The Impact of LED Street Lighting on Sky Glow

Bruce Kinzey, Pacific Northwest National Laboratory

Solid-State Lighting Program Webinar  July 27, 2017
Have These Concerns Impacted Your Local System Design?

50% response

- 45% No
- 55% Yes
If Yes, How?

- 68% Changed CCT
- 19% Delayed Installation
- 13% Other
- Other categories are not shown in the diagram.
Are Any Wireless Controls Installed on Your Local System?

63% response

62% No
38% Yes
Are Wireless Controls Being Considered?

44% response

53% No
48% Yes
The Impact of LED Street Lighting on Sky Glow

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Street lighting, blue light and CCT are all the talk these days

- Potential issues have fired the public’s imagination
- Ongoing discussion contains many misperceptions and mischaracterizations
- The SSL Program’s position has always been to provide accurate, objective information to assist in decision-making
- Sky glow and health issues overlap, both related to light at night
What is anthropogenic sky glow?

“An increase in human-induced night brightness resulting from use of supplemental illumination for any purpose.”

Photo: Dan Duriscoe, NPS
CCT is insufficient as both a measure and solution

- Color temperature describes only the appearance of a light source...
- and is only a rough gauge of its spectral content or associated influences
An exclusive focus on “blue” is also misdirected

- The scotopic function accounts for the particular sensitivity of the human eye in low light conditions.
- Indicates, for example, which wavelengths present in the night sky have greater ability to obscure visibility of stars to a naked eye.

Even a generous definition of “blue” covers less than half the sensitivity function.

The source in the following table uses this range to calculate “% Blue” based on the potential ability for affecting sky glow.

The 1951 CIE Scotopic Luminosity Function
LED property ranges shown are based on a total of more than 450 real product SPDs.
Scotopic potential extends across much of SPD

- Two LEDs, one incandescent, all at 2800 K CCT
- Graphic shows the radiant power emitted in each wavelength
- Scotopic potential of each product is the sum of the weighted area under the curve
Collectively, the improved distribution, elimination of hot spots and uplight, etc., enabled a >50% reduction in fixture output.
• Photo taken above Portland, OR January, 2017
• Darkened areas in foreground are residential converted to 4000 K LED
• Compare these areas to others with previous incumbent products
• Are these areas still a concern? How much additional attention, e.g., to spectrum, should they warrant?
SkyGlow Simulator: Miroslav Kocifaj, PhD
Institute of Construction and Architecture, Slovak Academy of Sciences

Variables:
• City (size, shape, location)
• Position of observer
• Fixtures (number, output, percent uplight, SPD)
• City emission function (intensity as a function of zenith angle)
• Atmospheric conditions (cloudless, cloudy, overcast; aerosol content/type)
• Obstacles (horizon shielding)
• Output quantity (unweighted or weighted)
• Option to write input files
The scenarios

• Each run of the model increments a single parameter to determine its individual influence with all other parameters fixed (i.e., results generated for every single combination of input parameters)

• Input parameters include:
  - 3 cities of varying population (3,500 to 500,000)
  - 2 lumen output levels
  - 2 emission functions (Garstang or cosine)
  - 5 atmospheric conditions (4 clear with increased loading, 1 cloudy)
  - 11 SPDs
  - 4 uplight percentages (0%, 2%, 5%, 10%)
  - 2 observer locations
  - 2 output types (non-weighted irradiance or scotopic illuminance)
  - full SPD or 80 individual spectral increments (5 nm each)

=> ~215,000 runs
A few words about modeling

• Results are only as accurate as their underlying assumptions
• All atmospheric models incorporate many assumptions/simplifications
• Our approach was to investigate what happens in a typical conversion in the U.S., but Your Mileage May Vary!
• E.g., a couple of comments to the published report stated that many 0% uplight HPS cobra heads have already been installed, but...
• We contend this is a more representative scenario across the U.S.:

Chicago area, 2012
Photo credit: Nathan Rupert via Flickr, no alterations
The visible difference of conversion

- Los Angeles – 2017
DOE sky glow investigation results

- Each variable tested separately, then combined for overall comparison with HPS baseline
- The following show impacts of changing SPD, light output, and uplight for near and distant (40 km) observers, across 5 different atmospheric conditions (4 clear with increasing turbidity, 1 cloudy)
- Impacts are displayed in both unweighted and scotopically-weighted values (all sky irradiance and illuminance on a horizontal surface at the observer’s location)

SPDs tested in this study

<table>
<thead>
<tr>
<th>Specifications and Calculated Metrics/Values</th>
<th>SPD1</th>
<th>SPD2</th>
<th>SPD3</th>
<th>SPD4</th>
<th>SPD5</th>
<th>SPD6</th>
<th>SPD7</th>
<th>SPD8</th>
<th>SPD9</th>
<th>SPD10</th>
<th>SPD11</th>
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<tbody>
<tr>
<td>Source type</td>
<td>N/A^1</td>
<td>HPS</td>
<td>LPS</td>
<td>MH^2</td>
<td>LED^2</td>
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<td>CCT (K)</td>
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<td>2041</td>
<td>1778</td>
<td>3924</td>
<td>1872</td>
<td>2704</td>
<td>2981</td>
<td>3960</td>
<td>4101</td>
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<td>Photopic lux</td>
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<tr>
<td>Scotopic lux</td>
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<td>629</td>
<td>218</td>
<td>1381</td>
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<td>1345</td>
<td>1650</td>
<td>1797</td>
<td>1970</td>
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<tr>
<td>S/P ratio (relative to HPS)</td>
<td>3.60</td>
<td>1.00</td>
<td>0.35</td>
<td>2.19</td>
<td>0.71</td>
<td>1.86</td>
<td>1.89</td>
<td>2.14</td>
<td>2.62</td>
<td>2.85</td>
<td>3.13</td>
</tr>
</tbody>
</table>

^1 Equal energy  
^2 Metal halide  
^3 Phosphor-converted (PC) Amber LED
DOE sky glow investigation results – Near Observer

- Short wavelength content does contribute towards increased sky glow...
- ...but CCT is not always a reliable predictor of that impact
DOE sky glow investigation results – Distant Observer

- Greater variability for the distant observer occurs due to different atmospheric effects.
- Much of the current public discussion reflects this comparison (in isolation of other factors).

Impact of SPD in isolation of other variables

Increasing CCT

HPS Baseline “1.0”
All unweighted results now show reduced sky glow for all SPDs.

With scotopic weighting, some SPDs reduce sky glow relative to HPS baseline and others increase it.
• Again the greater travel distance through the atmosphere enables greater variation in the results
DOE sky glow investigation results – Near Observer

- Reduction in uplight from 2% (primarily emitted at low elevation angles) to 0% increases the range of impacts for the near observer...

Impact of SPD, 50% reduction in output, and 0% uplight

Increasing CCT
• And almost eliminates sky glow (by 95+%) for the distant (40 km) observer, from the street lighting system.
Remember: street lighting is only one component of sky glow

- And not necessarily the primary source!
- Significant reductions in sky glow are likely to require concerted efforts across a range of applications.

There is much work ahead

Chicago, 2007

Credit: Premshree Pillai via Flickr, no alterations
Thank you and Q&A

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Related resources: https://energy.gov/eere/ssl/street-lighting-and-blue-light

Includes, among others:

• Sky Glow Investigation Report
• Frequently Asked Questions: Street Lighting and Blue Light
• Webinar: Get the Facts on LED Street Lighting
• SSL Posting: Getting the Facts Straight About LED Street Lighting

August 3: “A Technical Discussion of DOE’s Sky Glow Study, Modeling Methods, and Key Variables”
Register on the DOE SSL Website