Improving Lighting Simulations for Application Efficiency

Sarah Safranek

January, 2020
Simulation Tools for Lighting Design

Lighting recommendations for visual needs:

• Horizontal or vertical illuminance on target surface
Simulation Tools for Lighting Design

Luminaire Spectral Power Distribution

Surface Reflectance Distributions

Ceiling
Walls
Floor
Simulation Tools for Lighting Design

![Diagram of a room with a table and shelves, illustrating surface reflectance distributions.](image)

**Surface Reflectance Distributions**

- **Dupont Yellow Photopic** $p = 56\%$

![Graph showing % reflectance versus wavelength (nm)](image)
Simulation Tools for Lighting Design

Surface Reflectance Distributions

Luminaire Spectral Power Distributions

Radiant Power (W/nm)

Wavelength (nm)

- 6200 K
- 4700 K
- 3800 K
- 3500 K
- 2700 K

% Reflectance

Wavelength (nm)

- Dupont Pale Blue
- Dupont Yellow

Photopic $\rho = 56\%$
Lighting Recommendations – Beyond Visual Needs

• **Equivalent Melanopic Lux (EML)**
  • WELL Building Standard, from Lucas paper, ipRGCs, m-lx

• **Melanopic Irradiance**
  • CIE, micro-W/cm²

• **Circadian Stimulus (CS)**
  • Lighting Research Center, ipRGCs + rods & cones

Intensity, spectrum, duration, timing, prior exposure, individual differences, etc.
Lighting recommendations – Beyond visual needs

Equivalent Melanopic Lux (EML) & Circadian Stimulus (CS) Recommendations

- WELL Building Standard v1 (May 2016)
  \texttt{\textgreater 250 EML} at 75\% of view positions, 4’ AFF, 4 hours

- WELL Building Standard v1 (Q3 2017)
  \texttt{\textgreater 200 EML} at 75\% of view positions, 4’ AFF, 9 AM – 1 PM

- WELL Building Standard v2 (Q2 2019)
  1 pt: \texttt{\textgreater 150 EML OR \texttt{\textless 0.3 CS}} at 100\% view positions, 4’ AFF, 9 AM – 1 PM
  3 pts: \texttt{\textgreater 240 EML} at 100\% view positions, 4’ AFF, 9 AM – 1 PM

- UL Design Guideline 24480 (2020)
  \texttt{\textgreater 0.3 CS} at 100\% view positions, 43” AFF, 2+ hours between 7 AM – 4 PM
Horizontal Point Illuminance Calculations
3’ AFF

0 lx  300 lx
Vertical View
Illuminance Calculations
4.5’ AFF
Vertical View
EML Calculations
4.5’ AFF

44 EML

247 EML

99 EML
CCT = N/A  
Avg. EML = 181

CCT = 3800K  
Avg. EML = 98

CCT = 6200K  
Avg. EML = 137
Measured Luminaire Information

SPDs of white-tunable LED luminaire

- 3800 K
- 6200 K
- 2700 K

Power draw across range of intensity settings

Luminaire Power

Luminaire Output (% Lumens)
Measured Surface Information

<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Avg. Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Paint</td>
<td>0.75</td>
</tr>
<tr>
<td>Flooring - Dark Grey</td>
<td>0.30</td>
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<tr>
<td>White Ceiling Tile</td>
<td>0.84</td>
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<tr>
<td>Silver Window Frame</td>
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<tr>
<td>Blonde Wood Furniture</td>
<td>0.37</td>
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</tbody>
</table>
Baseline Condition

**Simulation Goals:**
- Lighting meets IES visual requirements
  - **300** lx horizontal 30” above floor
  - **150** lx vertical 18” above work plane
- Lighting meets WELL v2 Pilot (2019) Circadian Lighting Design Credit
  - **100%** of desk locations receive at least **150 EML** OR **CS > 0.3** (1 point)
  - OR **100%** of desk locations receive at least **240 EML** (3 points)

**Simulation Input:**
- 5000 annual operating hours
- Typical lighting solution
  - **3800 K**
  - (32) 2x2 Recessed LED Luminaires
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**30% Increase in annual energy usage**

**Annual Energy Usage w/ 4hr limit (kWh)**

| ALTERNATE USAGE SCENARIO | 4185 |
Effects of Surface Reflectance

Blonde Finishes

Warm Finishes

Cool Finishes

Avg = 36%

Avg = 18%

Avg = 66%
Effects of Surface Reflectance

**Blonde Finishes**

<table>
<thead>
<tr>
<th>CCT [K]</th>
<th>Avg EML</th>
<th>Avg CS</th>
<th>WELL v2 1 point via EML</th>
<th>WELL v2 1 point via CS</th>
<th>WELL v2 3 points via EML</th>
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@ 100% Lumen Output
Lighting recommendations – Beyond visual needs

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- WELL Building Standard v1 (Q4 2019)?
  \[ \text{>150 EML at 100% view positions, 4’ AFF, 9 AM – 1 PM (Electric light only)} \]
  \[ \text{>200 EML at 75% view positions, 4’ AFF, 9 AM – 1 PM (Electric light and daylight)} \]

- UL Design Guideline 24480 (2020)
  \[ \text{>0.3 CS at 100% view positions, 43” AFF, 2+ hours between 7 AM – 4 PM} \]
Effects of Surface Reflectance – Adjusted for WELL v2 2020

(All conditions achieve 150 EML at all view positions)
Key Takeaways

• It’s still the early days!
  • Science, software, and recommendations are still developing

• Know your limits
  • Limitations of simulation tools may have broader impact

• Spectrum matters
  • Many surfaces attenuate short wavelengths

• Optimizing lighting application efficiency requires new tools
  • Improved software tools allow for more data driven decisions