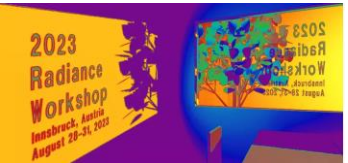
A NEW RADIANCE-BASED SIMULATION WORKFLOW FOR MODELLING ANNUAL VISUAL AND NON-VISUAL METRICS

Marshal Maskarenj
FNRS Postdoctoral Researcher,
Architecture et Climat, LAB
Universite' catholique de Louvain

Victoria Crevits
Graduate student,
Architecture et Climat, LAB
Universite' catholique de Louvain

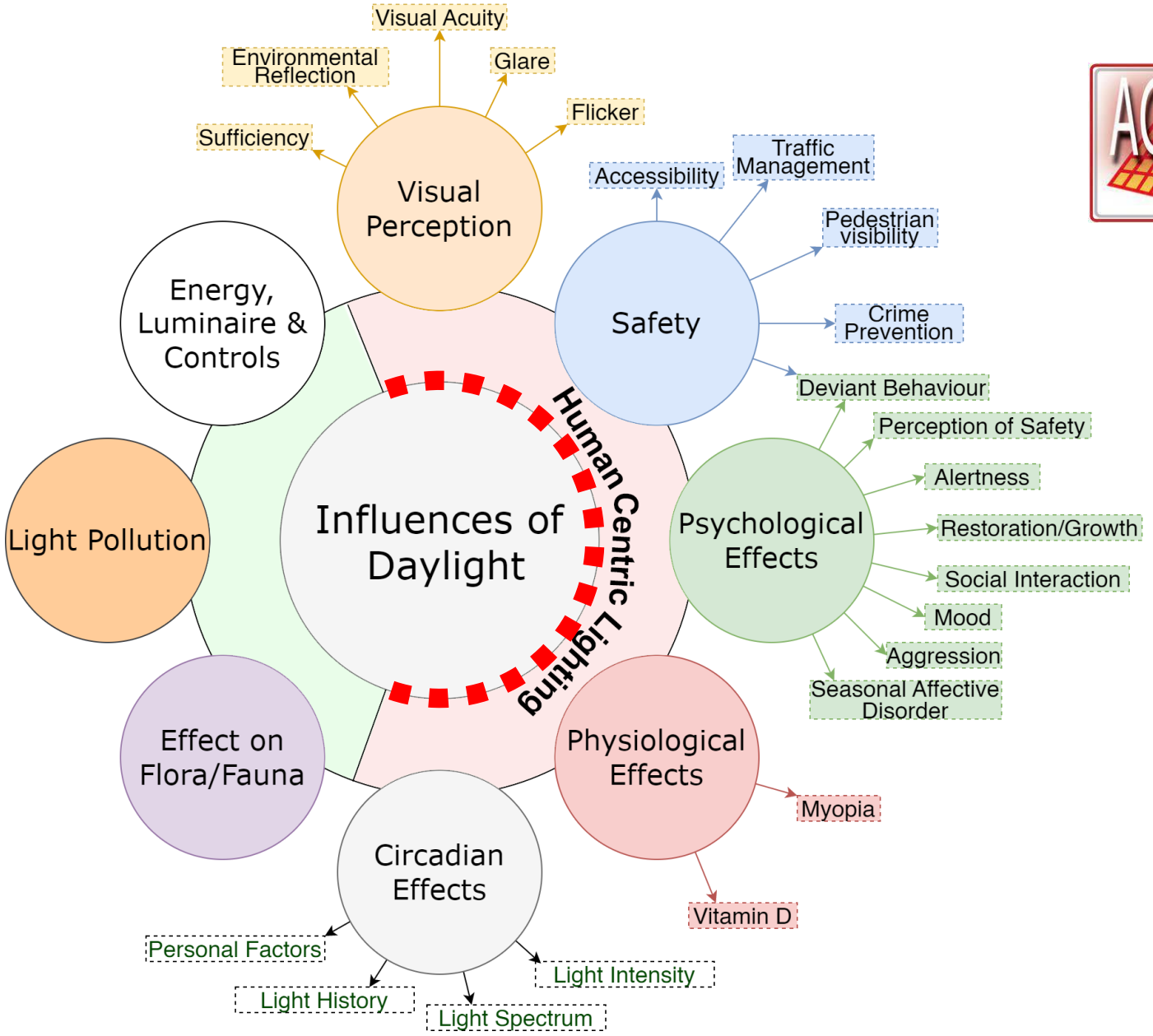
Sergio Altomonte
Professor of Arch Physics and Head,
Architecture et Climat, LAB
Universite' catholique de Louvain



universität innsbruck

UCLouvain
Louvain research institute for Landscape, Architecture, Built environment

More to light than vision



Lighting Simulation tools mostly focus on aspects of vision

AGi32 · DIALux · LightStanza · TracePro

Recent tools on non-visual aspects + metrics and recommendations

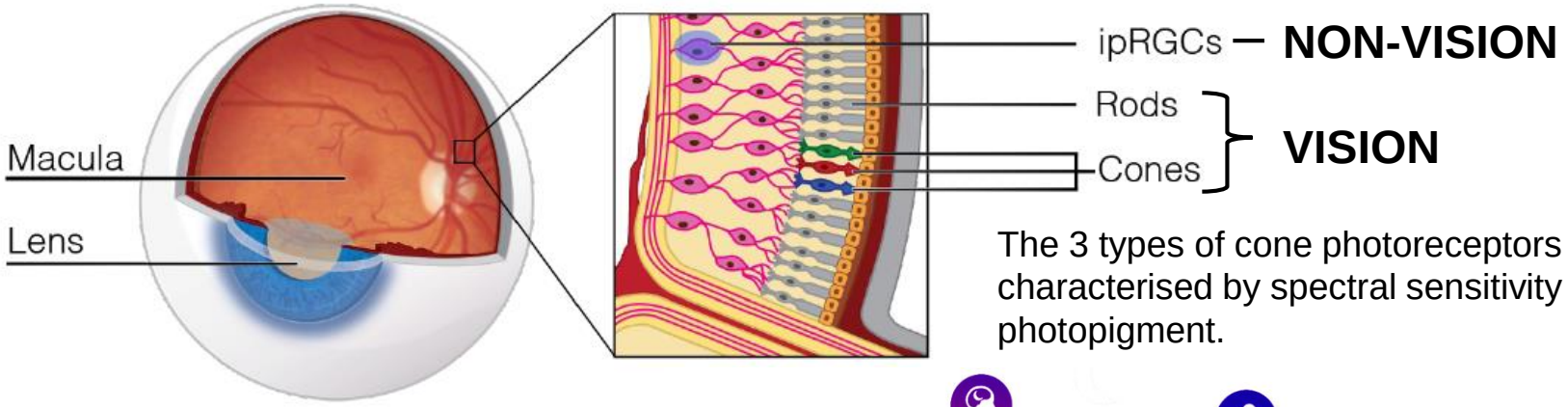
Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults

Timothy M. Brown, George C. Brainard, Christian Cajochen, Charles A. Czeisler, John P. Hanifin, Steven W. Lockley, Robert J. Lucas, Mirjam Münch, John B. O'Hagan, Stuart N. Peirson, Luke L. A. Price, Till Roenneberg, Luc J. M. Schlangen, [...], Kenneth P. Wright Jr [view all]

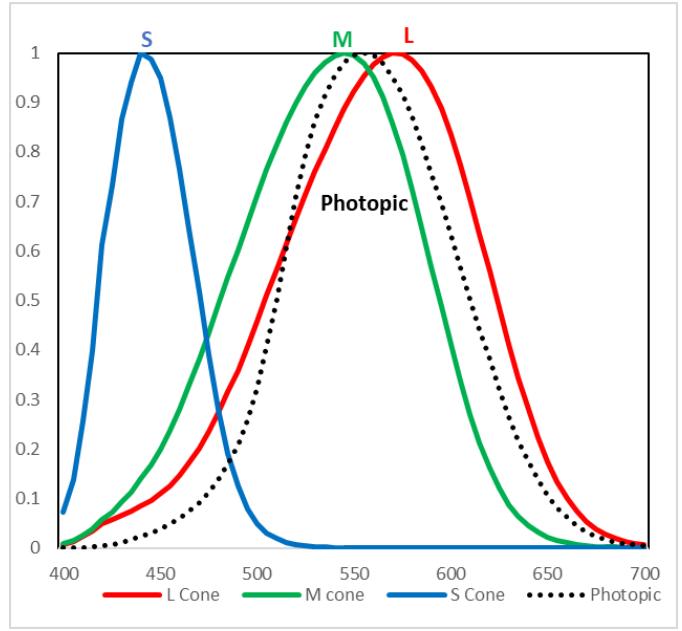
So, there have been advances in non-visual too !
This research seeks to take them further

Need to consider **visual AND non visual aspects** in our *façade + lighting design*

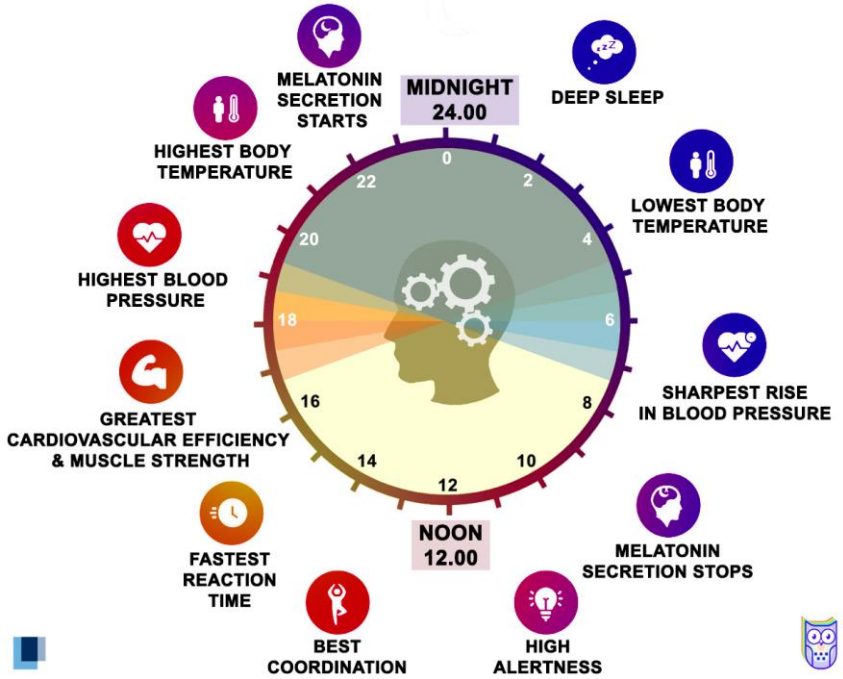
“Non-visual” light? First, let’s ask what “visual” light is



The 3 types of cone photoreceptors are characterised by spectral sensitivity of their photopigment.



The short, medium and long cones are sensitive in the blue- green- and red-wavelength regions of the optical spectrum

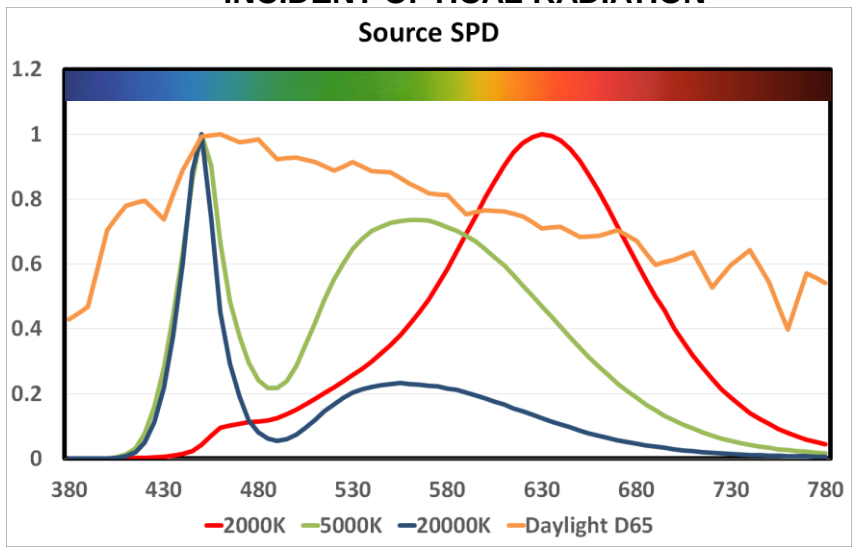


And then there’s the “Non-visual” aspect

- ✓ Intrinsically photosensitive retinal ganglion cells (ipRGCs) suppress expression of melanopsin when triggered
- ✓ Melanopsin induces sleep; suppression promotes alertness.
- ✓ ipRGC response is triggered by 480nm-rich radiation. This acts as the zeitgeber for circadian rhythms.

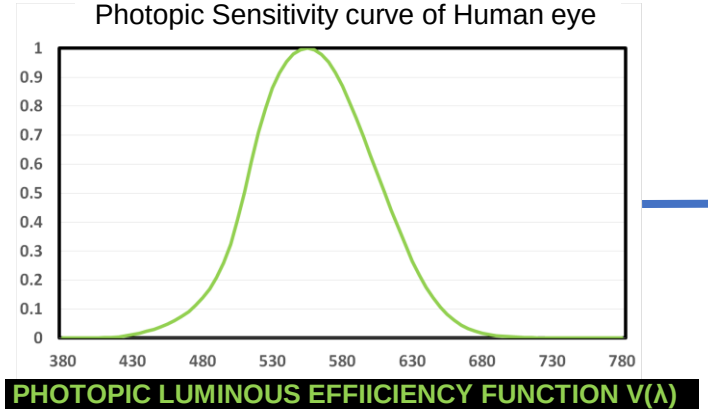
Approach for evaluating ‘visual’ and ‘non-visual’ illumination, via, Spectral sensitivity curves

INCIDENT OPTICAL RADIATION

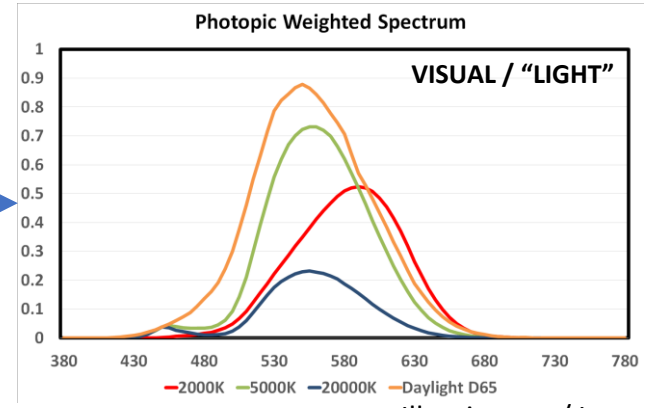


Normalized SPD curves for daylight & few LEDs

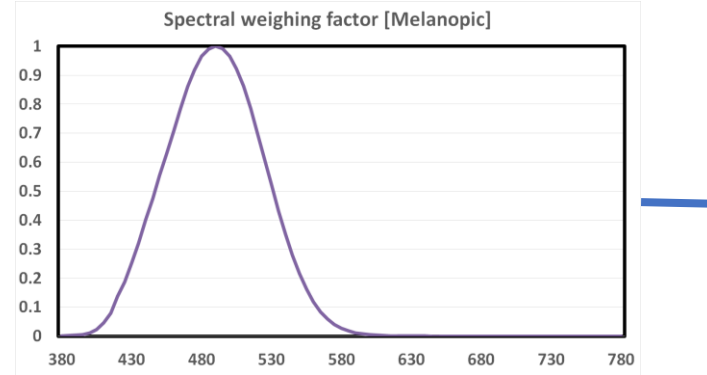
X



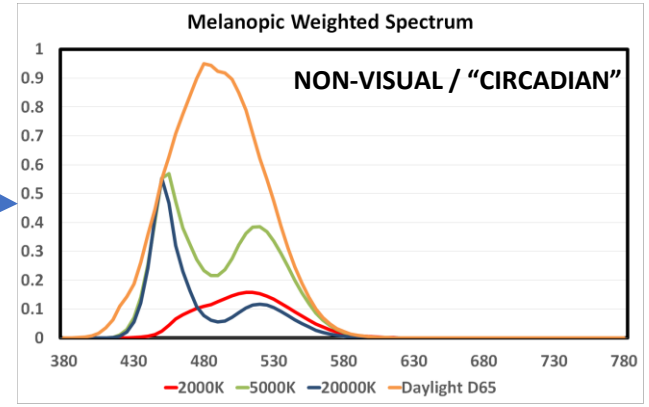
PHOTOPIC LUMINOUS EFFIICIENCY FUNCTION V(λ)



Illuminance / Lux



CIRCADIAN SPECTRAL EFFIICIENCY FUNCTION C(λ)



Melanopic-equivalent Daylight Illuminance (mEDI) / Equivalent Melanopic Lux (EML)

- **Important to know a source’s SPD across wavelengths**
- Photopic Luminous Efficiency Function V(λ) characterizes human responses to Optical Radiation
- Factoring Circadian spectral efficiency curve C(λ) evaluates non-visual/circadian metrics (EML)
- Area under curve signifies illuminance (photopic) or mEDI (circadian).

To evaluate mEDI, or CS, so we need the spectrum first

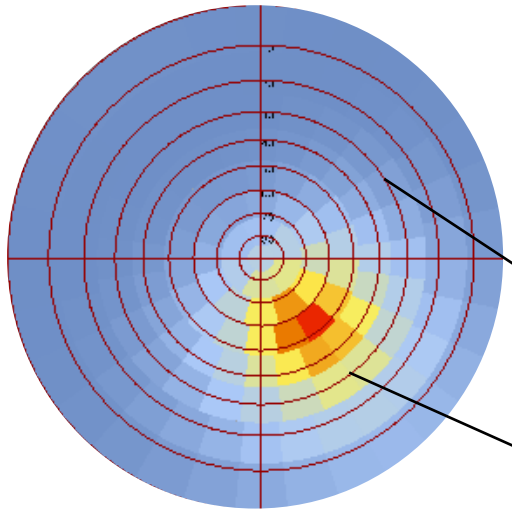
Addressing the variability in sky spectrum:

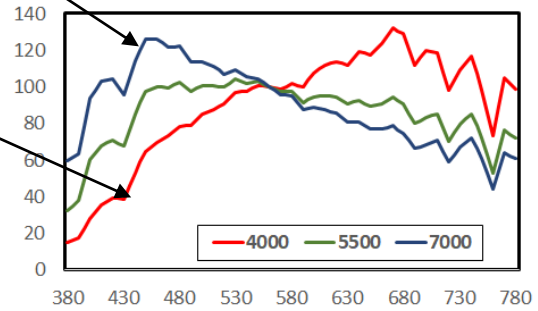
1. Daylight is highly dynamic, D65 approximation not good enough.
2. Spectrum varies with time, with location, and for different patches of sky in observer's scene.

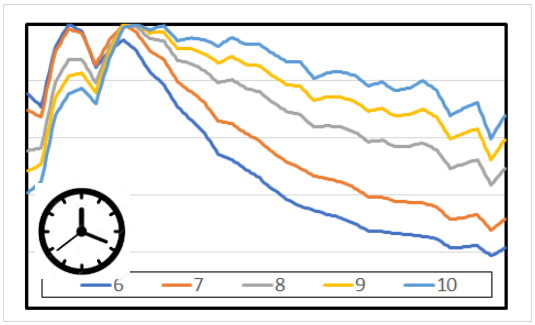
To incorporate this dynamic, Spectral sky models approach was extended towards occupant-centric evaluations.

Defining luminance (measurement or simulation) → Predicting CCT_{Si} upon existing spectral sky models → Reconstructing SPD (according to CIE 015:2018) → Calculating α-opic irradiances (according to CIE S 026/E:2018) → Calculating $K_{mel,v}$ and $\gamma^{D65}_{mel,v}$

Diakite-Kortlever & Knoop, LRT 2021





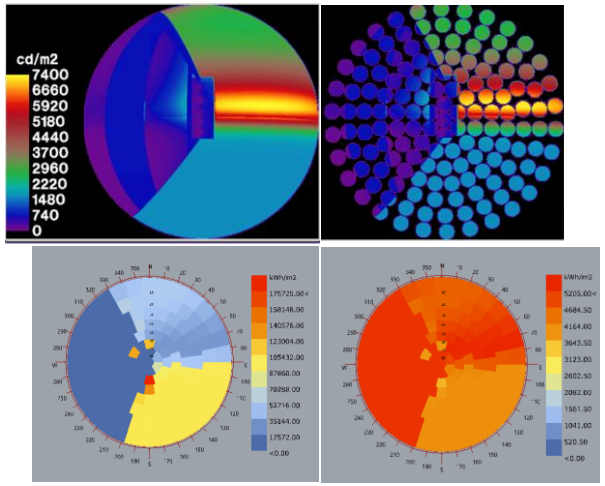


Using cumulative sky SPD as input for spectral simulations

Assessing hemispherical lum from view position (image-based sim)

Discretising luminance to patch-luminance

Patch-luminance >> CCT >> SPD >> NIF (CIE & LRC)



Dashboard of OWL: Occupant Wellbeing through Lighting

WEATHER FILE

SCENE/VIEW

DiscreteLum True

View 7

Rhino View name

0 SittingRight

ANALYSIS PERIOD

Hour of Day 7

Day of Month 21

Month of Year 6

VIEW MASK

Mask 1

View-mask [bino,human,fish]

Region-mask [patches]

Radiance Sky-type

3

Image scaling factors

0.5 0.8

NIF@Sky

Illuminance

0 19450.05

Melan-Irrad

0 28.21

Melanopic ELR

0 1.4506

Melanopic DER

0 1.0938

Melanopic EDI

0 21274.47

Circad_Light

0 53539.78

Circad_Stim

0 0.697231

DASHBOARD

imagePath_ imagePath

coordinates_ values

scale GIF

GEOMETRY/MATERIAL

NIF@view

Illuminance

0 6162.61

Melanopic Irradiance

0 9.15

Melanopic ELR

0 1.4853

Melanopic DER

0 1.12

Melanopic EDI

0 6902.13

Circad_Light

0 15223.67

Circad_Stim

0 0.68905

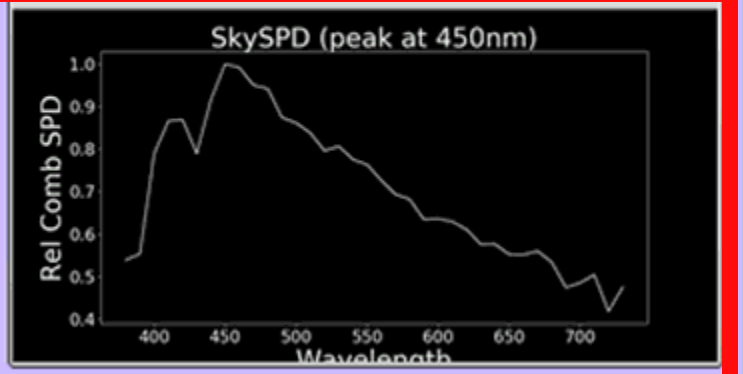
Relative combined SPD from Sky

imagePath_ imagePath

coordinates_ values

scale GIF

SKY LUMINANCE AND SPD



Region-average sky luminance

imagePath_ imagePath

coordinates_ values

scale GIF

Region-average view luminance

imagePath_ imagePath

coordinates_ values

scale GIF

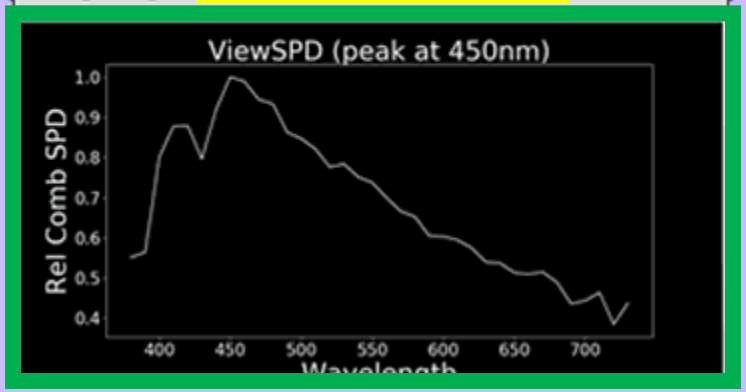
Relative Combined SPD at View

imagePath_ imagePath

coordinates_ values

scale GIF

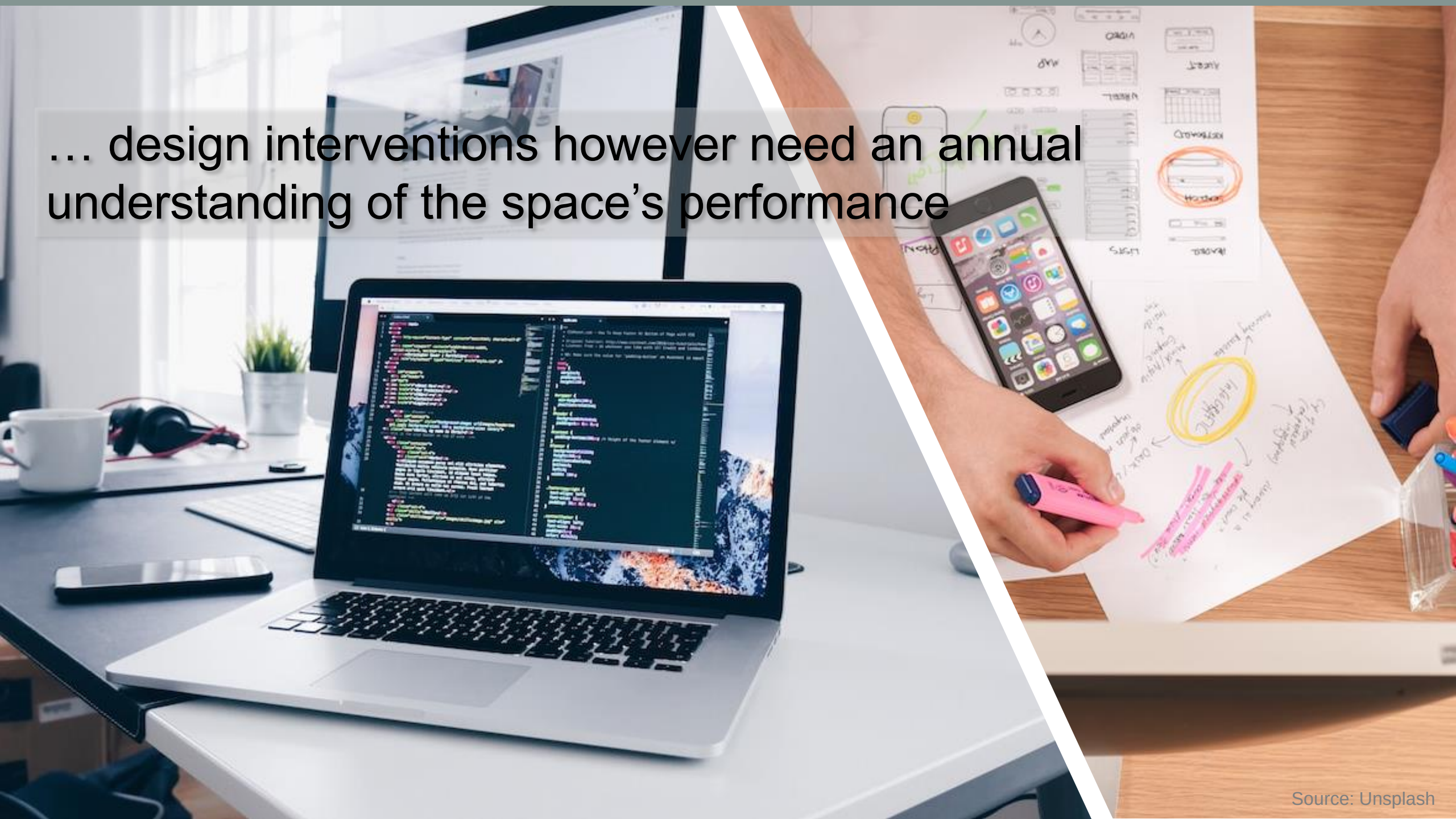
VIEW LUMINANCE AND SPD



While OWL offers an easier pre-design alternative to actual post-occupancy measurements…

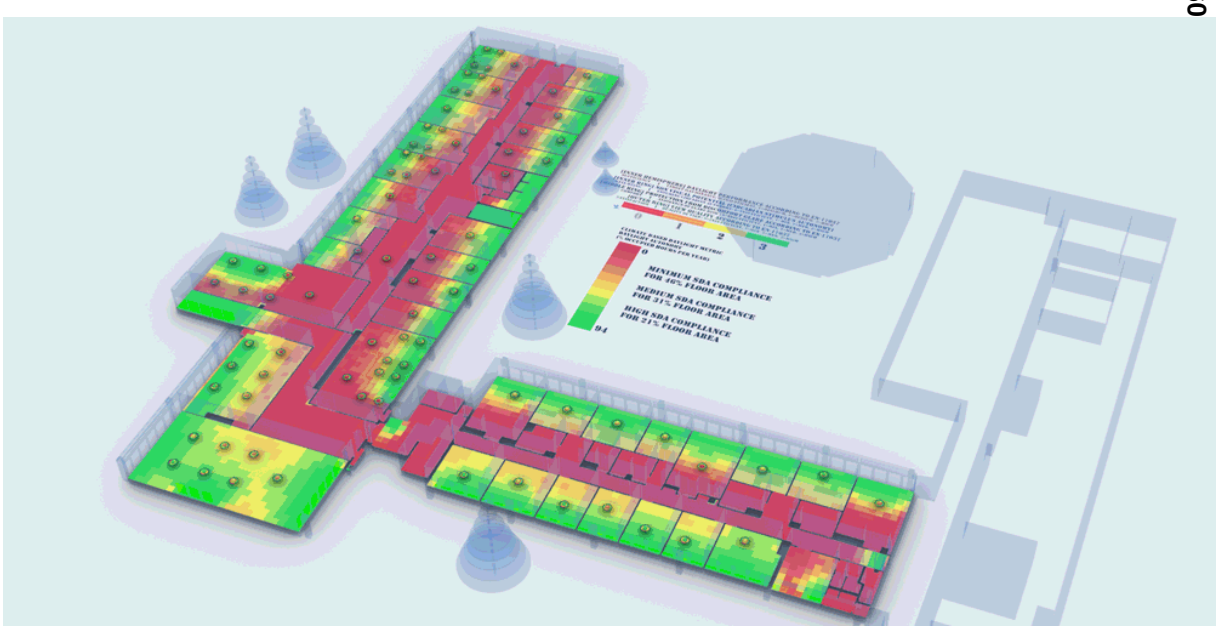
Source: Unsplash

… design interventions however need an annual understanding of the space’s performance

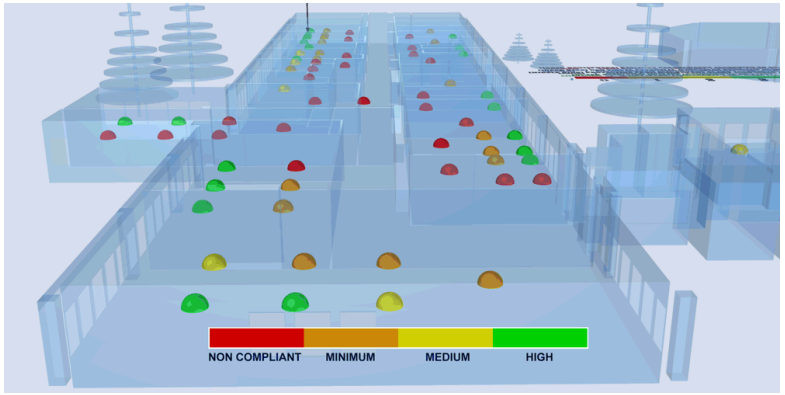


Source: Unsplash

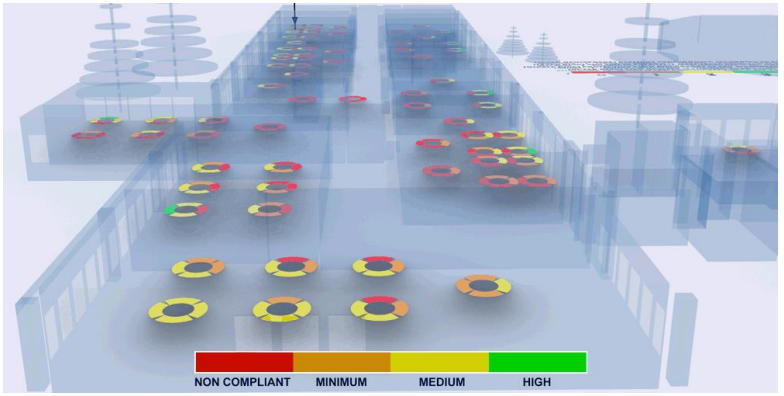
Presenting AnnuOWL: our latest tool for Occupant-centered and space-centered evaluations



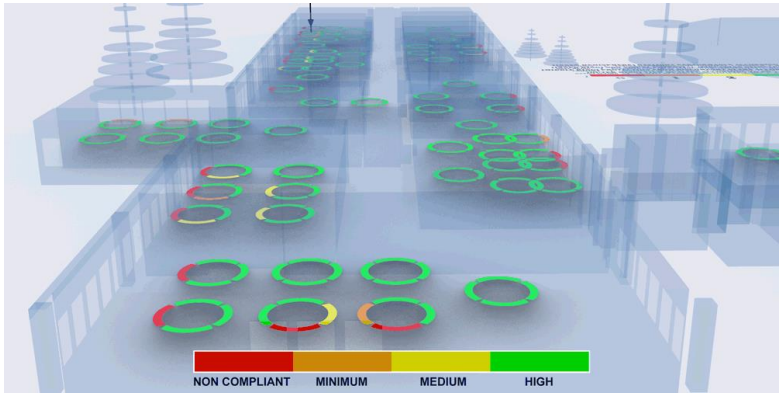
Occupant-centred visualizations via OVNI diagram



Daylight Provision

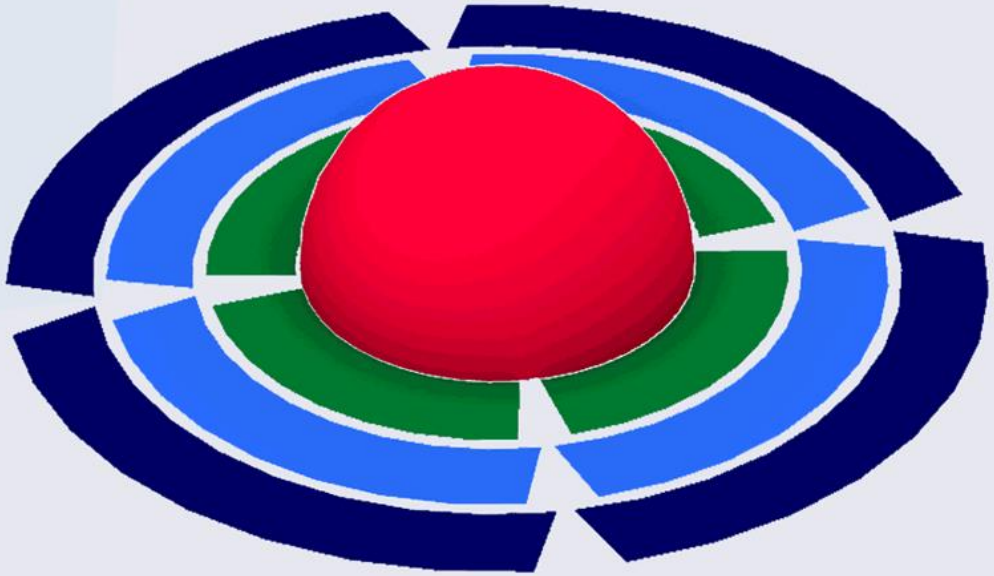


Non visual/Circadian Potential



Glare Protection

Visualizing human factors in lighting, via OVNI diagrams.

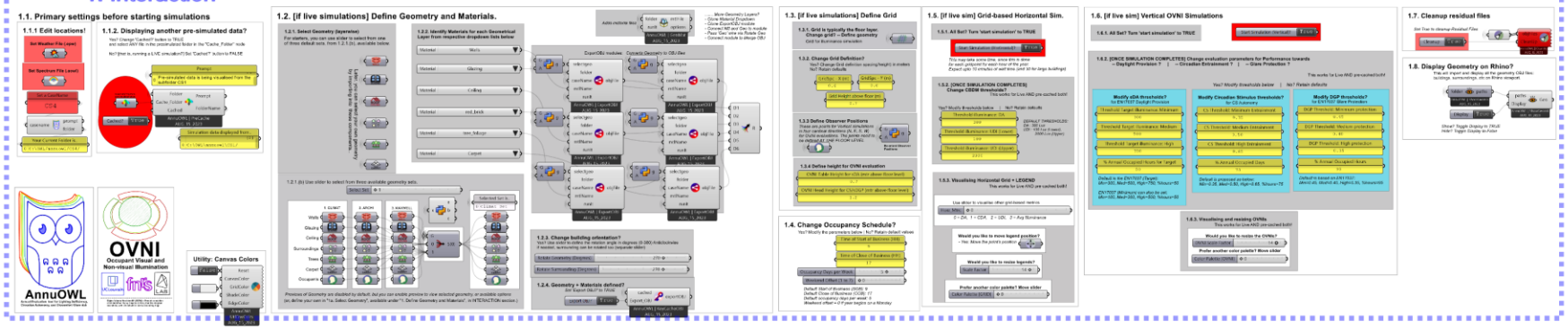


Unidentified Flying Objects

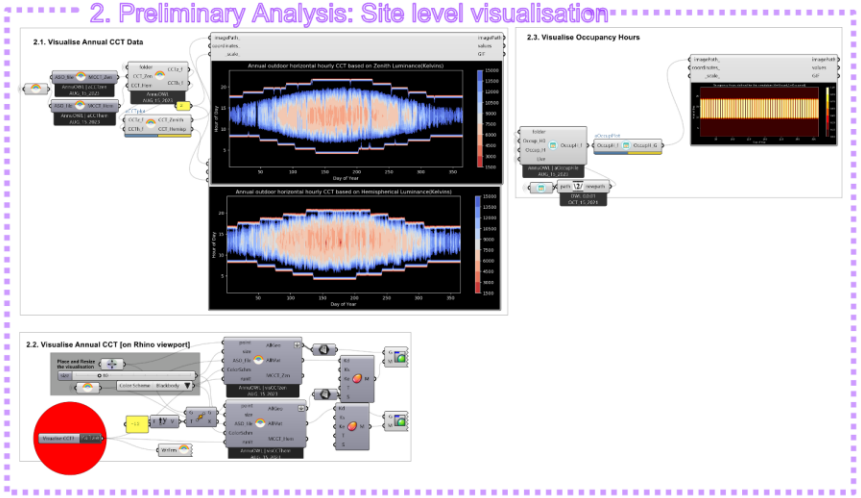
Objets Volant Non-identifie

AnnuOWL Grasshopper dashboard

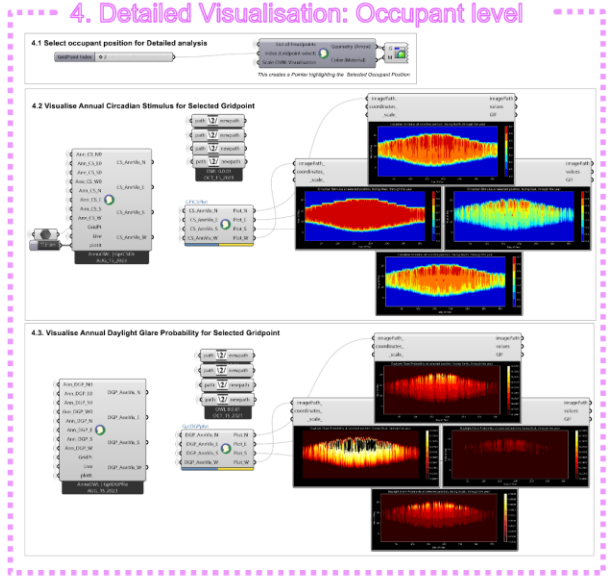
1. Interaction



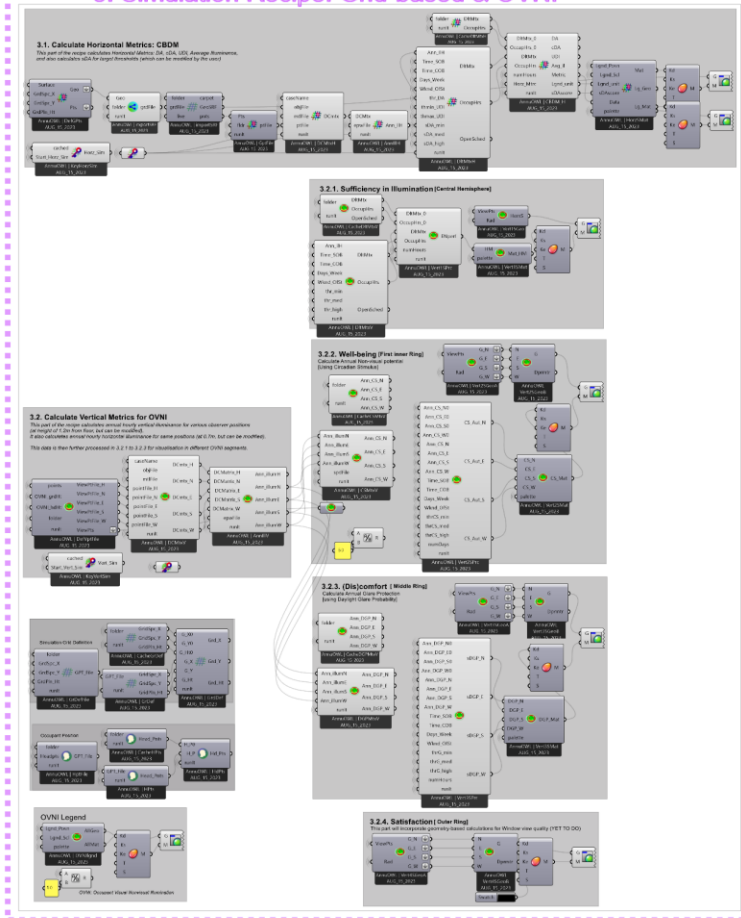
2. Preliminary Analysis: Site level visualisation



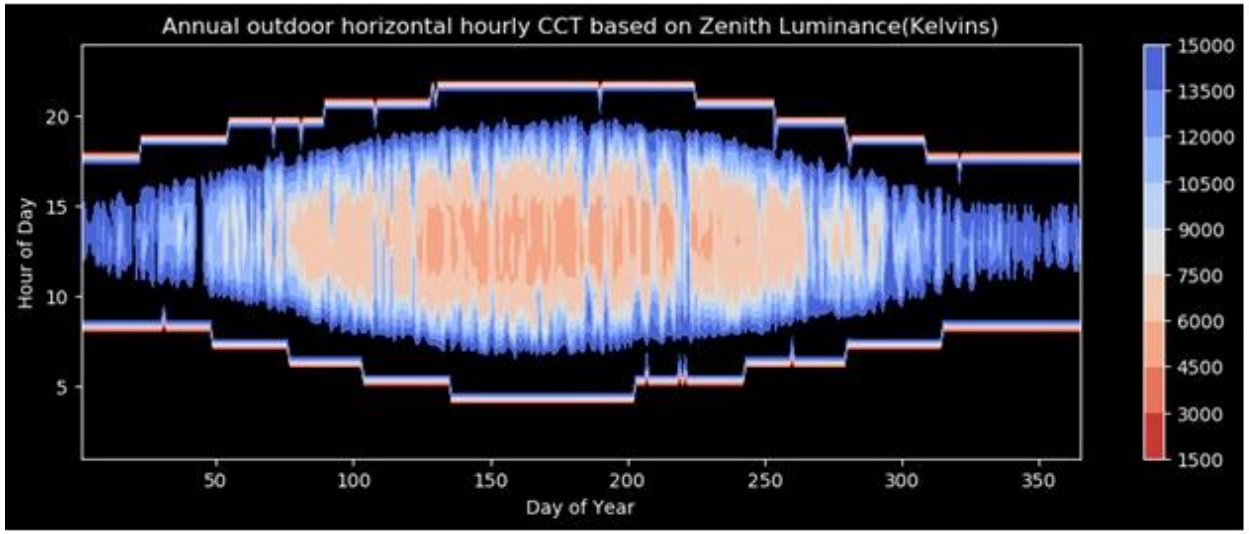
4. Detailed Visualisation: Occupant level

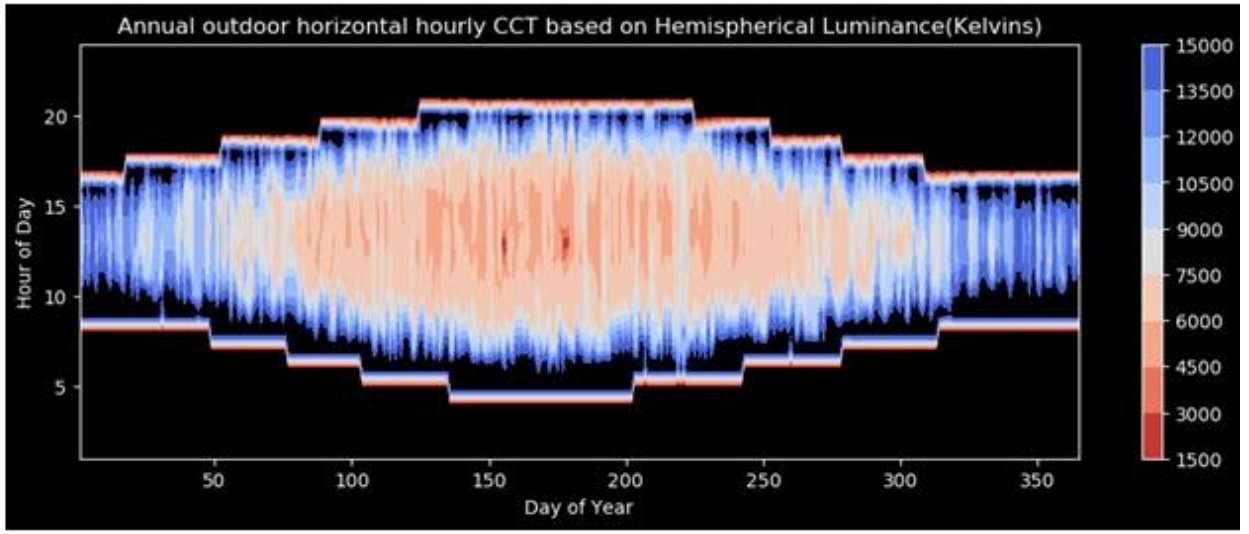


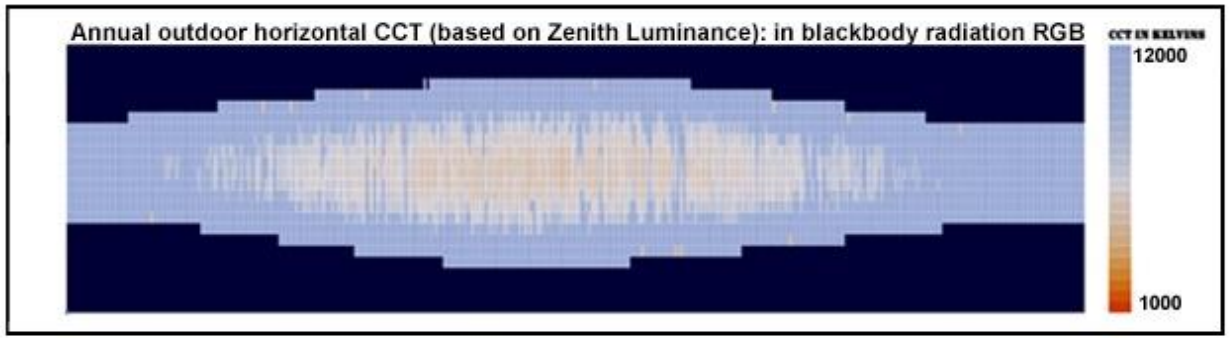
3. Simulation Recipe: Grid-based & OVNI

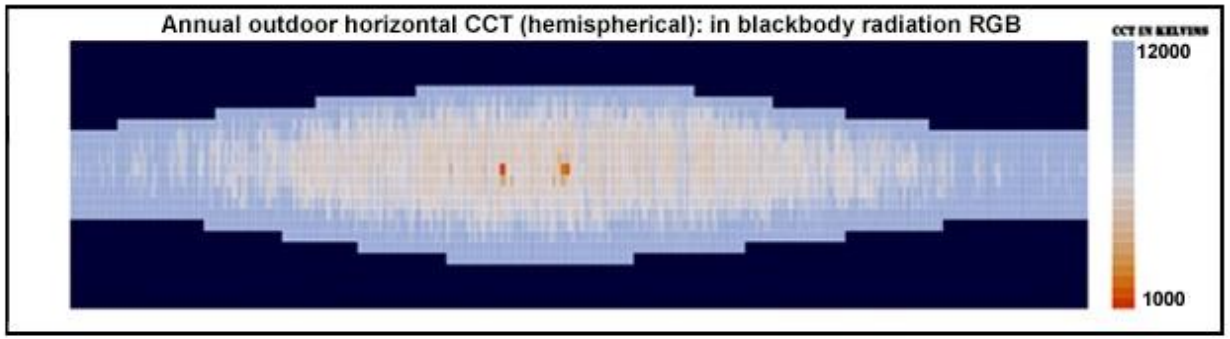


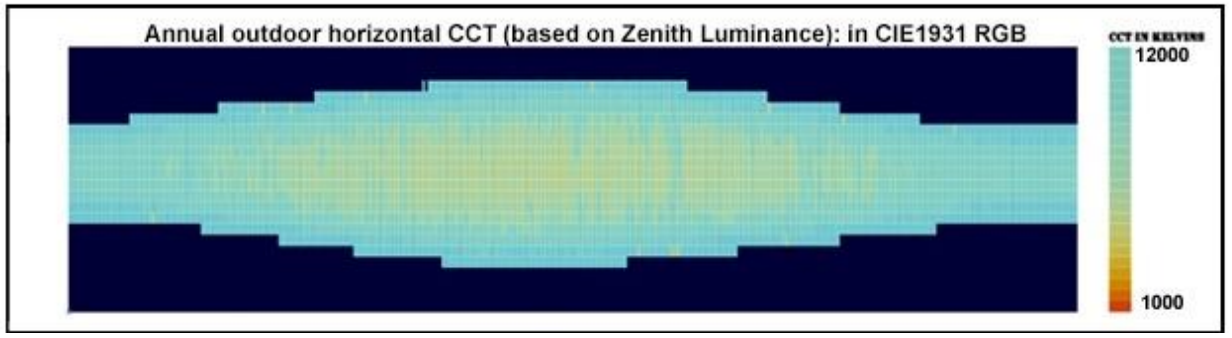
Annual compilation of sky spectrum

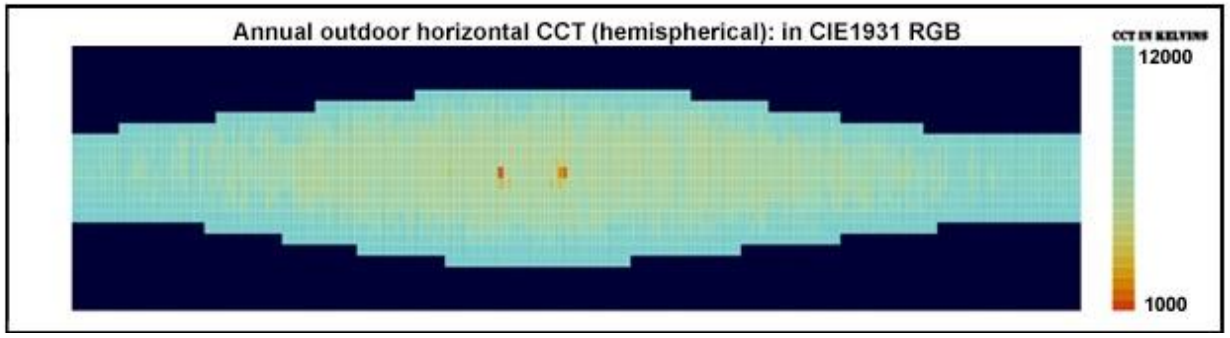












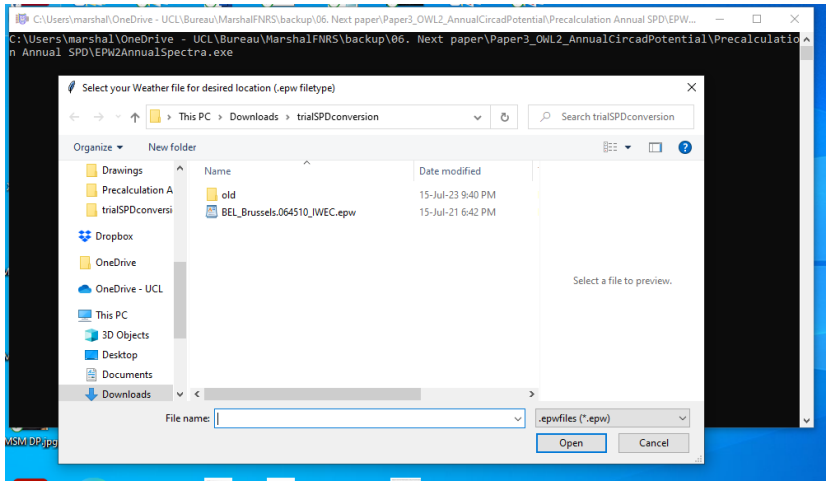
Composition of the AOWL file, and the converter utility.

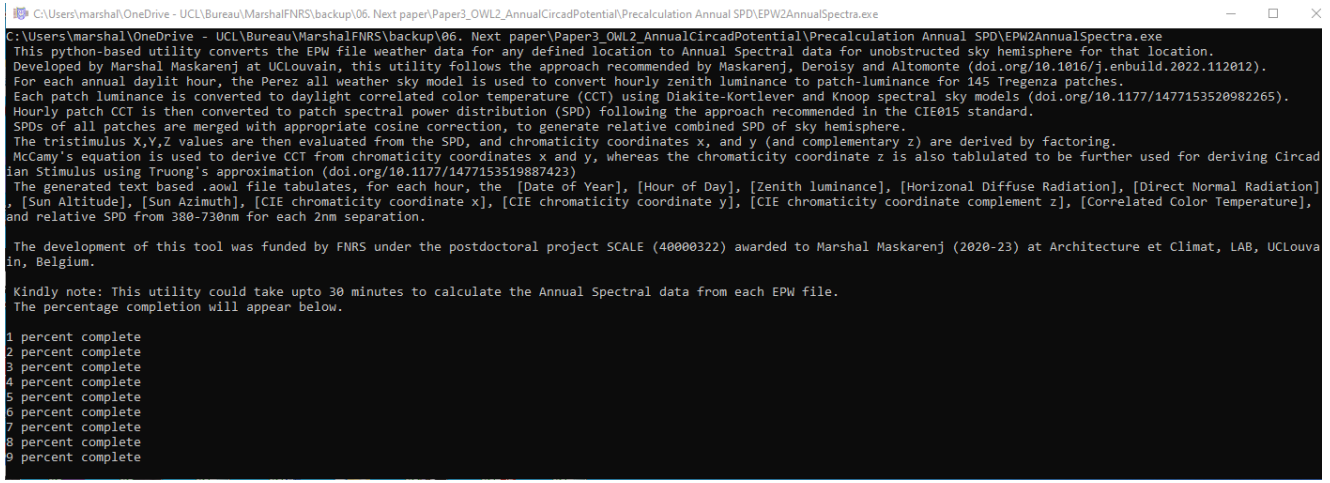
For each hour, the text-based spectrum file contains:

- Date of Year, Hour of Day,
- Zenith luminance, Horizonal Diffuse Radiation, Direct Normal Radiation,
- Sun Altitude, Sun Azimuth,
- CIE chromaticity coordinate x, y, z,
- Correlated Colour Temperature,
- Relative SPD from 380-730nm for each 2nm separation.

Effectively, each spectral file contains 187 columns across 8760 rows, excluding headers.

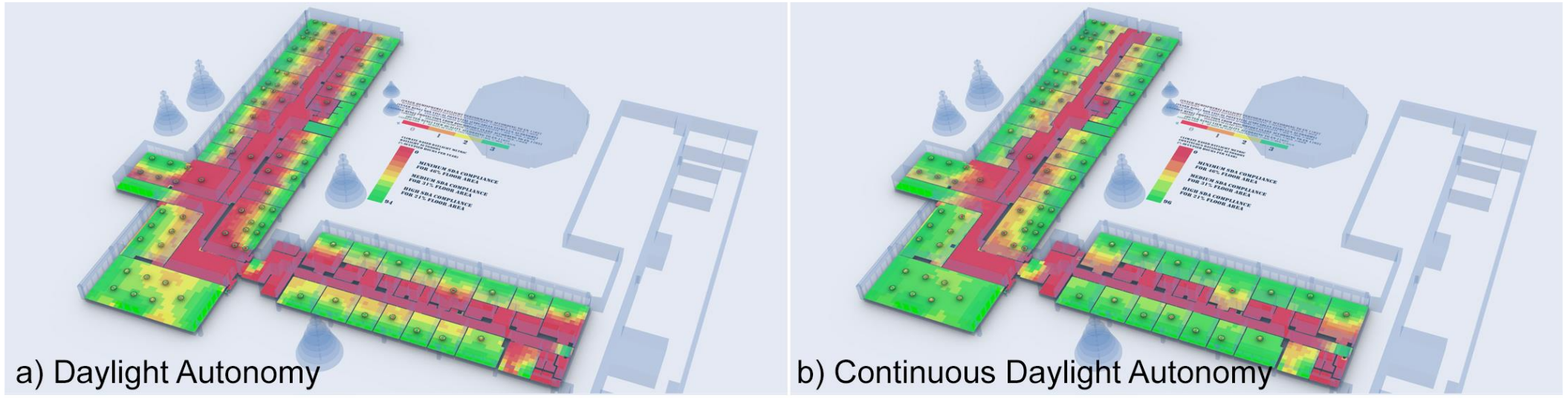
Python-based EXE for converting .EPW for any location to the appropriate .aowl file: The pre-calculation step





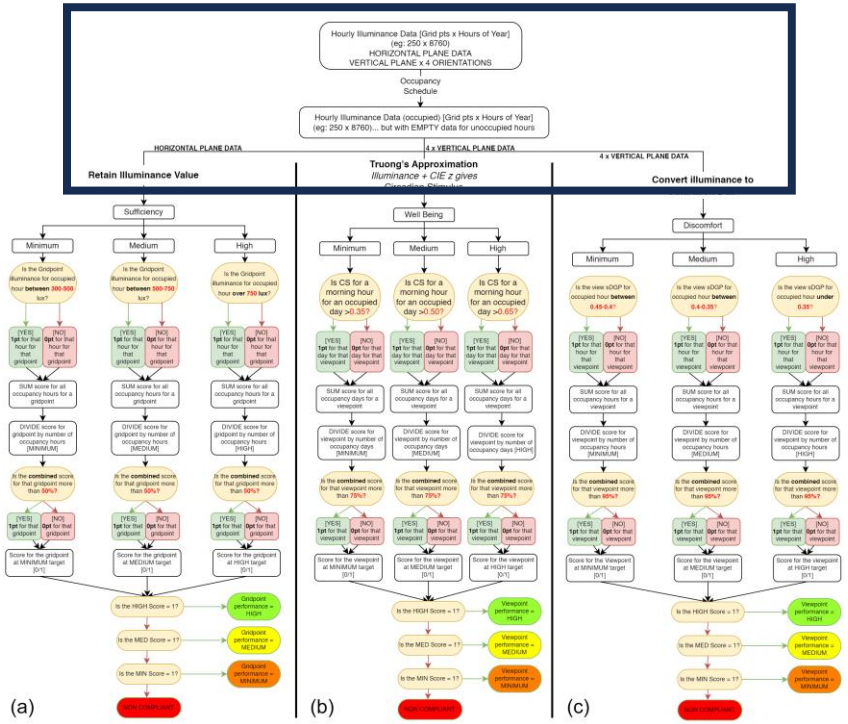
Radiance illuminance-based simulation approach in AnnuOWL components, via DC method.

(for space-centric Grid-based evaluations)



Radiance illuminance-based simulation approach in AnnuOWL components, via DC method.

(for occupant-centric OVNI-based evaluations)



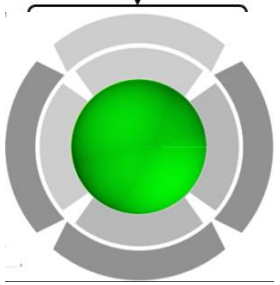
Hourly Illuminance Data [Grid pts x Hours of Year]
(eg: 250 x 8760)
HORIZONTAL PLANE DATA
VERTICAL PLANE x 4 ORIENTATIONS

Occupancy Schedule

Hourly Illuminance Data (occupied) [Grid pts x Hours of Year]
(eg: 250 x 8760)... but with EMPTY data for unoccupied hours

HORIZONTAL PLANE DATA

Retain Illuminance Value

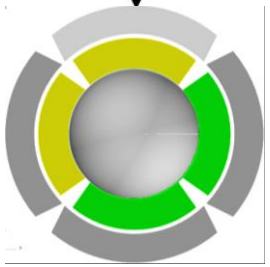


4 x VERTICAL PLANE DATA

Truong's Approximation

Illuminance + CIE z gives

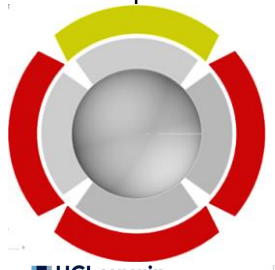
Circadian Stimulus



4 x VERTICAL PLANE DATA

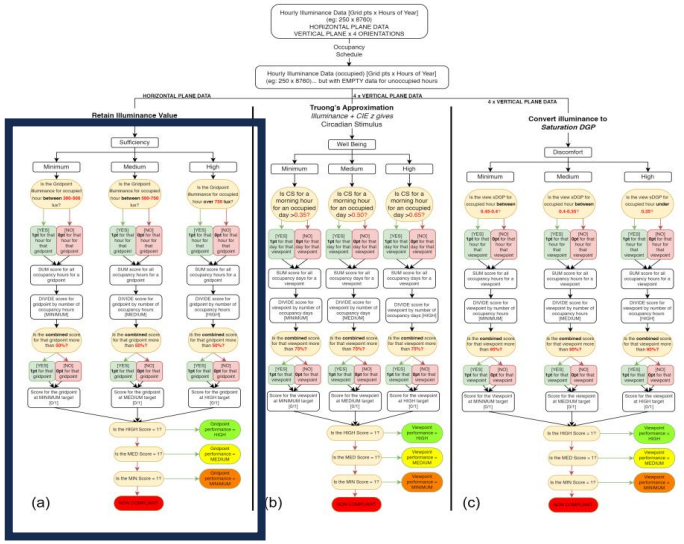
Convert illuminance to

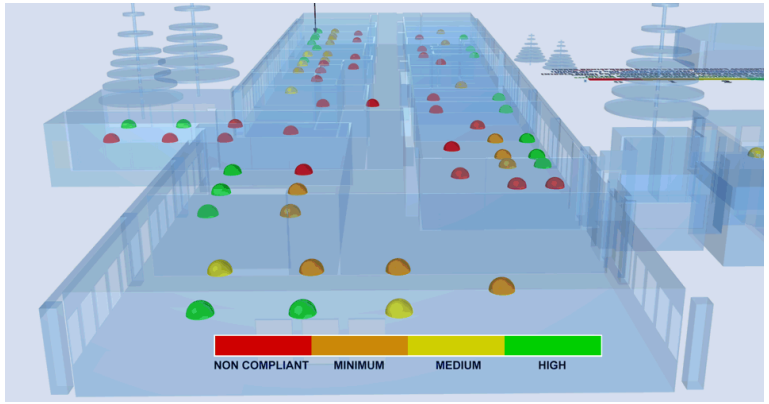
Saturation DGP

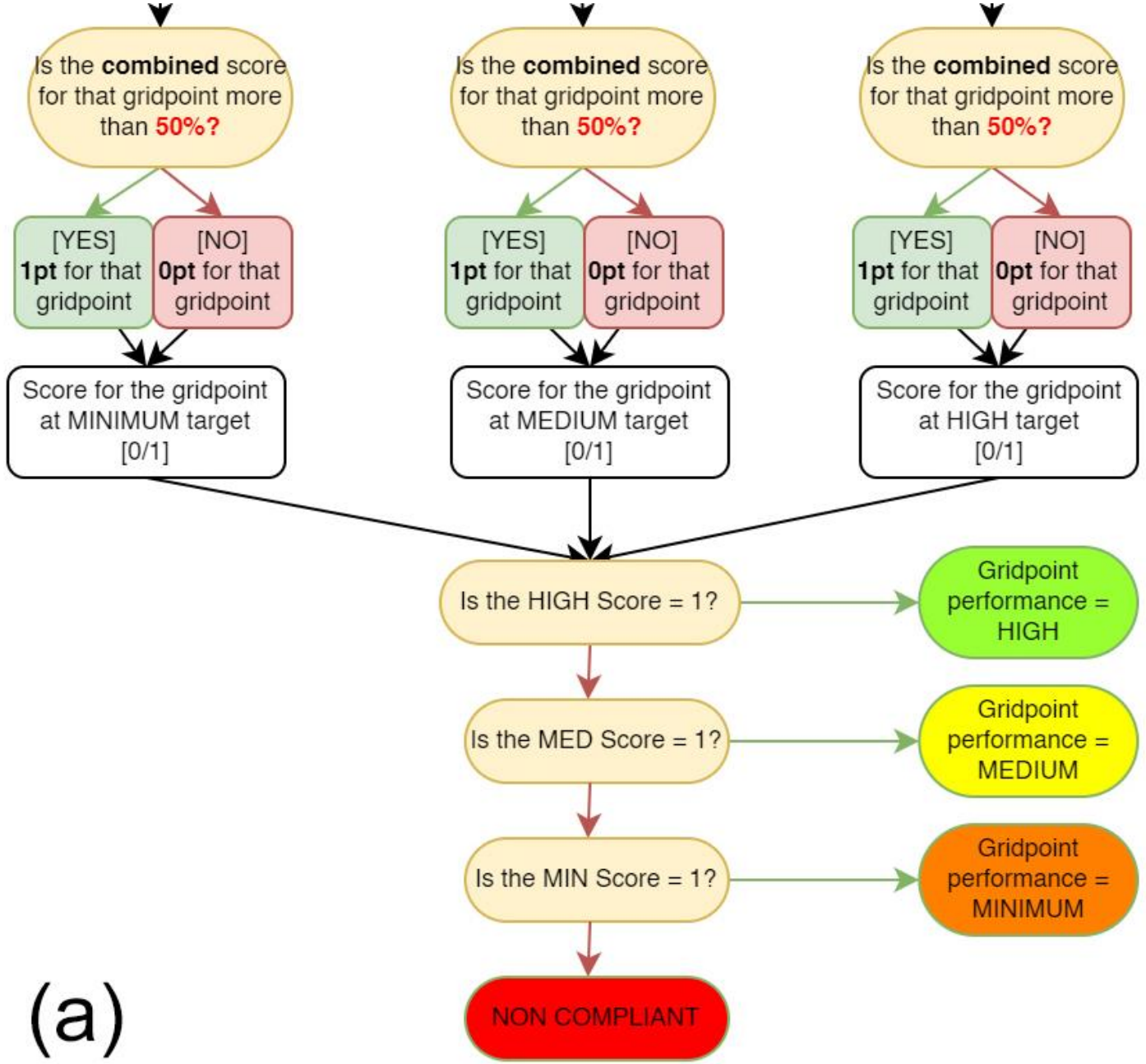


OVNI evaluations for annual performance

1. Hemisphere: evaluating daylight provision



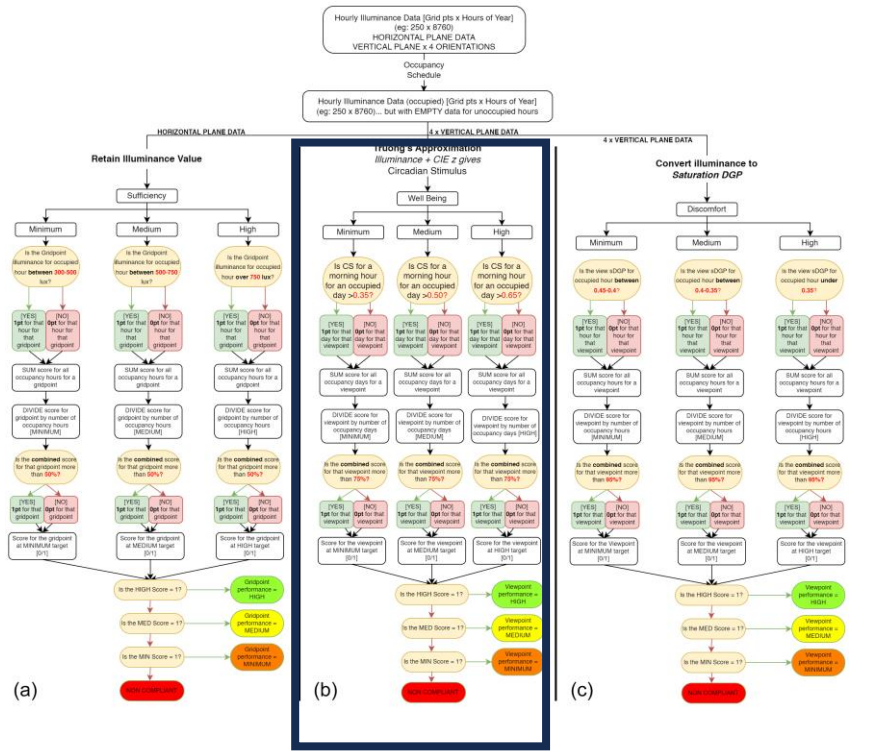


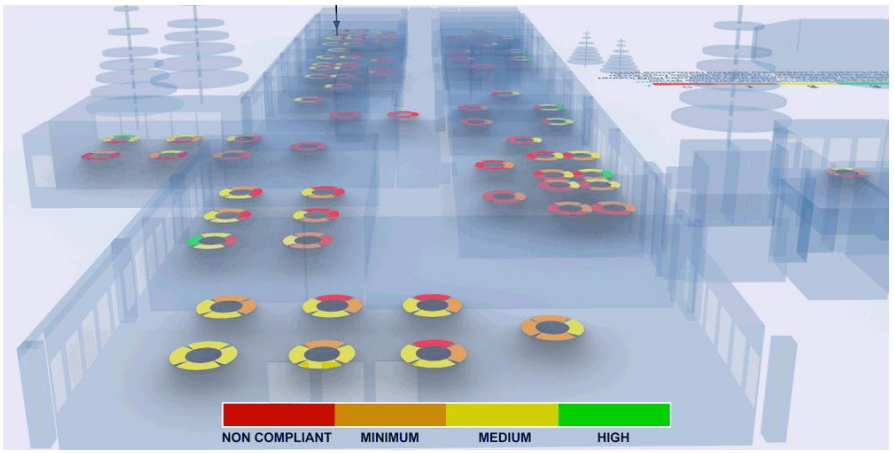


(a)

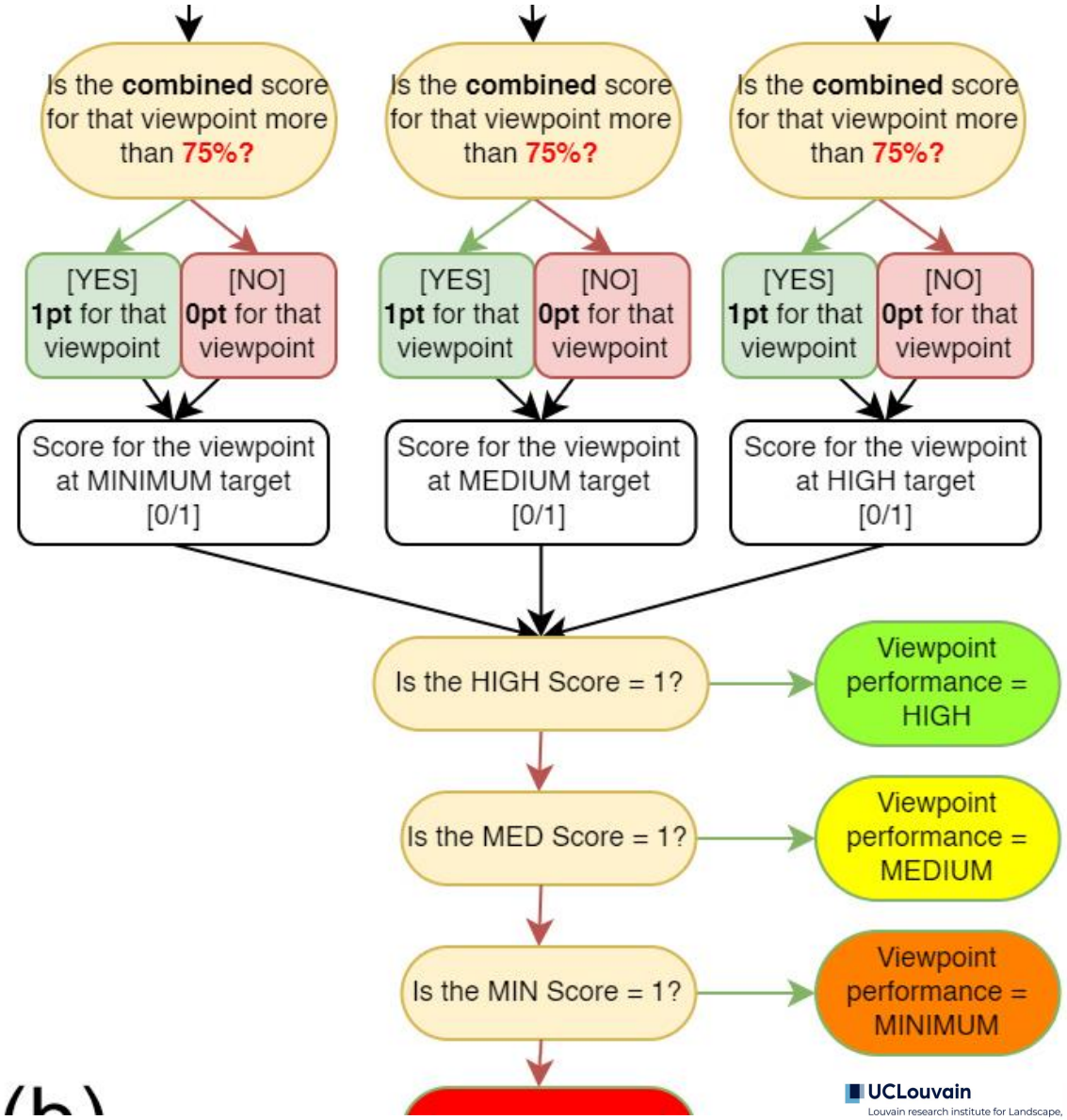
OVNI evaluations for annual performance

2. First ring, Non-visual potential. Truong approximation



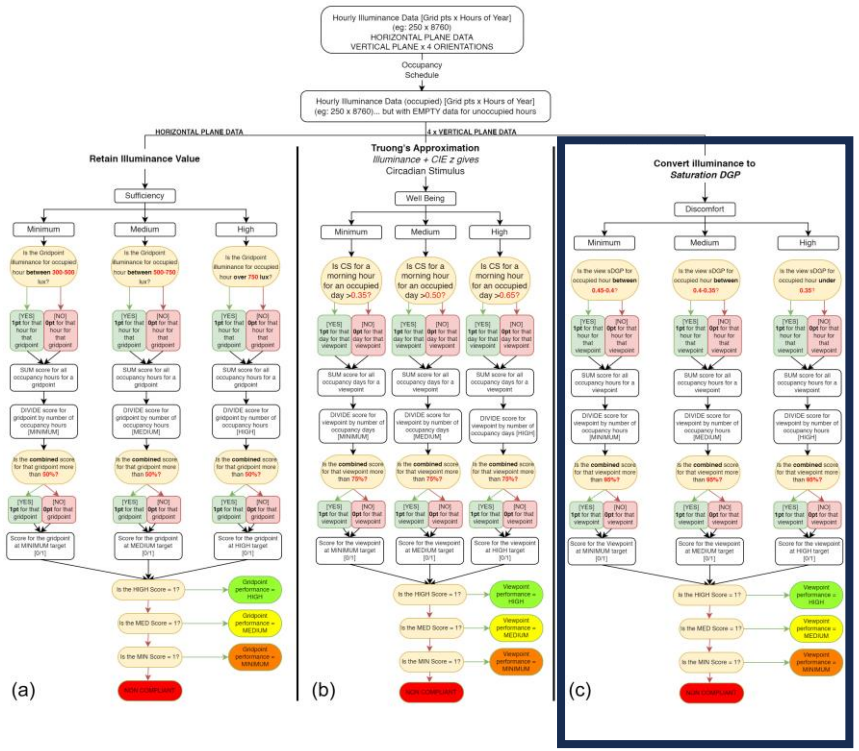


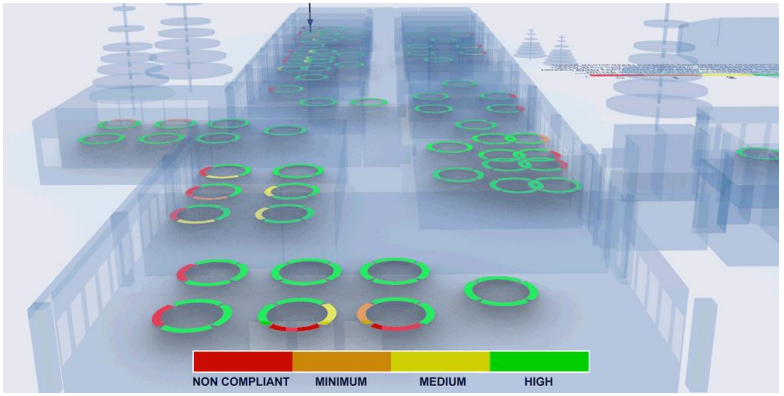
$$CS(z, E_v) = \begin{cases} 0.7 - \dfrac{0.7}{1 + 0.016781 \cdot (z \cdot E_v^{0.509265})^{2.268904}} & \text{if } z > 0.195 \\ 0.7 - \dfrac{0.7}{1 + 0.011376 \cdot (z \cdot E_v)^{1.109998}} & \text{if } z \leq 0.195 \end{cases}$$

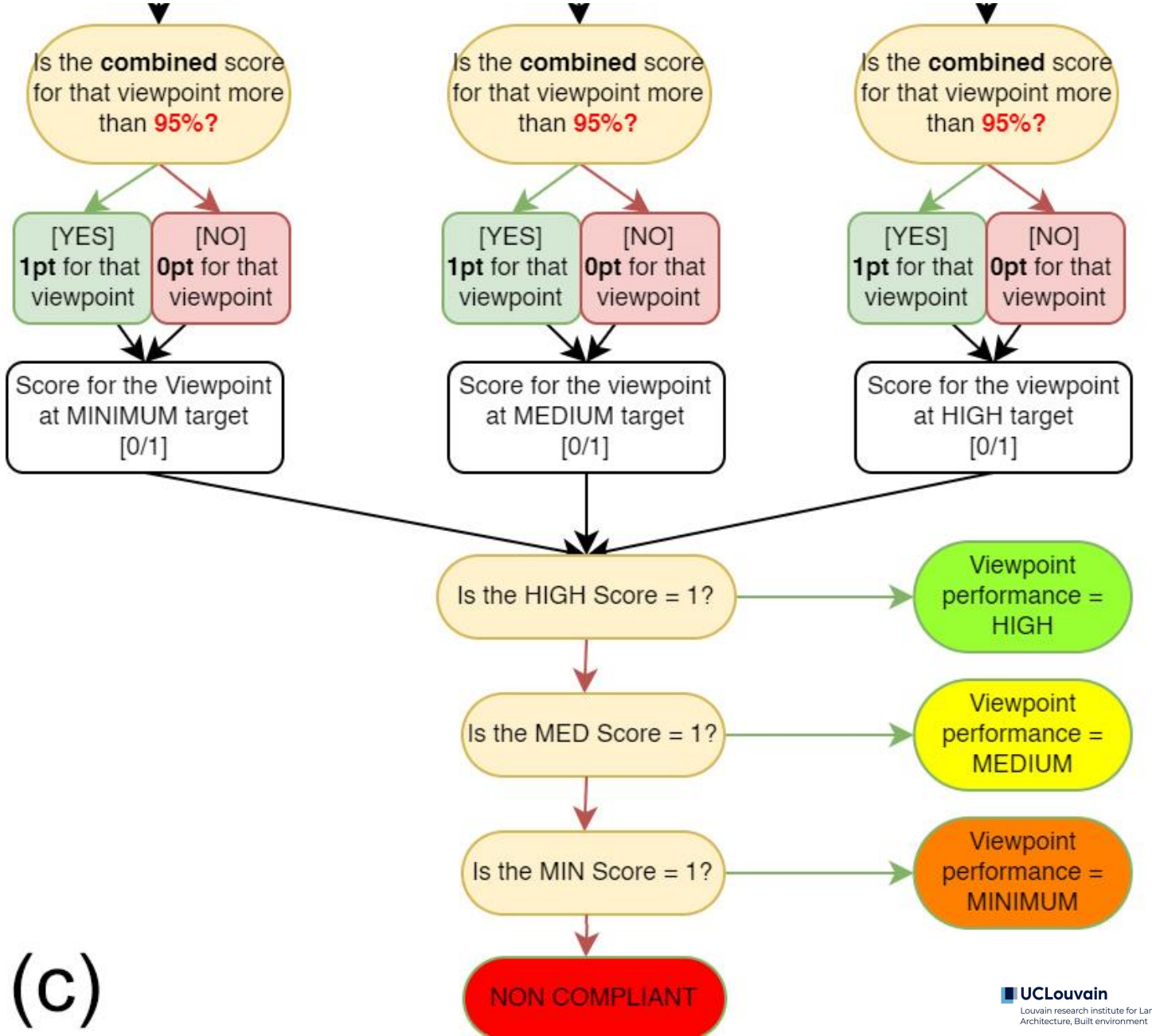


OVNI evaluations: from point in time evaluations to annual performance

3. Second ring, protection from visual discomfort due to glare, using the sDGP approach

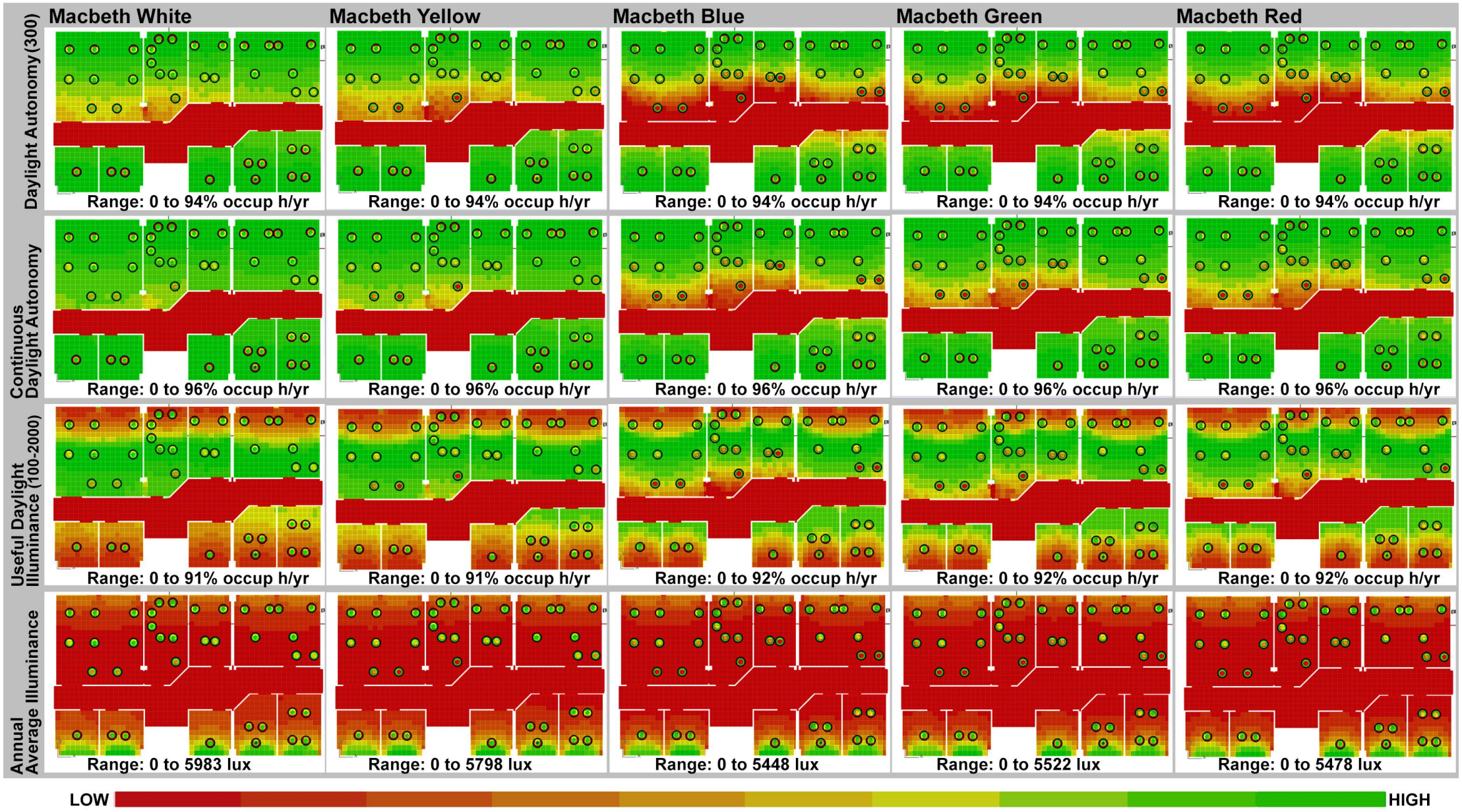






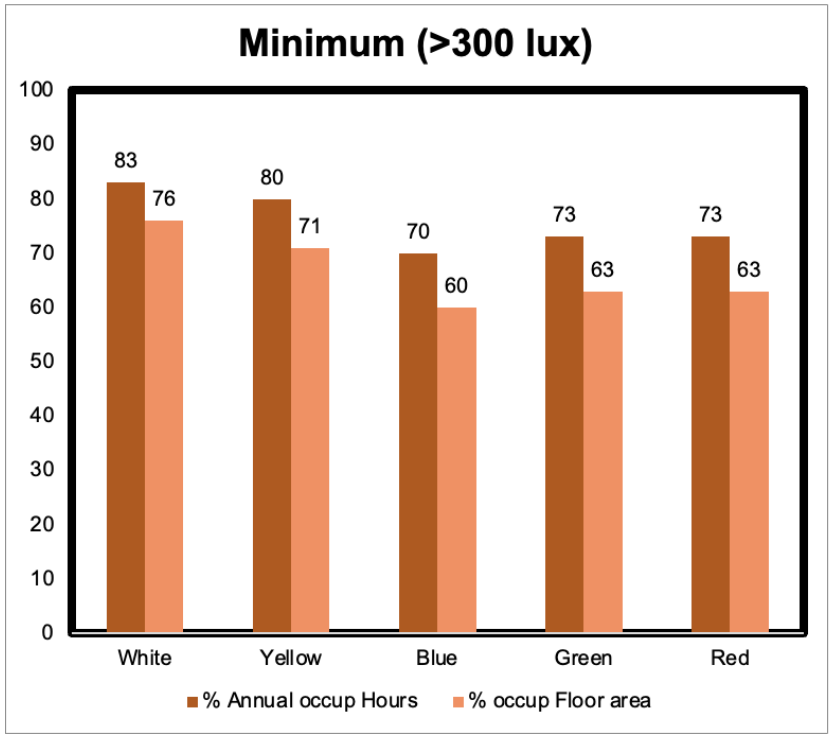
(c)

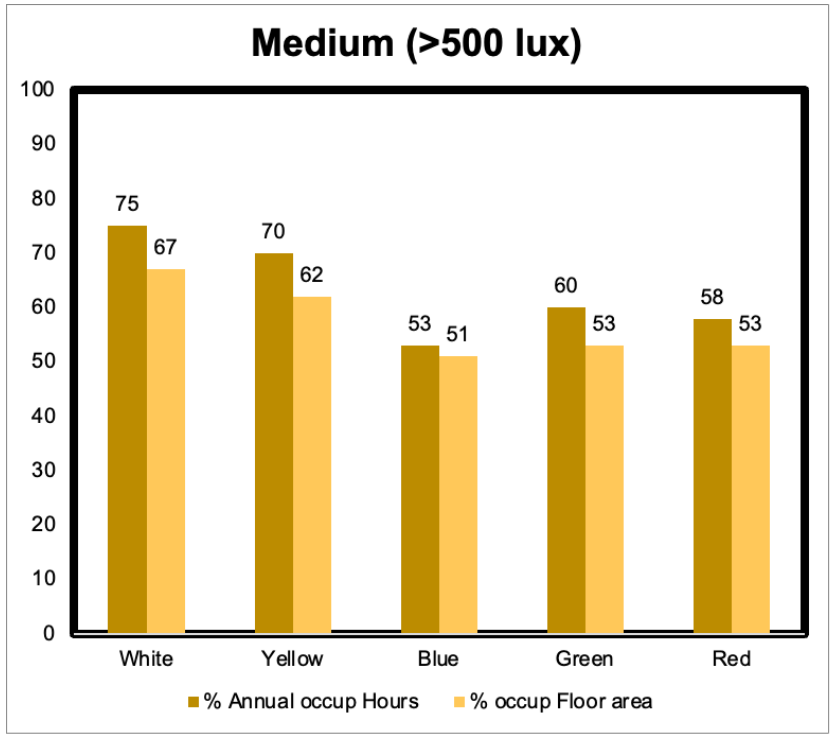
Grid-based metrics and their evaluation. (Parametric study on wall Colors)

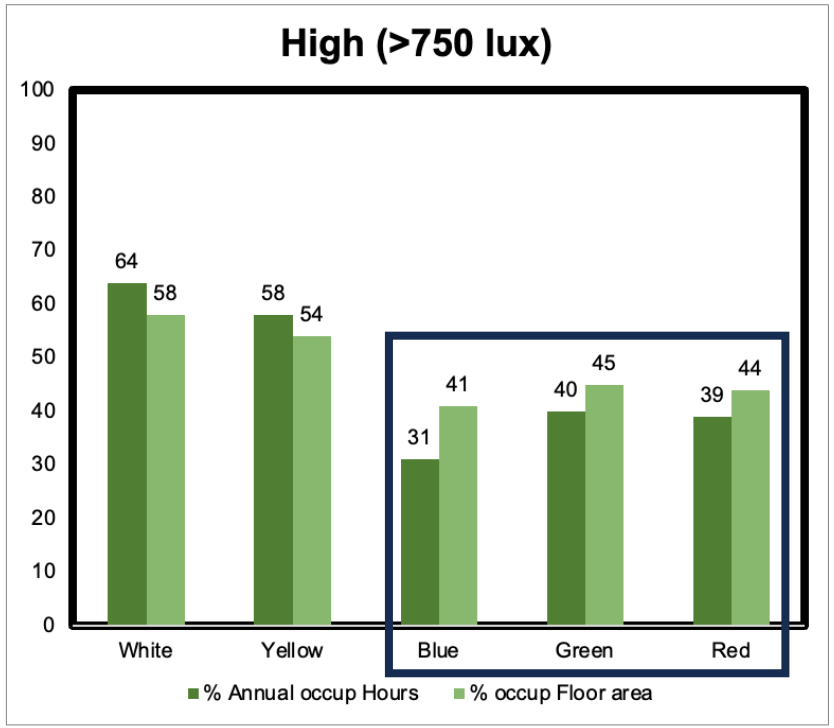


Grid-based compliance metric, and evaluating sDA. (Parametric study on wall Colors)

sDA compliance through different criteria



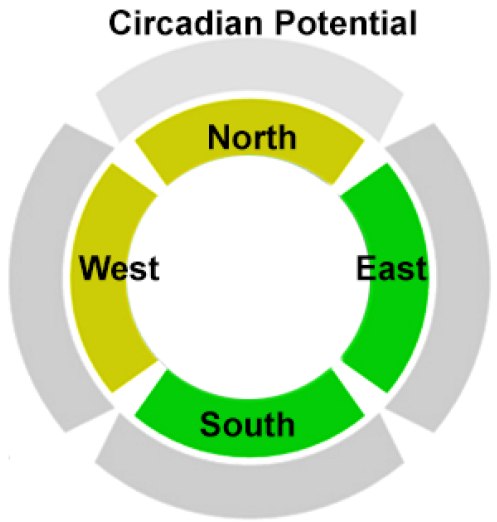


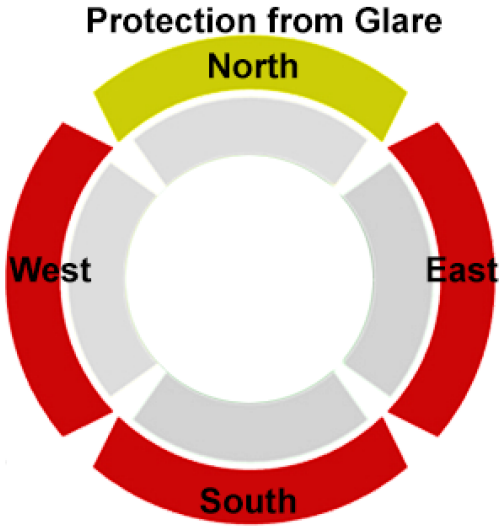


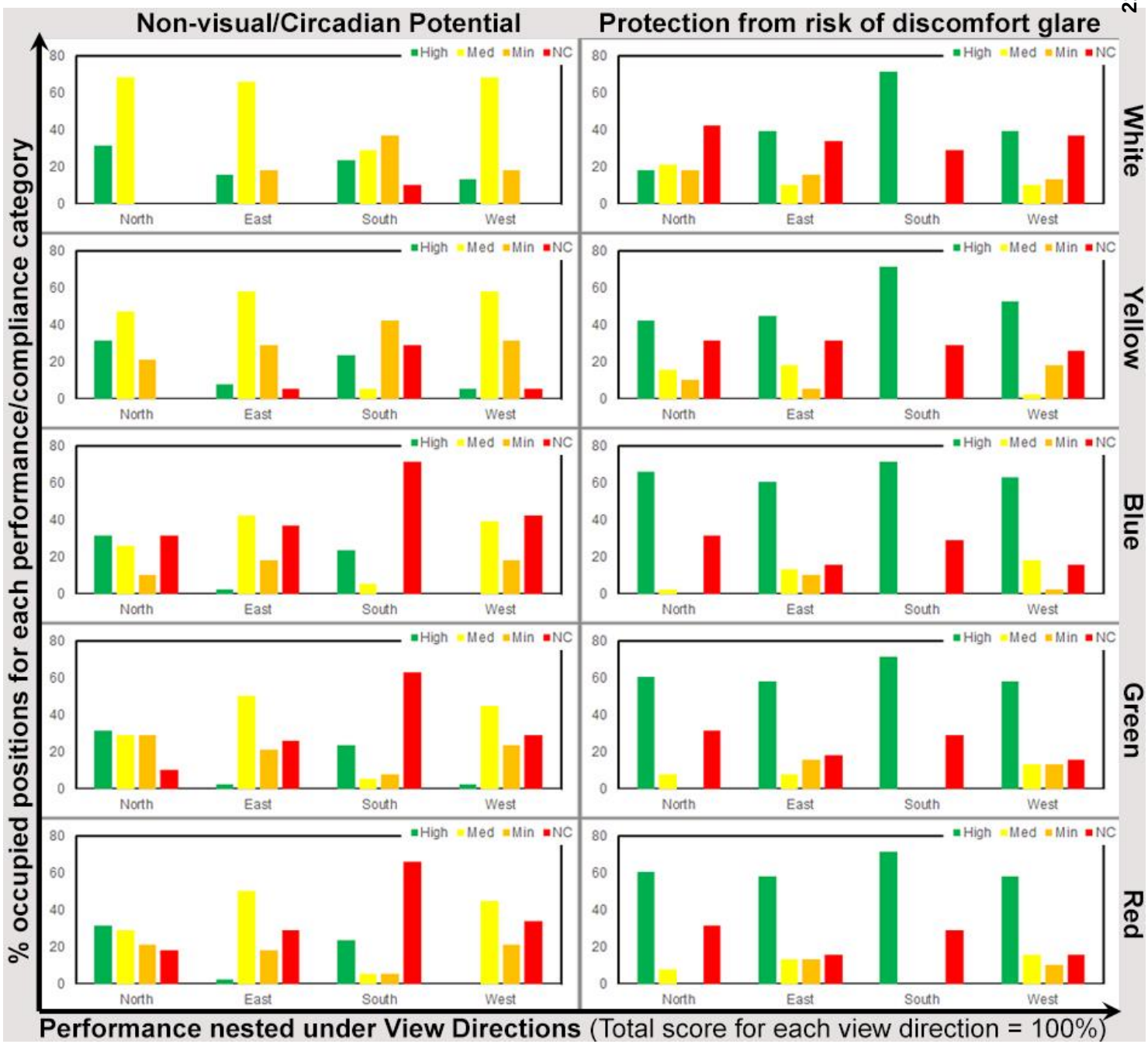
Left: % annual occupied hours for 50% occupied floor area (Current EN17037)

Right: % occupied floor area for 50% annual occupied hours (Proposed EN17037, similar to IES LM83)

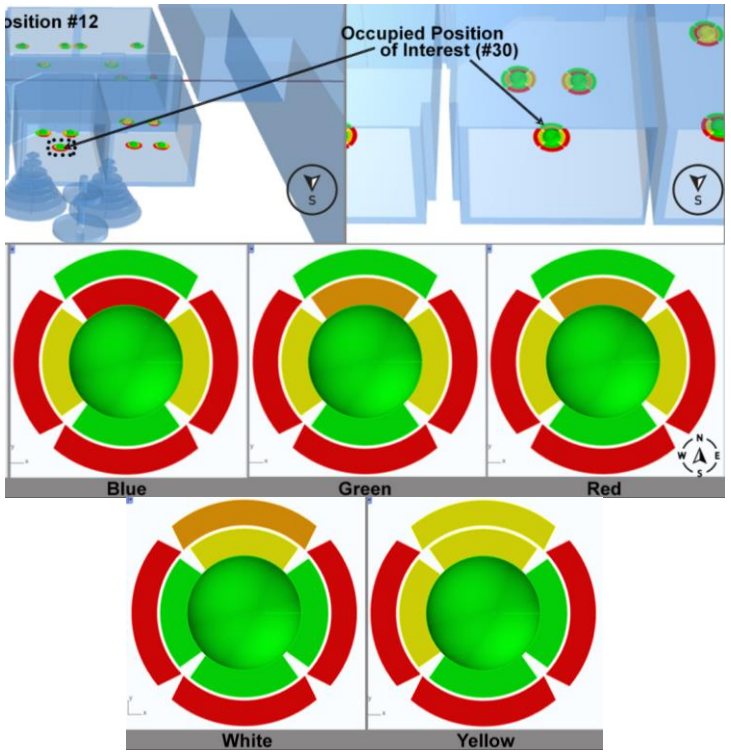
OVNI-based metrics and their evaluation. (Parametric study on wall Colors)

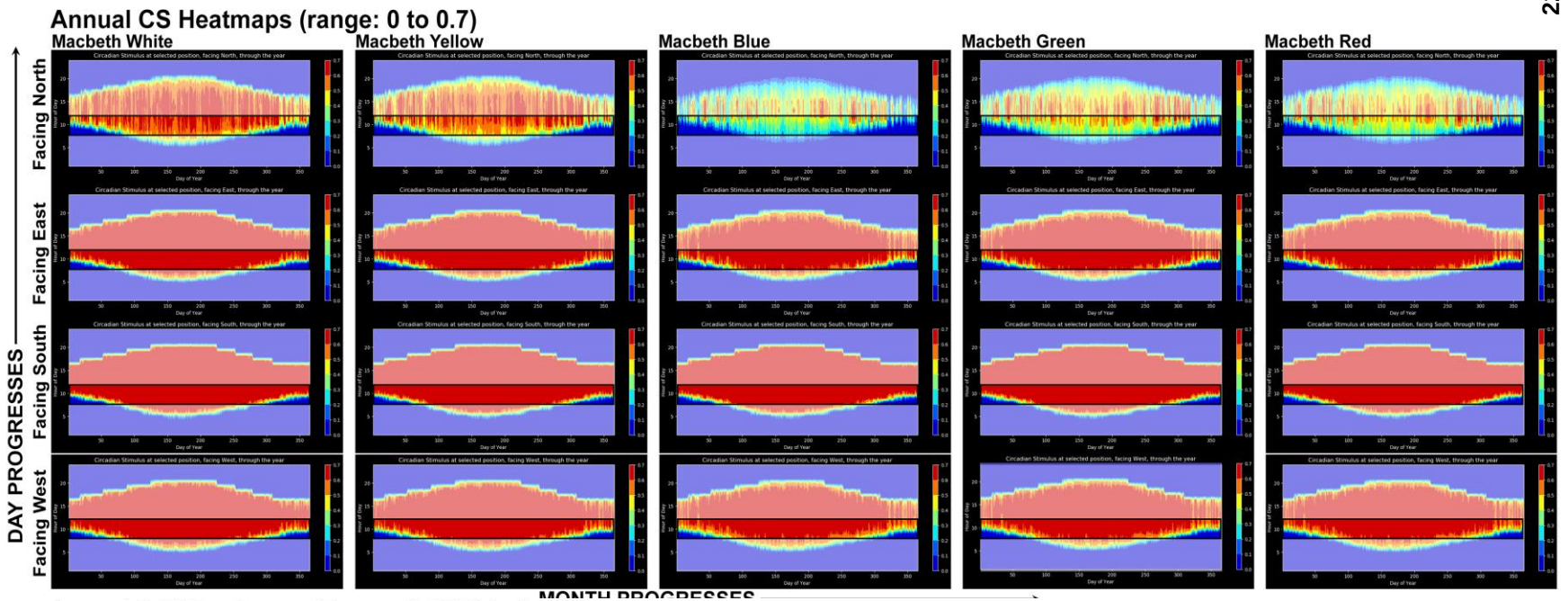


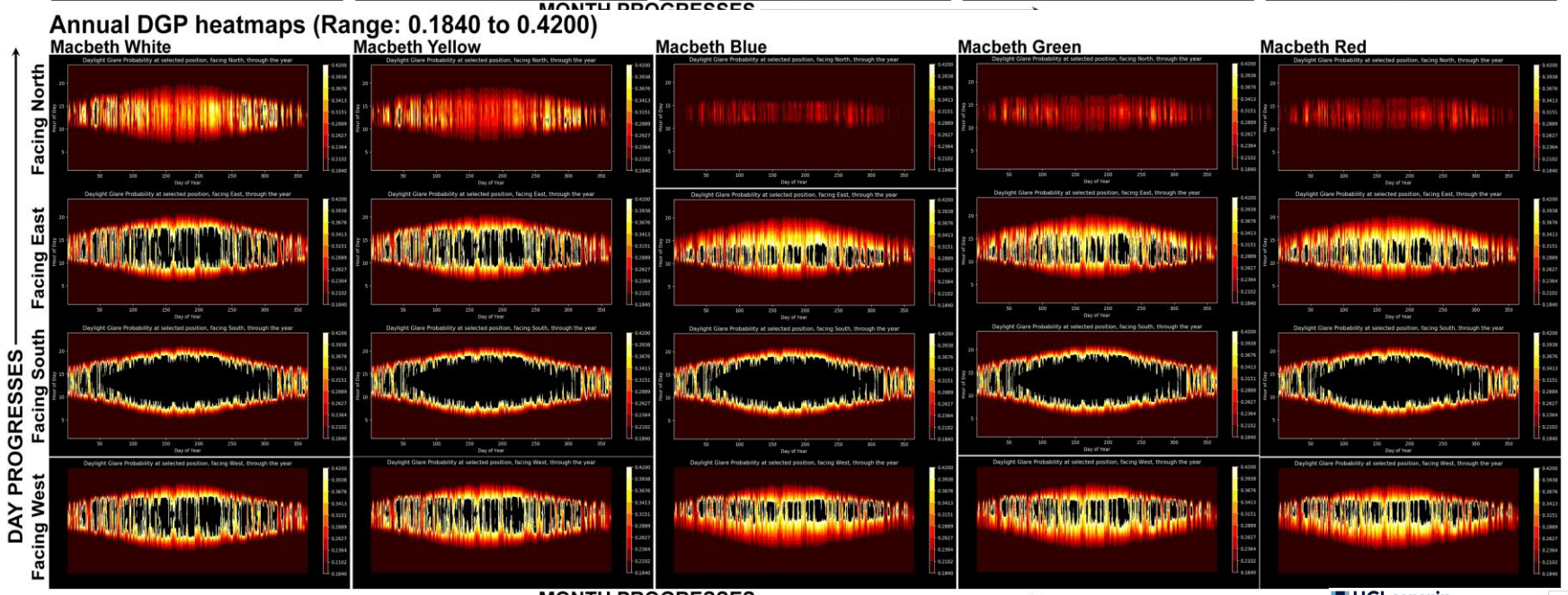




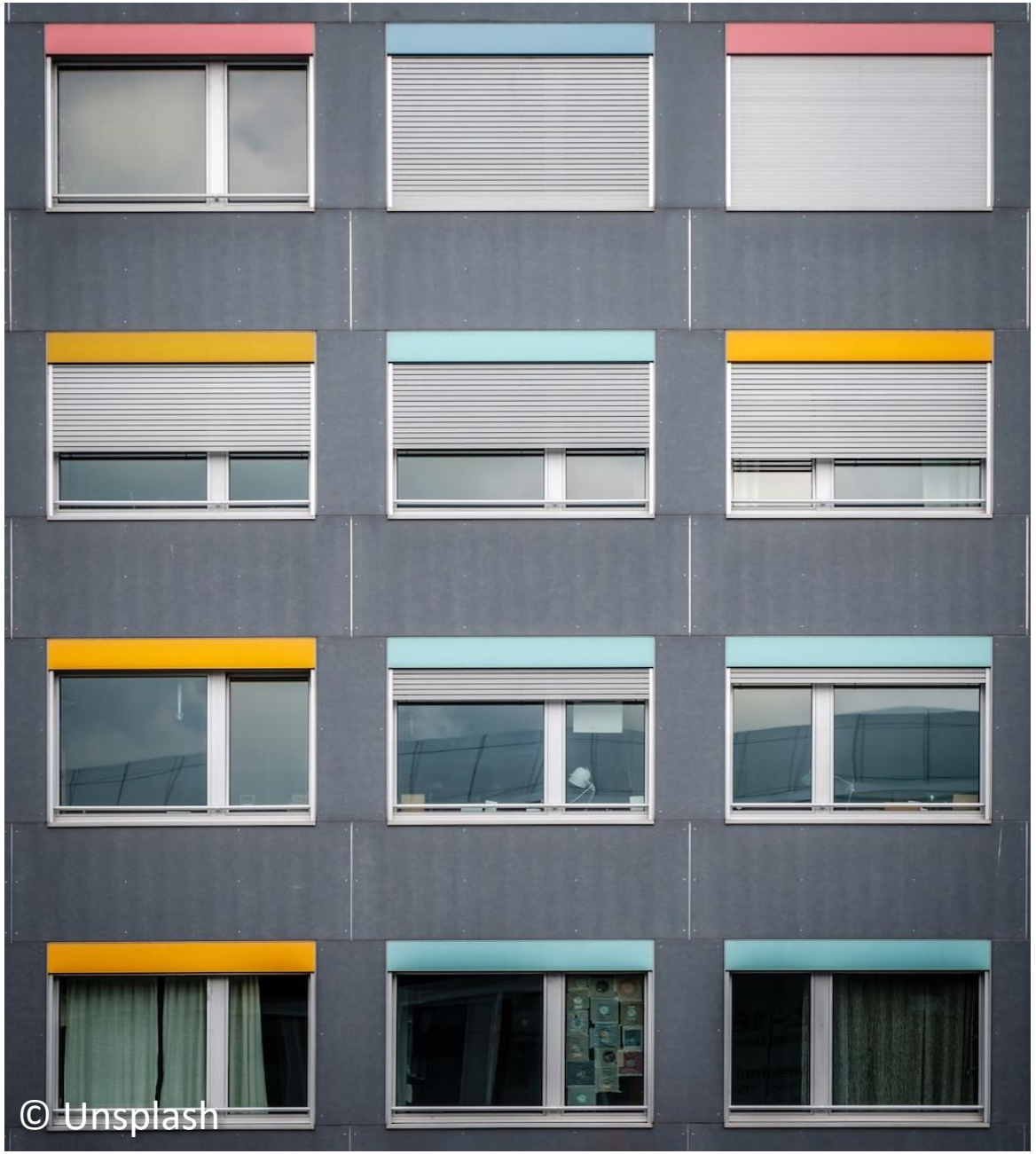
Occupant-centric annual heatmaps for CS and DGP (Parametric study on wall Colors)



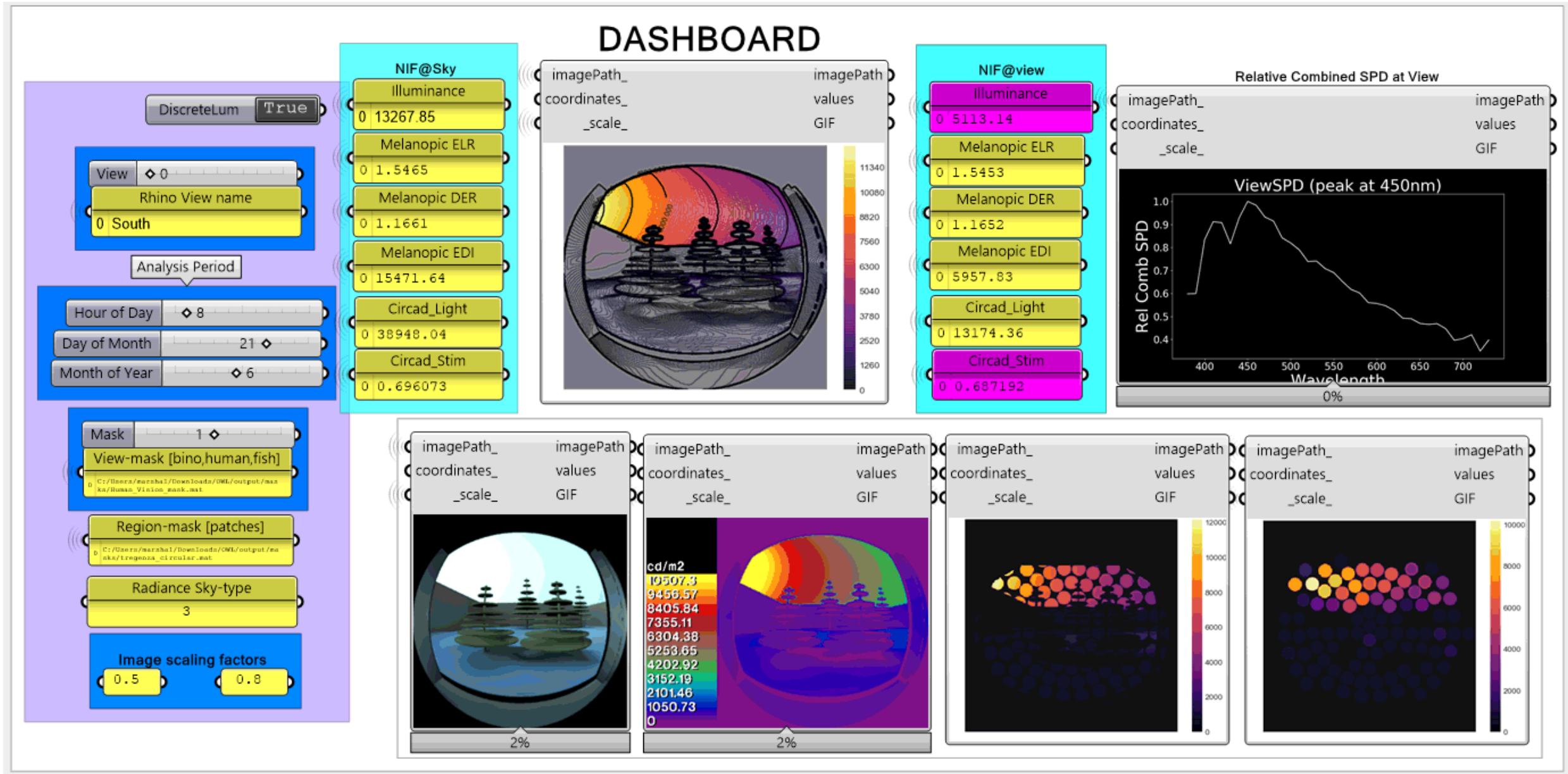




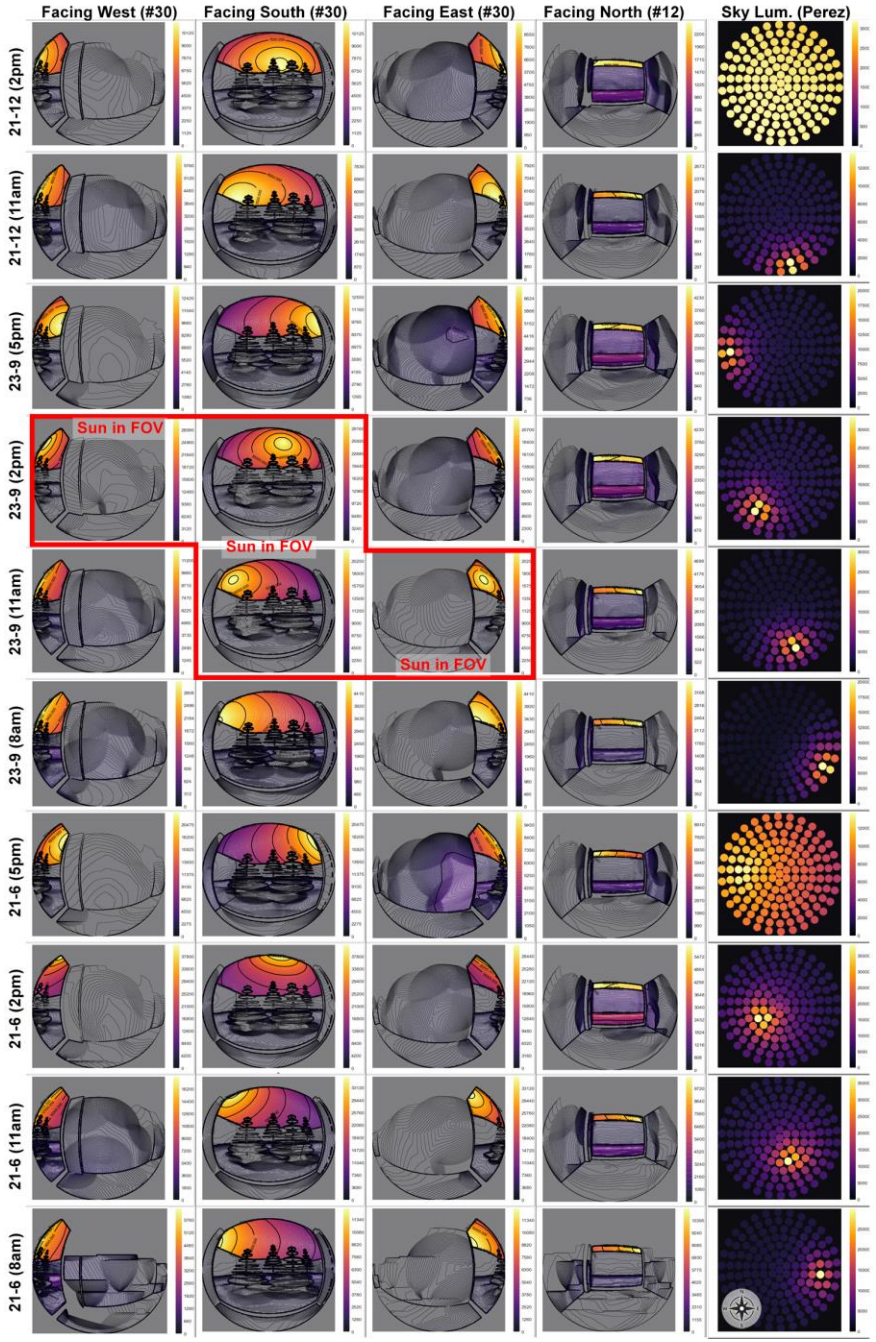
Annual Heatmaps as support for scheduling controls: Shading and Circadian Effective Lighting

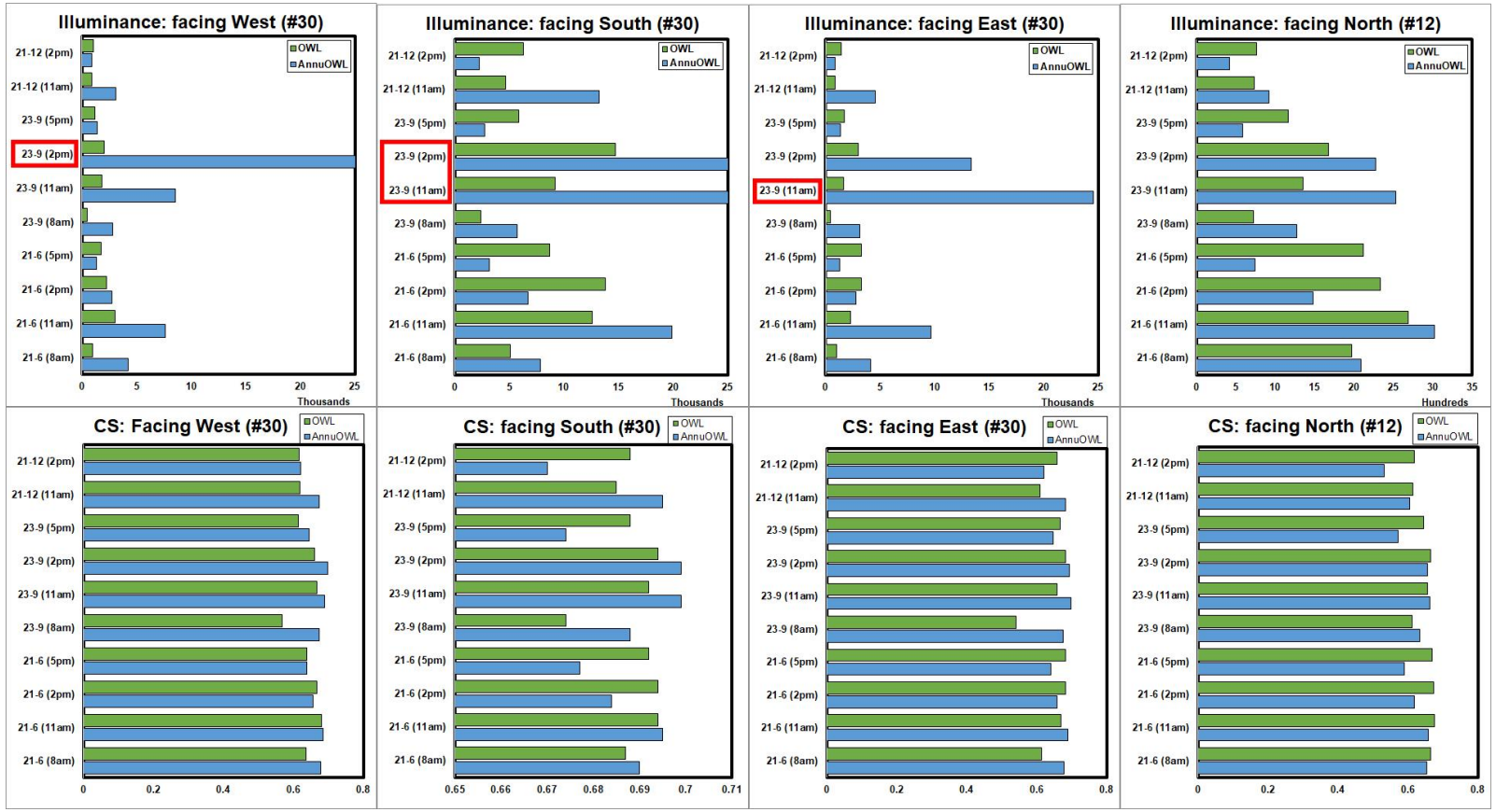


Comparing with point-in-time simulation tools: OWL results



Comparing with point-in-time simulation tools: OWL vs AnnuOWL (continued)





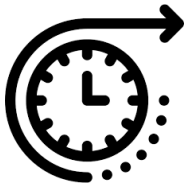
Discussions:

1. **Utility** (possibility for design intervention makes it useful)

2. **Speed** (Quite fast, *but it uses the 2 phase DC method*)

3. **Accuracy** (Better than OWL because internal reflections are considered)

4. **Limitations**
   a) Single channel approach for evaluating NV potential (*as against traditional multichannel* evaluation)
   b) Use of sDGP approach for evaluating glare protection (*as against eDGP or other advanced methods*)



5. **Future scope and plans**
   a) Multichannel evaluations (SpectrOWL?)
   b) Multichannel Annual evaluations (AnnSpectOWL?)
   c) Incorporation of view ring.

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maskarenj.marshal@uclouvain.be

UCLouvain
Louvain research institute for Landscape, Architecture, Built environment