Predicting the non-visual effects of lighting in buildings
University of Washington

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Spectral lighting simulation

Applications of spectral light simulation
- Color appearance of interiors
- Agriculture
- Human health

Research on accurate simulation of color indoors

Project goal to further development of LARK multispectral simulation tool
1. Spectral Interaction with daylight
2. How is this implemented in LARK
3. Improvements in LARK and why is it important?
4. Predicting color of the sun
Spectral Interaction with daylight

- **Spectral Power Distribution (SPD)**
  - Showing energy levels of a light source through a range of wavelengths

- **Visible Light Transmittance (VLT)**
  - Amount of light in the visible portion of the spectrum that passes through a glazing material

- **Transmitted Light**
  - Energy levels of transmitted light
Spectral Interaction with daylight - example

Spectral Power Distribution (SPD)
Showing energy levels of a light source through a range of wavelengths
Spectral Interaction with daylight - example

Amount of light in the visible portion of the spectrum that passes through a glazing material

Visible Light Transmittance (VLT)

Amount of light in the visible portion of the spectrum that passes through a glazing material
Spectral Interaction with daylight - example

Energy levels of transmitted light

Transmitted Light

Energy levels of transmitted light
Spectral Interaction with daylight - example

Spectral Reflectance
wavelengths of light that reflect off a surface
Spectral Interaction with daylight - example

Reflected Light
Energy levels of reflected light
Spectral Interaction with daylight - example

Spectral Reflectance

wavelengths of light that reflect off a surface
Spectral Interaction with daylight - example

Reflected Light
Energy levels of reflected light
Spectral Interaction with daylight - example

Reflected Light Entering eyes
Energy level of reflected light entering our eyes
Spectral Interaction with daylight

Light entering eyes
Light is processed through light-sensitive cells (rods, cones, ipRGCs)

These cells contain proteins that interact with light-sensitive chemicals to enable vision, circadian rhythms, and other light-induced neuroendocrine responses

Opsin 1 (Photopic)
Visual Sensitivity to Light

Opsin 4 (Melanopic)
Non-visual Sensitivity to Light
Regulates sleep-wake cycle & Alertness

Opsin 5 (Neuropic)
Regulates temperature and metabolic rate

Together, inputs from opsins regulate neuroendocrine responses in our body
Spectral Interaction with daylight

Reflected Light Entering eyes
Energy level of reflected light entering our eyes

Opsin 1 (Photopic)
Opsin 4 (Melanopic)
Opsin 5 (Neuropic)

\[ \begin{align*}
\text{Energy level of reflected light} & \leq 400 \text{ lux} \\
\text{Energy level of reflected light} & \leq 300 \text{ lux} \\
\text{Energy level of reflected light} & \leq 100 \text{ lux}
\end{align*} \]
LARK

LARK Input

1. Light Source
   - Sky
   - Electric Light

2. Material
   - Surface Reflectivity
   - Window Transmissivity

3. Geometry

LARK Output

Radiance Simulation

- Opsin 1 (Photopic)
  - Visual Sensitivity
    - Color Sensitivity
    - Brightness of scene

- Opsin 4 (Melanopic)
  - Non-Visual Sensitivity
    - Entraining Circadian System
    - Regulating physio-endocrine system

- Opsin 5 (Neuropic)

Light Source
- Sky
- Electric Light

Material
- Surface Reflectivity
- Window Transmissivity

Geometry
**LARK v1.0**

1. **Sky (Diffuse horizontal)**
   - Correlated Color Temperature in K (Kelvin): 5600 K
   - Wavelength (nm):
     - 5600 K: W/m²
     - 5500 K: W/m²

2. **Sun (Direct Solar)**
   - Correlated Color Temperature in K (Kelvin): 5500 K
   - Wavelength (nm):
     - 5500 K: W/m²
LARK v3.0

1. **Sky (Diffuse horizontal)**
   - Correlated Color Temperature: 5600 K
   - Wavelength Distribution

2. **Sun (Direct Solar)**
   - Correlated Color Temperature: 4250 K
   - Wavelength Distribution

<table>
<thead>
<tr>
<th>Correlated Color Temperature in K (Kelvin)</th>
</tr>
</thead>
<tbody>
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<td>2000</td>
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Wavelength (nm)
Spectral Sky + Sun - why is it important?

No Color

Colored Sky (V.0)

Colored Sky + Colored Sun (V.3)

June 21 10am - Clear Sky

Intensity of the sun: 863 W/m²

Intensity of the sky: 167 W/m²

X5 intensity

Color of the sun has large impact in the amount of light received.
Spectral Sky + Sun - why is it important?

7000K sun + 9000K sky
June 21 10am

3000K sun + 9000K sky
June 21 10am
Spectral Sky + Sun - why is it important?

clear
9000k sky + 3000k sun

clear
9000k sky + 7000k sun

clear
9000k sky + 5000k sun

intermediate
5000k sky + 5500k sun

overcast
7000k sky + 3000k sun
Color of the Sun

2020 Solar Spectra Data

Clean Data
- Cull Night Time
- Cull measurement Errors

Categorize Data
- Overcast
- Intermediate
- Clear Turbid
- Clear

Relationship with Sun Angle

Golden, CO

Eugene, OR
How to put in Sky + Sun in LARK

1. Light Source
   - Sky
   - Electric Light

2. Material
   - Surface Reflectivity
   - Window Transmissivity

3. Geometry

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Sky (Diffuse horizontal)

Sun (Direct Solar)

Full spectrum
- Measured (user input)
- Default values

Simplified 9C color representation

Radiance Simulation
Conclusions

• LARK v3.0 scheduled to be realised by June 15th

• Conference paper for IBPSA
  (Jung BY, Cheng Z, Brennan M, Inanici M. Multispectral Lighting Simulation Approaches for Predicting Opsin-driven Metrics and their Application in a Neonatal Intensive Care Unit. Paper presented at: 18th International IBPSA Conference and Exhibition; 2023 Sept 4-6; Shanghai, China.)

• Color of the sun largely impacts quality of light and finding the variability of sunlight is a major contribution to the scientific community

• This finding is going to be submitted for publication in LEUKOS -Journal of Illuminating Engineering Society
  (Jung BY, Brennan M, Inanici M. Variability of sun spectra: findings from collected data. Leukos, the Journal of the Illuminating Engineering Society)

• Acknowledgement - sky spectra data collected on Gould Hall funded by UW & ARC
• Continuing this research for my PhD
Next Steps

• Add sample database for sun spectra based on CCT
• Create LARK tutorial videos