Evaluating the visual and non-visual performance of shading systems through a novel simulation workflow

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ABSTRACT: If properly designed and operated, shading systems such as venetian blinds can be effective to control solar ingress and contribute to reduce the occurrence of discomfort due to glare. By redirecting daylight into deeper areas, these systems also improve light distribution inside spaces.

In addition to the energy and visual comfort aspects of lighting and shading systems, substantial interest has recently focused on the non-visual or non-image-forming (NIF) effects of daylight. NIF effects are associated with the entrainment of the circadian rhythm, and can play a major role in the health, well-being and task performance of occupants by helping to regulate their biological clock. The change in colour and intensity of daylight through a 24-hour period helps in synchronizing this rhythm, this process being regulated by the blue-light-sensitive intrinsically photosensitive retinal ganglion cells (ipRGCs) present in the human eye. ipRGCs convert electromagnetic luminous stimuli into neurochemical signals by the expression of melanopsin. The regulation of circadian rhythm depends, among other aspects, on the spectral dosage of different wavelengths through the daily light cycle.

For evaluating the NIF performance of lighting and shading systems, their spectral properties (e.g., colour, spectral reflectivity) are important. NIF effects are currently evaluated using metrics such as the Melanopic equivalent daylight illuminance (m-EDI), M/P ratio, or Circadian Stimulus. In this study, we use a newly developed spectral simulation tool[1] for estimating a series of NIF metrics inside a space (the dashboard of the tool shown in Figure 1) and for assessing the performance of glazing and shading systems to support the occupants' visual and non-visual requirements.

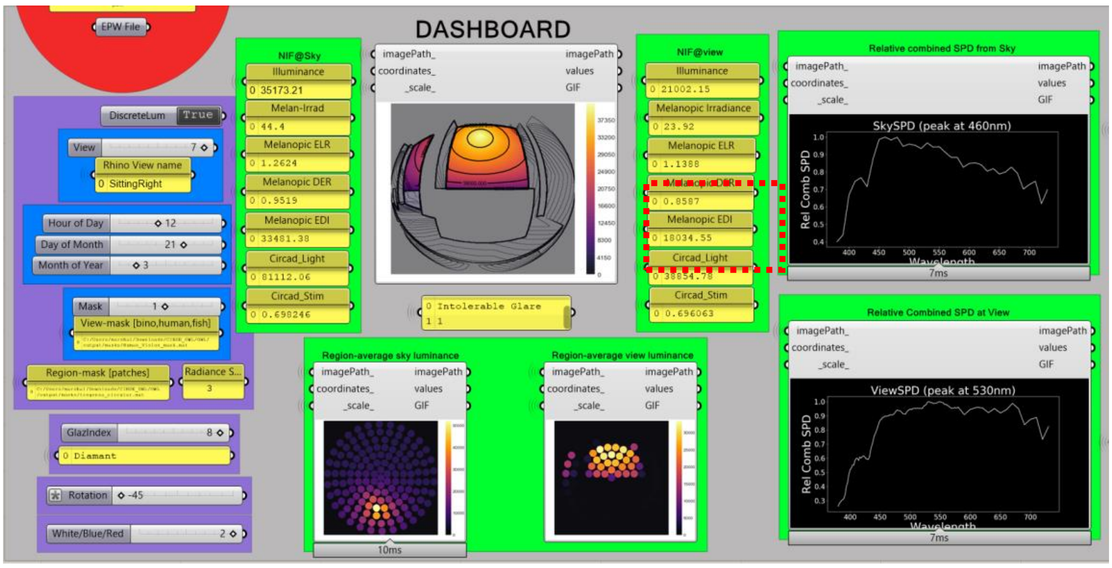

Figure 1. Dashboard illustrating the workflow proposed in the newly developed NIF evaluation tool. The workflow is based on originally-designed Rhino Grasshopper components

[1] Marshal Maskarenj, Bertrand Deroisy, Sergio Altomonte, A new tool and workflow for the simulation of the non-image forming effects of light, Energy and Buildings, Volume 262, 2022, 112012, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2022.112012.

INTRODUCTION: This case study presents the parametric evaluation of the NIF performance of a space due to the use of different glazing and shading systems. This allows estimating potential opportunities to respond to occupants' visual and non-visual requirements, which can be used as indicators of comfort and wellbeing. The study uses a newly-developed spectral simulation tool: OWL (Occupant Wellbeing through Lighting). Through this tool, 378 simulations are run for 4 independent variables: time of year; material and colour of blind slats; slats' tilt-angles; spectral characteristics of glazing. Two NIF metrics are presented in this case study as the dependent variables to evaluate non-visual effects: Melanopic-over-Photopic [M/P] ratio (or melanopic daylight efficacy ratio [mDER]) and melanopic Equivalent Daylight Illuminance [mEDI]. The likelihood of occurrence of visual discomfort is assessed through the calculation of Daylight Glare Probability (DGP). The OWL tool[2] has been designed to provide a range of further circadian metrics: Circadian Light and Circadian Stimulus (proposed by the Lighting Research Centre at Rensselaer Polytechnic Institute), melanopic Efficacy of Luminous Radiation, melanopic irradiation, instantaneous spectral power distribution at the scene, etc.

THE CASE STUDY: A shoebox room with south-facing windows located in London, UK. The observer sits at a position perpendicular to one of the widows while fixating a computer screen.

MODEL SETTINGS: London, South Facing, Fixed Window-View Position, Human Vision Mask.

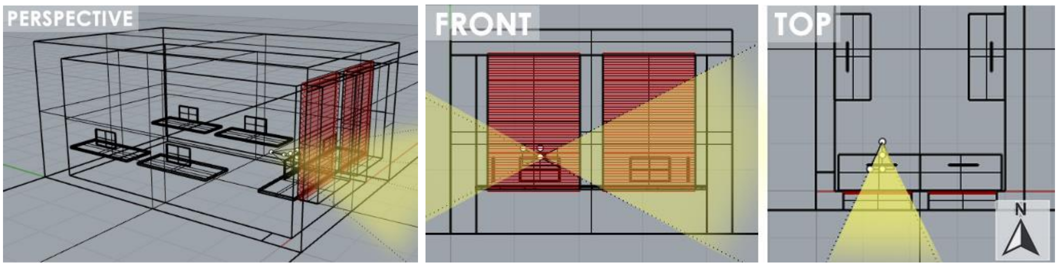

Figure 2. Geometry and View position for the scene

INDEPENDENT VARIABLES:

Time of Year [2], Blind materials [3], Blind angles [7], Glazing Material [9]

Total Simulations: 2 x 3 x 7 x 9 (378)

DEPENDENT VARIABLES:

- Glare rating
- DGP
- SPD data (380 to 730 in 2nm bins)
- Illuminance
- melanopic-Irradiation
- melanopic ELR
- melanopic DER
- melanopic EDI
- Circadian lighting
- Circadian Stimulus

INDEPENDENT VARIABLE | TIMES OF THE YEAR:

- 21-Mar (Day 80) at 1200h (Hour 1908): Spring Equinox - Sun close to center of view (fovea)
- 21-Jun (Day 172) at 0700h (Hour 4111): Summer Solstice - Sun close to the view periphery

INDEPENDENT VARIABLE | BLIND-SLAT COLOURS:

Standard (RGB=200, 206, 202) Red-shifted (RGB=200, 206, 0) Blue-shifted (RGB=0, 206, 202)

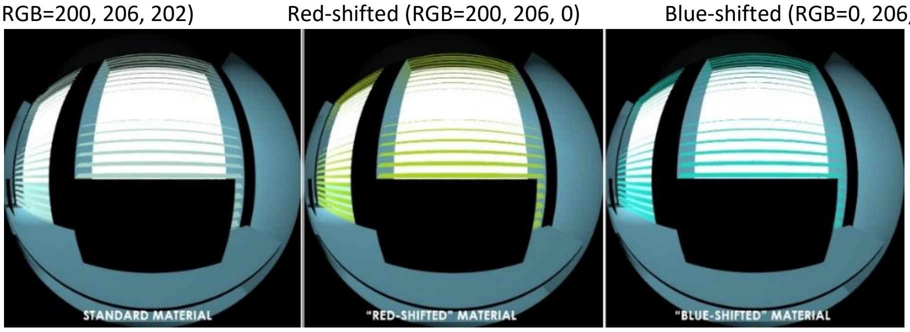

Figure 3. Materials selected for blind-slats: Standard, Red-shifted, and Blue-shifted

[2] https://marshalmaskarenj.github.io/OWL_Web

INDEPENDENT VARIABLE | BLIND ANGLES:

- -45 degrees
- -30 degrees
- -15 degrees
- 0 degrees
- 15 degrees
- 30 degrees
- 45 degrees

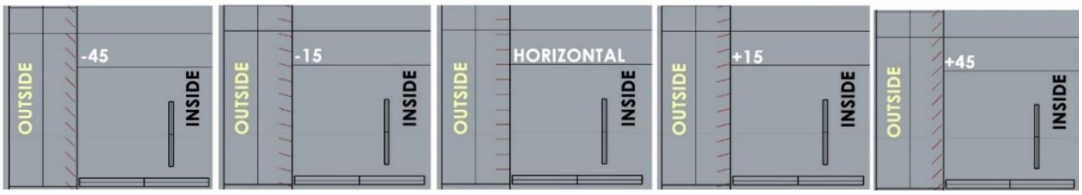

Figure 4. Blinds at various tilt angles from -45 to 45 with step increments of +/- 15 degrees

INDEPENDENT VARIABLE | GLAZING MATERIALS:

‘LINEAR-response’ Glass (T_{vis} = 80)
Cool Lite KNT 155 (T_{vis} = 49.041)
Planitherm Futur Ultra N (T_{vis}=78.865)
Bioclean (T_{vis} = 83.258)
Diamant (T_{vis}=89.113)
Cool Lite KNT 155 - Verde (T_{vis} = 32.723)
Planistar (T_{vis}=64.032)
Planitherm Total (T_{vis} = 80.443)
Planilux (T_{vis} = 86.515)

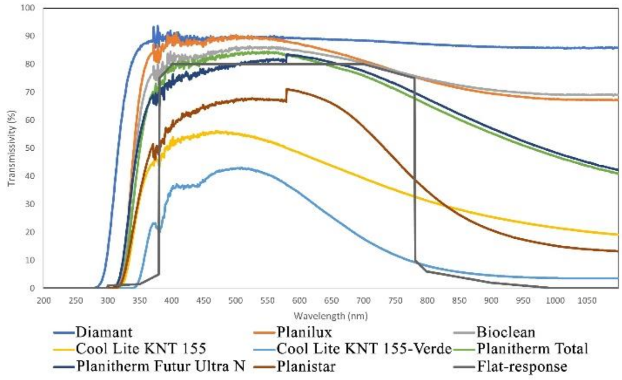

Figure 5. Spectral transmission characteristics[3] of the 9 different glazing materials used in the simulations

RESULTS AND DISCUSSIONS:

378 simulations were run from the observer’s view position (Figure 2) to evaluate metrics for non-visual response as highlighted in the dashboard (Figure 1). Among the four categories of independent variables, changing blind-slat colour to red- or blue-shifted type (see Figure 3) resulted only in marginal variations in the evaluated metrics. Therefore, only the results of the 126 distinct simulations run with the standard blind material are presented in Figures 6 and 7, for the two key metrics of mEDI and M/P ratio. Among the range of results obtained, the following general trends emerged:

- **Solar position**: When the was sun closer to the foveal position in the centre of view (e.g., 1200h on 21 March), mEDI increased to about 300% whereas the M/P ratio dropped, as compared to the simulations run when the sun was viewed in a peripheral position (e.g., 0700h on 21 June).
- **Blind slat angle**: The computational workflow used to estimate NIF metrics in the OWL tool depends primarily on sky luminance at view. Since certain angular positions of the blind slats (Figure 4), such as -15°, maximise the direct sky view component at the observer’s position, these generate maximum mEDI. However, this can also affect glare occurrence. In fact, bling slat angles leading to higher mEDI also entail the risk of higher glare ratings – going from Perceptible (when the sun is in a peripheral position) to Intolerable (when the sun is near the centre of view).
- **Spectral transmissivity**: Difference in visible transmittance properties between various glazing types can potentially led to variations in mEDI. However, since the transmission characteristics of

[3] Helenice Sacht, Luis Bragança, Manuela Almeida, Rosana Caram, Specification of Glazings for Façades Based on Spectrophotometric Characterization of Transmittance. Sustainability. 2021, 13. 5437. https://doi.org/10.3390/su13105437.

the nine glazing materials used in these simulations did not show significant differences of spectral selectivity in the blue wavelength region, a significant variation in M/P ratio was not observed between the glazing types.

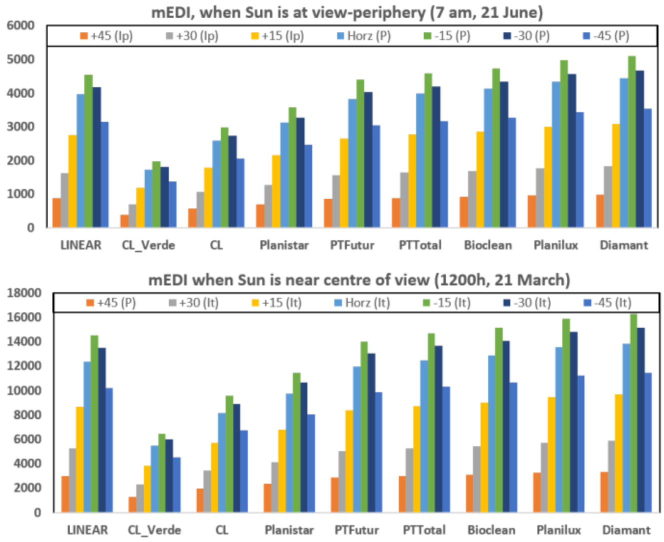

Figure 6: Glare probability is reduced by increasing the blinds' tilt angle (DGP glare rating in brackets), although this also reduces mEDI. Redirection towards ceiling (+) decreases DGP more than tilting inwards (-) , but reduces mEDI as well.

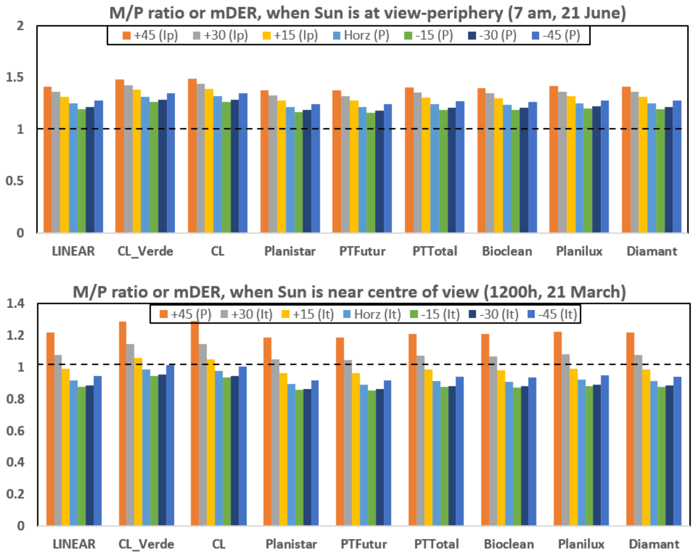

Figure 7: M/P ratio is high (alerting) in the morning, but often drops below 0.9 at noon for most blind tilt angles for all different glazing materials

CONCLUSIONS: This case study suggested that, among all the variables considered, the blind's tilt angle can be particularly effective to find an adequate compromise between responding to requirements of non-visual stimulation and reducing the risks of discomfort due to glare. Minimising the potential of glare occurrence though blind operation, however, might reduce daylight's melanopic potential, particularly at early hours of the day. Conversely, in the analysis performed, the material colour of the slats (standard, red-shifted or blue-shifted) did not lead to significant change in NIF metrics. Glazing materials with different spectral transmission characteristics can potentially lead to different M/P ratios, although this was not observed in our simulations. These results might be due to the prevailing influence of direct daylight in the luminous characteristics of the visual scenes.

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