Human Centric Lighting needs new quantities for light intensity

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Light for life: are we using the right light?

HUMAN CENTRIC LIGHTING:
designed to benefit human health & wellbeing

_the right light, at the right time & place_
Human Centric Lighting: non-visual responses to light

- Increasing light intensity (and blue content): increases alertness (all times of day)
- Decreasing light intensity (and blue content): supports relaxation (all times of day)
- Light at night must be handled with care: not to disrupt sleep and health

Opportunity: dynamic light solutions; mimic dawn and dusk, create a photoperiod of about 12 hours of sufficient brightness and 12 hours of dim, blue-deprived light, or darkness
Health and wellbeing (SSL-erate WP3) non-visual effects of light

- Identify non-visual effects for five application domains (education, healthcare, workplaces, homes, cities)
- Create dose-response curves (scientific studies): which non-visual effects occur in what light intensity ranges
- Give guidance on which light metrics to use in practice

*Accelerate uptake Solid State Lighting technology*
Quantify light via five photoreceptor inputs

**Spectral sensitivity**

- **S-Cone** (Blue)
- **M-Cone** (Green)
- **L-Cone** (Red)
- **Melanopsin** (480nm)
- **Rods** (nightvision)

*Start including melanopsin activation in our lighting designs, codes & standards*

**photoreceptors interplay & total spectral sensitivity depends on (non-visual) effect, timing, intensity, adaptation state...**

Rethinking light beyond vision and lux...

Visual system

spectrum * V(\lambda)

Lux

Non-visual system

spectrum * sensitivity: (eq.) opic Lux

new quantities for HCL
Measuring Light

- Tool 1: quantifies photoreceptor input in opic-lux (Lucas et al)

http://dx.doi.org/10.1016/j.tins.2013.10.004

Irradiance Toolbox

<table>
<thead>
<tr>
<th>Light source</th>
<th>Lambertian illuminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>L</td>
</tr>
<tr>
<td>Amount</td>
<td>1.00</td>
</tr>
</tbody>
</table>

For blackbody or narrowband sources:

- Blackbody temperature: 4200 n/a
- Narrowband peak: 420 n/a nm
- Narrowband FWHM: 42 n/a nm

Photopic Illuminance

- Photopic Visibility: 555.0 n/a
- Photopic Sensitivity: λmax (n/a)
- Photopic Curve: α_opic lux

Unweighted summations from 380 to 780 nm inclusive

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Units</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance</td>
<td>µW/cm²</td>
<td>0.55</td>
</tr>
<tr>
<td>Photon flux</td>
<td>L/cm²/s</td>
<td>1.62 x 10^12</td>
</tr>
<tr>
<td>Log photon flux</td>
<td>log₁₀ (L/cm²/s)</td>
<td>12.21</td>
</tr>
</tbody>
</table>

Prefix | α-opic lux
--- | ---
Cyanopic | 1.00
Melanopic | 1.00
Rhodopic | 1.00
Chloropic | 1.00
Erythropic | 1.00
CIE: make “opic-lux” approach SI compliant

<table>
<thead>
<tr>
<th>Radiometric</th>
<th>Photometric</th>
</tr>
</thead>
<tbody>
<tr>
<td>(equivalent) “melanopic Lux”</td>
<td>(equivalent) “melanopic Lux”</td>
</tr>
<tr>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>0.12</td>
<td>0.91</td>
</tr>
</tbody>
</table>

$\Downarrow$

melanopic irradiance

$in\ \mu W/cm^2$

$\Downarrow$

melanopic daylight-equivalent illuminance

$in\ Lux$

CIE is defining notations, definitions
making “opic lux” SI compliant via multiplication constants

http://div6.cie.co.at/?i_ca_id=611&pubid=490
Measuring Light

- Tool 2: extension also quantifies photoreceptor weighted irradiances, daylight equivalents and more light sources (Dieter Lang)
Melatonin suppression and light intensity

Melatonin @ night promotes good sleep and is suppressed by light.

Lux (photopic vision) does not predict melatonin suppression.

"Melanopic Lux" predicts melatonin suppression.

CIE: make "melanopic Lux" approach SI compliant.
Alertness and light intensity

Alertness correlates more strongly with log(“melanopic lux”)
Errors, depression scores and light intensity

• How does performance (errors) depend on light intensity?

• How do depression scores depend on light therapy?
  
  statistics & time frame (light intensity & therapy duration)

Work in progress........
Conclusions

- Melatonin suppression: lux (photopic vision) is not predicting the response

- $\alpha$-opic irradiances are expected to be useful predictors for non-visual effects of light in HCL, especially for narrow spectral bands, mixed colors or special whites

- The lighting practice needs SI compliant metrics:
  - unit “$\alpha$-opic lux” is not SI-compliant
  - $\alpha$-opic irradiance & $\alpha$-opic daylight-equivalent illuminance
    (multiplication factors, definitions & notations pending in CIE)

- Start using $\alpha$-opic irradiances to design light conditions that achieve, or avoid, certain non-visual effects.

- Application example for dynamic light solutions:
  - offer high melanopic irradiances during daytime
  - and minimize melanopic irradiance during the night
This is the result of collaborative efforts by

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Thank you for your attention!

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