EPFL

Glare from the sun behind Electrochromic glazing

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LIPID
Laboratory of Integrated Performance in design

Visual comfort under Electrochromic windows

What are the transmittance levels required for glare protection when sun is visible through EC glazing?

Are current glare metrics able to predict glare in low-light EC glazing scenarios with sun in FOV of observer?

Glare from Electrochromic windows

What is the subjective perception under EC glazing?

How to simulate?

How to measure?

Are current glare metrics capable of predicting glare in such situations?

Glare from Electrochromic windows

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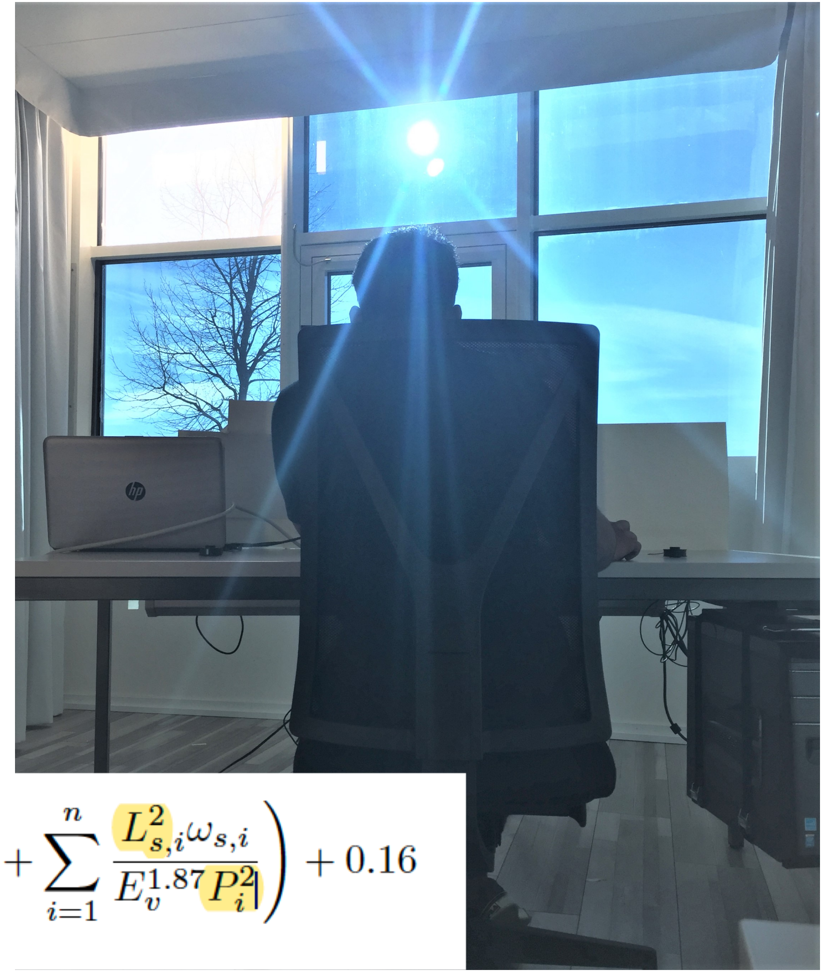
User assessment study

Independent variables	1. Luminance of glare source 2. Viewing direction in relation to glare source
Response variable	Discomfort glare perception
Number of participants	20



$$DGP = 5.87 * 10^{-5} E_v + 9.18 * 10^{-2} log\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16$$

EC glazing Transmittance

Daylight window	3.7%	3.7%
3.7%	0.14% Sun Window	3.7%

Visual Scene 0.14C

Daylight window	3.7%	3.7%
3.7%	0.6% Sun Window	3.7%

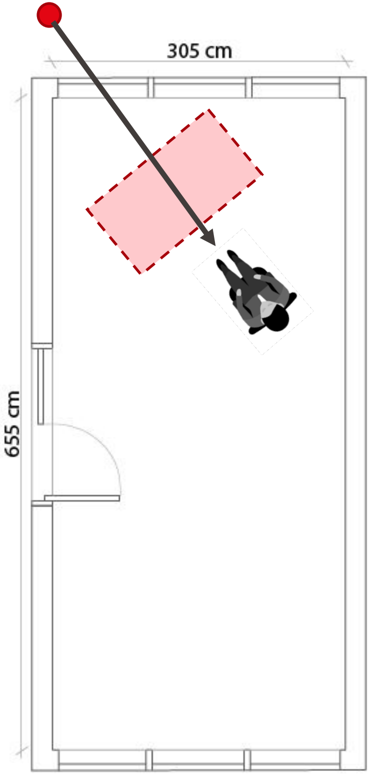
Visual Scene 0.6C/0.6P

Daylight window	3.7%	3.7%
3.7%	1.6% Sun Window	3.7%

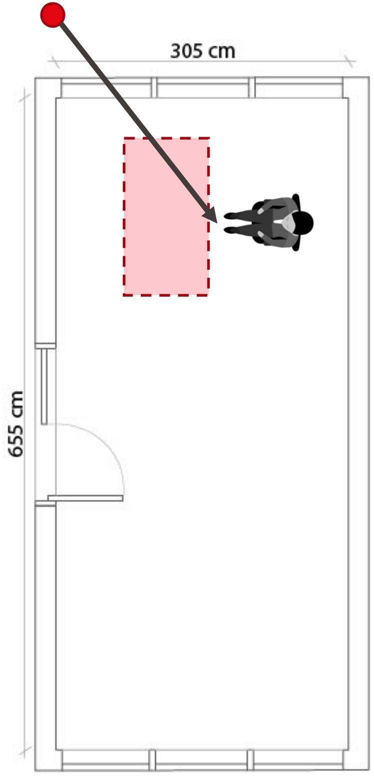
Visual Scene 1.6C

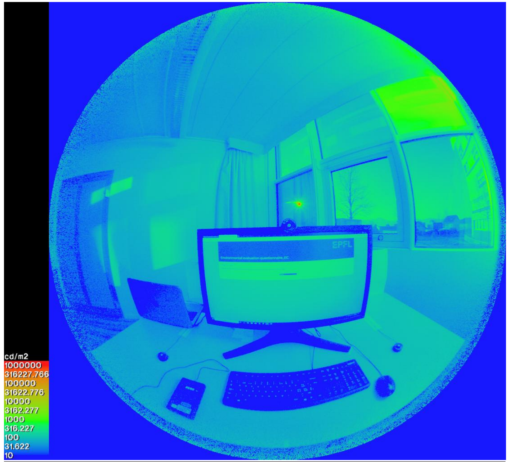
Viewing direction in relation to sun

1.
"C" Sun close to central FOV of participant → critical

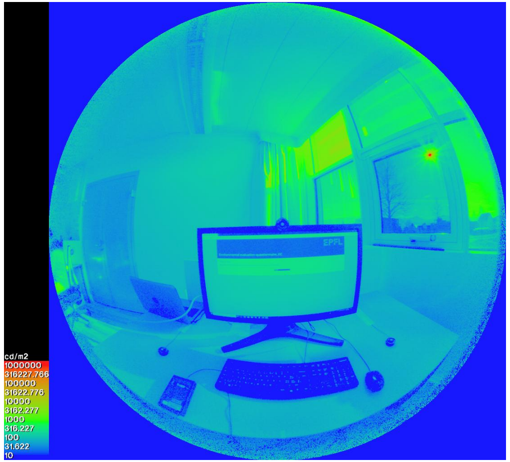


2.
"P" Sun in peripheral FOV of participant → non-critical

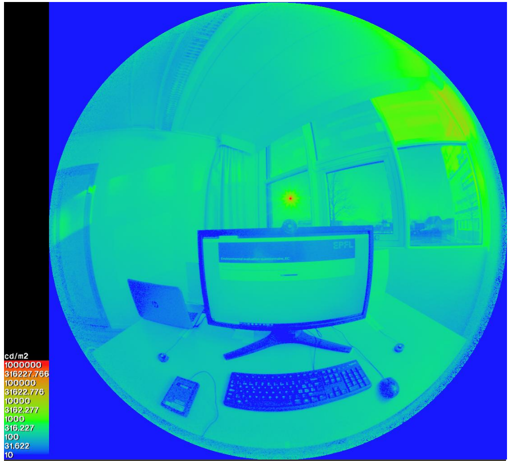




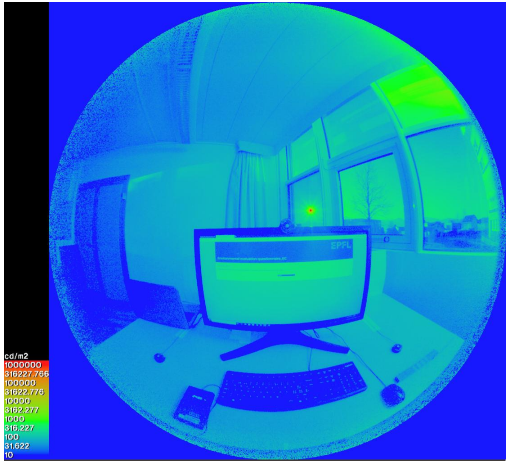
Visual condition 0.14C



Visual condition 0.6P



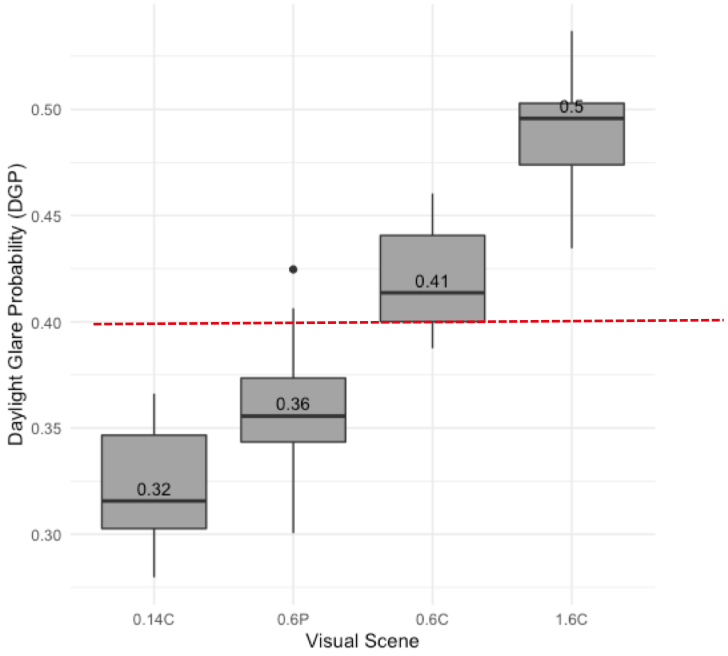
Visual condition 1.6C



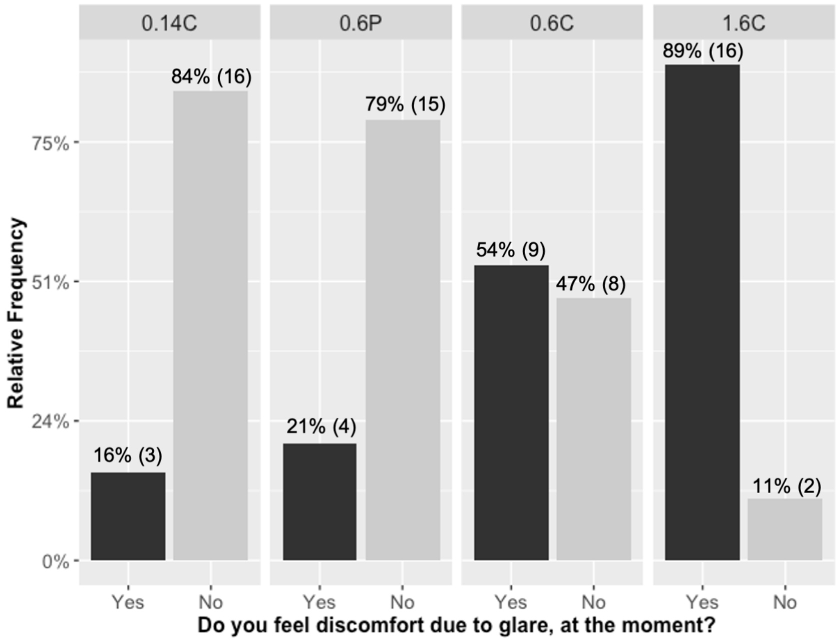
Visual condition 0.6C

Results

DGP Distribution



Subjective perception of glare



⇒ DGP follows user perception reasonably well

Results

A τ_v of 0.6% is sufficient to control glare in noncritical direction.

However, for critical viewing direction a τ_v of 0.14% is required to achieve comfortable conditions.

For scene 0.6C, 54% experienced discomfort glare, however, only 12% found the glare disturbing on 4-pt osterhaus scale.

To have a holistic evaluation of glare perception an annual evaluation is required, and frequency of such scenarios should be checked.

These results confirm the strong angular dependency of glare perception, expressed by the position index P in the glare metrics.

These findings are valid only for blue-tinted EC and might differ for other colored or color-neutral systems.

Glare from Electrochromic windows

What is the subjective perception under EC glazing?

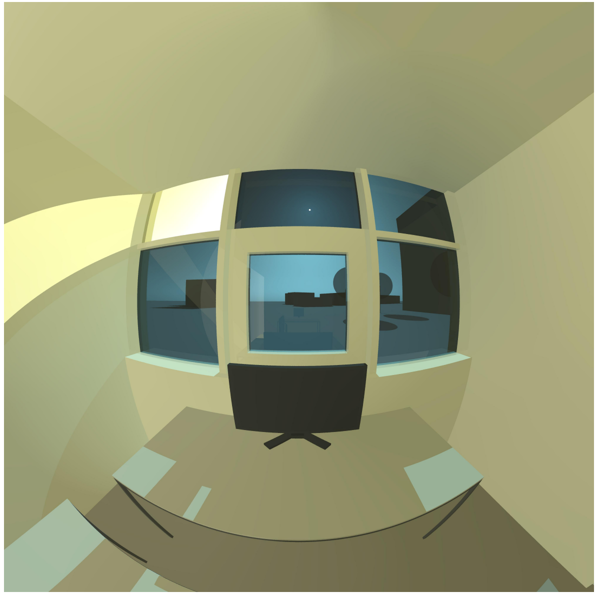
How to simulate?

How to measure?

Are current glare metrics capable of predicting glare in such situations?

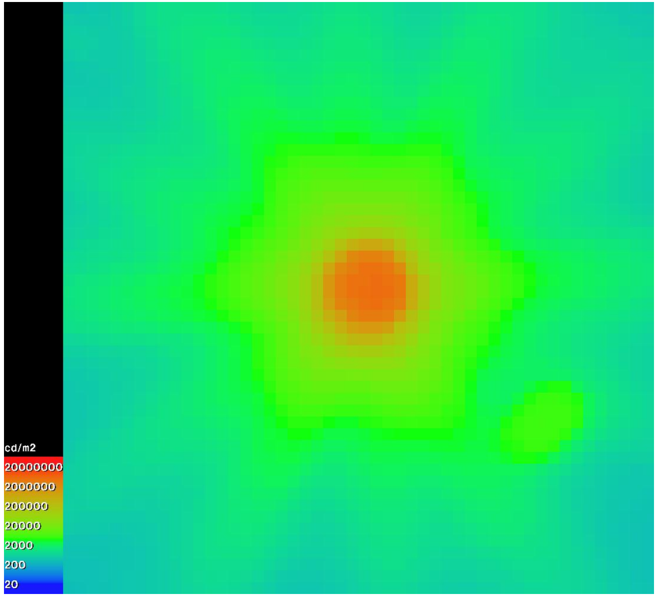
Simulation vs HDR-image : Sun disk

Measured HDR

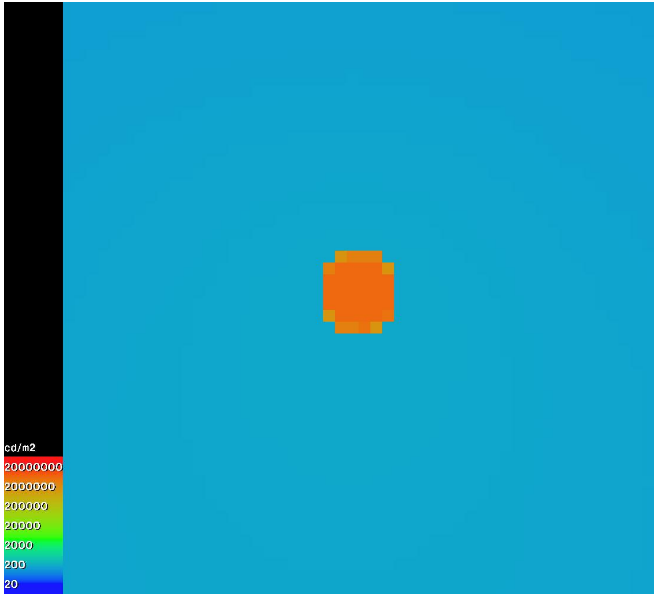


Simulated

Simulation vs HDR-image : Sun disk



Measured HDR



Simulated

Measured HDR "spreads" the energy of the sun disk to a larger area while keeping energy

Sun disk size – why does this matter?

- All glare metrics use the term $\mathbf{L^2 \cdot \omega}$ in their equation
- Spreading (or blurring) means reducing L and increasing ω

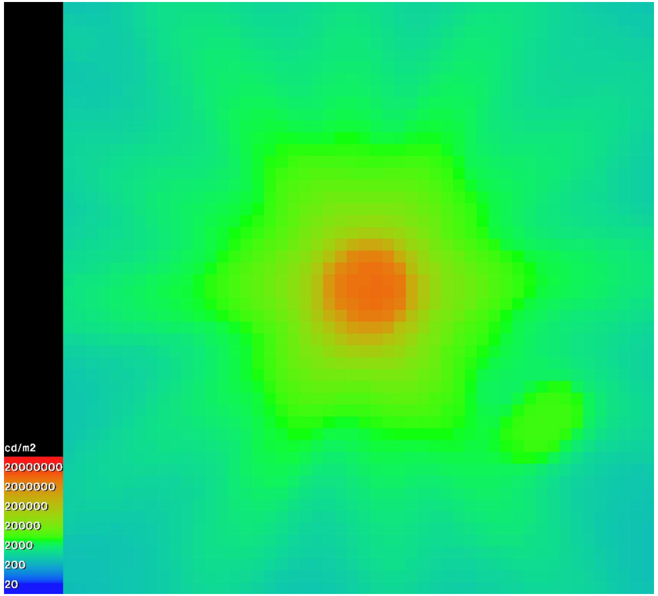
➠ Simulation results in significant higher glare values than measurements

But:

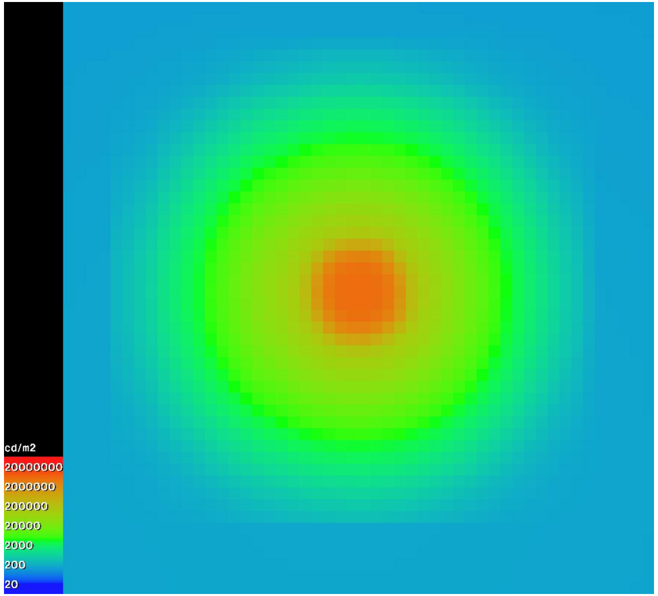
- Metrics are based on HDR images (and not on “ideal” simulation)
- Blur also happens in the eye and is quite similar to lens blur

➠ one solution is to blur the simulated HDR

Simulation vs HDR-image : Sun disk



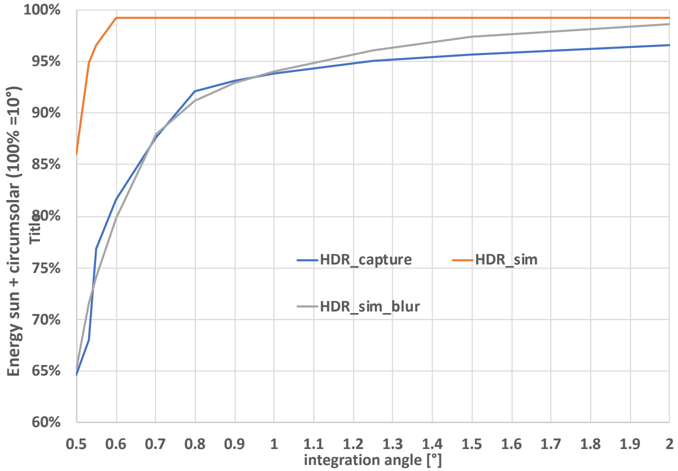
Measured HDR



Simulated and blurred

Simulation blur function

- Based on the function proposed by
  Ward, G.J., Wang, T., et al; Modeling specular transmission of complex fenestration systems with data-driven BSDFs, (2021) Building and Environment, 196, DOI: 10.1016/j.buildenv.2021.107774
- Lorentzian function is simulated by Gaussian function with FWHM=11

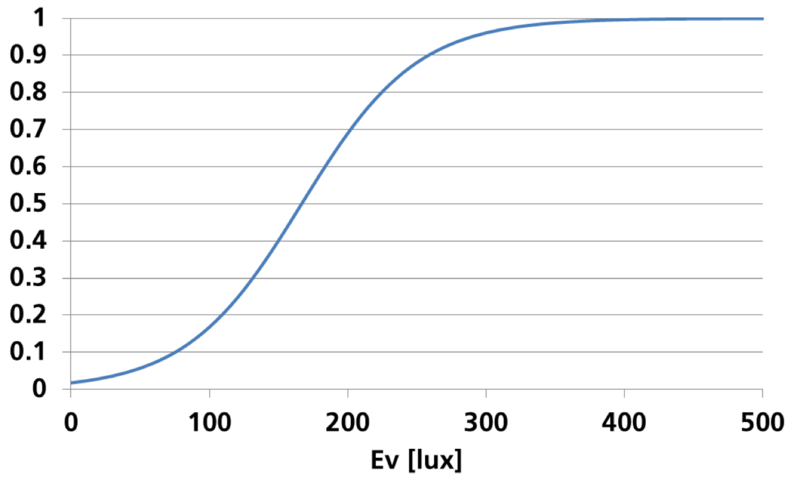


Energy of sun disk and circumsolar area for different integration angles

Potential problem for glare analysis of EC scenes: Low light correction of evalglare

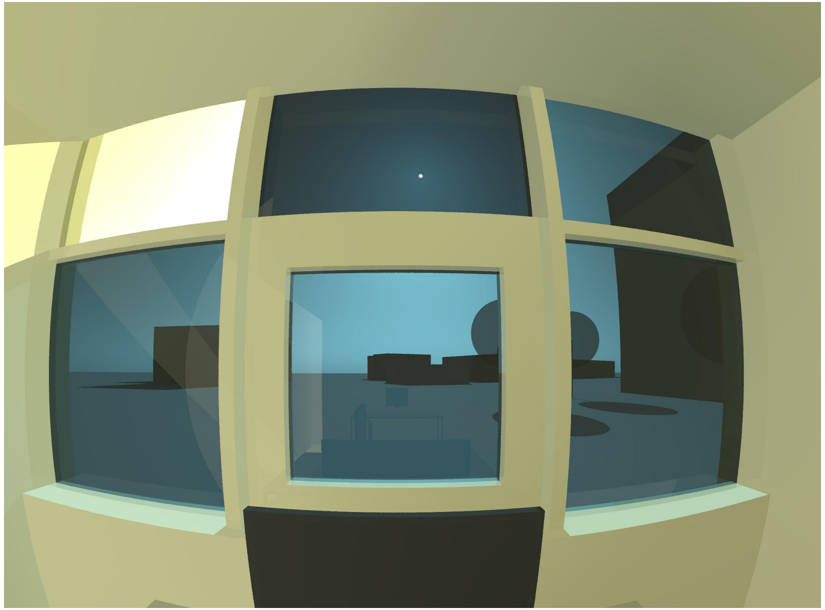
- For very dark scenes (E_v < 400 lux) the DGP values is lowered by the low-light function
- This causes a **severe underprediction of glare** in case of visible sun-disk through EC glazing
- Especially problematic in “boxed” annual simulation tools using evalglare
- **Solution**: Turn-off the low light correction by using following option (see manual page):

      -C -l-
  or -C 0



$$DGP\_lowlight = DGP \frac{e^{0.024*E_V-4}}{1+e^{0.024*E_V-4}}$$

How to include the "right" color to the glazing properties in RADIANCE?



How to include the “right” color to the glazing properties in RADIANCE?

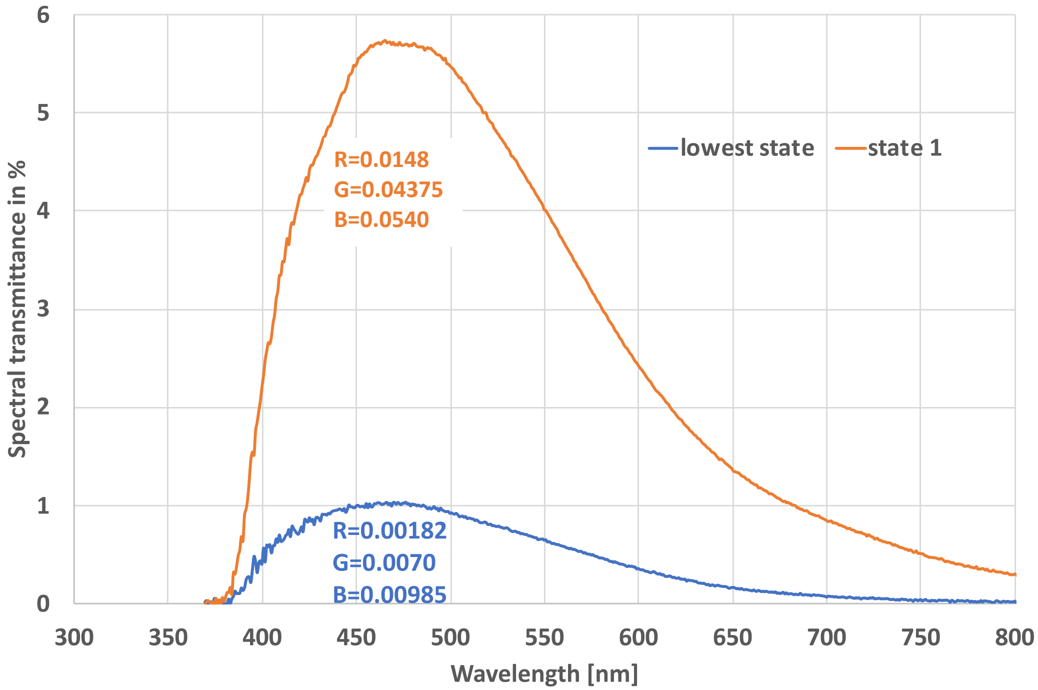
1. Measure spectral transmittance or the IGDB.

2. Apply “magic” script using the cie-response curve and the xyz- transformation (cieresp.cal and xyz_rgb.cal), can be found in the Radiance book:

```
#!/bin/bash
f=$1
rcalc -f cieresp.cal -e 'cond=if($1-359,831-$1,-1)' -e 'ty=triy($1)' -e
'$1=$2*trix($1);$2=$2*ty;$3=$2*triz($1);$4=ty' $f |total |rcalc -e  '$1=$1/$4;$2=$2/$4;$3=$3/$4' |rcalc
-f xyz_rgb.cal -e '$1=R($1,$2,$3)/100;$2=G($1,$2,$3)/100;$3=B($1,$2,$3)/100'
```

How to include the “right” color to the glazing properties in RADIANCE?

Example



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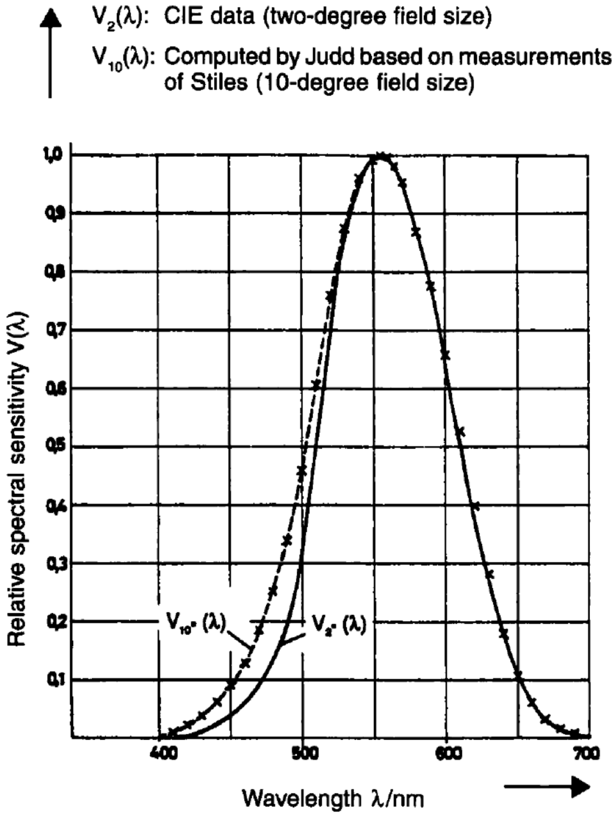
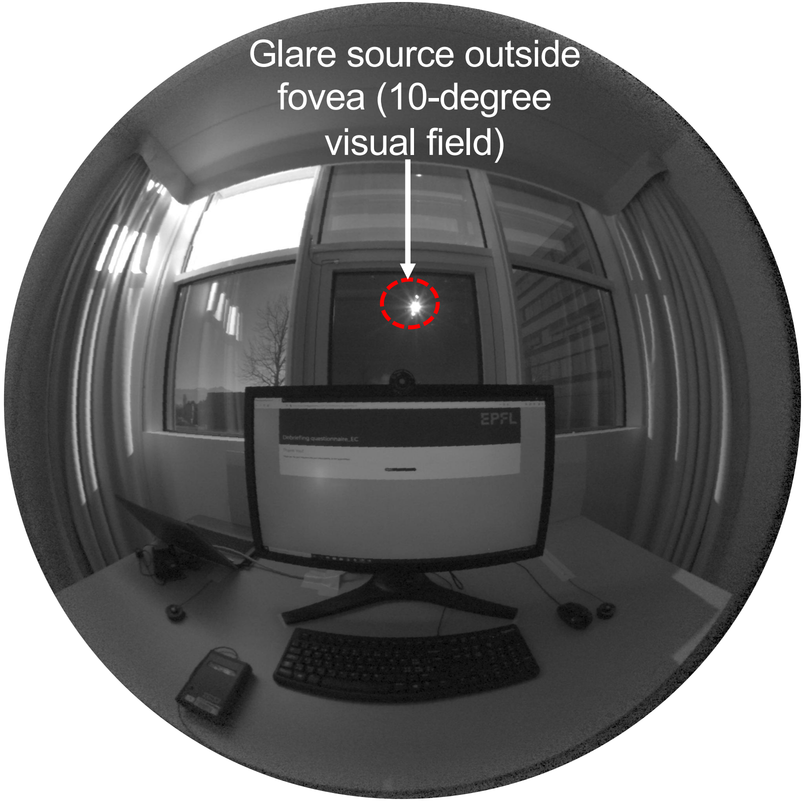
Are current glare metrics capable of predicting glare in such situations?

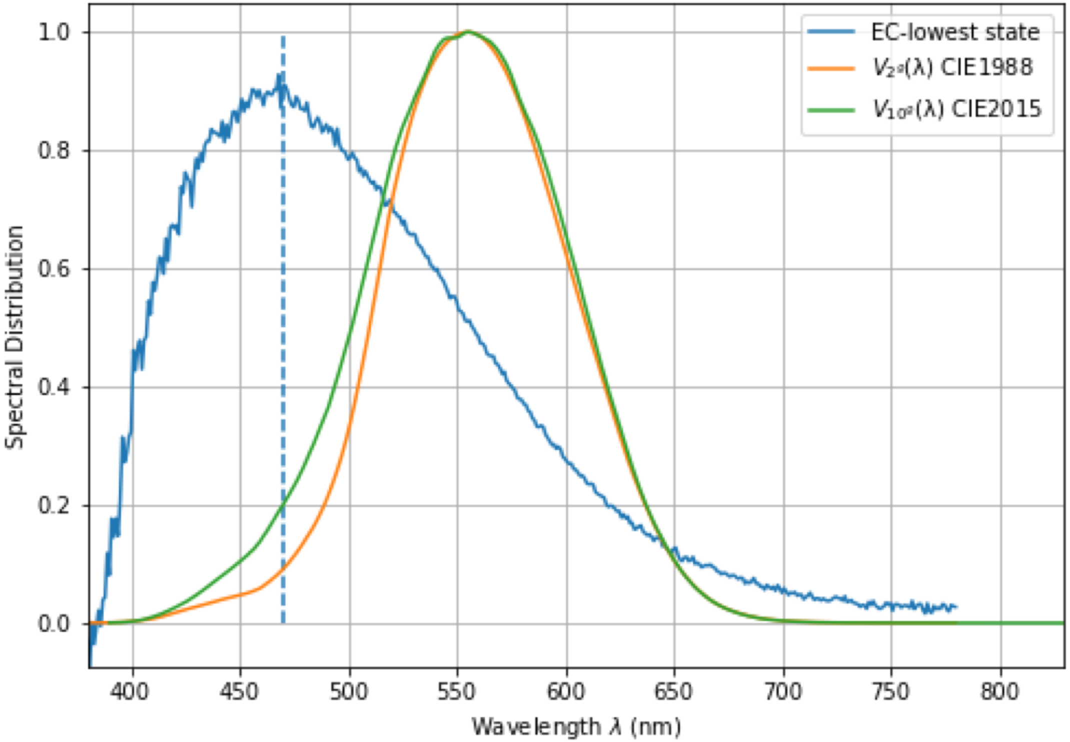
Correct use of V(λ): Do we measure luminance correctly?





Judd DB. Radical changes in photometry and colorimetry foreshadowed by CIE actions in Zurich. JOpt Soc Amer 1955; 45; 897- 898
CIE. (2005). 10 degree photopic photometric observer. CIE Publication No. 165:2005. Central Bureau of the Commission Internationale de l'Eclairage, Vienna.

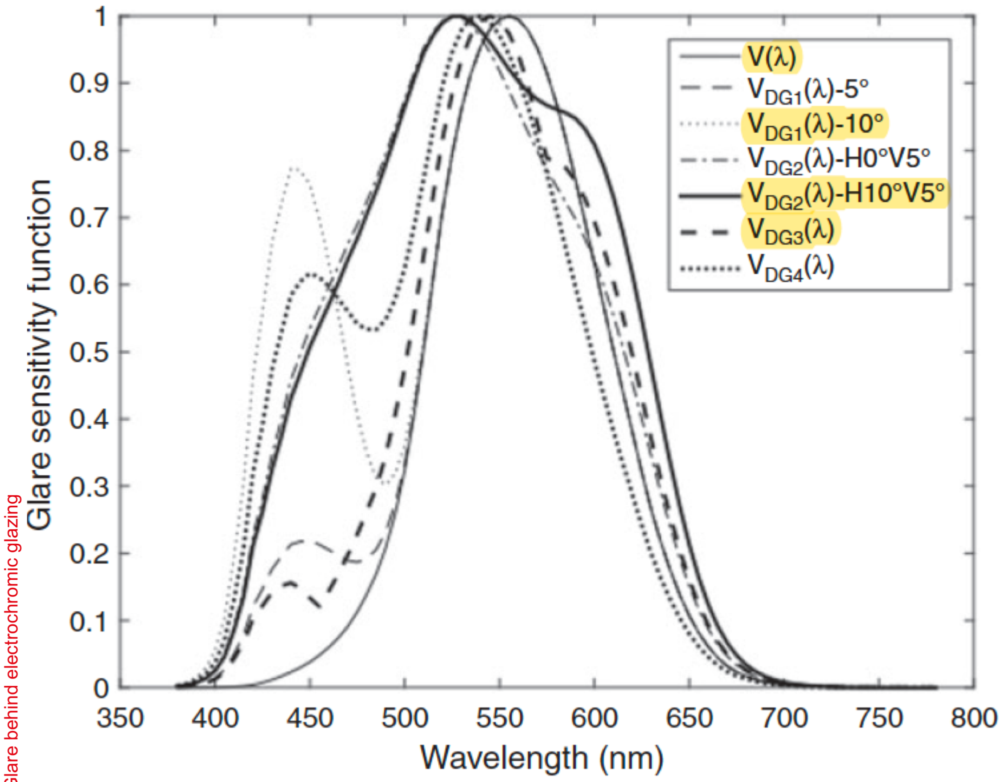
CIE $V_{2^o}(\lambda)$ vs CIE $V_{10^o}(\lambda)$



- For a larger field of 10 degrees, spectral sensitivity follows a curve that shows enhanced sensitivity in the blue part of the spectrum. This becomes more relevant for blue-tinted EC glazing
- The difference in spectral sensitivity between 2 and 10 degree fields is attributed to the absorption of the macular pigment that covers the foveal region.

CIE TC 1-36 Fundamental Chromaticity Diagram with Physiological Axes-Part II. Draft, Commission Internationale de l'Eclairage, Vienna (2015).

Spectral discomfort glare sensitivity functions



$V_{2^\circ}(\lambda)$

$V_{10^\circ}(\lambda)$

$V_{DG1}(\lambda)\text{-}10^\circ = V_{10^\circ}(\lambda) + (0.75\, s_S(\lambda))$

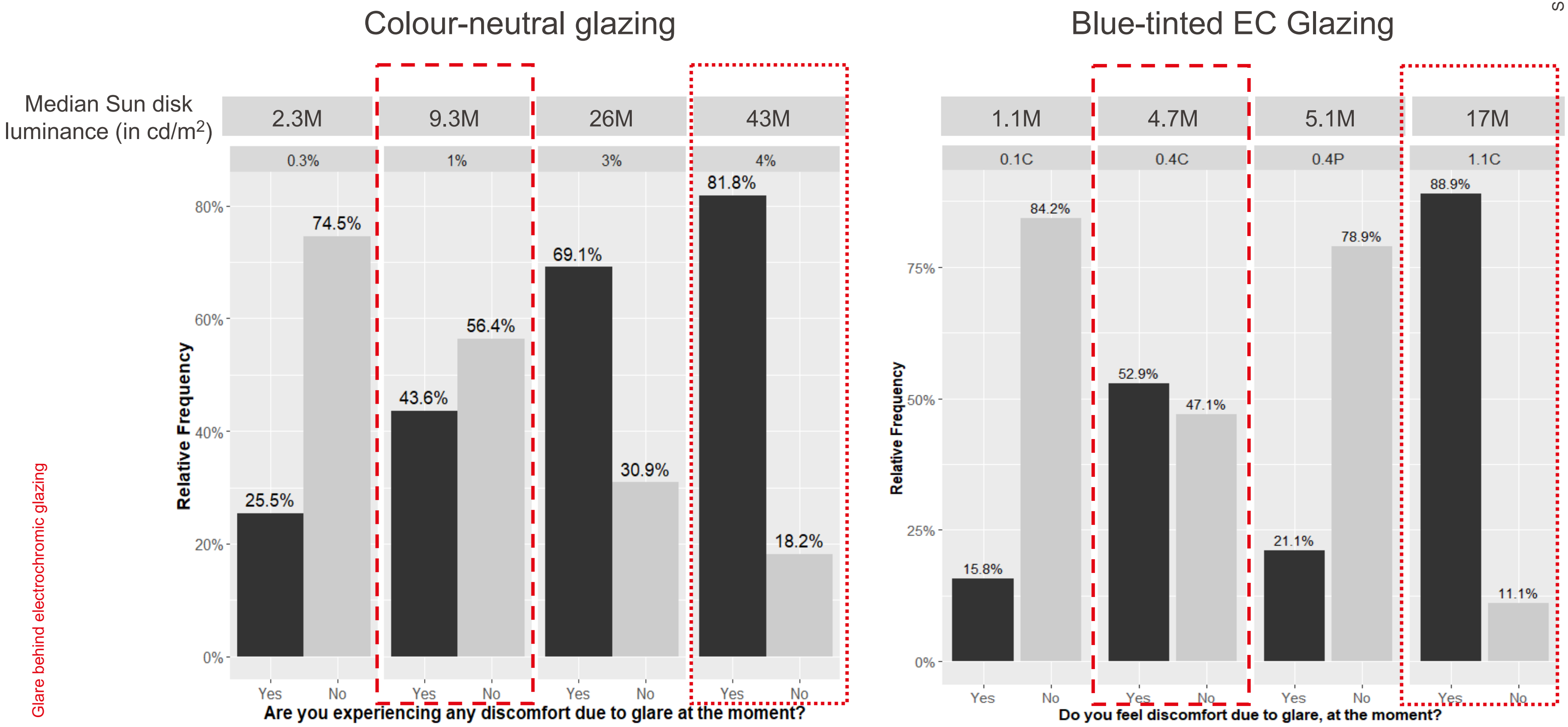
$$V_{DG2}(\lambda)\text{-}10^\circ = \{a \cdot V'(\lambda) + b \cdot [1.62L(\lambda) + M(\lambda)]\} + c \cdot [L(\lambda) - M(\lambda)] + d \cdot [(1.62L(\lambda) + M(\lambda)) - eS(\lambda)]$$

$$V_{DG3}(\lambda) = V(\lambda) + k_1 |r - g|_{(\lambda)} + k_2 |y - b|_{(\lambda)}$$

$$V_{DG4}(\lambda) = B(\lambda) = V(\lambda) + 0.5Mel(\lambda) + gS(\lambda)$$

Y Yang, M Ronnier Luo and WJ Huang, Assessing glare, Part 3: Glare sources having different colours, Lighting Res. Technol. 2016;

Comparison of subjective evaluations



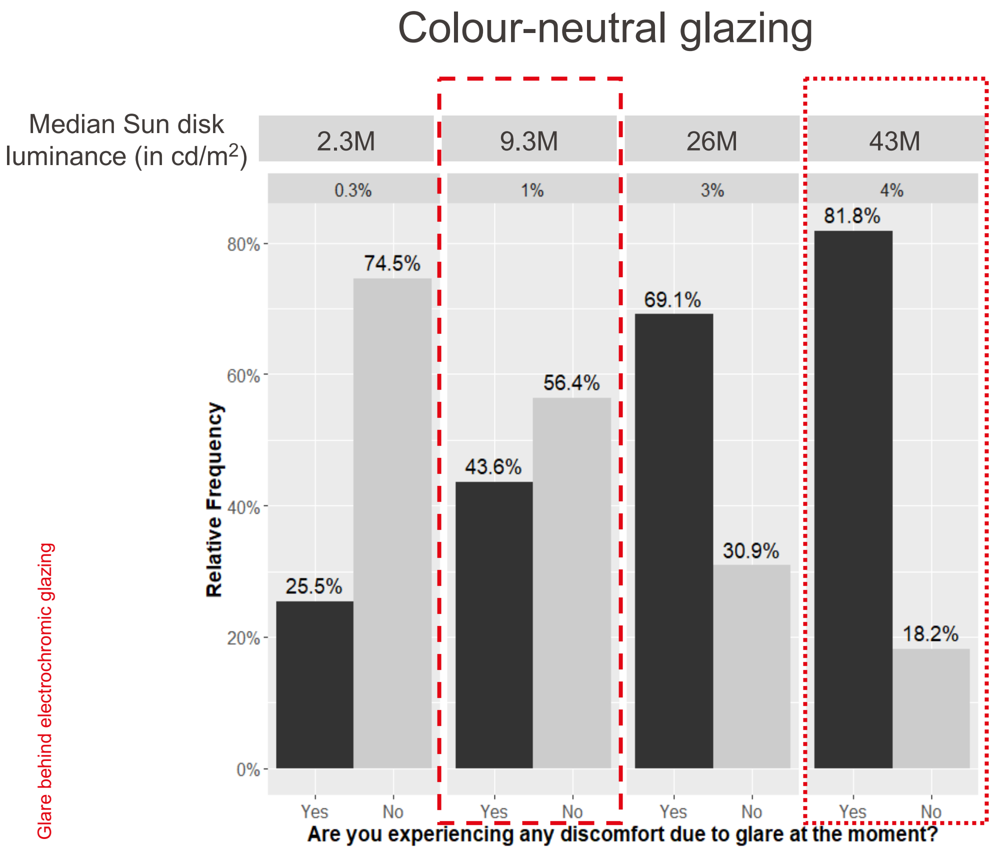
Comparison of subjective evaluations

- Double the luminance for neutral glazing is perceived similar to the luminance for blue tinted EC!

- Existing V(l) function seems to be not suitable for glare evaluations in situation with (strong) blue color.
- DGP overestimates glare for colour neutral glazing

HDR-Imaging: Luminance range necessary

Sneha Jain



- "Interesting" area between 1M - 50Mcd/m^2
- Therefore HDR camera should be able to capture that range without pixel overflow
- Usage of neutral density filters
- Check of pixel overflow necessary
- Checking the measured sun disk luminance with "theoretical" luminance useful
- E_v comparison might miss overflow in case E_v is not mainly driven by the sun disk (e.g. some other windows are switched to fully bleached)

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Glare metrics performance under EC glazing*

	DGP	E_v	CGI	UGP	DGI
Spearman's rank correlation coefficient	0.59	0.43	0.58	0.58	0.56
AUC	0.86	0.69	0.87	0.88	0.84

- Metrics that possess positional sensitivity performed better.
- Solely saturation-based metrics (Ev) are not suitable to predict glare for low transmittance glazing with sun visible through the façade.

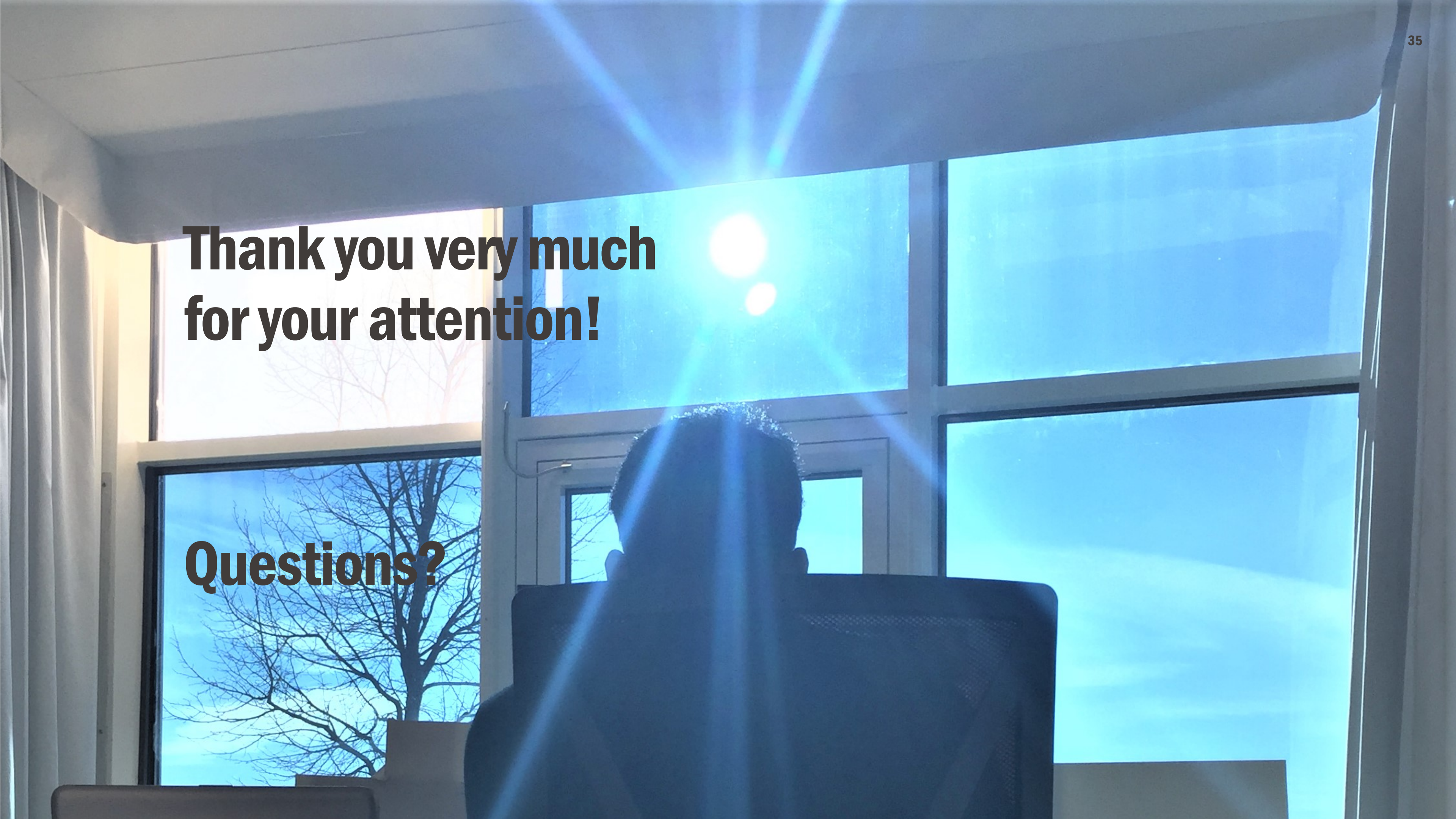
*Results are valid only when using CIE 1988 2º standard observer photopic luminous efficiency function

Conclusions

- Predicting glare behind electrochromic glazing is challenging.
- For simulation, blur function is necessary.
- Low light correction of evalglare should be de-activated.
- $V(\lambda)$ is not the correct weighting function for glare evaluations! Further research is needed.
- $V(\lambda)$ underestimates the glare source luminance for blue-tinted EC glazing.
- Glare is perceived stronger in blue-tinted EC glazing compared to colour-neutral glazing (with similar transmittance, which is based on $V(\lambda)$).
- DGP more or less reliable for blue tinted glazing (using $V(\lambda)$).
- DGP overestimate the glare under colour-neutral glazing (using $V(\lambda)$).
- HDR camera should be able to capture up to 50Mcd/m^2.

Acknowledgement

This study is funded by the Swiss National Foundation project (SNF) grant for the project "Visual comfort without borders: interactions on discomfort glare" number 200020_182151.



Thank you very much for your attention!

Questions?