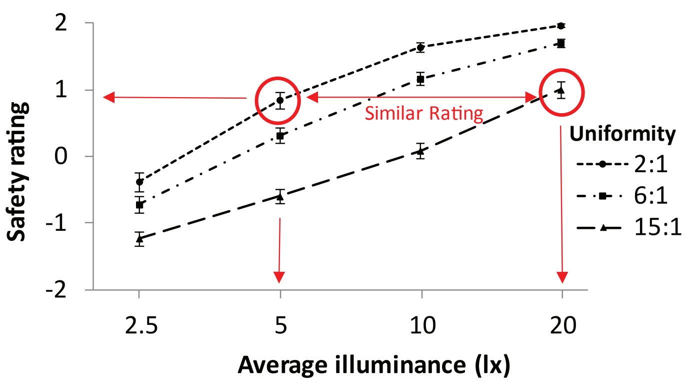


Figure 1: Scaled physical model used for laboratory test of parking lot lighting uniformity, average illuminance, and CCT



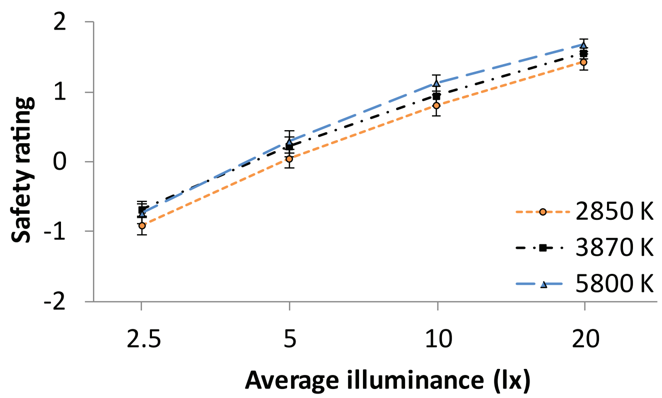


Figure 2: The laboratory scale model showed that higher uniformity (top) promoted perceptions of safety more than higher CCT (bottom). Similar safety ratings can be achieved at lower average illuminances by maximizing uniformity. Higher average illuminance also promoted perceived safety.

Laboratory Study

This previous research showed that the following characteristics of parking lot lighting can all have an impact on perception of safety: the average illuminance, the spectral characteristics (e.g., CCT), and the uniformity of illumination. To understand how these factors interact, the Lighting Research Center (LRC) built a scaled physical model of a parking lot (Figure 1) to systematically manipulate four average illuminances (from 2.5 to 20 lux), three correlated color temperatures (CCTs from 2850 K to 5800 K), and three illuminance uniformity ratios (from 2:1 to 15:1). For each of the conditions, laboratory participants rated perceived safety and brightness perception (-2 to +2).

The laboratory tests showed that, for the same illuminance, uniformity provides greater leverage in promoting the perception of safety compared to increasing CCT from 2850 K to 5800 K (Figure 2). The upward slope of the curves in Figure 2 also confirms that perception of safety improves with higher average illuminances. Furthermore, there may be a limit to how safe a non-uniform lighting design can appear, even with relatively high (~20 lux) average illuminances.

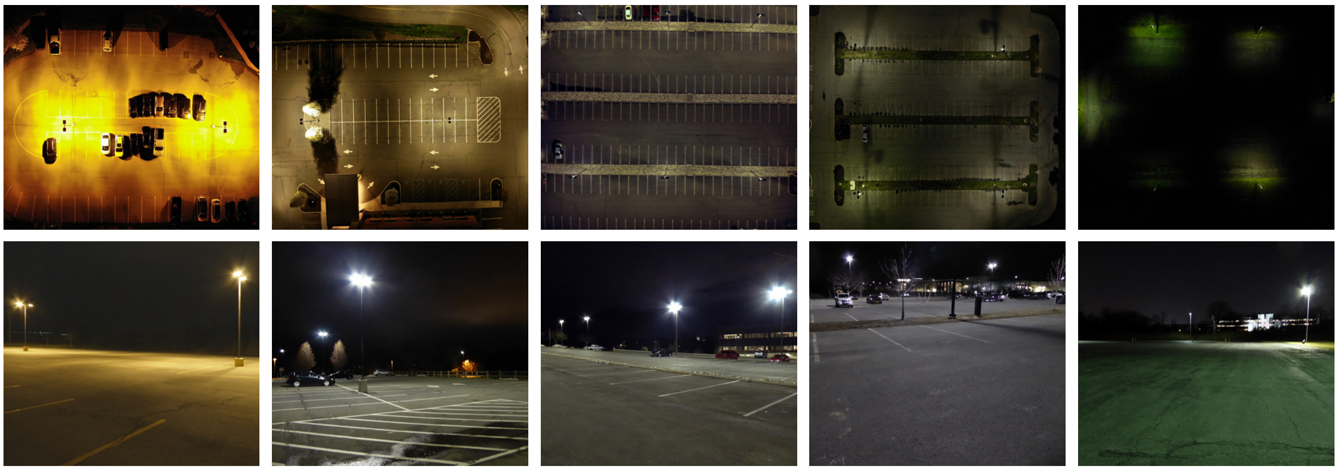
Figure 2 shows that a parking lot lighted with an average of 6 lux and 2:1 uniformity ratio would have a similar safety rating as a parking lot lighted with an average of 20 lux with a 15:1 uniformity ratio. As this represents a three-fold difference in average light levels, designing for uniformity presents a strategy with great leverage for saving energy.

Using the laboratory data, the LRC created mathematical models to predict perceptions of brightness and safety in parking lots. The formulas include three factors: average illuminance, spectral distribution (CCT), and uniformity of illumination (Bullough et al. in press). These are available in an online Parking Lot Lighting Safety Perception Calculator. Visit https://www.lrc.rpi.edu/programs/energy/Parking-Lot-Lighting-Safety-Perception-Calculator.xlsx to get the calculator. Please note that clicking this link will automatically download the calculator as an Excel file to your computer.

Field Validation

LRC researchers performed a field study to compare visitor ratings to mathematically-predicted responses of brightness and safety. The participants visited five parking lots with a wide range of average illuminances, uniformity ratios, CCTs, and source types (Table 1).

Table 1: Participants evaluated safety and brightness in five parking lots



Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Avg. Illum.: 51 lux	Avg. Illum.: 19 lux	Avg. Illum.: 18 lux	Avg. Illum.: 7 lux	Avg. Illum.: 6 lux
Uniformity: 58	Uniformity: 2.5	Uniformity: 6.2	Uniformity: 4.4	Uniformity: 195
CCT: 2161 K	CCT: 3786 K	CCT: 4306 K	CCT: 5536 K	CCT: 4718 K
Source: HPS	Source: LED	Source: LED	Source: LED	Source: MH

For both the brightness and safety questions, the mathematical models were strongly correlated (R^2>0.96) with the actual occupant feedback (Figure 3).

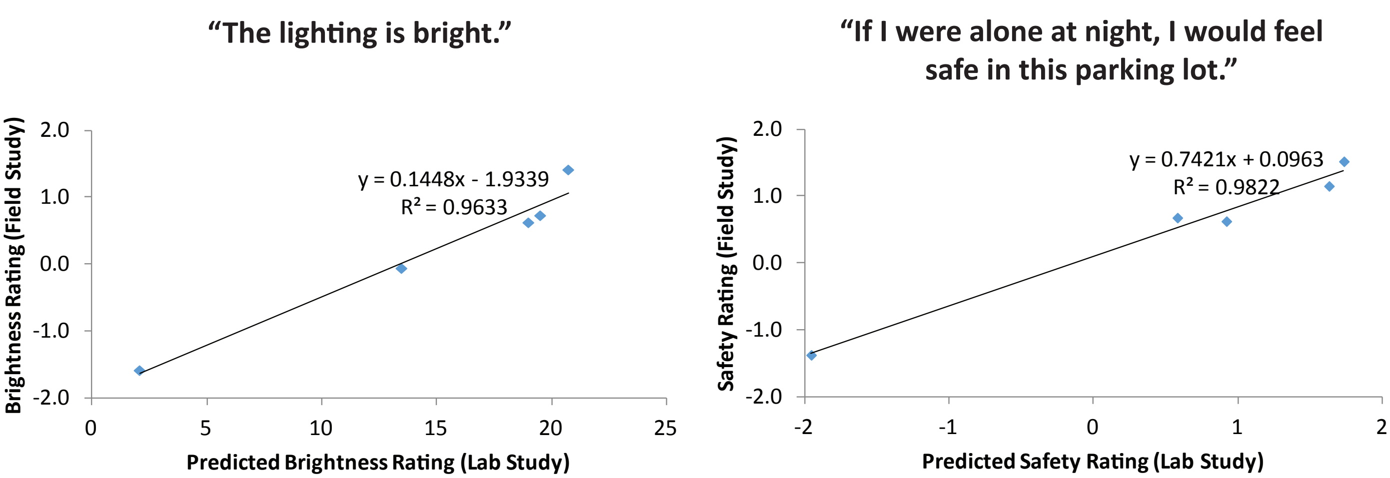


Figure 3: Results for brightness and safety perception, compared to mathematical predictions

Guidance: Applying the Research in Parking Lot Lighting Design

Lighting specifiers can use these research results to compare performance of alternate parking lot lighting designs to the base case lighting design by following the steps on the next page.

Step 1 Establish a base case

You can typically use the existing parking lot lighting to establish the base case.

Step 2 Determine average illuminance, uniformity, and CCT of designs

When comparing to an existing parking lot, perform field measurements using the procedures described in IES LM-64-01, *Guide for the Photometric Measurement of Parking Areas* (IES 2001). Use photometric software to perform calculations for proposed lighting designs.

Step 3 Use the calculator

Use the Parking Lot Lighting Safety Perception Calculator. Visit https://www.lrc.rpi.edu/programs/energy/Parking-Lot-Lighting-Safety-Perception-Calculator.xlsx to download the calculator as an Excel file to your computer.

Enter the following photometric values:

1. Average illuminance on the ground plane
2. Max:min illuminance (uniformity) ratio
3. CCT of the light source
    - For conventional high intensity discharge sources, assume:
        - -High pressure sodium: 2200 K
        - -Metal halide: 4200 K
        - -Mercury vapor: 5600 K
    - For new LED sources, use manufacturer-reported CCT.
    - Note: exclude the symbol for kelvins ("K") from the calculator.

Step 4 Compare performance

Compare predicted brightness/safety ratings to relative power demand.
Below is an example of this analysis.

Suppose the base case parking lot lighting (Figure 4) has with four high pressure sodium (HPS) luminaires (1776 W total power; CCT: 2200 K) mounted on two poles in the center of the lot, and providing an average of 35 lux and a uniformity ratio of 1928:1. Using the Parking Lot Lighting Safety Perception Calculator, this base case lighting design is predicted to provide a very low safety rating (-1.99).

Option 1 (Figure 5) replaces each luminaire on a one-for-one basis with new LED luminaires (CCT 3000 K), for a total of 1284 W (72% of the base case), with an average illuminance of 24 lux, and a uniformity ratio of 91:1. The Calculator predicts an improved (but still negative) perception of safety for Option 1.

Option 2 (Figure 6) involves replacing the HPS luminaires with 77 W LED luminaires, and adding five poles (each with one LED luminaire) along the perimeter of the lot to improve uniformity. The total power is 691 W (a 61% reduction), producing an average of 15 lux and a uniformity ratio of 11:1. Despite the lower average illuminance, the improved uniformity leads to a positive (+0.94) rating of safety. Even higher safety ratings could be possible, but would require higher wattages.

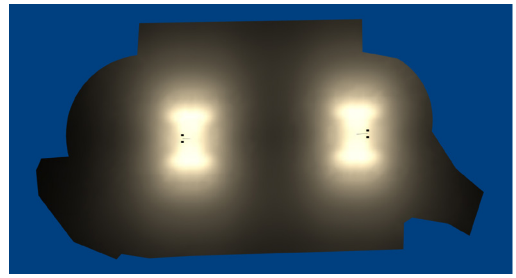


Figure 4: Base Case, photometric rendering

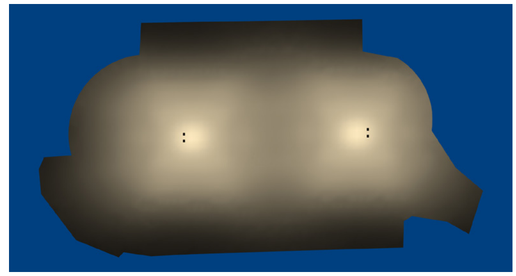


Figure 5: Option 1, photometric rendering

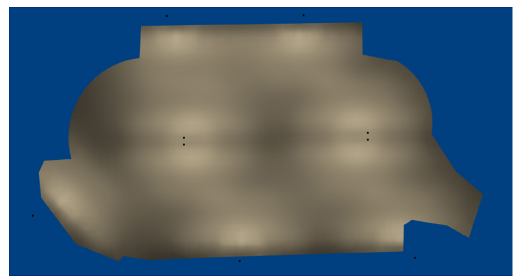


Figure 6: Option 2, photometric rendering

Implications for Designing Parking Lot Lighting

Average light levels are important contributors to perceptions of safety in parking lots. But to minimize power demand, lighting specifiers should strive to maximize uniformity. While higher CCT sources will be perceived as brighter than low CCT sources, this is limited in importance compared to uniformity. With improved uniformity, much lower average illuminances can be provided while achieving equivalent (or improved) perceived safety and brightness.

When considering upgrades of parking lot lighting with existing pole locations, there may be limitations in improvements to uniformity; it may be necessary to add/change pole locations to achieve positive safety ratings.

Taking advantage of uniformity has implications not only for energy savings but also for minimizing light pollution such as sky glow; evaluations of glare and light trespass would require additional photometric analysis (Brons et al. 2008).

Overall, by setting a criterion perceived safety value (such as "+1"), alternate lighting designs can be evaluated to minimize power demand while balancing the other design criteria (e.g., equipment cost, style, light pollution).

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