

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

Marshal Maskarenj

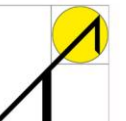
*FNRS Postdoctoral Researcher,
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Victoria Crevits

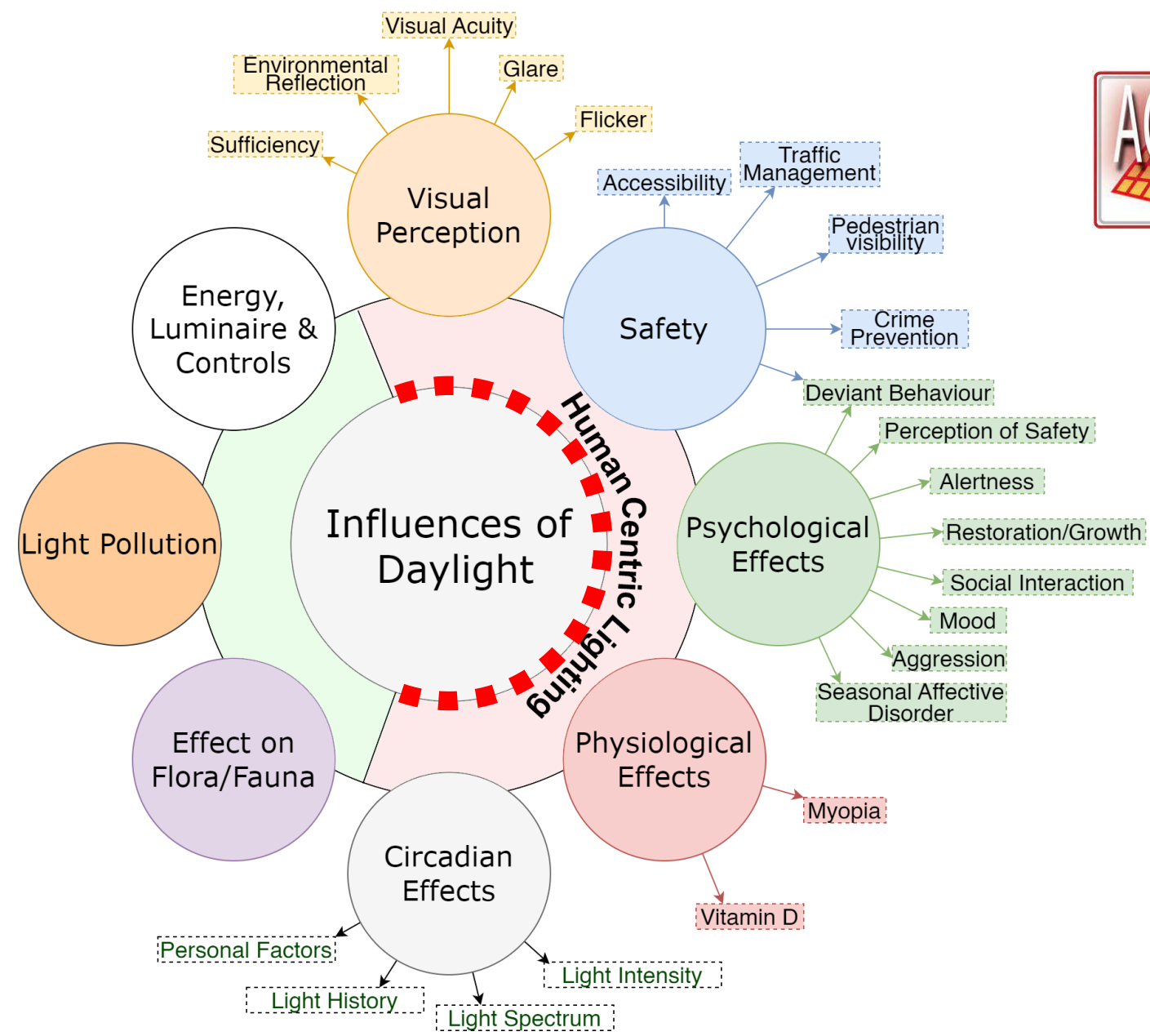
*Graduate student,
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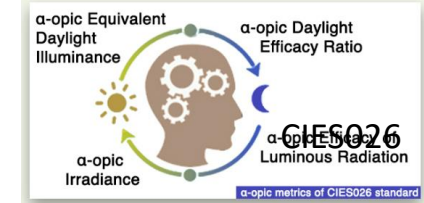
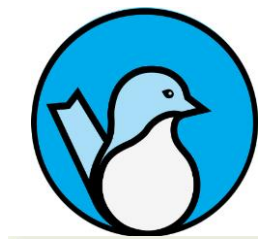
More to light than vision



Lighting Simulation tools mostly focus on aspects of vision



Recent tools on non-visual aspects + metrics and recommendations



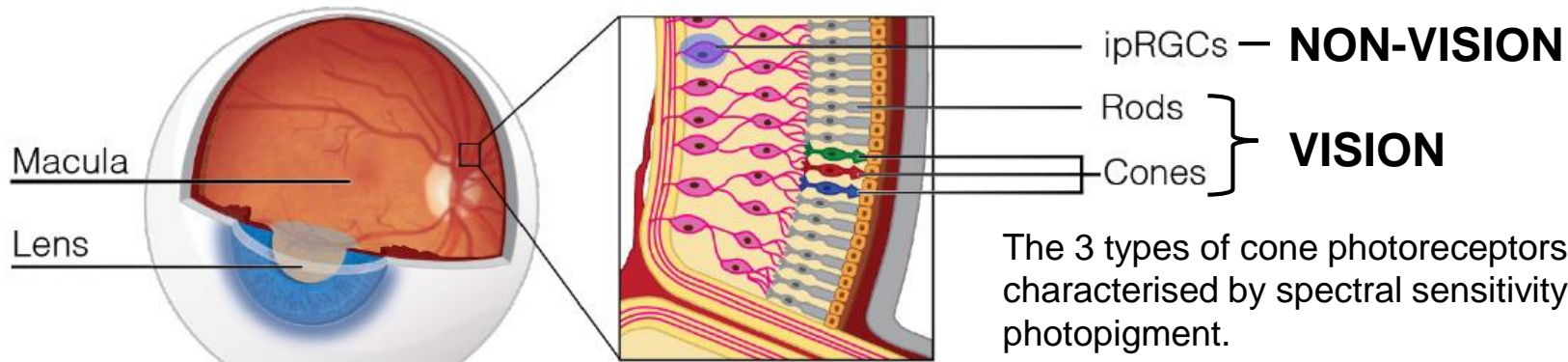
Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults

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. Scllangen, [...], Kenneth P. Wright Jr [view all]

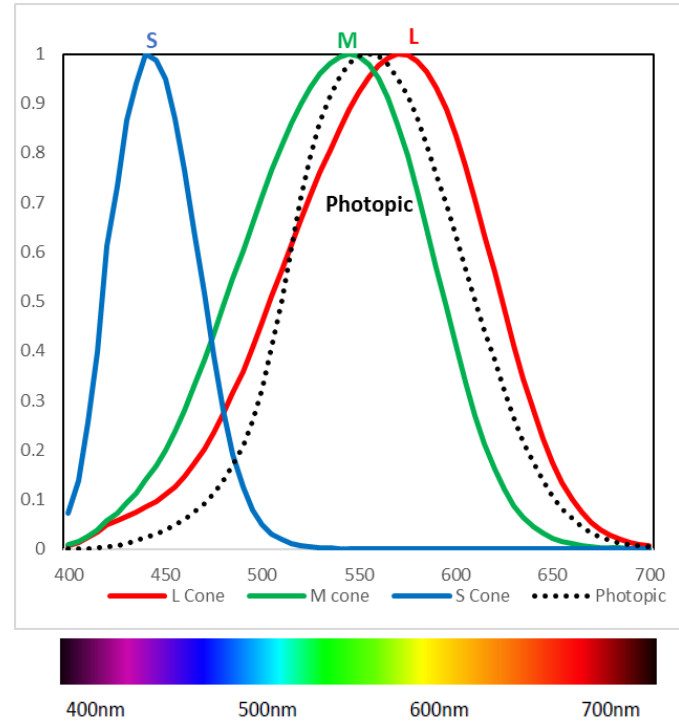
So, there have been advances in non-visual too ! This research seeks to take them further

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

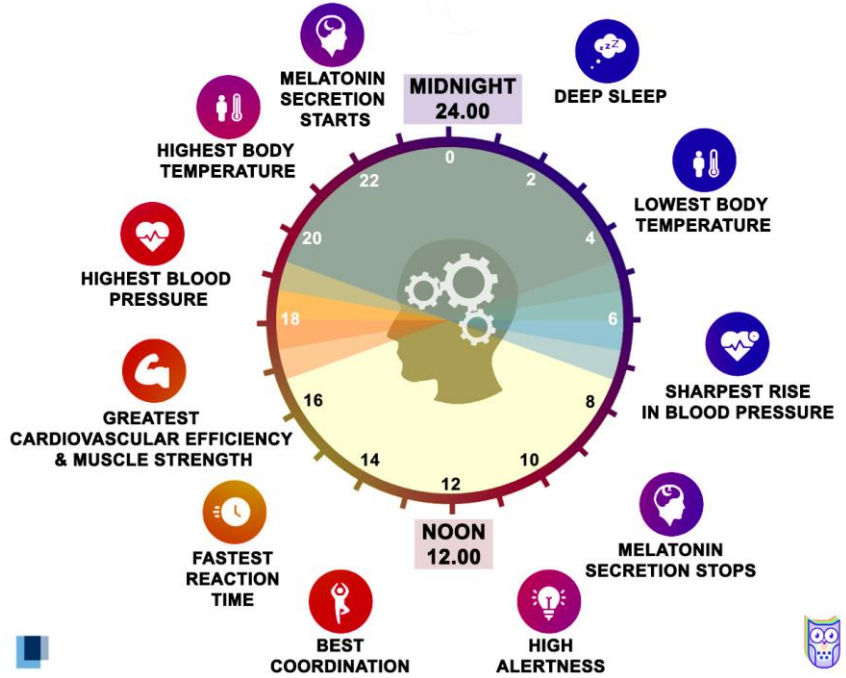
“Non-visual” light? First, let’s ask what “visual” light is



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



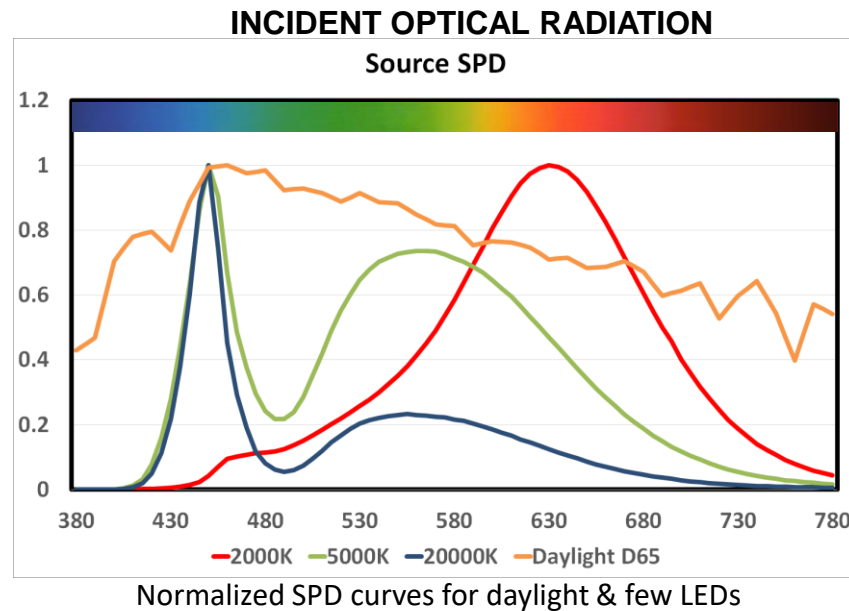
The short, medium and long cones are sensitive in the blue- green- and red-wavelength regions of the optical spectrum



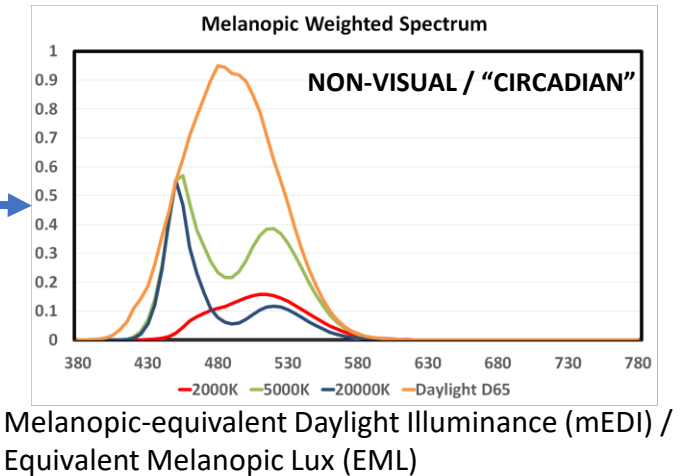
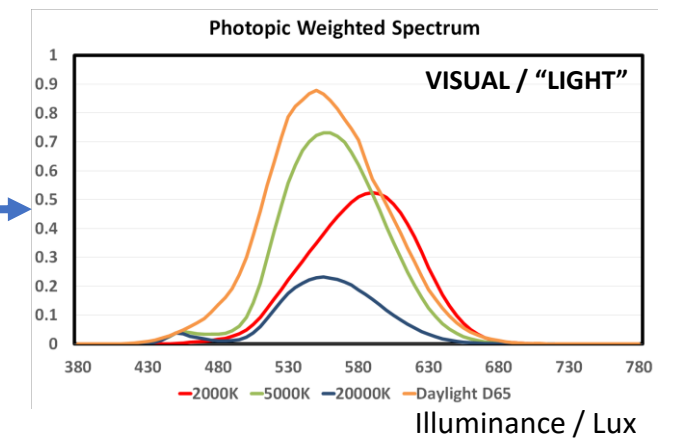
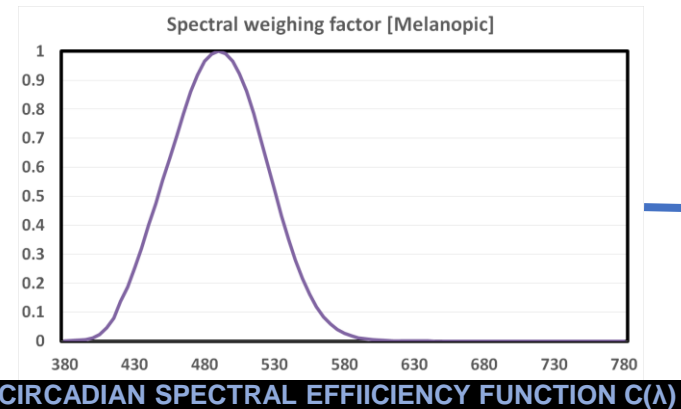
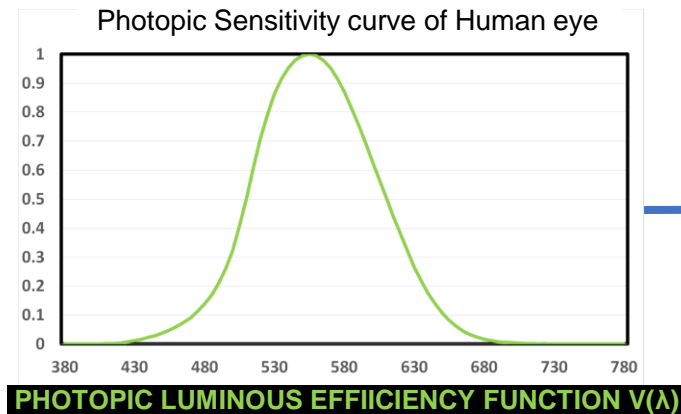
And then there’s the “Non-visual” aspect

- ✓ 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



X



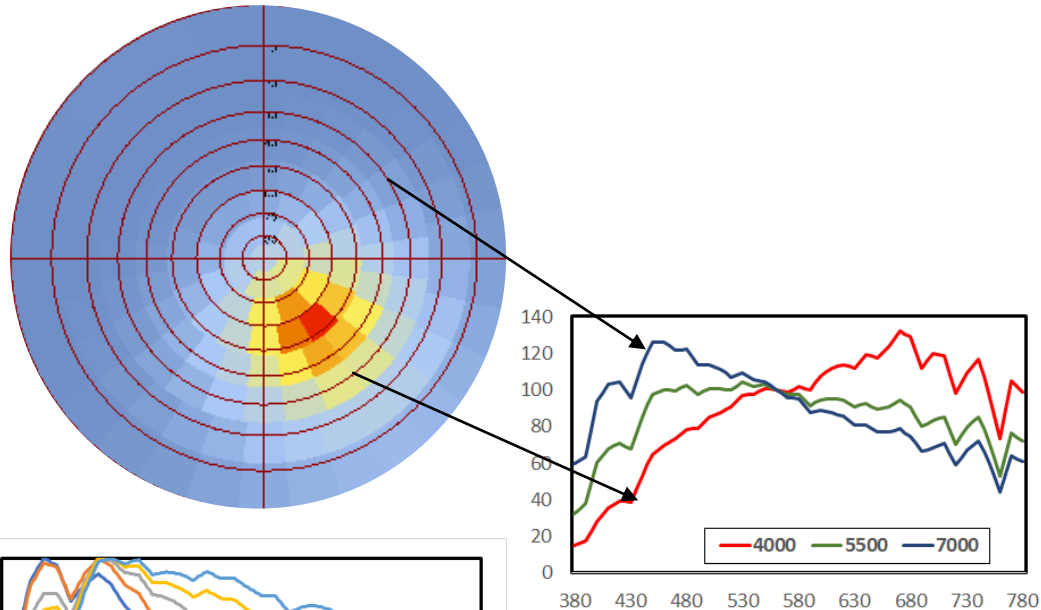
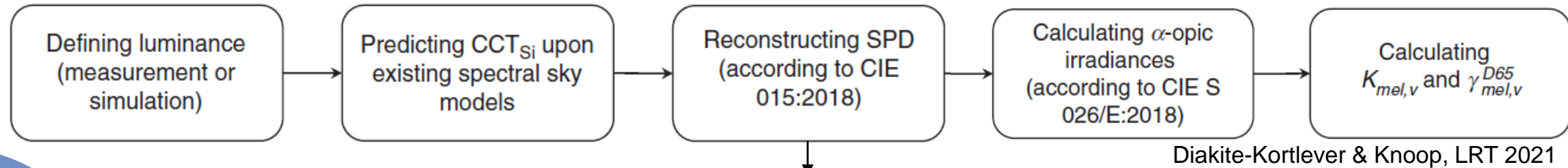
- Important to know a source's SPD across wavelengths
- Photopic Luminous Efficiency Function $V(\lambda)$ characterizes human responses to Optical Radiation
- Factoring Circadian spectral efficiency curve $C(\lambda)$ evaluates non-visual/circadian metrics (EML)
- Area under curve signifies illuminance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

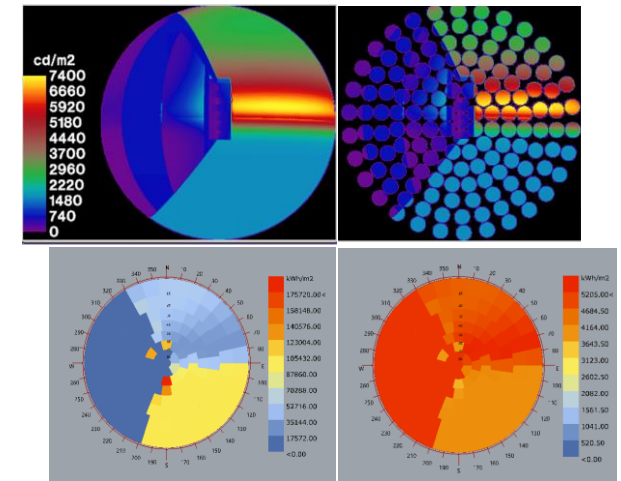


Using cumulative sky SPD
as input for spectral
simulations

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

Discretising luminance to
patch-luminance

Patch-luminance \gg CCT
 \gg SPD \gg NIF (CIE & LRC)



Dashboard of OWL: Occupant Wellbeing through Lighting

WEATHER FILE

SCENE/VIEW

ANALYSIS PERIOD

VIEW MASK

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

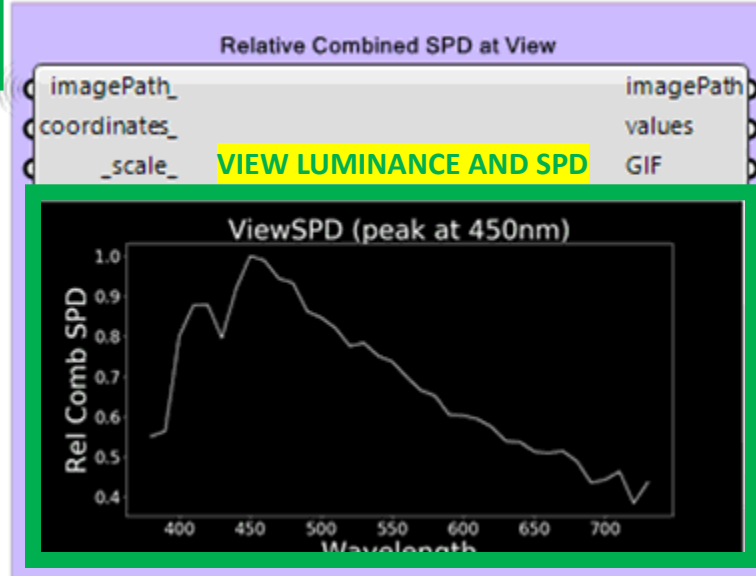
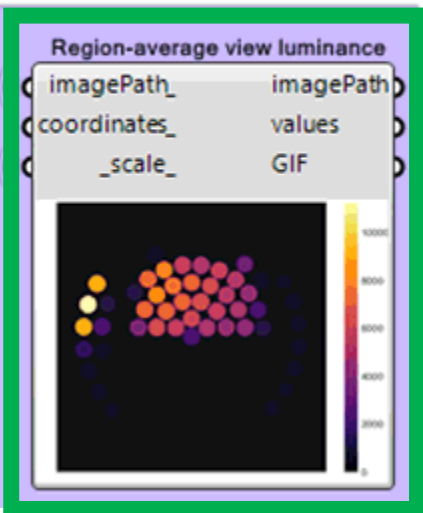
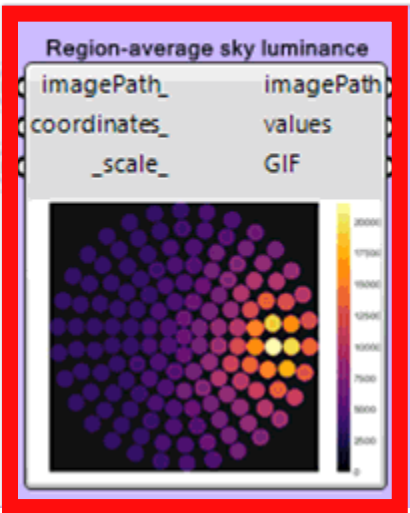
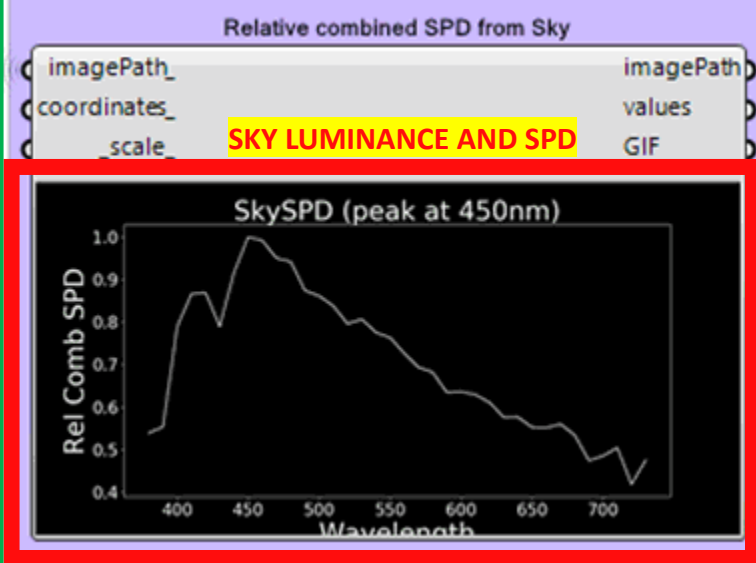
DASHBOARD

imagePath_ coordinates_ _scale_ imagePath_ values GIF

GEOMETRY/MATERIAL

NIF@view

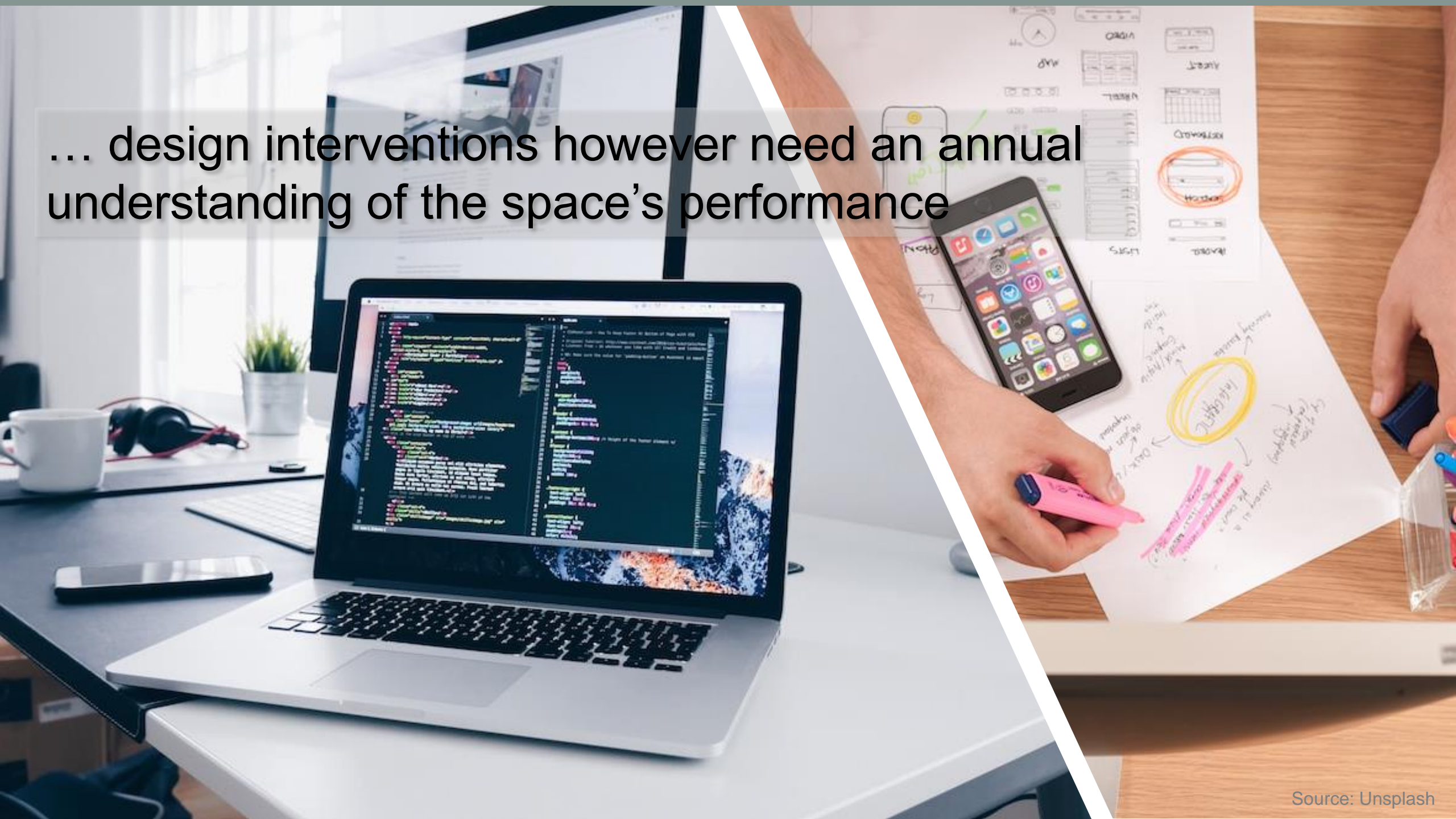
illuminance	0 6162.61
Melanopic Irradiance	0 9.15
Melanopic ELR	0 1.4853
Melanopic DER	0 1.12
Melanopic EDI	0 6902.13
Circad_Light	0 15223.67
Circad_Stim	0 0.68905



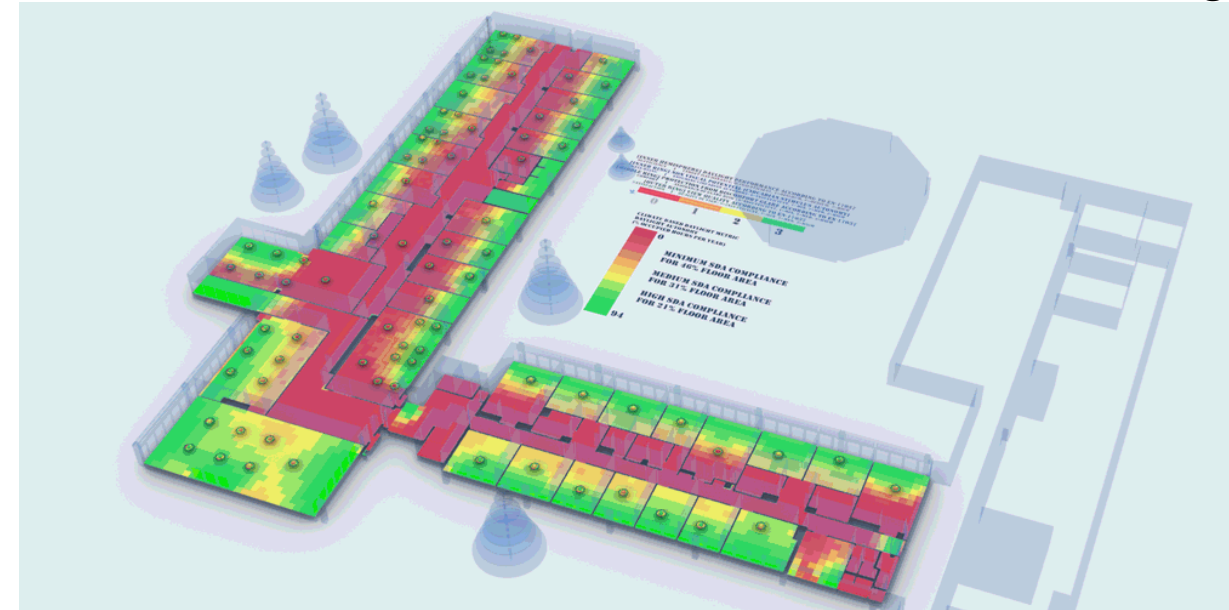
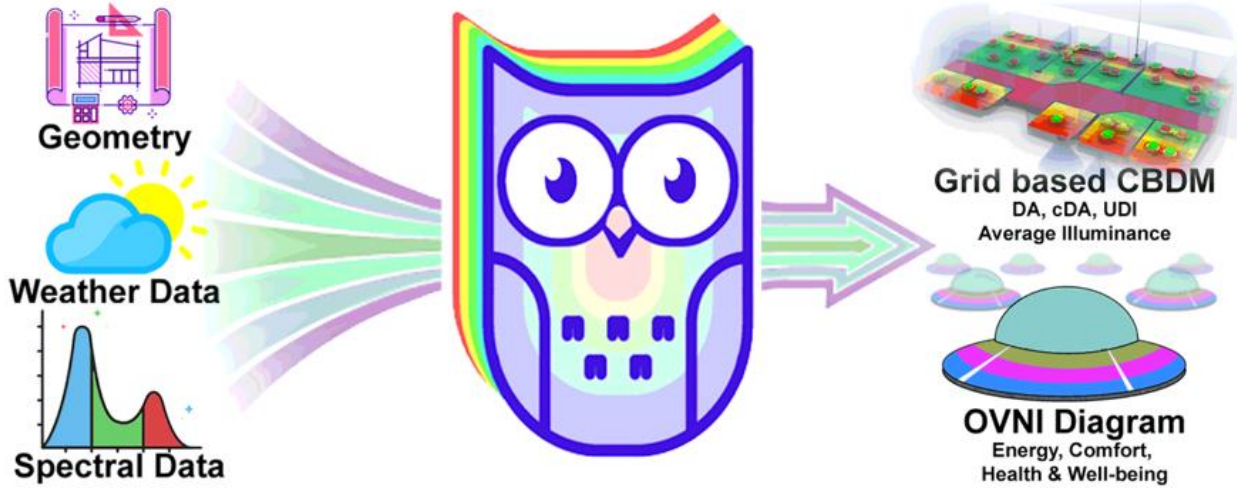


While OWL offers an easier pre-design alternative to actual post-occupancy measurements...

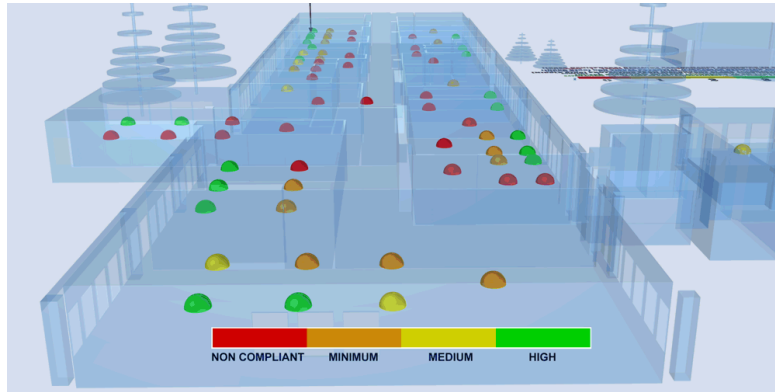
... design interventions however need an annual understanding of the space's performance



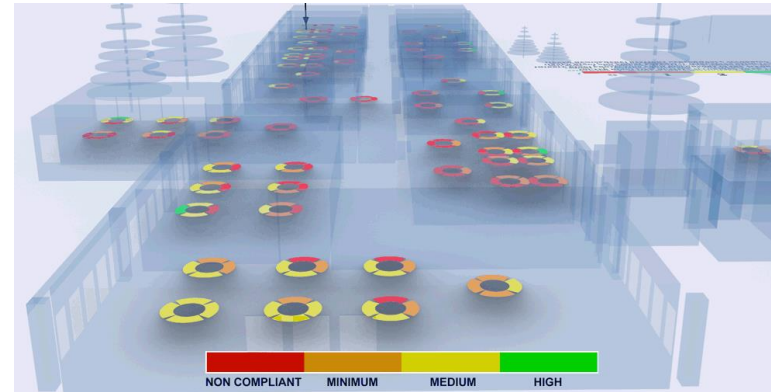
Presenting AnnuOWL: our latest tool for Occupant-centered and space-centered evaluations



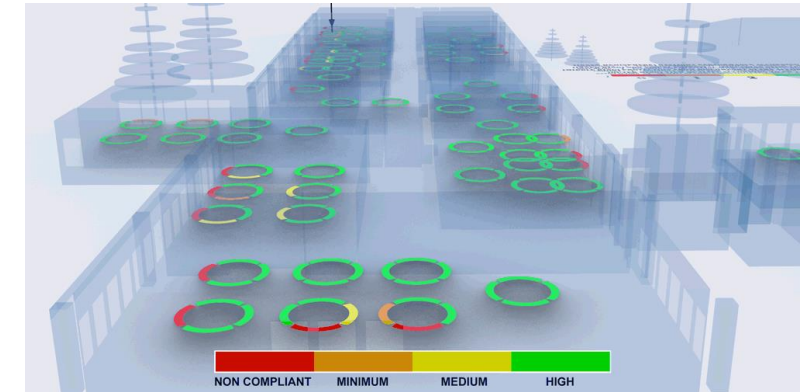
Occupant-centred visualizations via OVNI diagram



Daylight Provision



Non visual/Circadian Potential



Glare Protection

Visualizing human factors in lighting, via OVNI diagrams.



Unidentified Flying Objects
Objets Volant Non-identifie



1. Interaction

1.1. Primary settings before starting simulations

- 1.1.1 Edit locations!
- 1.1.2 Displaying another pre-simulated data?

1.2. [if five simulations] Define Geometry and Materials.

- 1.2.1 Select Geometry (spheres)
- 1.2.2 Identify Materials for each Representative
- 1.2.3 Change building orientation?
- 1.2.4 Geometry's Material Definition?

1.3. [if five simulations] Define Grid

- 1.3.1 Grid to replicate the floor base
- 1.3.2 Define Occupancy Positions
- 1.3.3 Change occupancy schedule?
- 1.3.4 Change occupancy schedule?

1.4. [if five simulations] Grid-based Horizontal Sim.

- 1.4.1 All Set Turn Start consistent to TRUE
- 1.4.2 DIME SIMULATION COMPLETE! Change evaluation parameters for Performance forecasts

1.5. [if five simulations] Vertical OVNI Simulations

- 1.5.1 All Set Turn Start consistent to TRUE
- 1.5.2 DIME SIMULATION COMPLETE! Change evaluation parameters for Performance forecasts

1.6. [if five simulations] Vertical OVNI Simulations

- 1.6.1 All Set Turn Start consistent to TRUE
- 1.6.2 DIME SIMULATION COMPLETE! Change evaluation parameters for Performance forecasts

1.7. Cleanup residual files

1.8. Display Geometry on Rhino?

2. Preliminary Analysis: Site level visualisation

2.1. Visualise Annual CCT Data

2.2. Visualise Annual CCT [on Rhino viewport]

2.3. Visualise Occupancy Hours

4. Detailed Visualisation: Occupant level

4.1. Select occupant position for Detailed analysis

4.2. Visualise Annual Circadian Stimulus for Selected Gridpoint

4.3. Visualise Annual Daylight Glare Probability for Selected Gridpoint

3. Simulation Recipe: Grid-based & OVNI

3.1. Calculate Horizontal Metrics: CBDM

3.2.1. Sufficiency in Illumination (Central Hemisphere)

3.2.2. Well-being (Post-noon Ring) Calculate Annual Discomfort

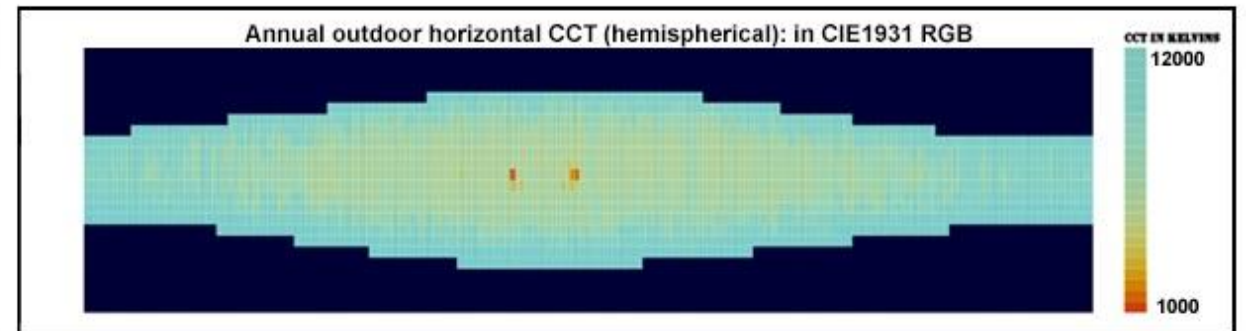
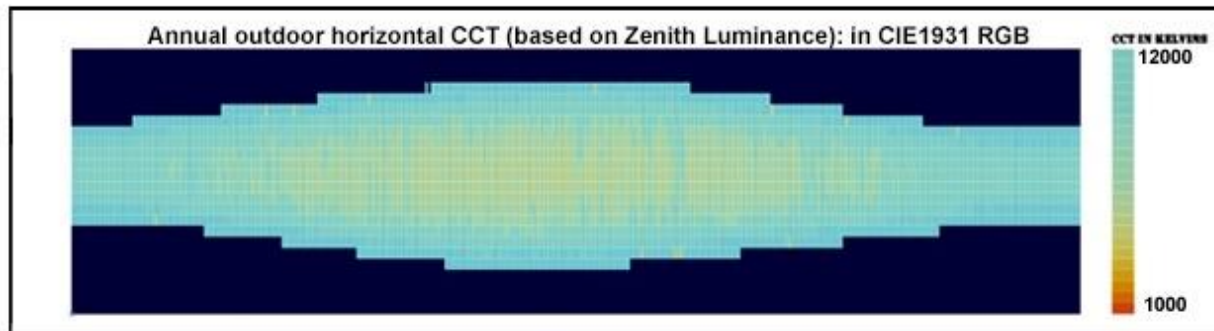
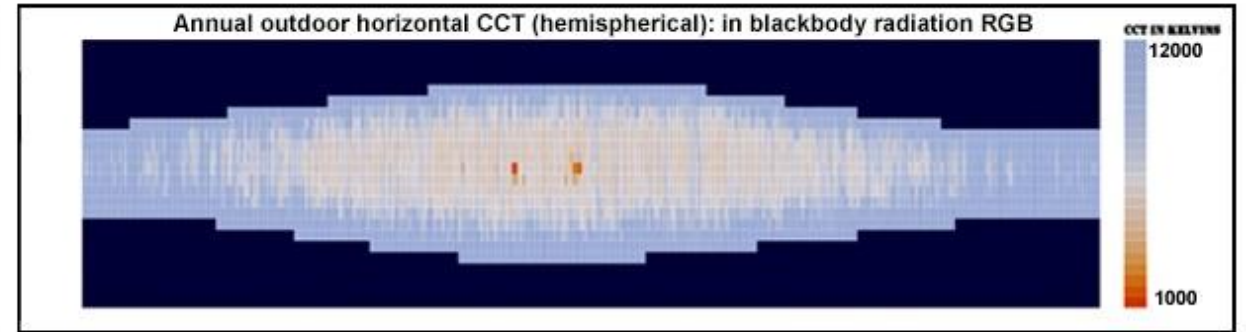
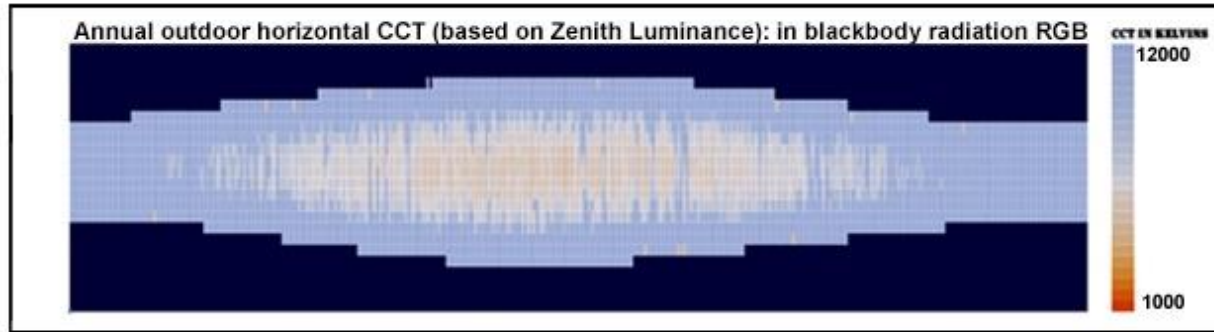
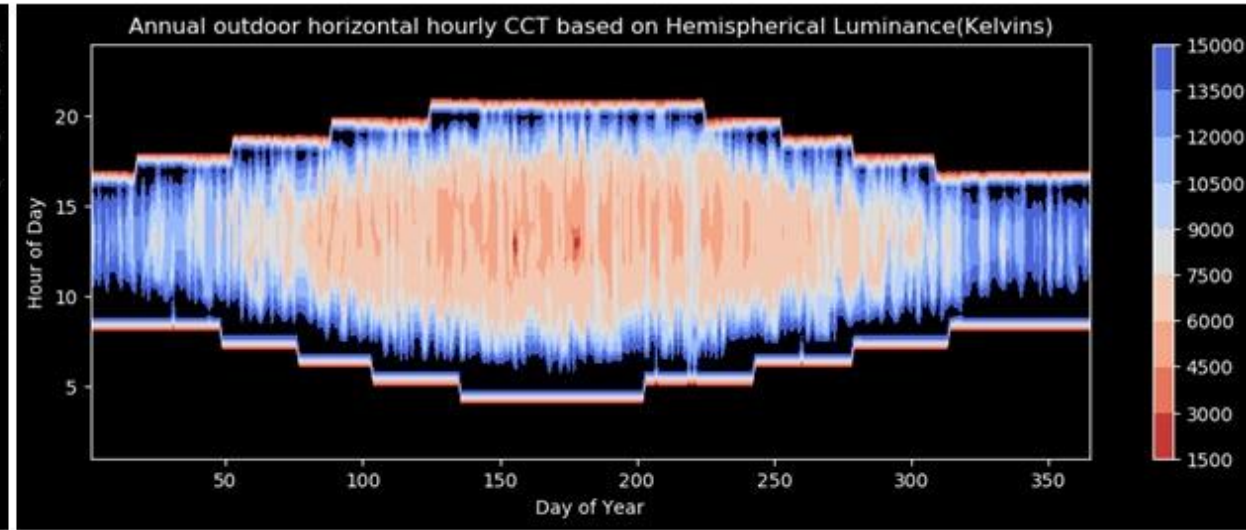
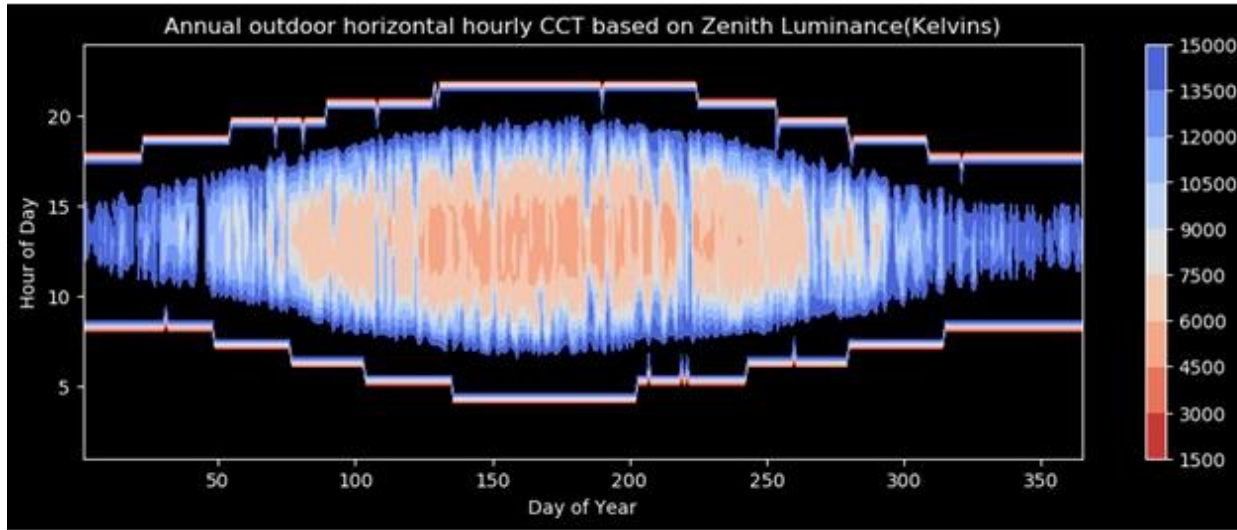
3.2.3. (Dis)comfort (Work Ring) Calculate Annual Discomfort

3.2.4. Satisfaction (Color Ring)

3.3. Calculate Vertical Metrics for OVNI

OVNI Legend

Annual compilation of sky spectrum



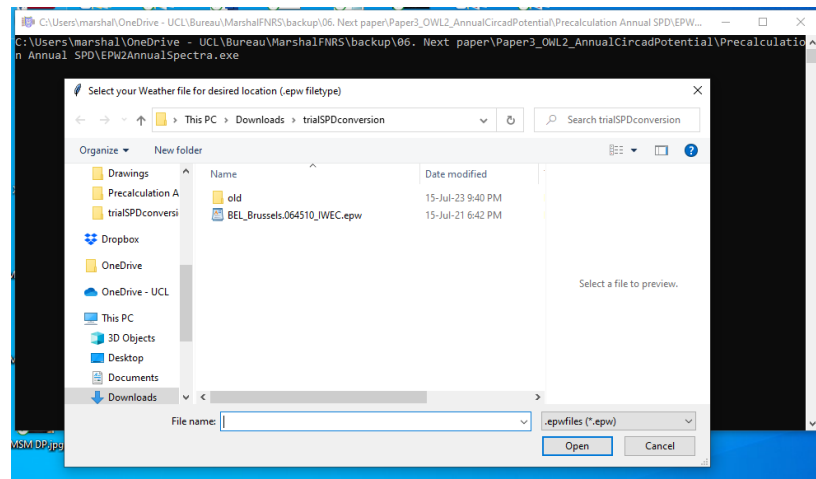
Composition of the AOWL file, and the converter utility.

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

- Date of Year, Hour of Day,
- Zenith luminance, Horizontal 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



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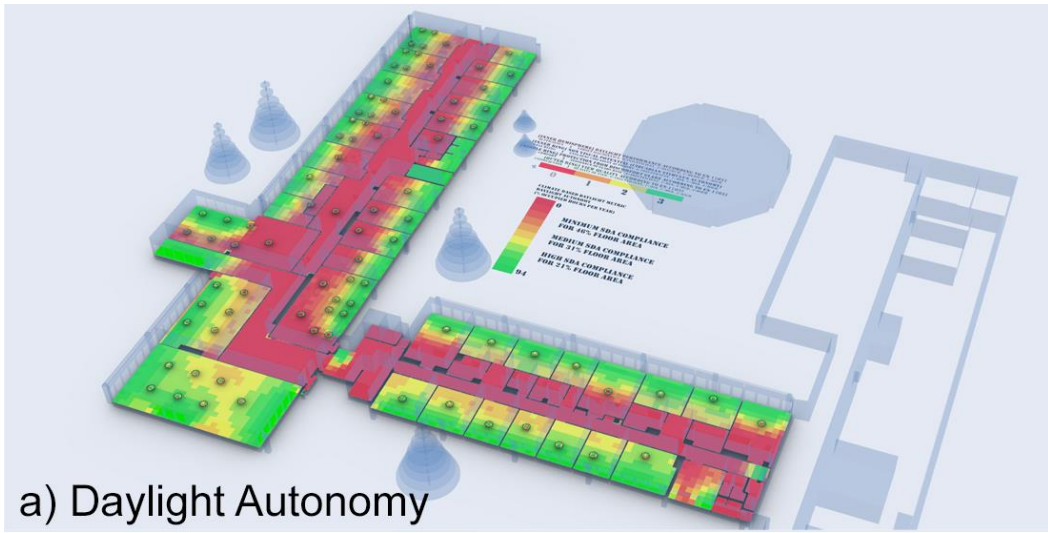
C:\Users\marshal\OneDrive - UCL\Bureau\Marshal\FNRS\backup\06_Next paper\Paper3_OWL2_AnnualCircadPotential\Precalculation Annual SPD\EPW2AnnualSpectra.exe
This python-based utility converts the EPW file weather data for any defined location to Annual Spectral data for unobstructed sky hemisphere for that location.
Developed by Marshal Maskarenj at UCLouvain, this utility follows the approach recommended by Maskarenj, Deroisy and Altomonte (doi.org/10.1016/j.enbuild.2022.112012).
For each annual daylight hour, the Perez all weather sky model is used to convert hourly zenith luminance to patch-luminance for 145 Tregenza patches.
Each patch luminance is converted to daylight correlated color temperature (CCT) using Diakite-Kortlever and Knoop spectral sky models (doi.org/10.1177/1477153520982265).
Hourly patch CCT is then converted to patch spectral power distribution (SPD) following the approach recommended in the CIE015 standard.
SPDs of all patches are merged with appropriate cosine correction, to generate relative combined SPD of sky hemisphere.
The tristimulus X,Y,Z values are then evaluated from the SPD, and chromaticity coordinates x, and y (and complementary z) are derived by factoring.
McCamy's equation is used to derive CCT from chromaticity coordinates x and y, whereas the chromaticity coordinate z is also tabulated to be further used for deriving Circad
ian Stimulus using Truong's approximation (doi.org/10.1177/1477153519837422)
The generated text based .aowl file tabulates; for each hour, the [Date of Year], [Hour of Day], [Zenith luminance], [Horizontal Diffuse Radiation], [Direct Normal Radiation],
[Sun Altitude], [Sun Azimuth], [CIE chromaticity coordinate x], [CIE chromaticity coordinate y], [CIE chromaticity coordinate complement z], [Correlated Color Temperature],
and relative SPD from 380-730nm for each 2nm separation.

The development of this tool was funded by FNRS under the postdoctoral project SCALE (40000322) awarded to Marshal Maskarenj (2020-23) at Architecture et Climat, LAB, UCLouvain, Belgium.

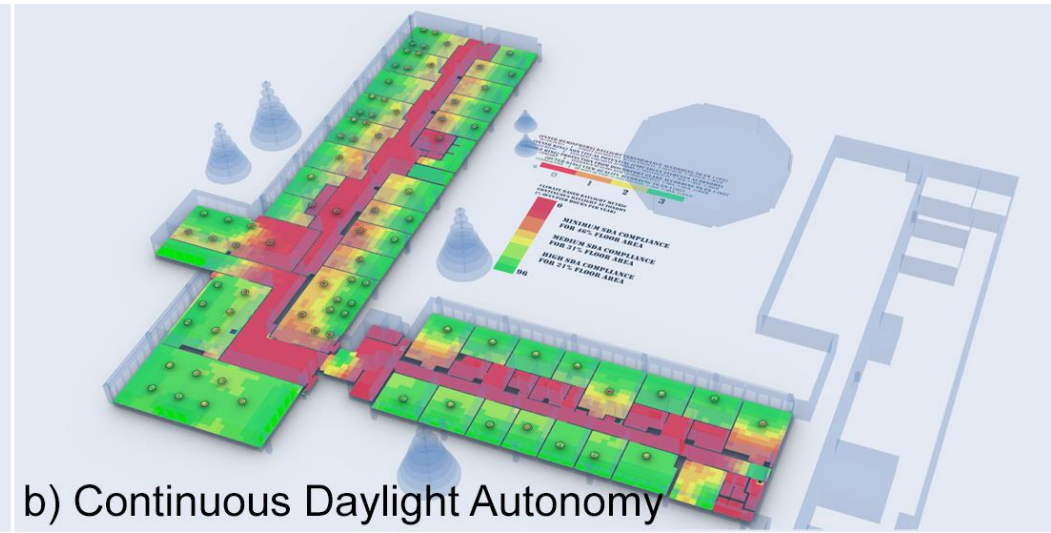
Kindly note: This utility could take up to 30 minutes to calculate the Annual Spectral data from each EPW file.
The percentage completion will appear below.

1 percent complete
2 percent complete
3 percent complete
4 percent complete
5 percent complete
6 percent complete
7 percent complete
8 percent complete
9 percent complete
  
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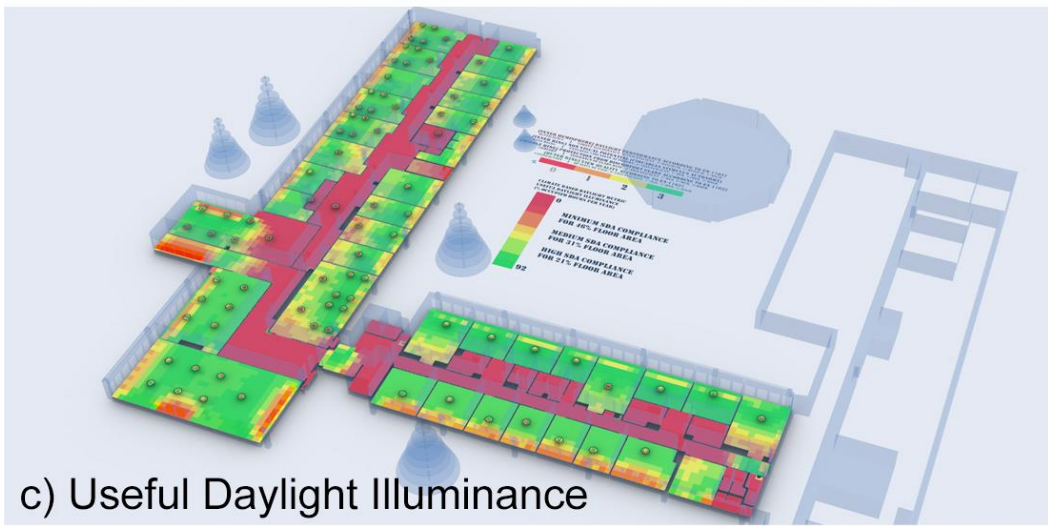

Radiance illuminance-based simulation approach in AnnuOWL components, via DC method. (for space-centric Grid-based evaluations)



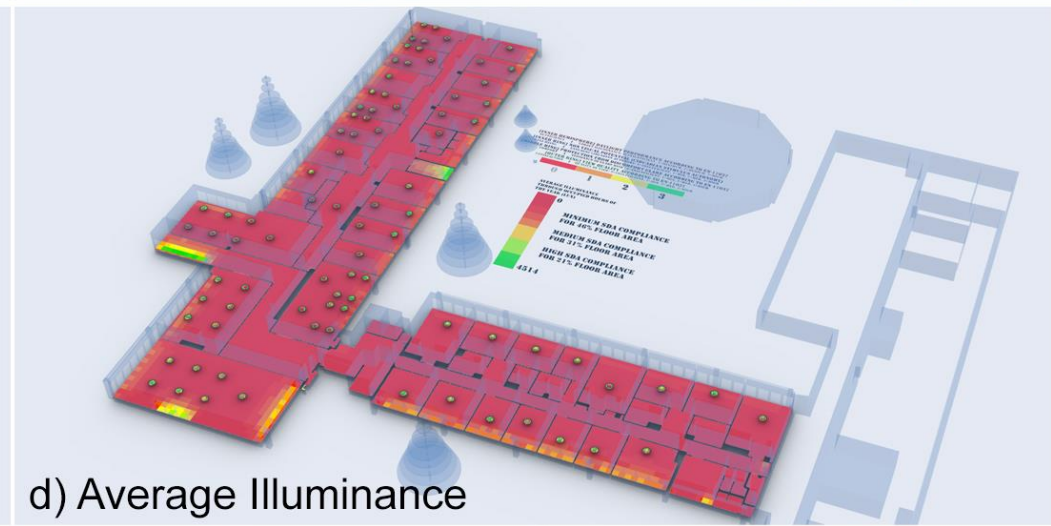
a) Daylight Autonomy



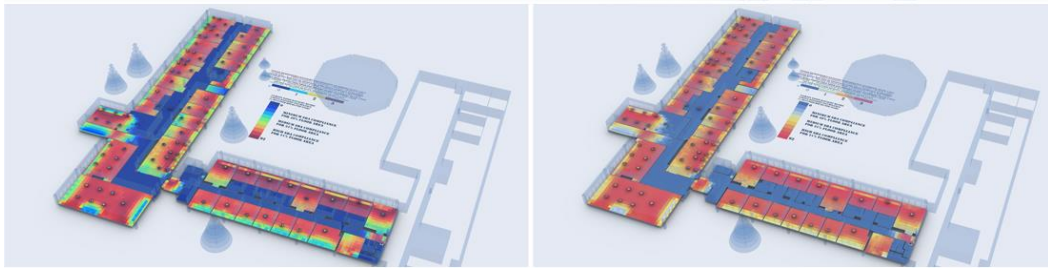
b) Continuous Daylight Autonomy



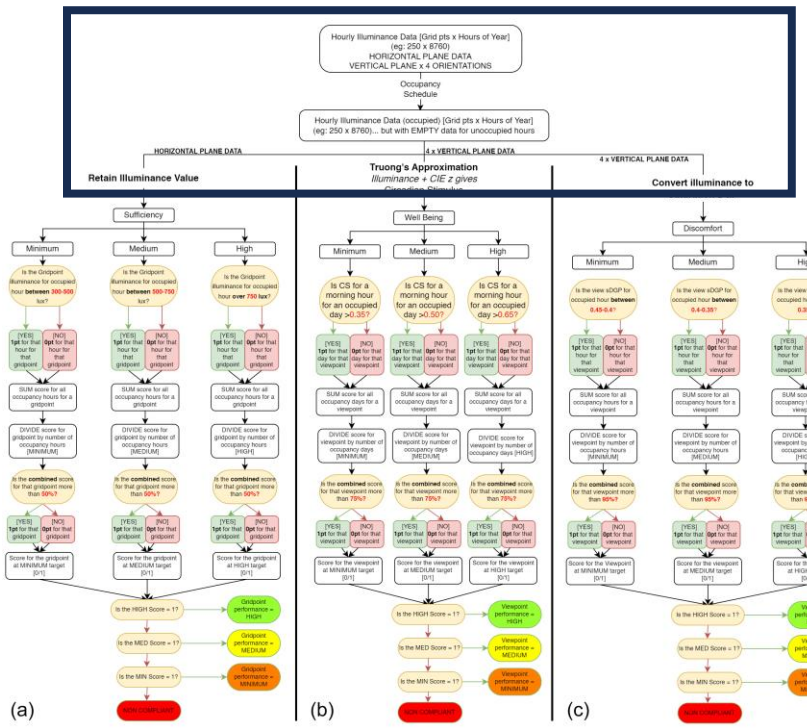
c) Useful Daylight Illuminance



d) Average Illuminance



Radiance illuminance-based simulation approach in AnnuOWL components, via DC method. (for occupant-centric OVNI-based evaluations)



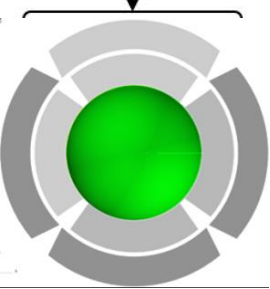
Hourly Illuminance Data [Grid pts x Hours of Year] (eg: 250 x 8760)
 HORIZONTAL PLANE DATA
 VERTICAL PLANE x 4 ORIENTATIONS

Occupancy Schedule

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

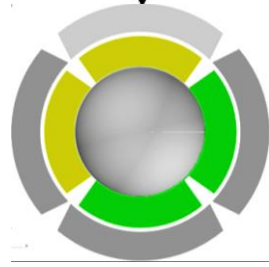
HORIZONTAL PLANE DATA

Retain Illuminance Value



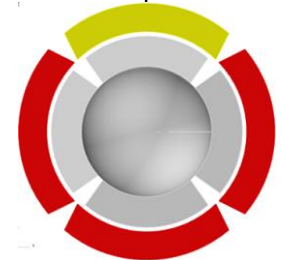
4 x VERTICAL PLANE DATA

Truong's Approximation
Illuminance + CIE z gives
 Circadian Stimulus



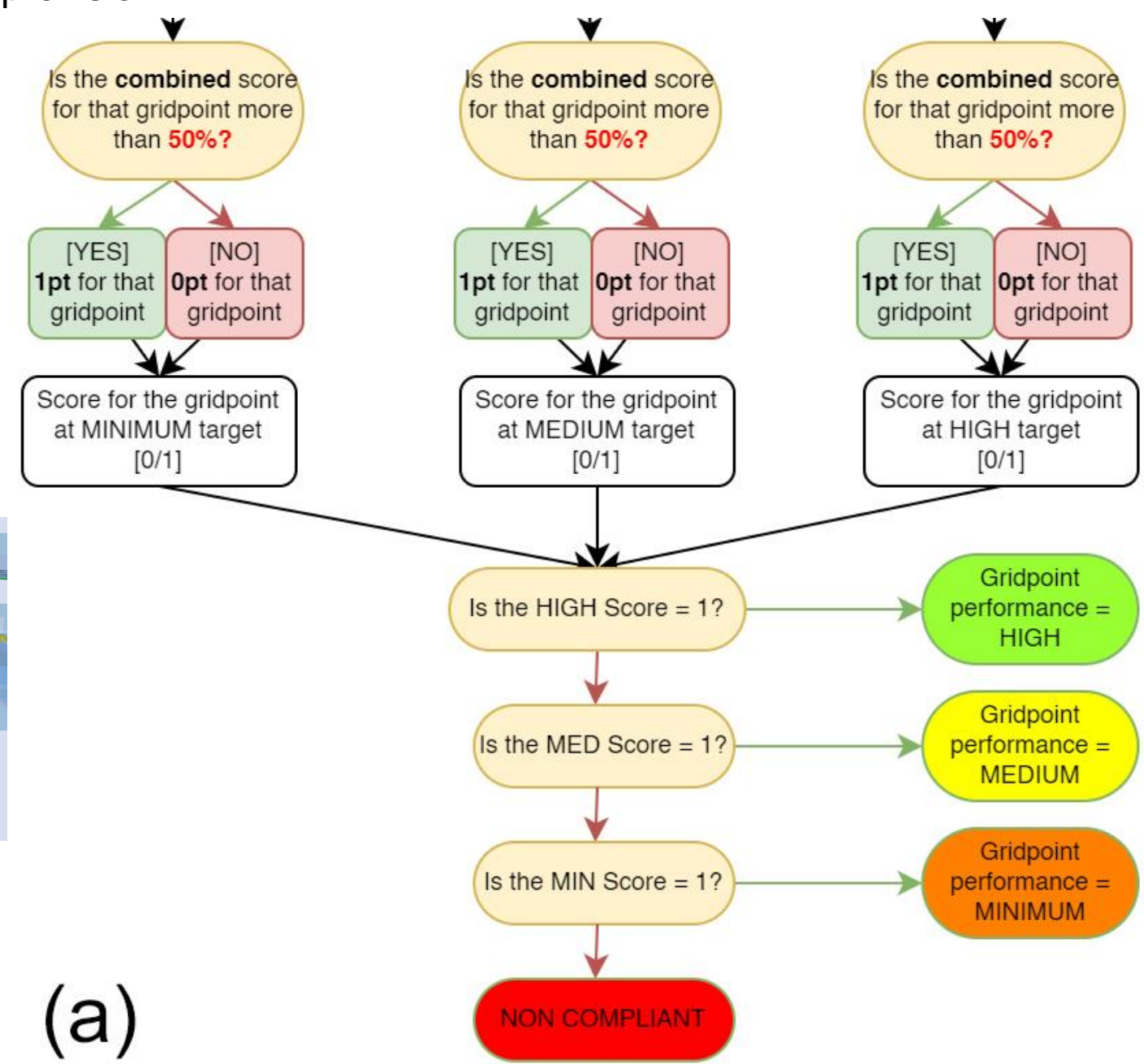
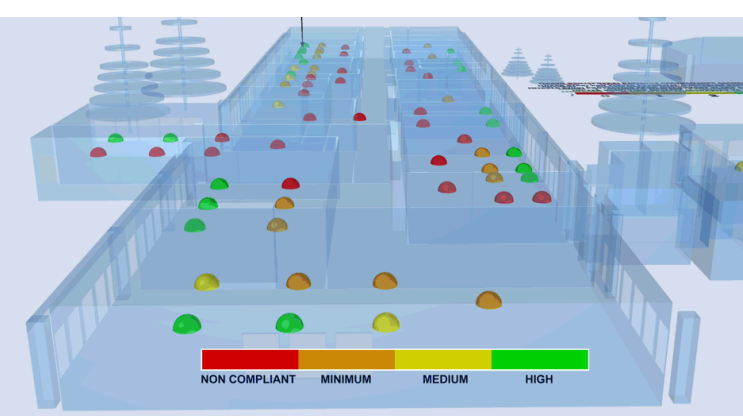
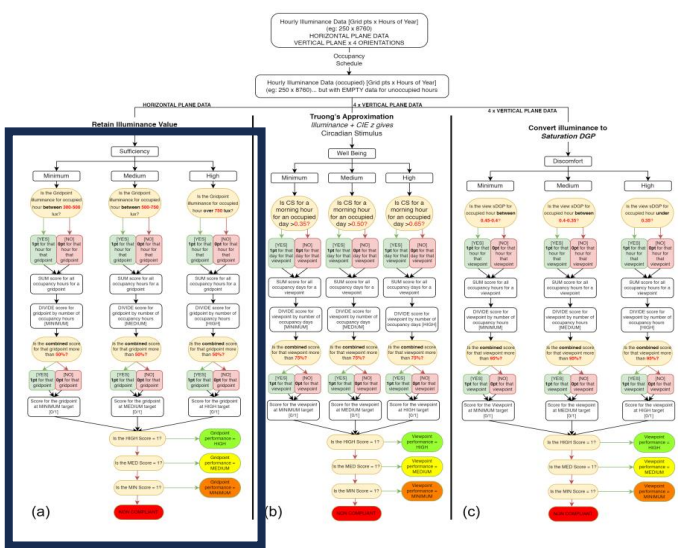
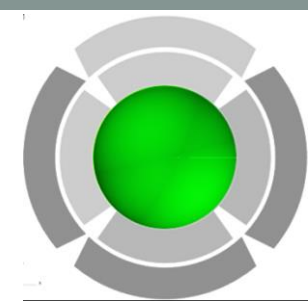
4 x VERTICAL PLANE DATA

Convert illuminance to
Saturation DGP



OVNI evaluations for annual performance

1. Hemisphere: evaluating daylight provision

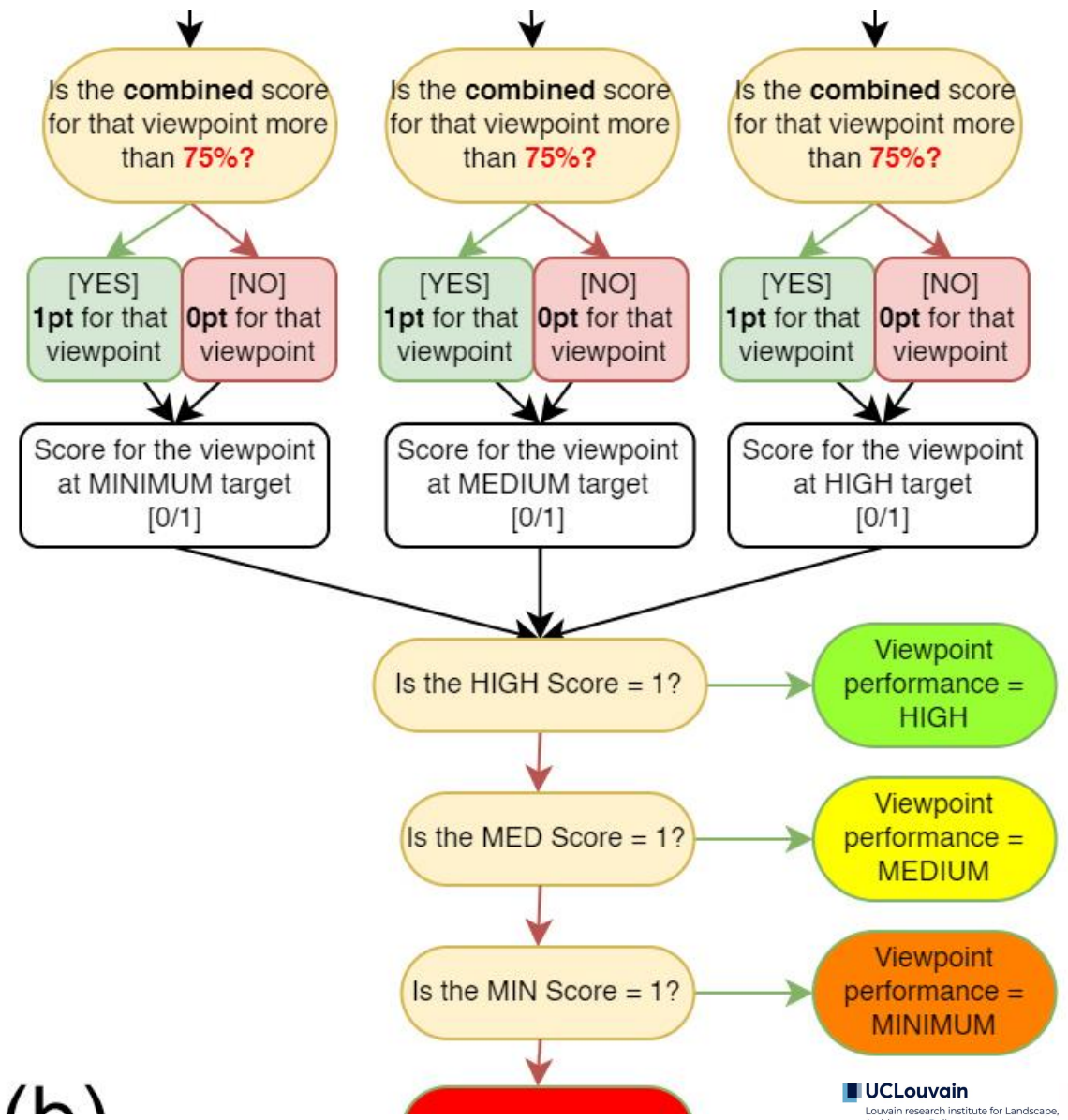
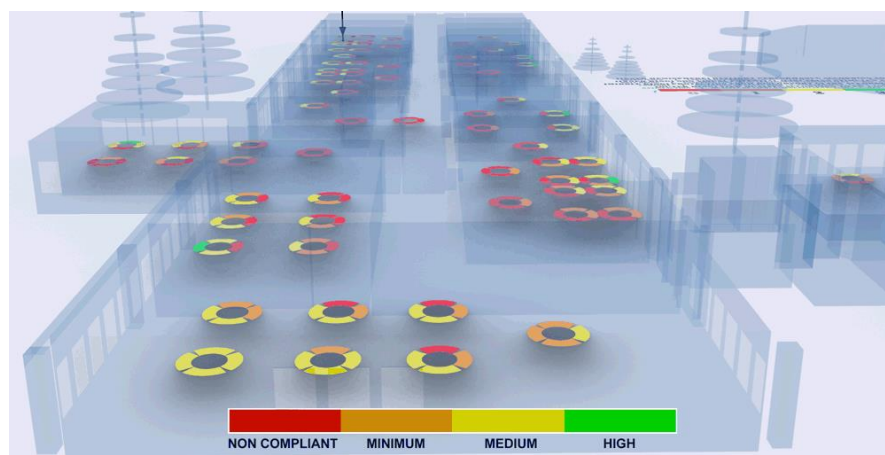
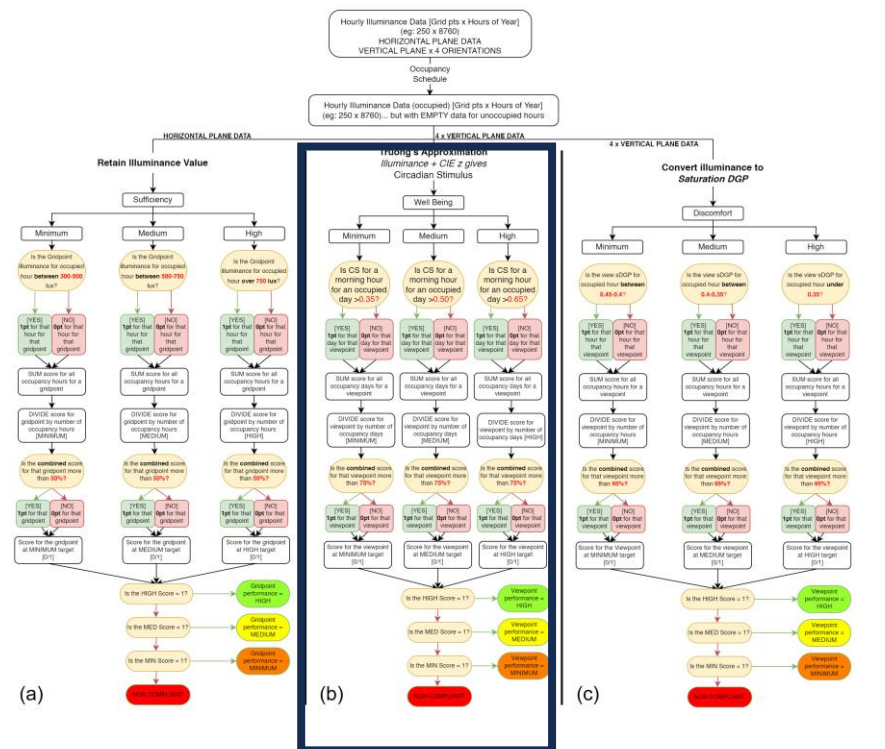


(a)

OVNI evaluations for annual performance

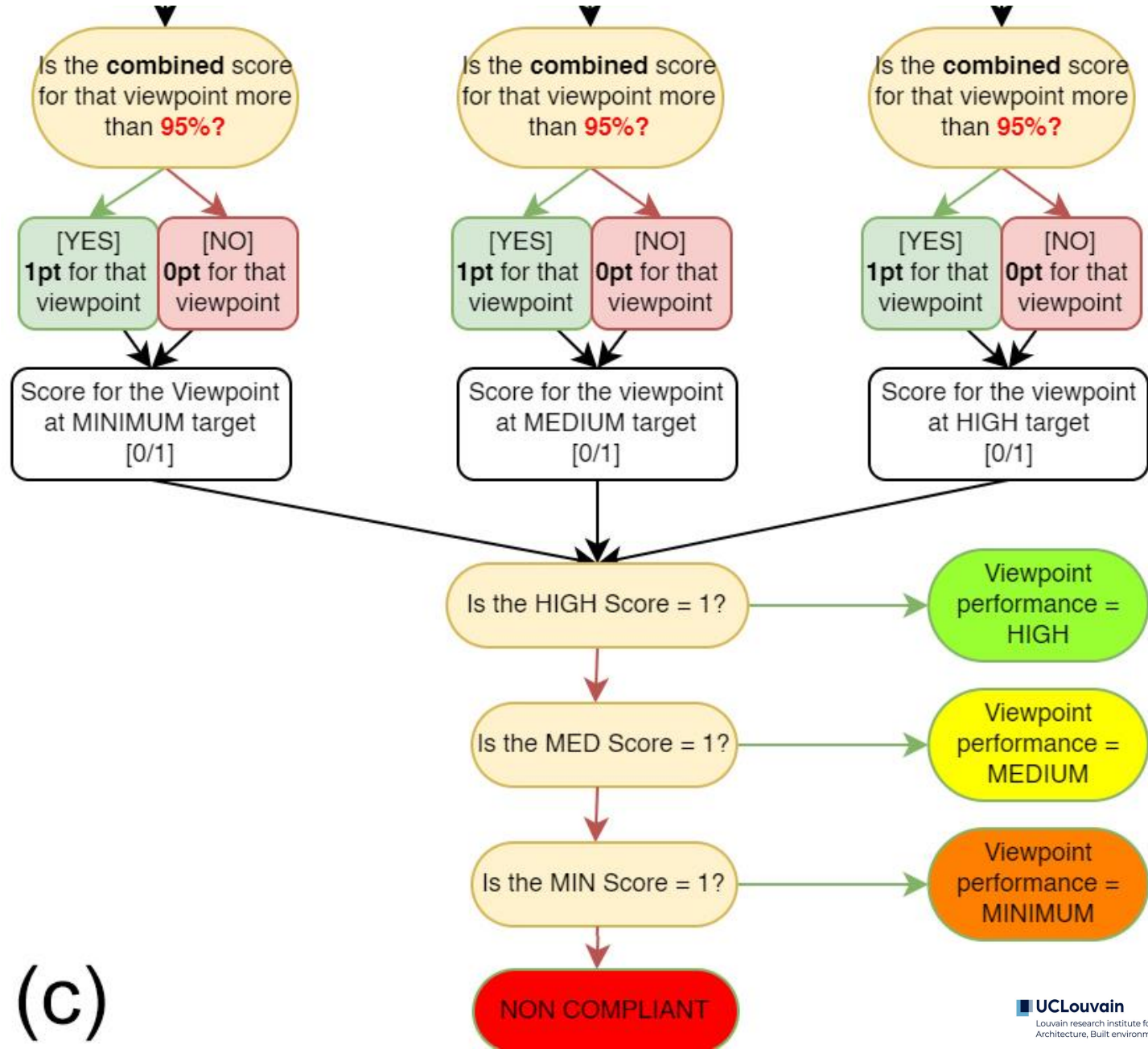
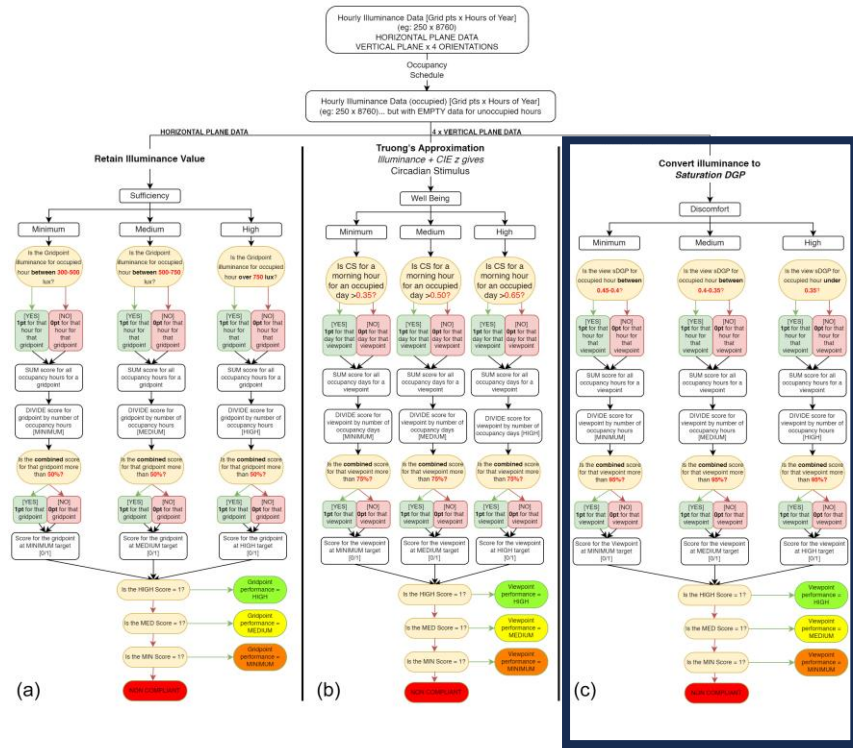
2. First ring, Non-visual potential. Truong approximation

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

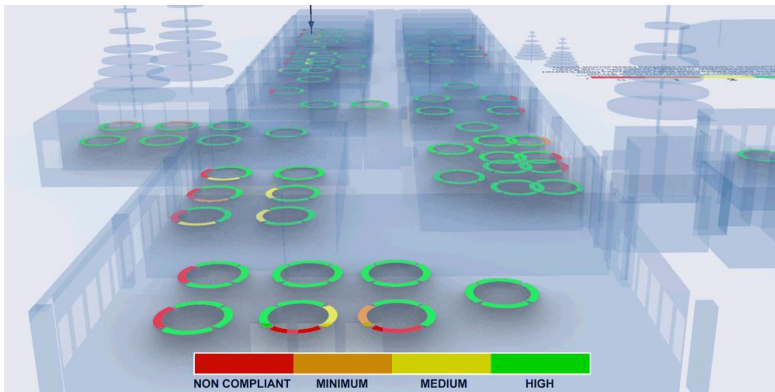


OVNI evaluations: from point in time evaluations to annual performance

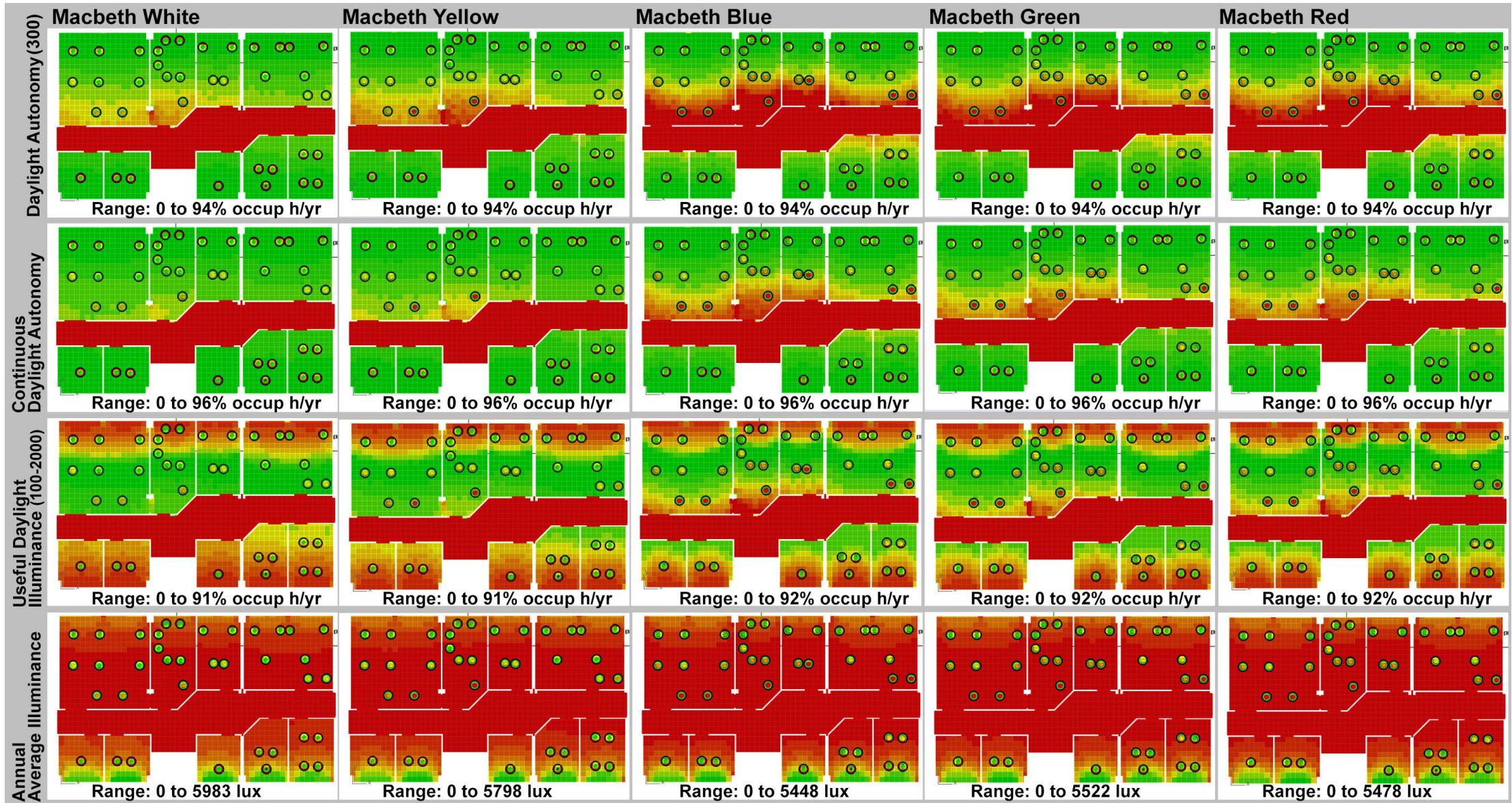
3. Second ring, protection from visual discomfort due to glare, using the sDGP approach



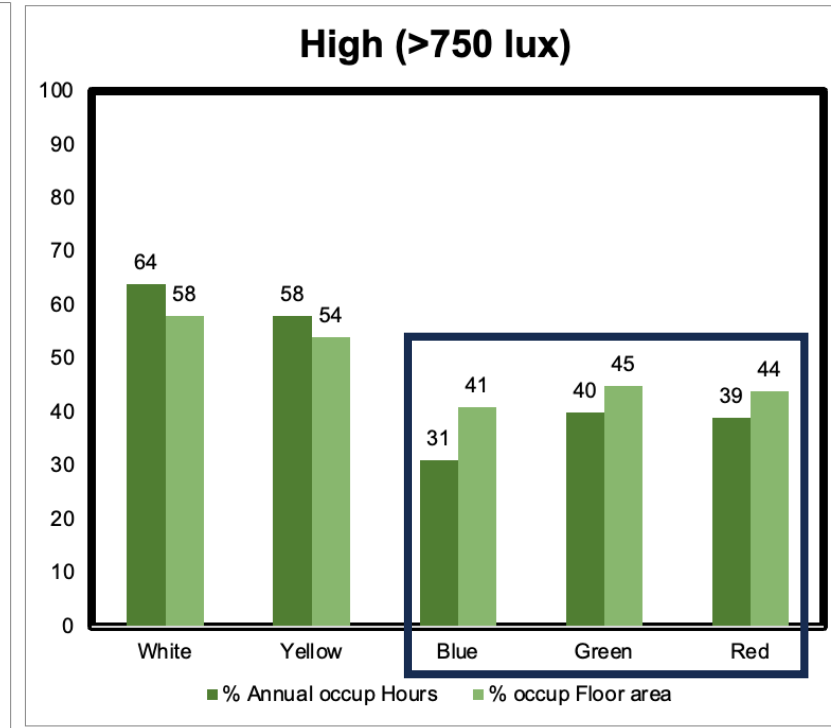
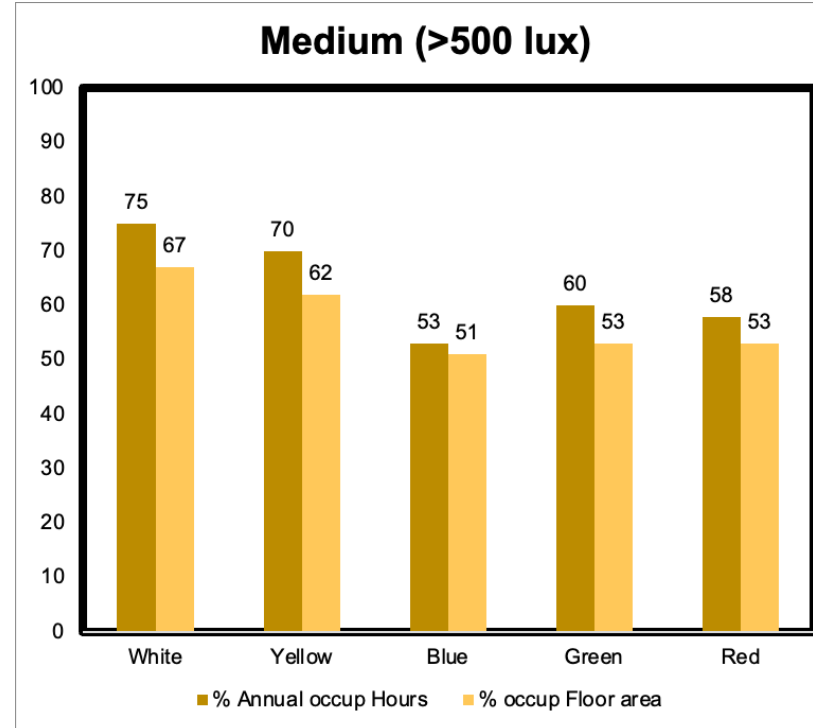
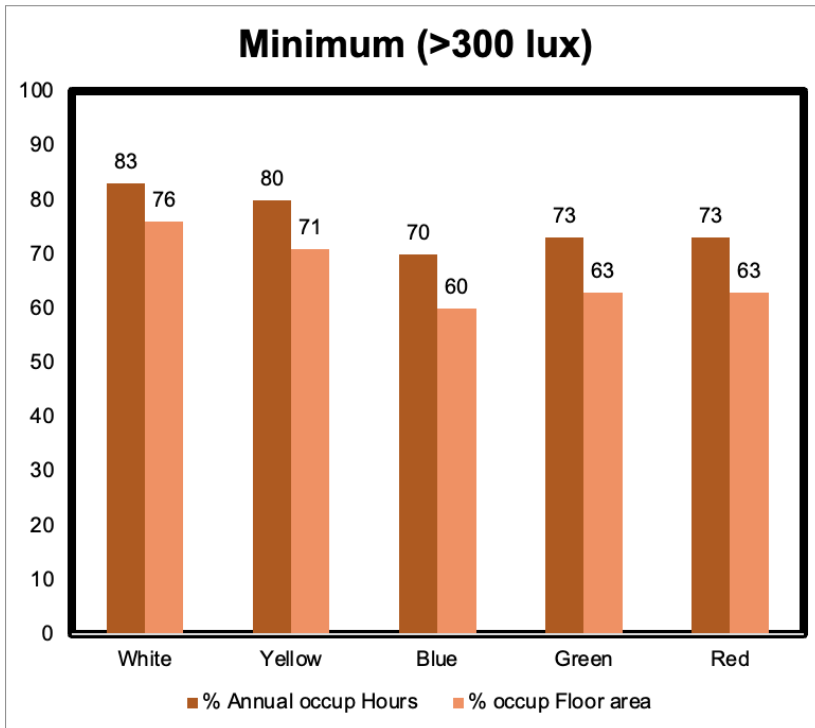
(c)



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



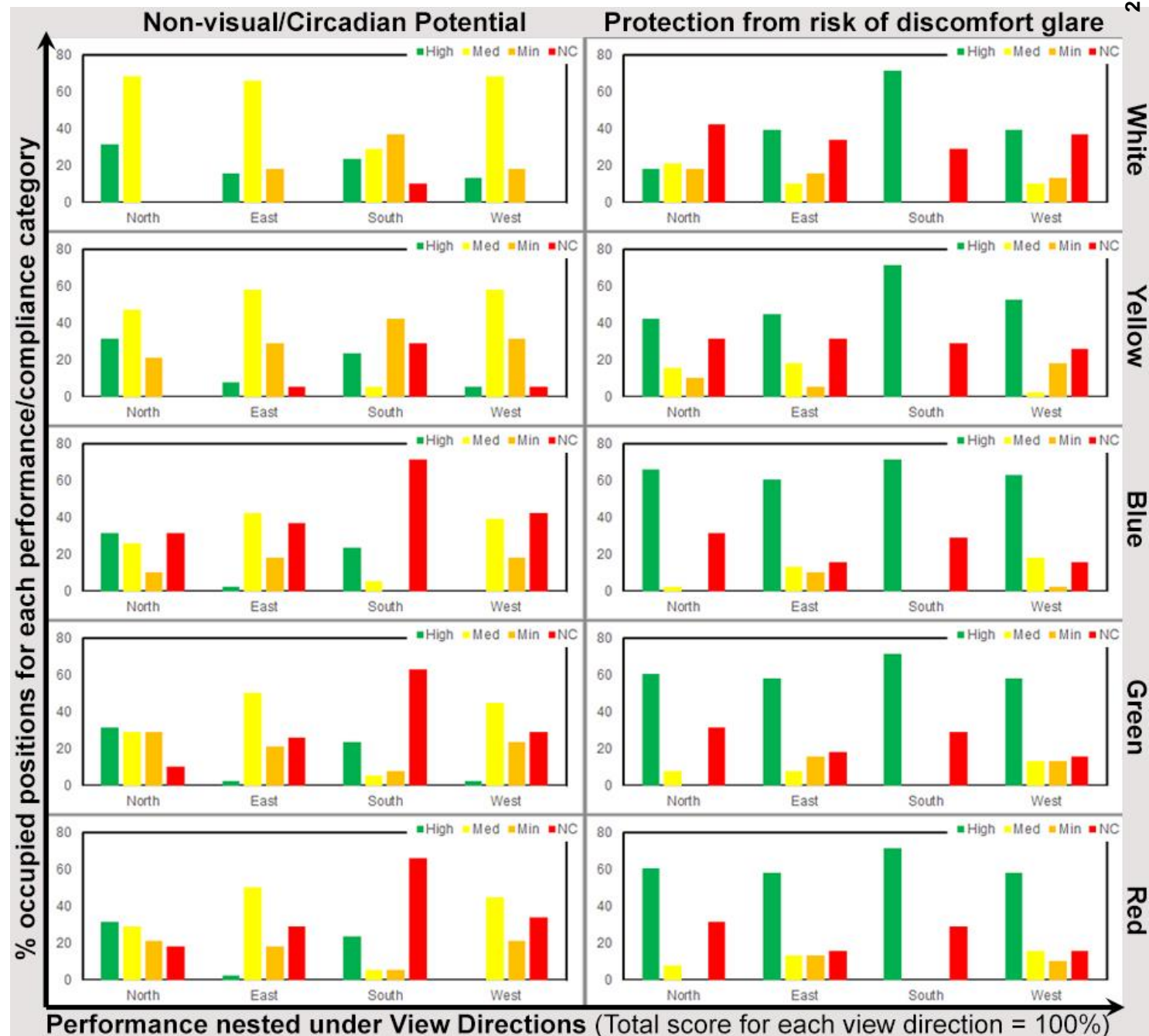
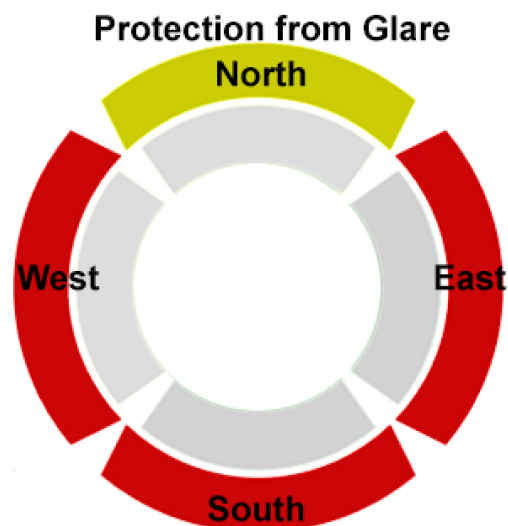
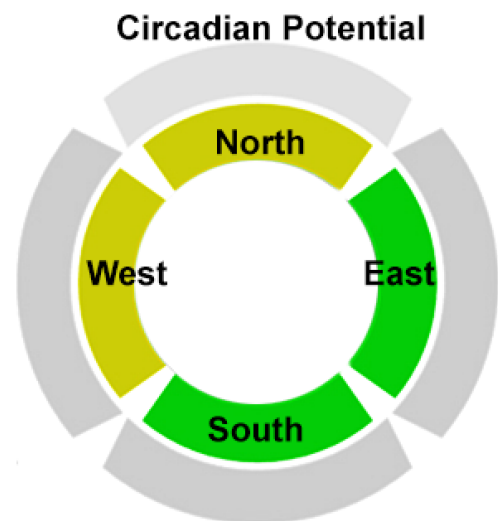
sDA compliance through different criteria



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

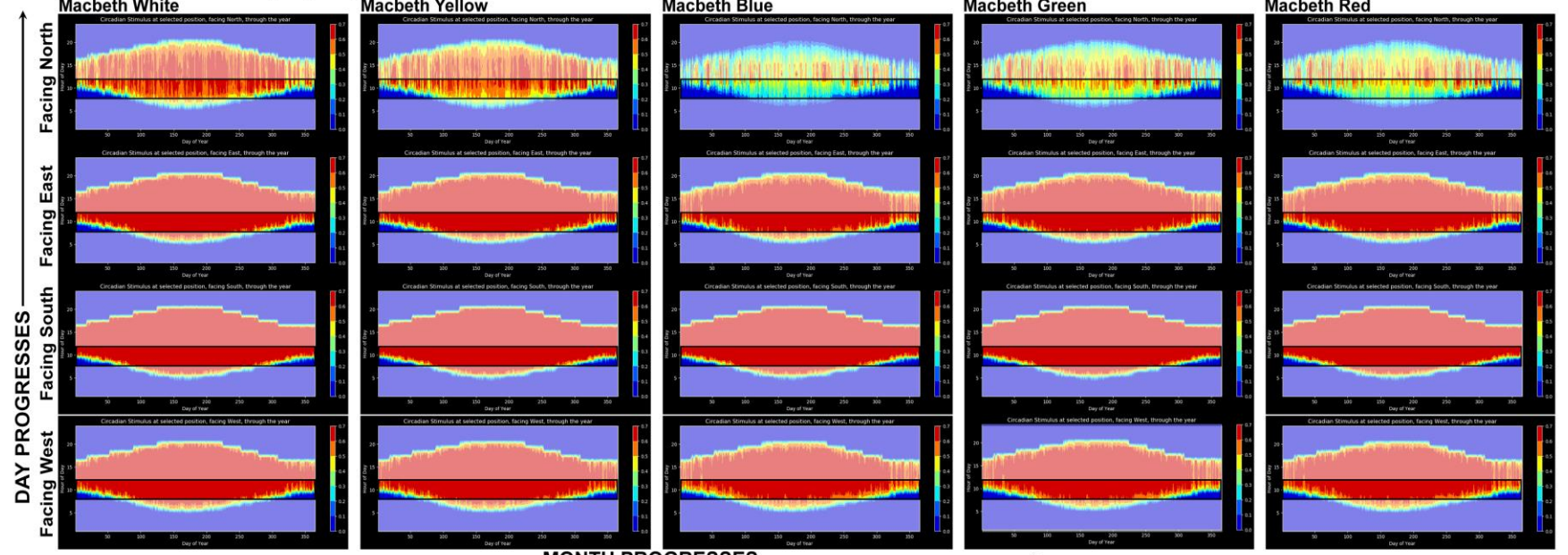
Right: % occupied floor area for 50% annual occupied hours (Proposed EN17037, similar to IES LM83)

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

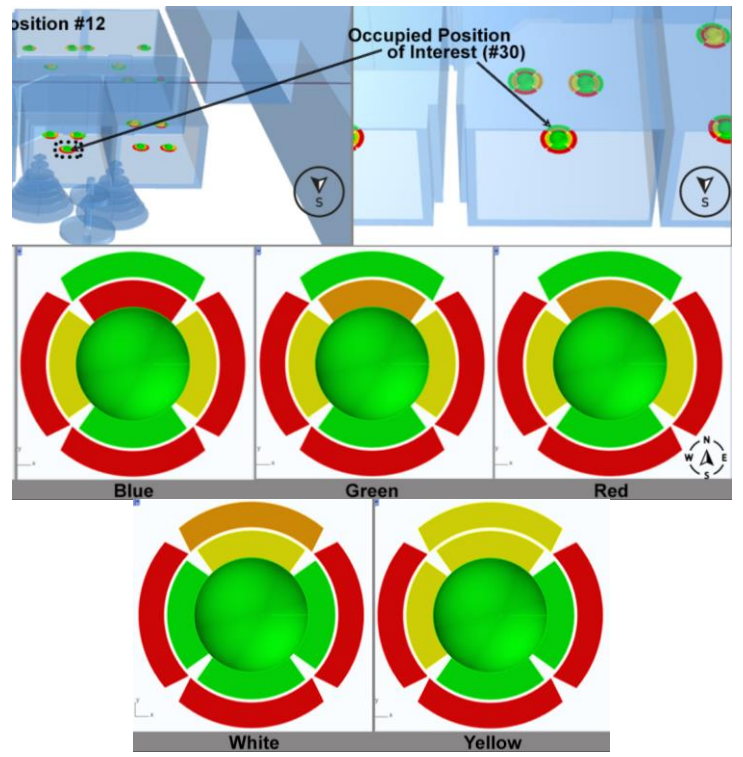
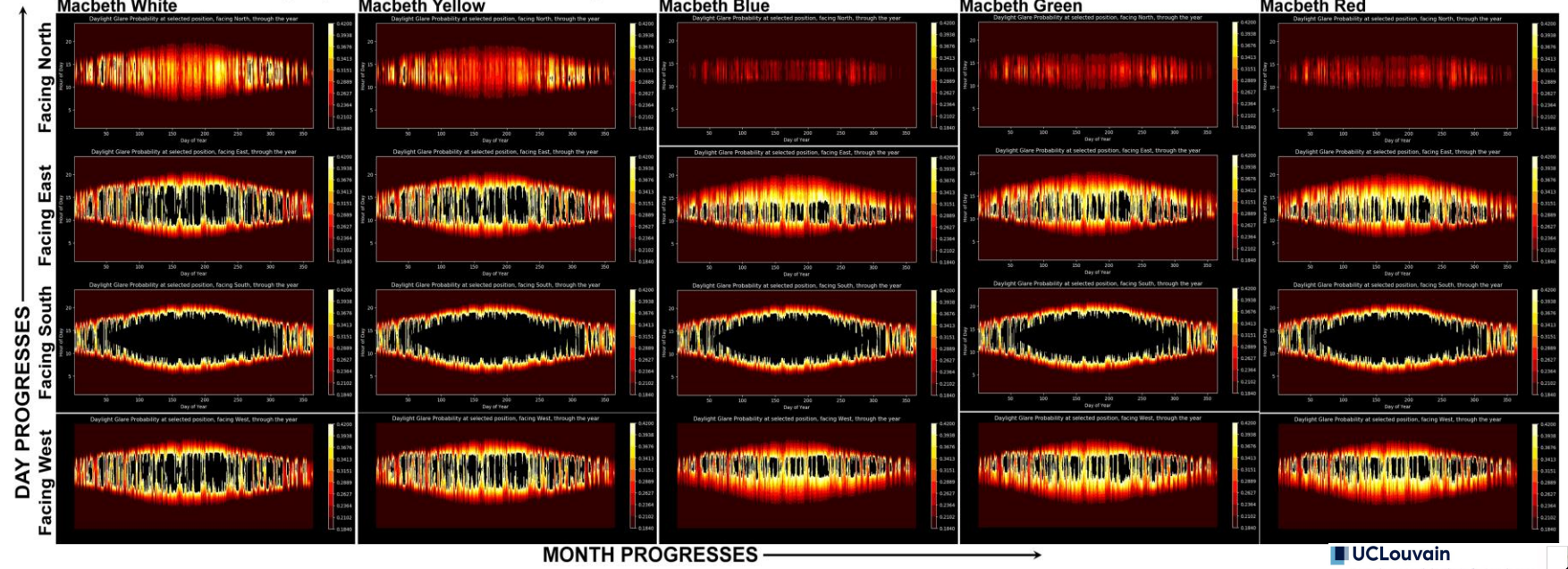


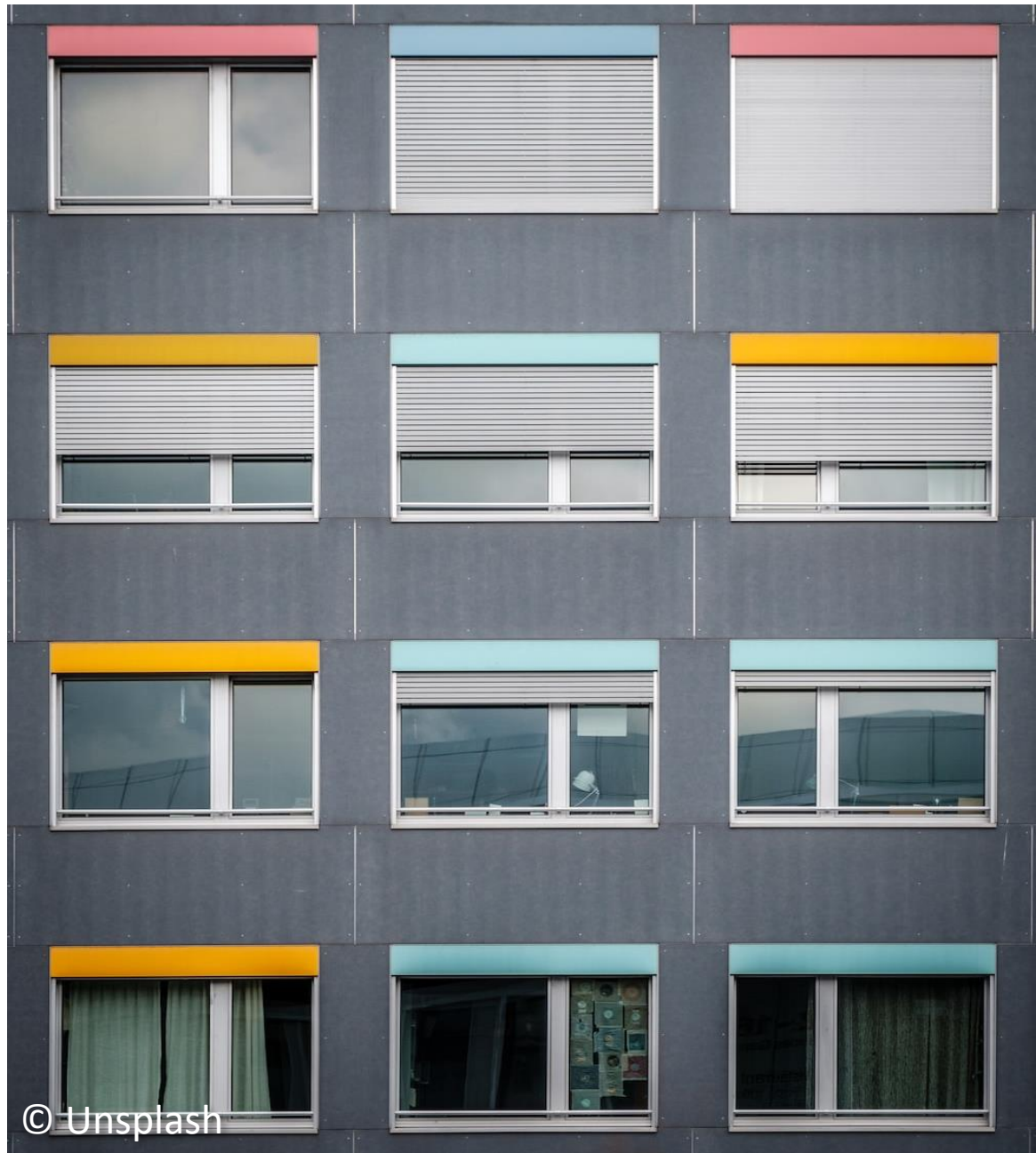
Occupant-centric annual heatmaps for CS and DGP (Parametric study on wall Colors)

Annual CS Heatmaps (range: 0 to 0.7)



Annual DGP heatmaps (Range: 0.1840 to 0.4200)





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DASHBOARD

DiscreteLum

View Rhino View name

Analysis Period

Hour of Day

Day of Month

Month of Year

Mask View-mask [bino, human, fish]
C:/Users/maraha1/Downloads/OWL/output/masks/Basic_Viewno_mask.mat

Region-mask [patches]
C:/Users/maraha1/Downloads/OWL/output/masks/regions_circular.mat

Radiance Sky-type

Image scaling factors

NIF@Sky

illuminance
 13267.85

Melanopic ELR
 1.5465

Melanopic DER
 1.1661

Melanopic EDI
 15471.64

Circad_Light
 38948.04

Circad_Stim
 0.696073

imagePath_ coordinates_ _scale_ imagePath_ values GIF

NIF@view

illuminance
 5113.14

Melanopic ELR
 1.5453

Melanopic DER
 1.1652

Melanopic EDI
 5957.83

Circad_Light
 13174.36

Circad_Stim
 0.687192

Relative Combined SPD at View

imagePath_ coordinates_ _scale_ imagePath_ values GIF

imagePath_ coordinates_ _scale_ imagePath_ values GIF

2%

imagePath_ coordinates_ _scale_ imagePath_ values GIF

cd/m2

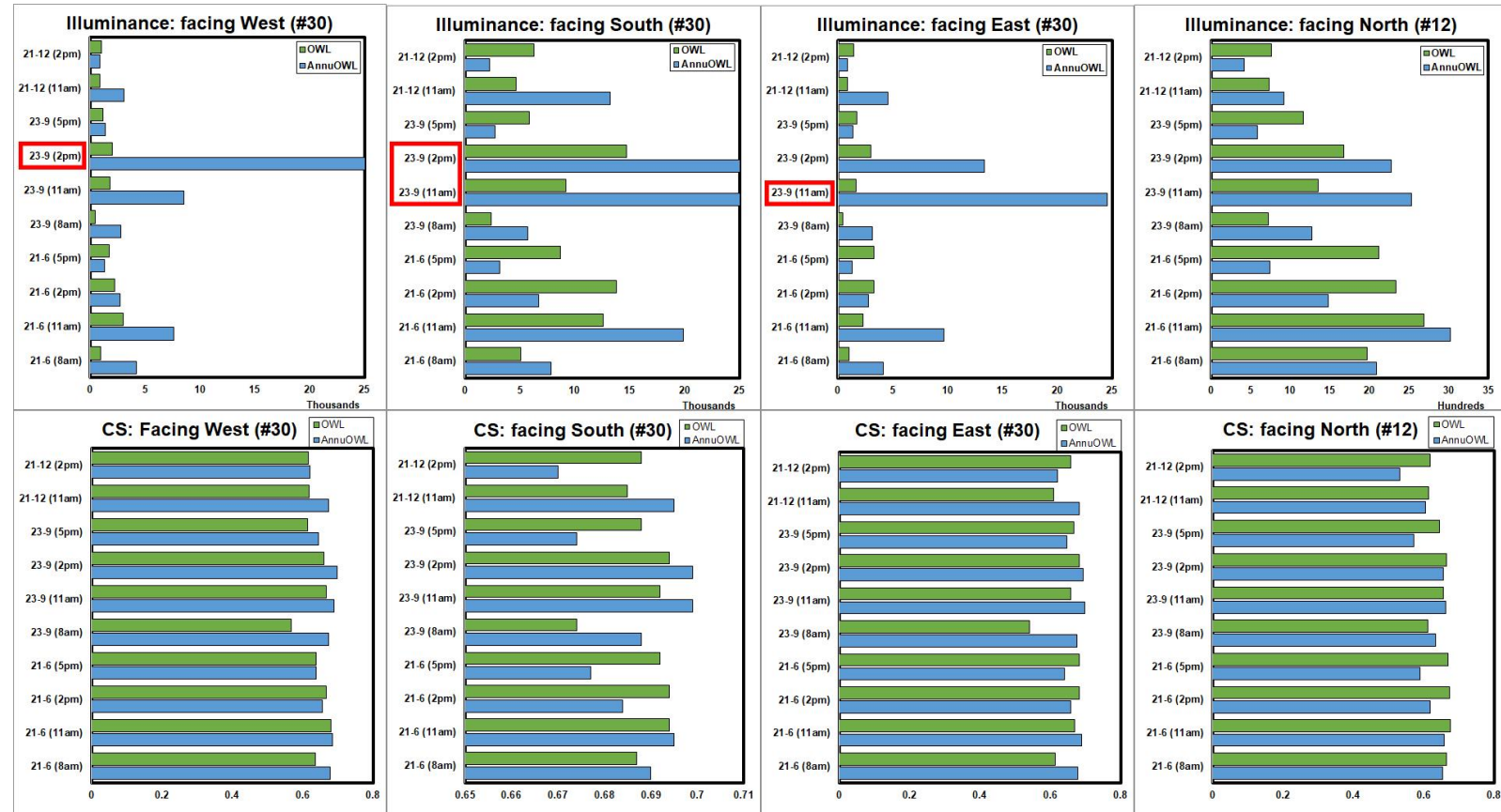
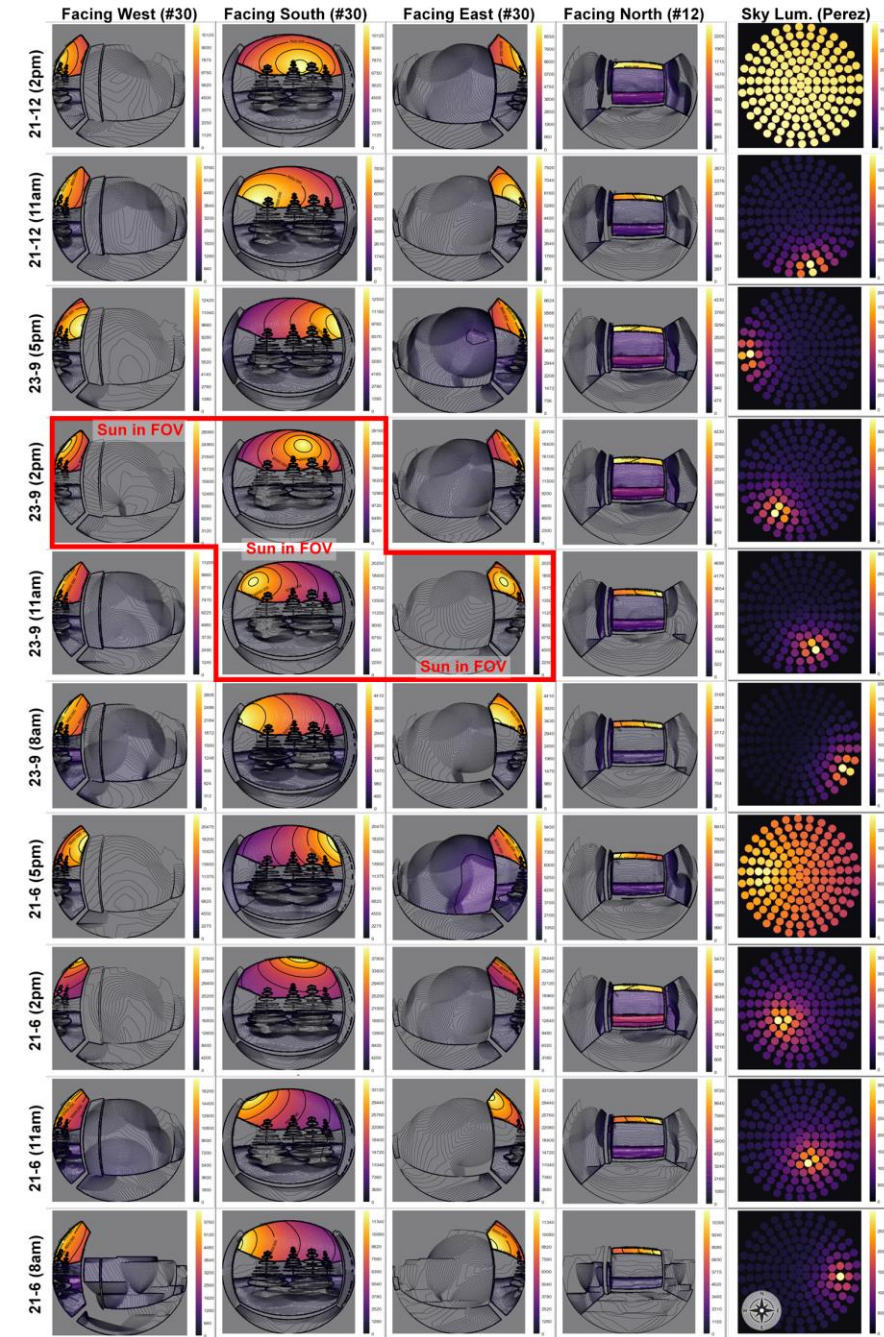
10507.3
9456.57
8405.84
7355.11
6304.38
5253.65
4202.92
3152.19
2101.46
1050.73
0

2%

imagePath_ coordinates_ _scale_ imagePath_ values GIF

imagePath_ coordinates_ _scale_ imagePath_ values GIF

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





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



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

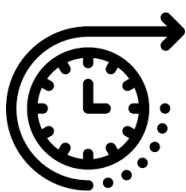


3. **Accuracy** (Better than OWL because internal reflections are considered)



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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