Outdoor Lighting and Mesopic Vision

John D. Bullough
Lighting Research Center, Rensselaer Polytechnic Institute
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Outdoor Lighting Specifications

- Are based primarily on conventional photopic illuminance, defined by $V(\lambda)$
  
  > Provides a reasonable characterization of the foveal and near-foveal cone photoreceptors for on-axis vision

  > Does not appear to characterize spectral sensitivity for some visual responses and tasks
    
    • Peripheral detection $\geq 10^\circ$ off-axis
    • Scene brightness perception
Alternatives to Conventional Photometry

- In 2010, the Commission International de l’Eclairage (CIE) recommended a system of unified photometry linking the photopic and scotopic luminous efficiency functions.

\[ V_{\text{mes}}(\lambda) = k[X \cdot V(\lambda) + (1 - X)V'(\lambda)] \]

- \( X \) is the proportion of photopic spectral sensitivity and is a function of light level and the spectral distribution of the light source.
  - S/P ratio is used to characterize the spectral distribution.
Limitations of Unified/Mesopic Photometry

- For detection of peripheral objects
- **Not** intended to equate brightness
  - We’ll come back to this
- Iterative method for computation can be complex for lighting specifications
A Simplified System of Unified Illuminance

- Rather than a continuous family of mesopic luminous efficiency functions, a subset of functions could be used:
  - Photopic (illuminance ≥ 25 lux)
  - “High” mesopic (10 lux ≤ illuminance < 25 lux)
  - “Low mesopic (1 lux ≤ illuminance < 10 lux)

(Rea, 2013)
Comparing Light Sources

<table>
<thead>
<tr>
<th>Description</th>
<th>(S/P)</th>
<th>lm/W</th>
<th>$V(\lambda)$</th>
<th>$V_{\text{mh}}(\lambda)$</th>
<th>$V_{\text{ml}}(\lambda)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS, 400 W</td>
<td>0.66</td>
<td>96</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Pulse-start MH, 320 W</td>
<td>1.61</td>
<td>72</td>
<td>1.33</td>
<td>0.98</td>
<td>0.68</td>
</tr>
<tr>
<td>LPS, 180 W</td>
<td>0.25</td>
<td>144</td>
<td>0.67</td>
<td>0.79</td>
<td>1.12</td>
</tr>
<tr>
<td>White LED, 6500 K</td>
<td>2.06</td>
<td>80</td>
<td>1.20</td>
<td>0.78</td>
<td>0.50</td>
</tr>
</tbody>
</table>

(Rea, 2013)
Why is scene brightness perception important?

Brighter outdoor locations are judged safer

(Rea et al., 2009)
Spectral Sensitivity for Brightness Perception

- Spectral sensitivity for scene brightness has increased short-wavelength sensitivity

- Different from increase in scotopic sensitivity for peripheral detection

- Most closely related to short-wavelength cone photoreceptors (Weale, 1953; Wooten et al., 1975)

(Rea et al., 2011)
Provisional Model for Scene Brightness Perception

- \( B(\lambda) = V(\lambda) + g \cdot S(\lambda) \)
  - \( g \) is the short-wavelength gain
  - \( g \) increases with increasing light level (Bezold-Brucke effect)

- If illuminance is 2 lux, \( g = 1.5 \)
- If illuminance is 20 lux, \( g = 2.5 \)
  - Change in short-wavelength sensitivity is opposite from the Purkinje shift for mesopic visual detection

(Rea et al., 2011)
A Simplified System of Bright Illuminance

- Rather than a continuous family of brightness luminous efficiency functions, a subset of functions could be used:
  - “High” (illuminance ≥ 25 lux)
  - “Low” (10 lux ≤ illuminance < 25 lux)
Comparing Light Sources

<table>
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<tr>
<th>Description</th>
<th>lm/W</th>
<th>Relative power $V_{B2}(\lambda)$</th>
</tr>
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<tr>
<td>HPS, 400 W</td>
<td>96</td>
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(Rea, 2013)
Discussion

- A simplified set of benefit metrics for outdoor lighting might facilitate their use in lighting practice
  - A small subset of fixed functions rather than a continuously sliding scale may be easier to implement
  - Some precision is lost

- Outdoor lighting is based on multiple objectives
  - Visual performance both on- and off-axis, brightness perception, cost, maintenance, etc.
Acknowledgments

- From the LRC:
  - Mark Rea
  - “Value Metrics for Better Lighting”
- LRC Partners:
  - 3M, AES Latin America, GE Lighting, NYSERDA, OSRAM Sylvania, Philips, Swedish Energy Agency, Xcel Energy