eurac research

Modelling and simulation of PDLC glazing in Radiance

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Context

Energy consumption

Comfort

Smart technologies

But what is Polymer Dispersed Liquid Crystal (PDLC) Glazing?

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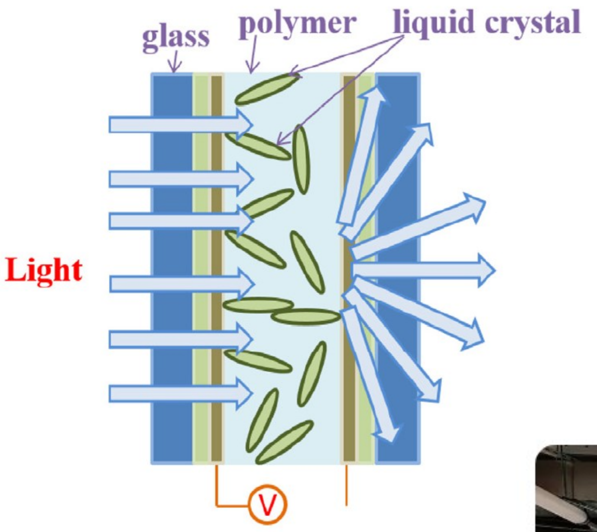
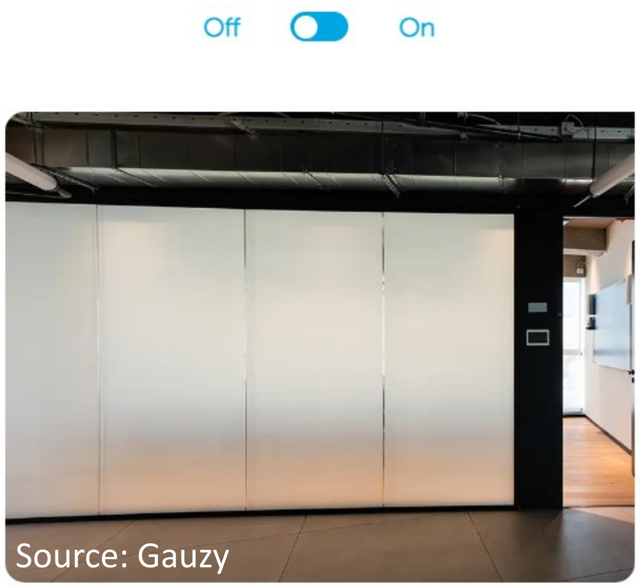
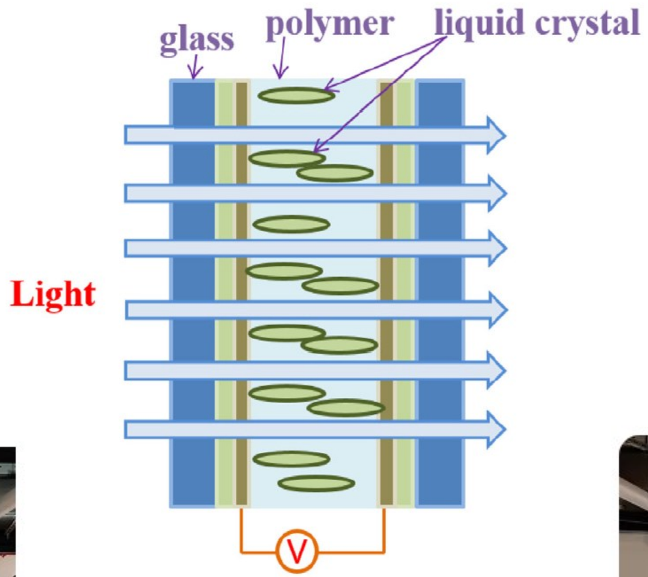
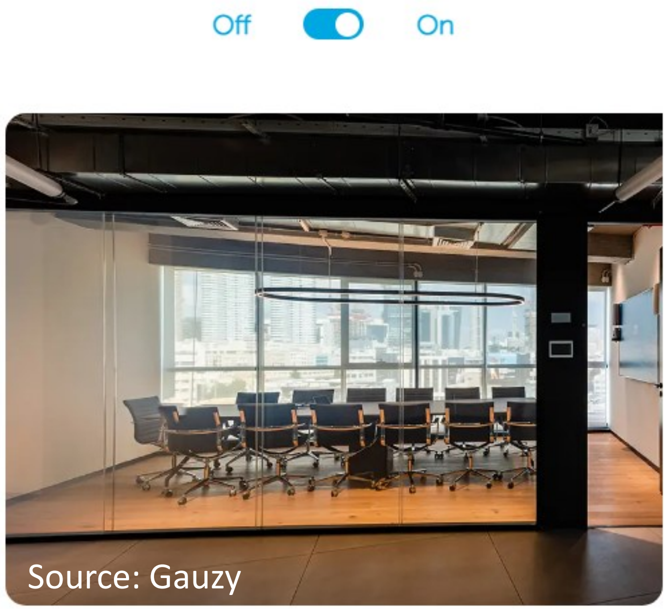


low voltage



Source: Gauzy





Source: Gauzy

Previous research

Authors	Modelling	Control
Oh and Park, 2019	Variable g	Baseline
Hemaida *et al.*, 2021	Variable g	Rule-based
Illuyemi *et al.*, 2022	Variable g, τ_{vis}	Rule-based
Shaik *et al.*, 2022	Variable g, τ_{vis}	Baseline

Previous research

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No advanced optical modelling.

Aim:

Development of an optical model of PDLC glazing capable of reproducing its characteristic diffusive behaviour, and the use of the model for daylighting and glare simulations

Optical modelling

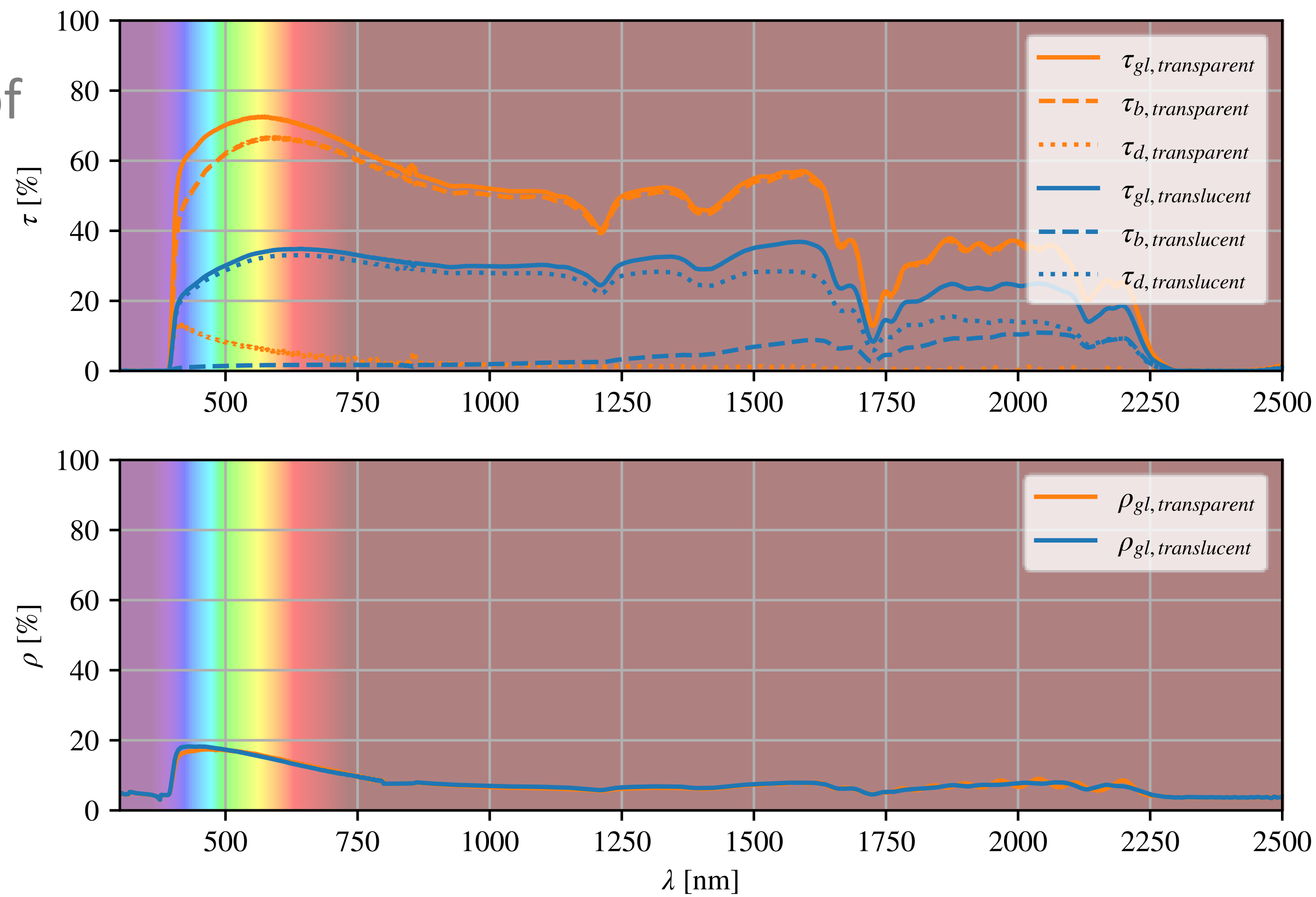
Bidirectional Scattering Distribution Functions (BSDFs)

BSDFs

- Three intermediate states generated from linear interpolation between *transparent* and *translucent* states
- Radiance function **iso2klems** used to generate **transmission** matrices
- **LBNL Window** (Furler, 1991) used to generate **reflection** matrices

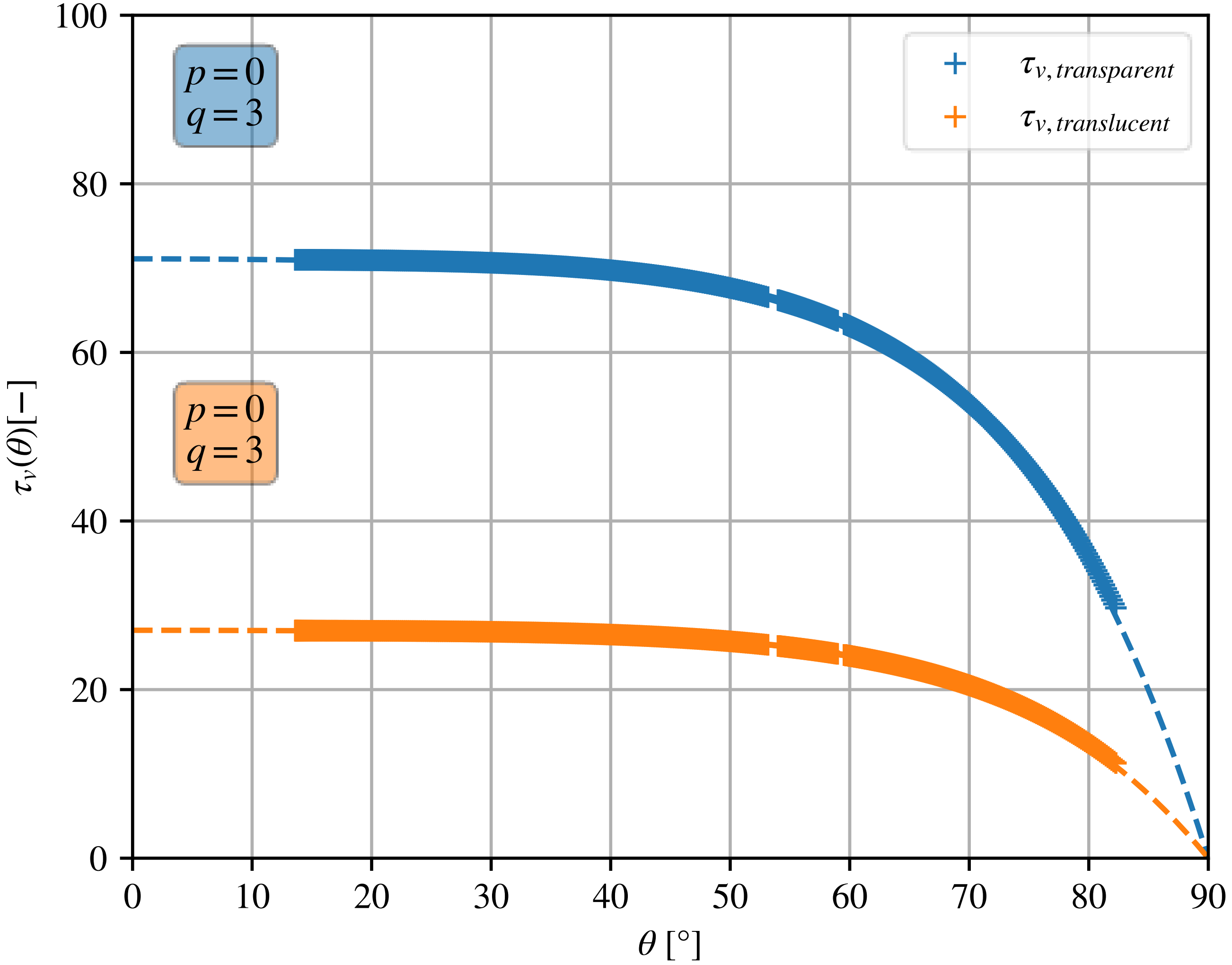
BSDFs

- Spectral data for more variable PDLC glazing obtained (Ghosh, University of Exeter)
- Ample difference between clear and cloudy states
- Data for beam/diffuse transmittivity



BSDFs

- Angular behaviour modelled as a polynomial according to Roos *et al.*, 2001
- $\boldsymbol{\tau(\theta) = \tau_0\left(1 - az^{\alpha} - bz^{\beta} - cz^{\gamma}\right)}$
  - $z = \frac{\theta}{90}$
  - $a = 8$
  - $b = \frac{0.25}{q}$
  - $c = 1 - a - b$
  - $\alpha = 5.2 + 0.7q$
  - $\beta = 2$
  - $\gamma = (5.26 + 0.06p) + q(0.73 + 0.04p)$



BSDFs

Tabular isotropic diffuse and specular transmittance (dummy Rs, Rd)

```
,Ts,Td,Rs,Rd
0.0,0.5192166899999999,0.0420134199999999,0.2,0.2
1.0,0.5192112358995501,0.04201297867094156,0.2,0.2
2.0,0.5191948735961853,0.04201165468360318,0.2,0.2
3.0,0.5191676030592118,0.04200944803550123,0.2,0.2
4.0,0.519129424110523,0.04200635871222384,0.2,0.2
5.0,0.5190803361231647,0.04200238666303984,0.2,0.2
6.0,0.5190203374469652,0.04199753175442237,0.2,0.2
7.0,0.5189494244755497,0.04199179369455467,0.2,0.2
8.0,0.5188675902741284,0.04198517192229485,0.2,0.2
9.0,0.5187748226925932,0.041977665454493475,0.2,0.2
10.0,0.5186711018935647,0.04196927268597072,0.2,0.2
11.0,0.5185563972300639,0.04195999113686717,0.2,0.2
12.0,0.5184306634124005,0.04194981714248017,0.2,0.2
13.0,0.5182938359087009,0.0419387454810887,0.2,0.2
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31.0,0.5135323746431399,0.04155346265829703,0.2,0.2
32.0,0.5130821659373166,0.04151703315244772,0.2,0.2
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34.0,0.5120829059146881,0.0414361761002218,0.2,0.2
3[illegible]139119341950639,0.2,0.2
36.0,0.510[illegible]28186,0.041342752152974886,0.2,0.2
```
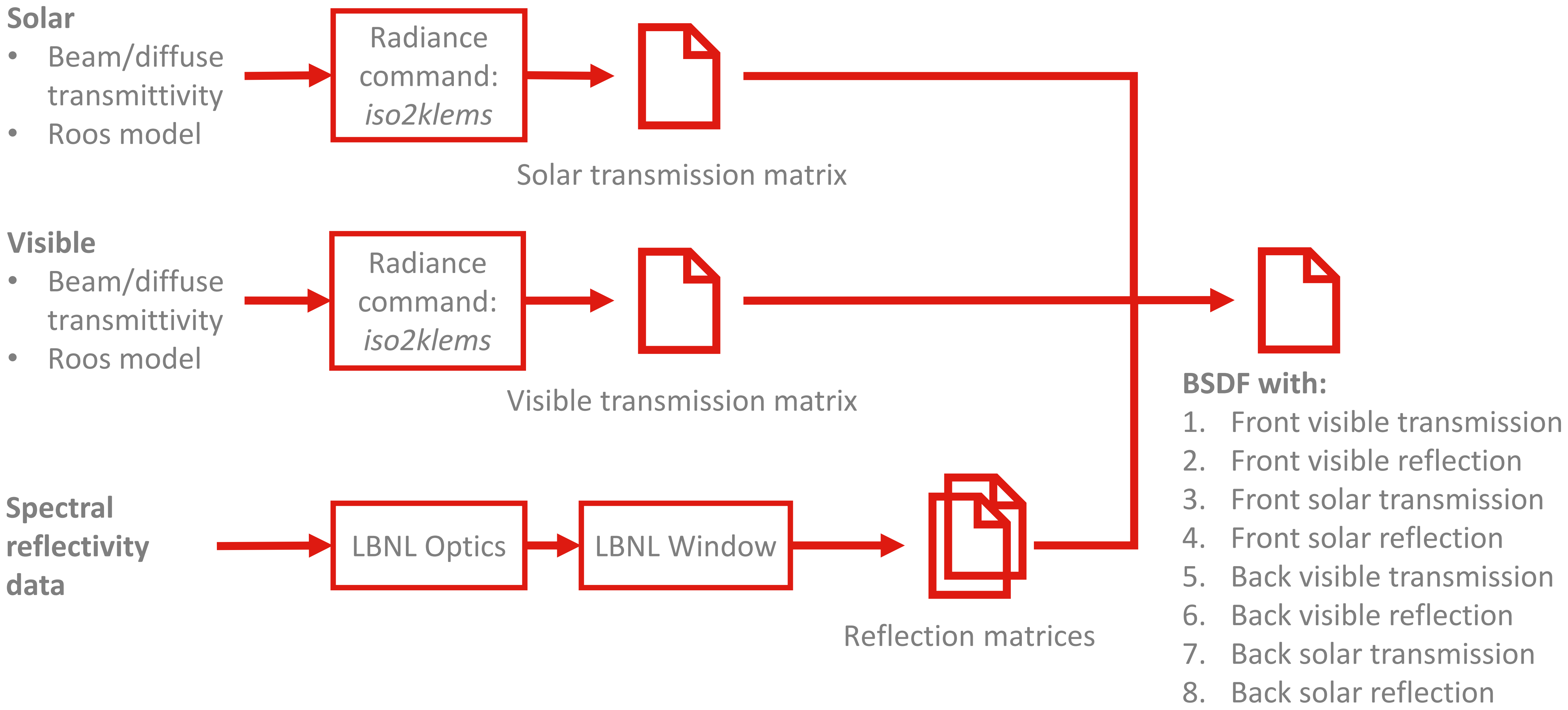

input_vis_off.dat

Iso2klems generates separate .xml files for visible and solar data

```
#!/bin/bash
#visible
iso2klems -t -f 'm=eurac;n=lcg;t=0.008;c=1;ef=0.84;eb=0.84;eo=0.001' input_vis_off.dat > vis_ off_.xml

#solar
iso2klems -t -f 'm=eurac;n=lcg;t=0.008;c=1;ef=0.84;eb=0.84;eo=0.001' input_sol_off.dat > sol_ off_.xml

#change delimiter to match WINDOW format
#visible
sed -z 's/\t\n/,/g' vis_off_.xml > vis_off.xml
rm vis_off_.xml

#solar
sed -z 's/\t\n/,/g;s/Visible/Solar/g' sol_off_.xml > sol_off.xml
rm sol_off_.xml


#last lines of each matrix must be edited manually :(
```

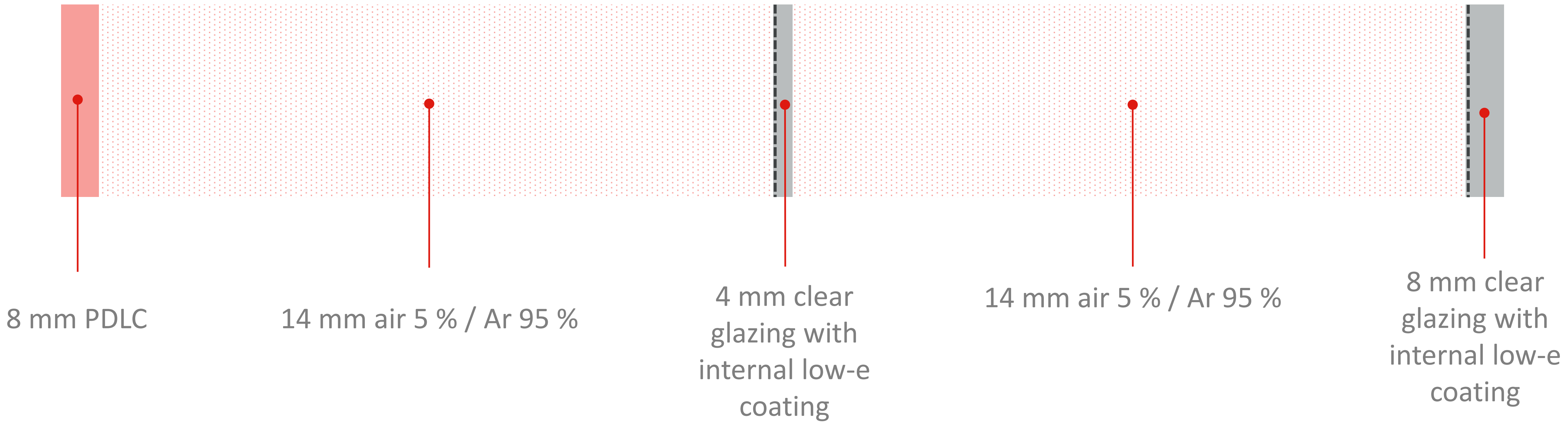
BSDFs



Solar
• Beam/diffuse transmittivity
• Roos model
Radiance command: *iso2klems*
Solar transmission matrix
Visible
• Beam/diffuse transmittivity
• Roos model
Radiance command: *iso2klems*
Visible transmission matrix
Spectral reflectivity data
LBNL Optics
LBNL Window
Reflection matrices
BSDF with:
1. Front visible transmission
2. Front visible reflection
3. Front solar transmission
4. Front solar reflection
5. Back visible transmission
6. Back visible reflection
7. Back solar transmission
8. Back solar reflection

BSDFs

- Liquid crystal layer BSDF combined with other glazing layers in LBNL WINDOW 7.8

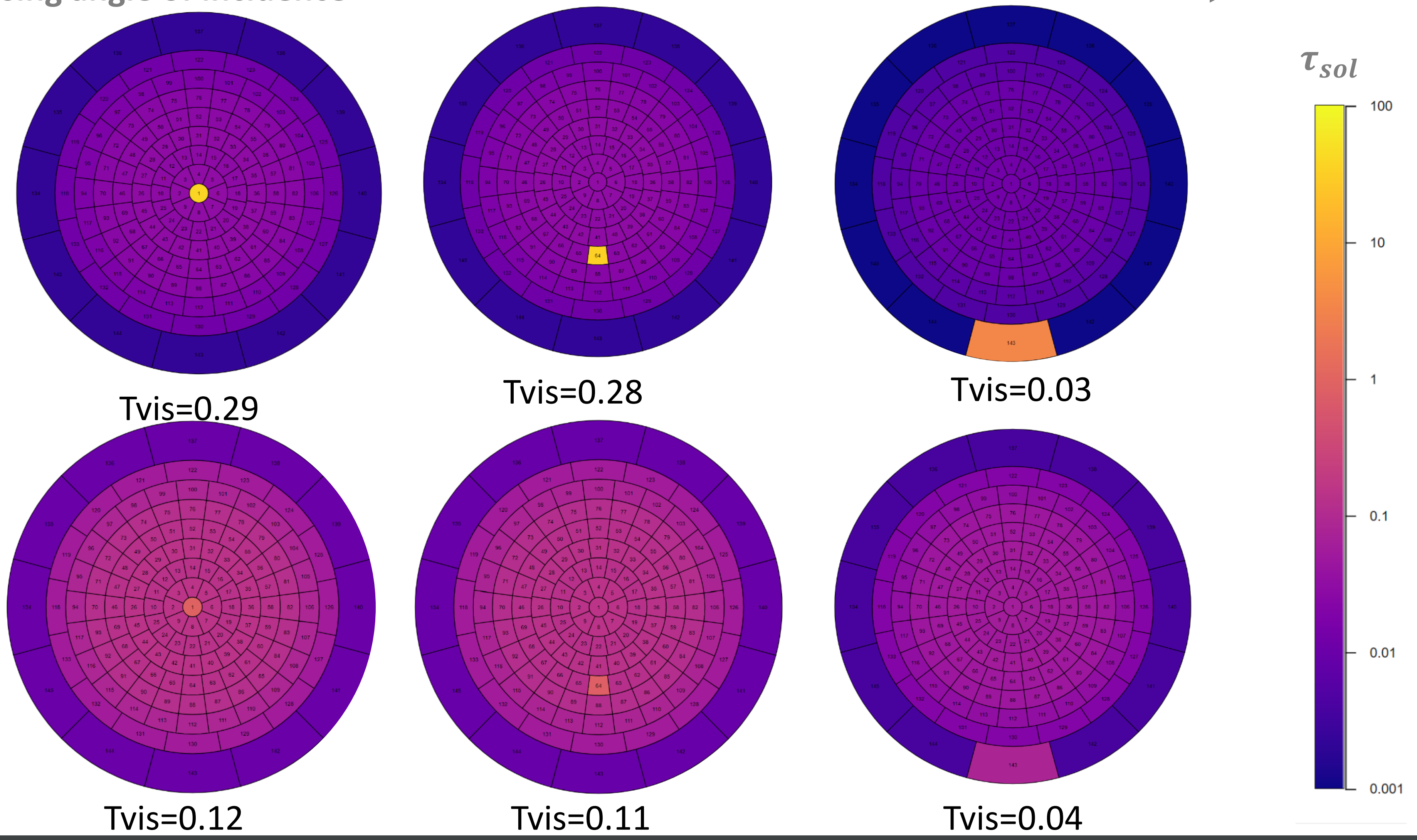


BSDFs

Increasing angle of incidence →

Transparent

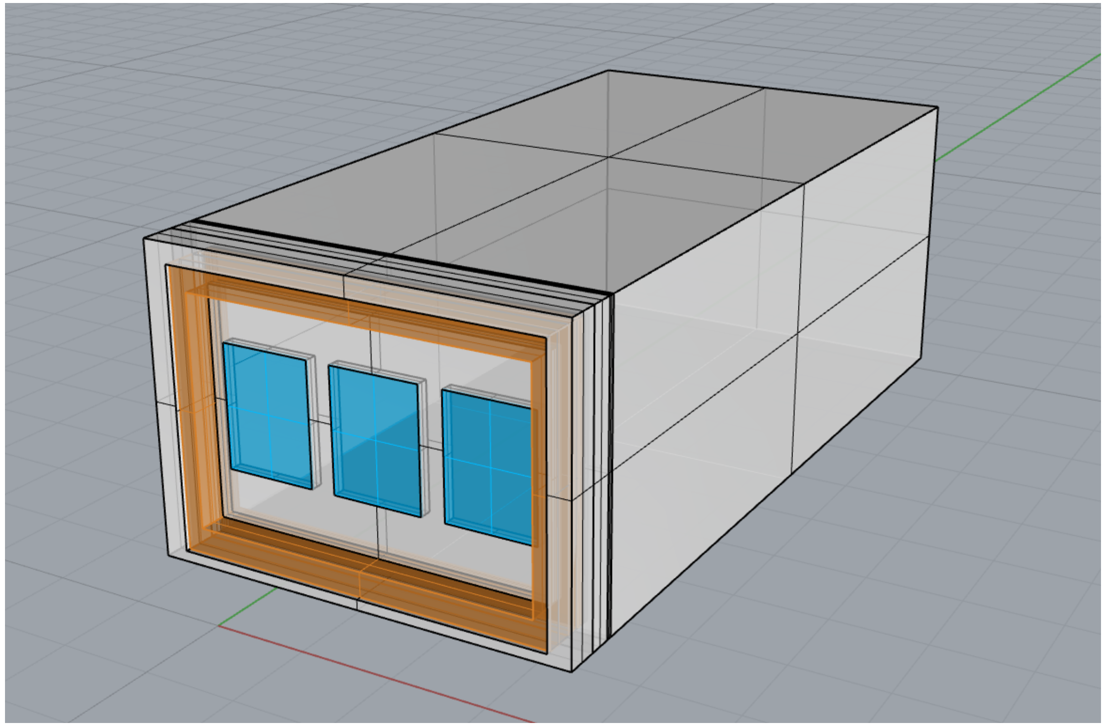
Translucent



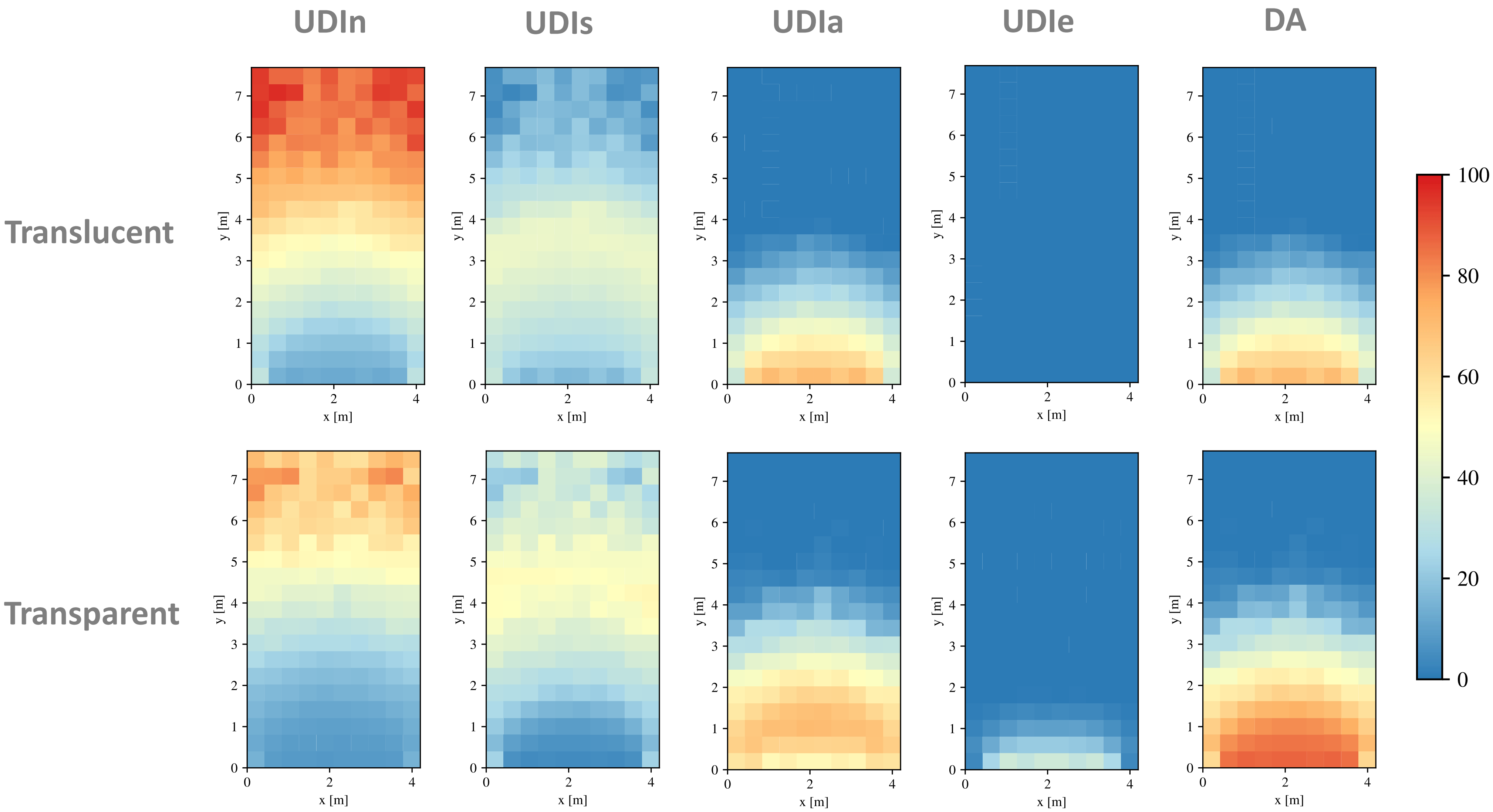
Daylighting simulation

Daylighting simulation

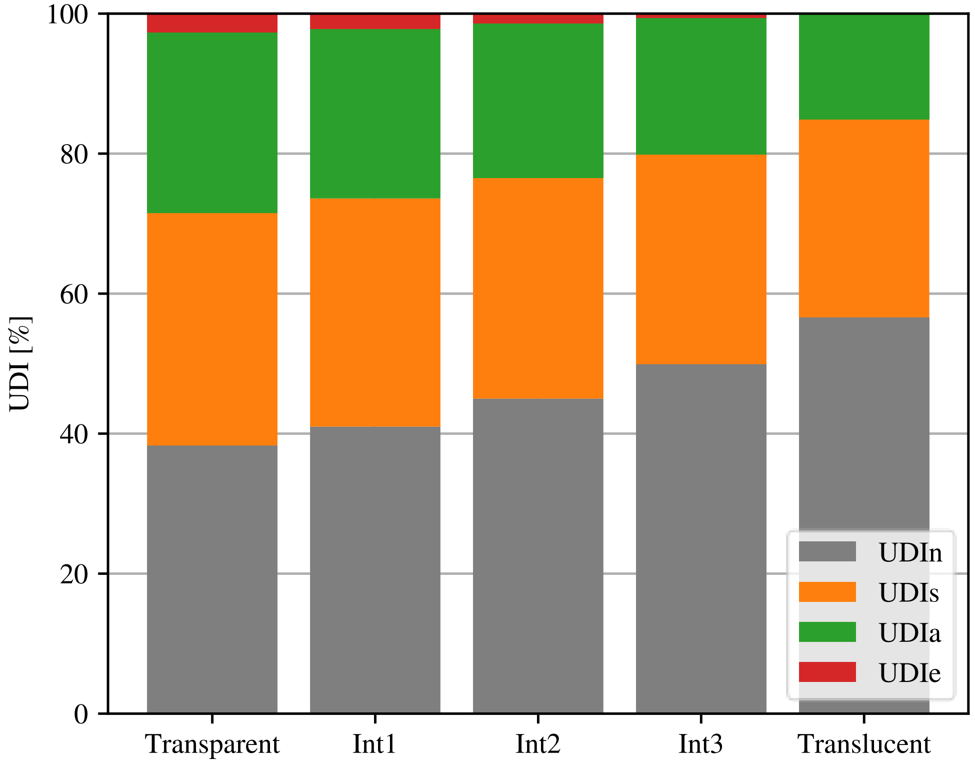
- Radiance model of *Façade System Interactions Lab*
- Three-phase method:
  - $\mathbf{E} = \mathbf{VTDS}$
- Grid size: 0.4 m (190 points)
- Grid height: 0.85 m (EN 17037:2022)
- Bolzano typical weather file (E+)

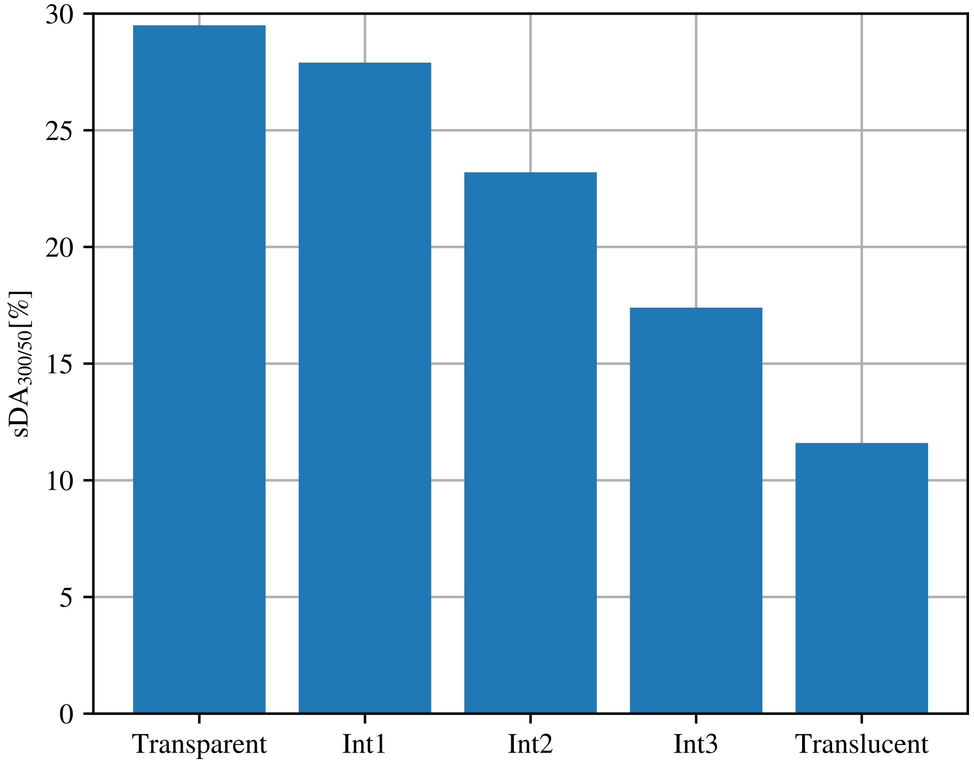


Daylighting simulation



Daylighting simulation





Daylight glare probability (DGP) calculation

Daylight Glare Probability

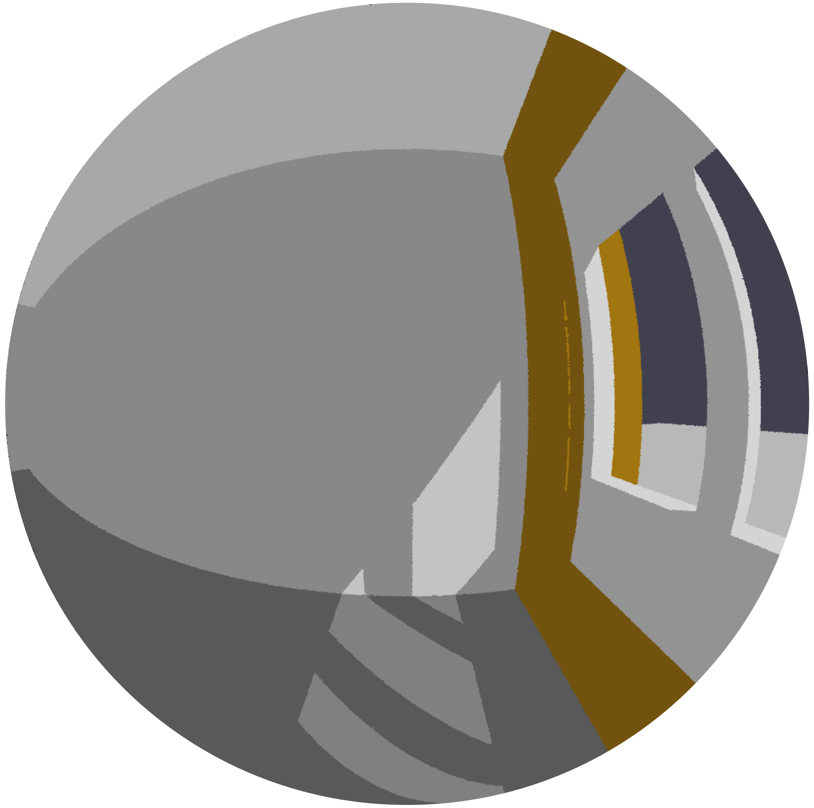
- Discomfort glare due to:
  - Luminance of the glare source
  - Angular size and position of glare source
  - Background luminance
  - Contrast
- $DGP = 5.82 \cdot 10^{-5} \cdot E_{v,v} + 9.18 \cdot 10^{-2} \cdot \log\left(1 + \sum_{i=1}^{n} \frac{L_{v,si}^{2} \cdot \omega_{s,i}}{E_{v,v}^{1.87} \cdot P_i^2}\right) + 0.16$

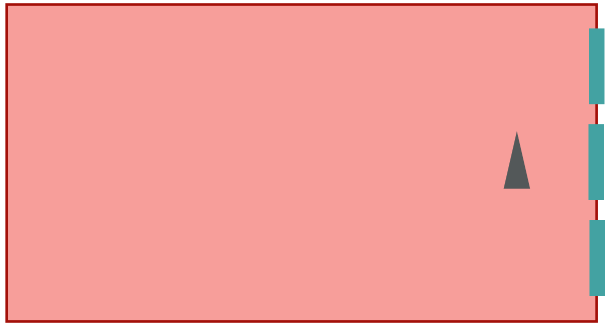
Background

Glare sources
Position
Contrast

Glare calculation

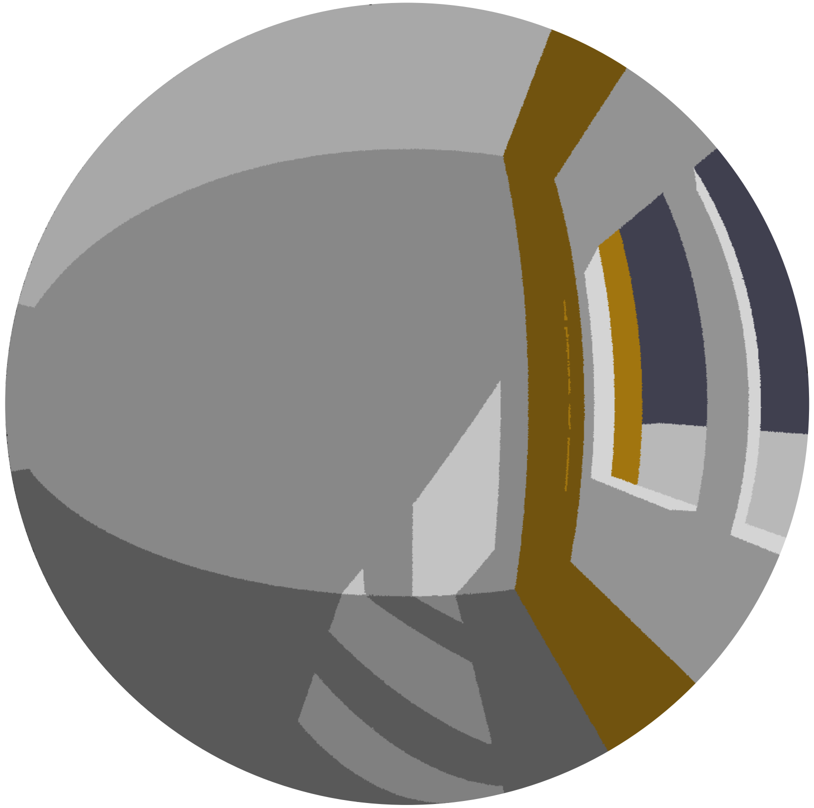
- CIE clear sky for Bolzano on:
  - 23 March, 12 p.m.
  - 21 June, 12 p.m.
  - 21 December, 12 p.m.
- View point:
  - 1 m from façade
  - 1.2 m height (EN 17037:2022)
  - Looking east



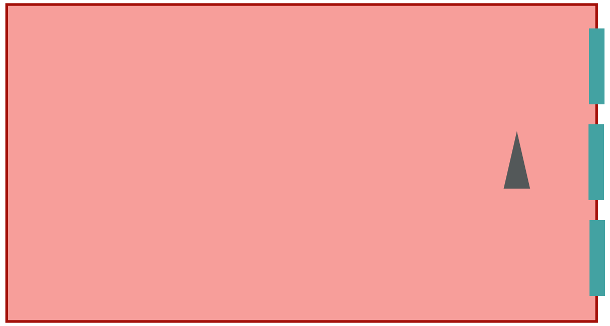


Glare calculation methods

- Three-phase image-based:
  - Image-based view matrix (145 x 145)
  - Low accuracy around circumsolar region
- Conventional ray-tracing with “BSDF” material type
  - Low accuracy around circumsolar region
- Conventional ray-tracing with “aBSDF” material type
  - Peak extraction algorithm (Moroder *et al.*, 2021)
  - Counteracts low BSDF resolution



- DGP with $ab = 4$
- eDGPs with $ab = 0$ and E_v from three-phase illuminance calculation (Abravesh *et al.*, 2019)

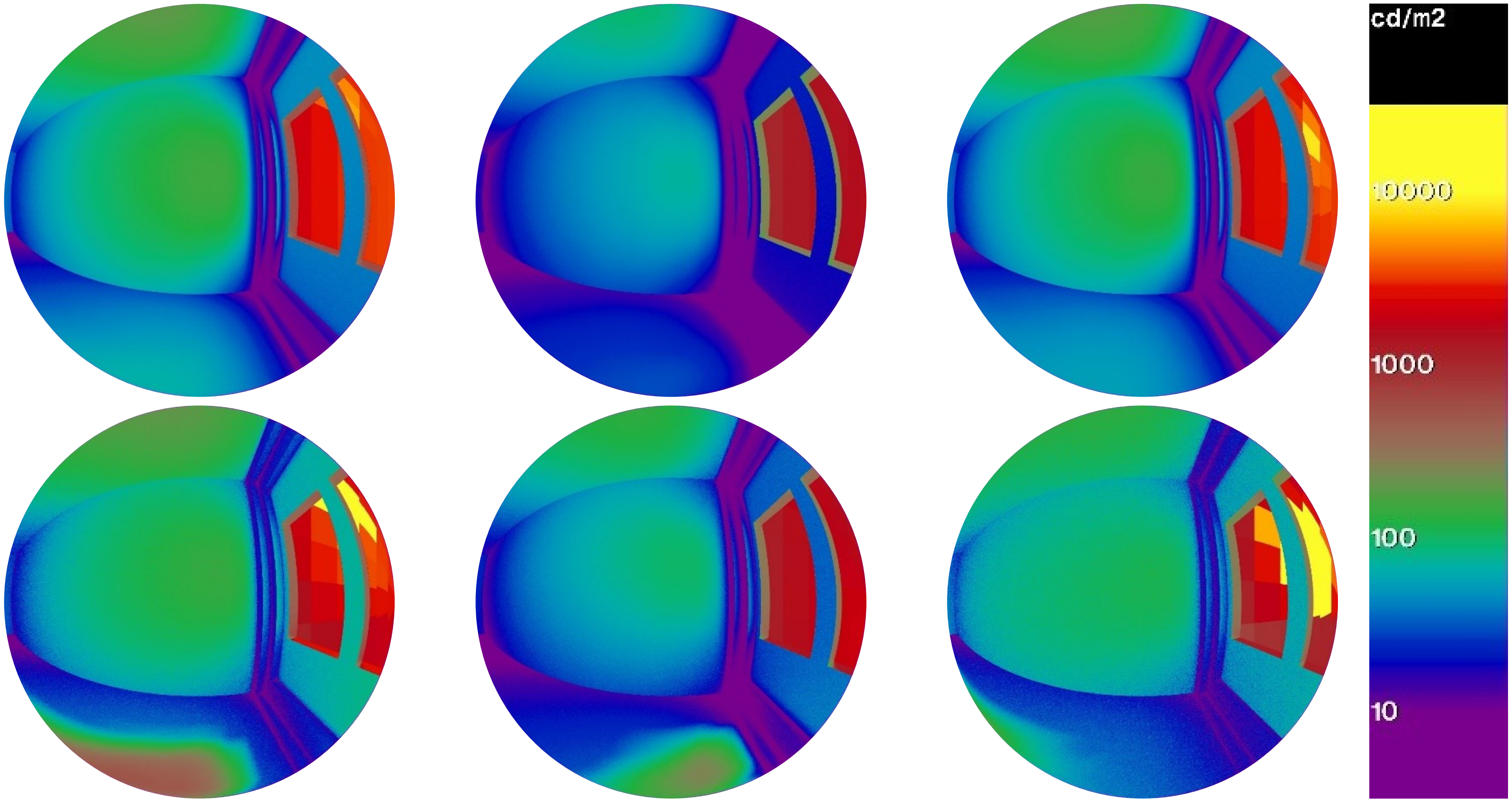


Glare calculation: three-phase image-based

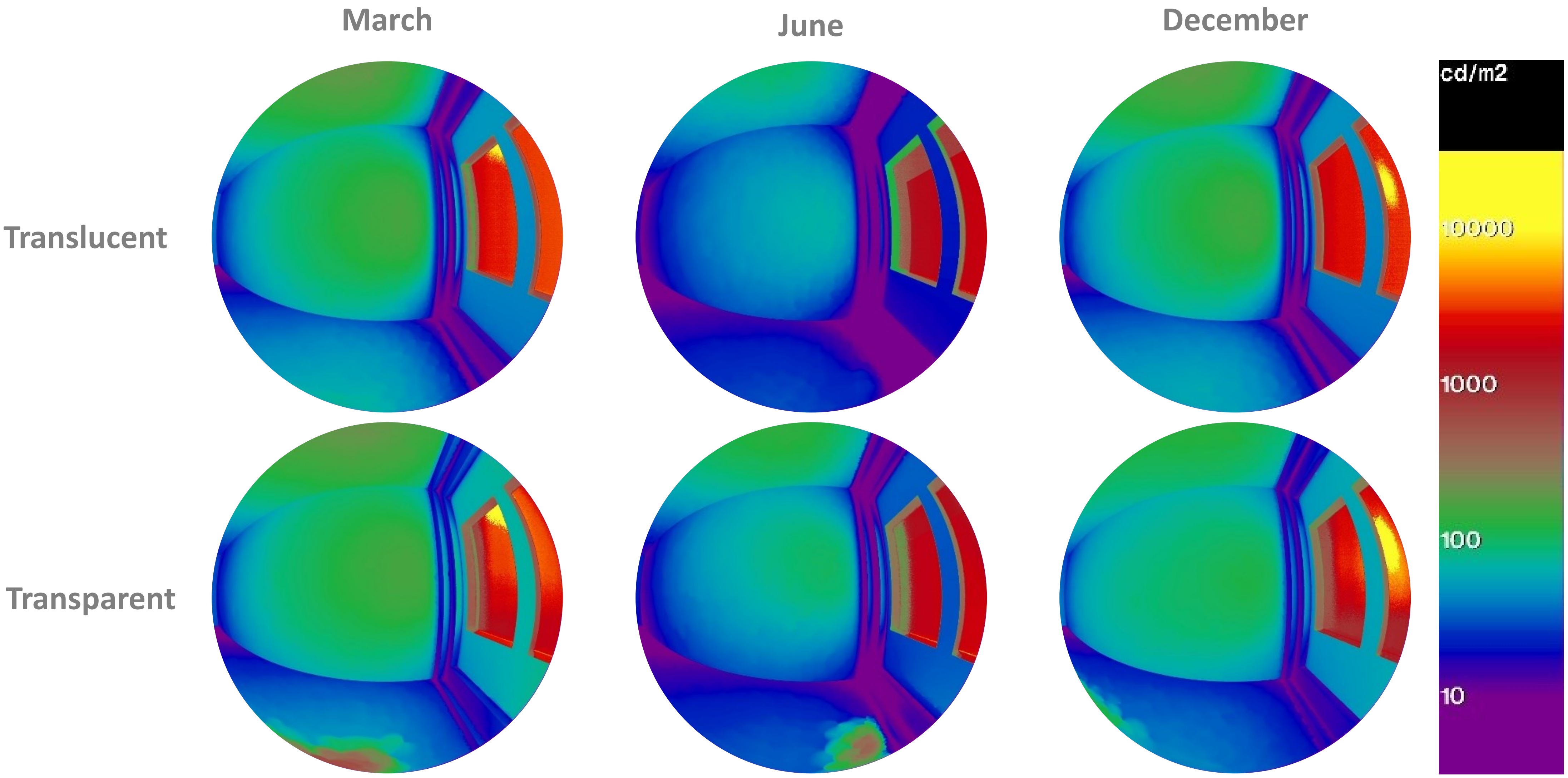
March | June | December

Translucent

Transparent



Glare calculation: ray-tracing + BSDF

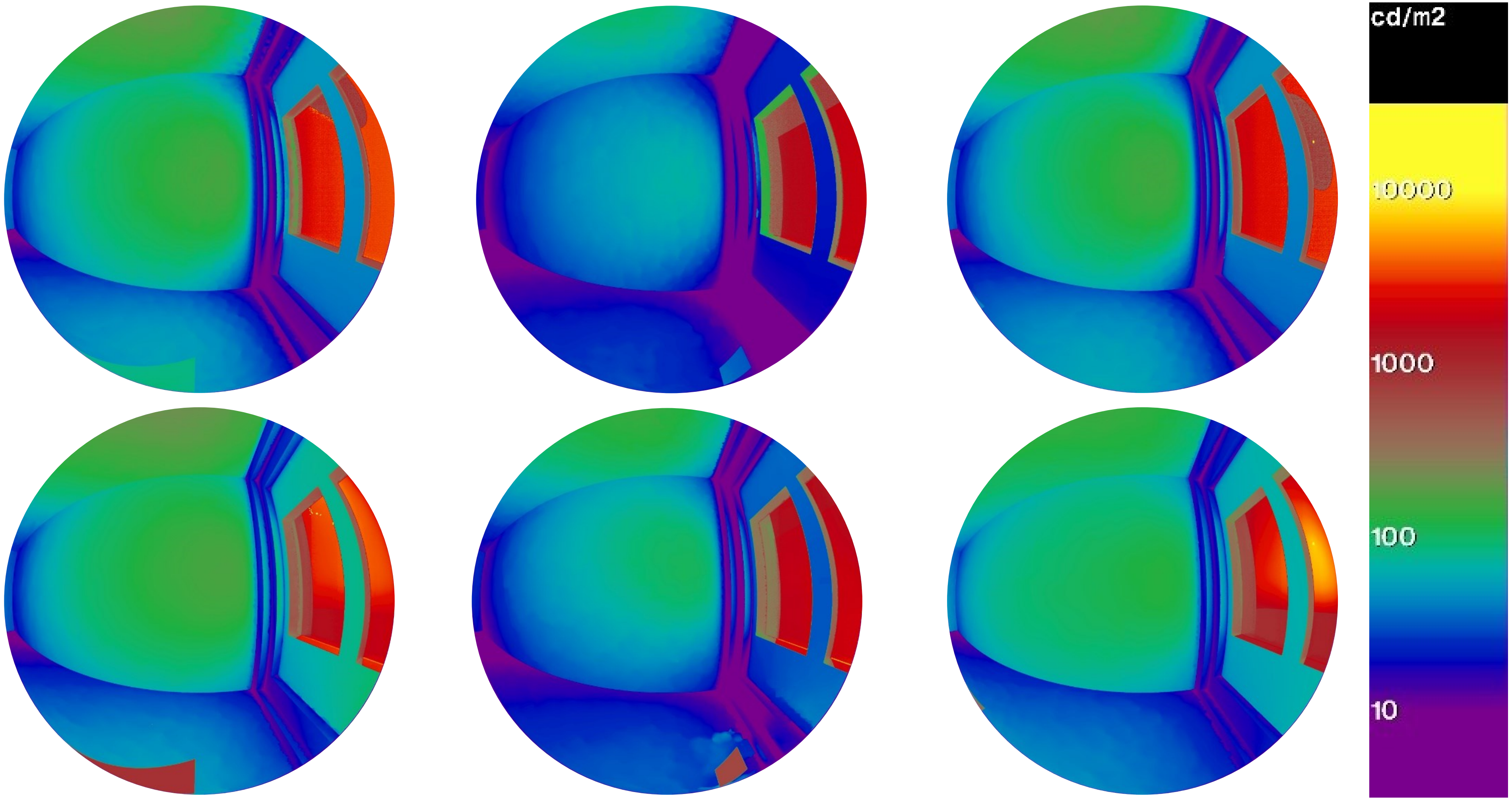


Glare calculation: ray-tracing + aBSDF

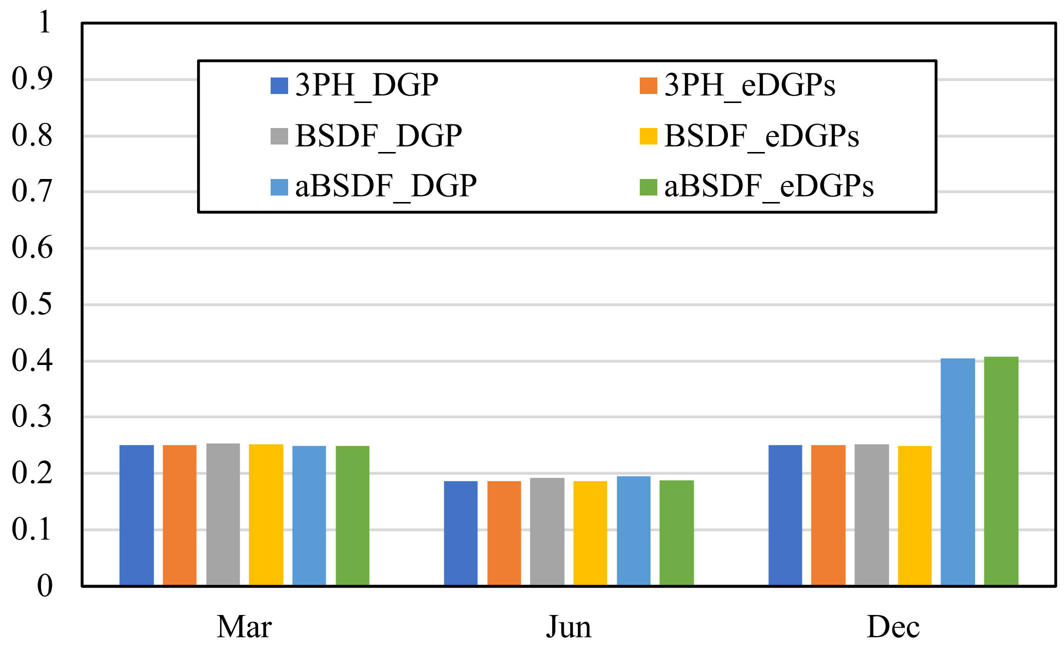
March | June | December

Translucent

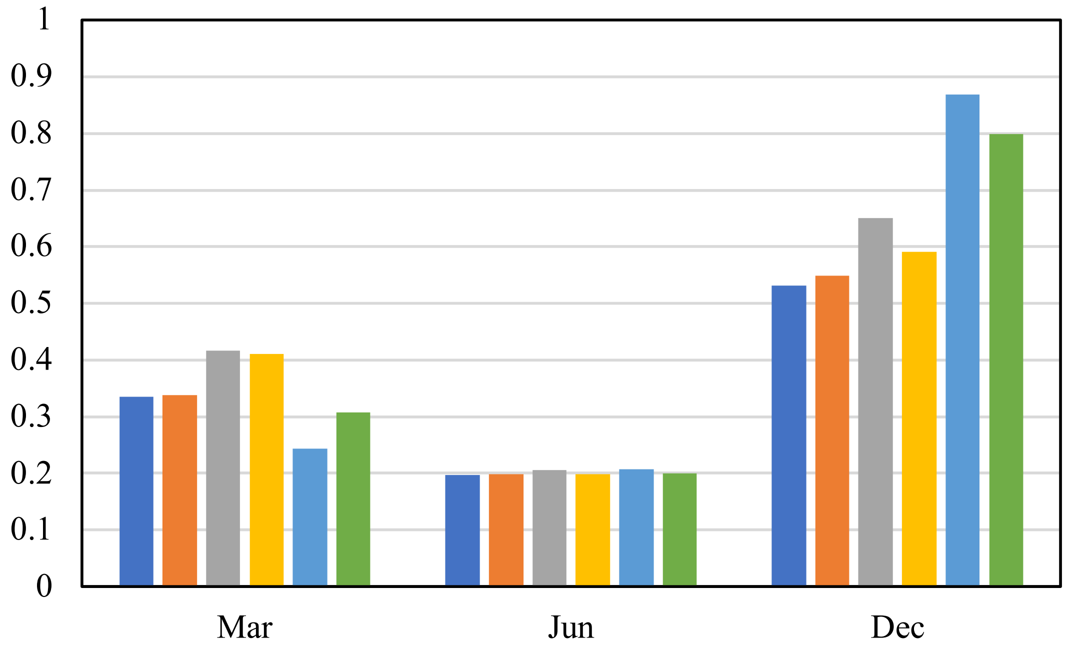
Transparent



Point in time glare calculation

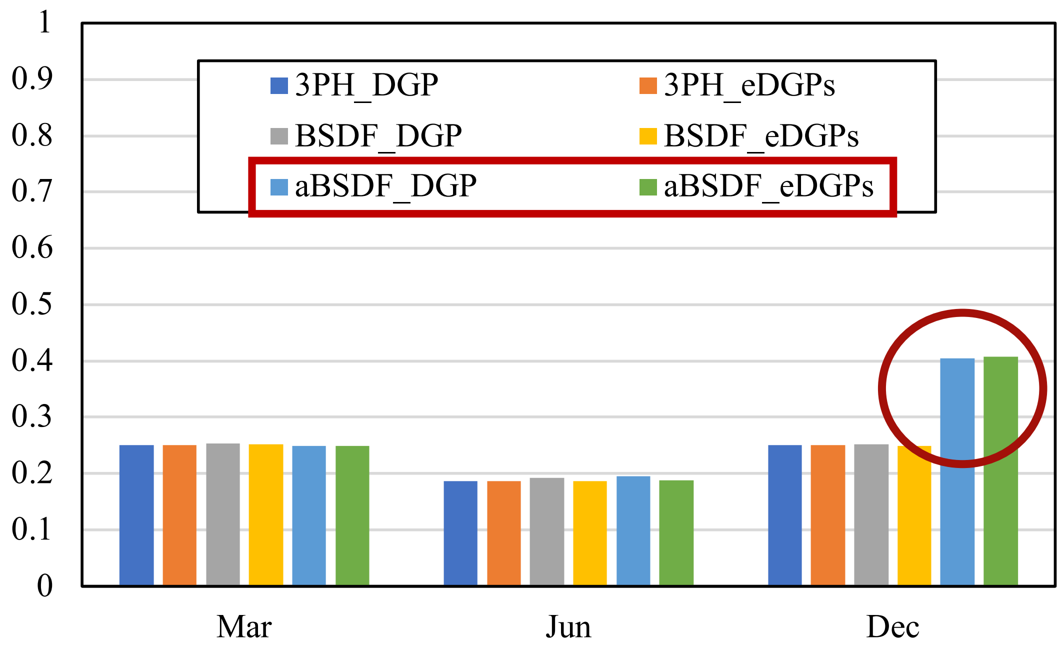


Translucent

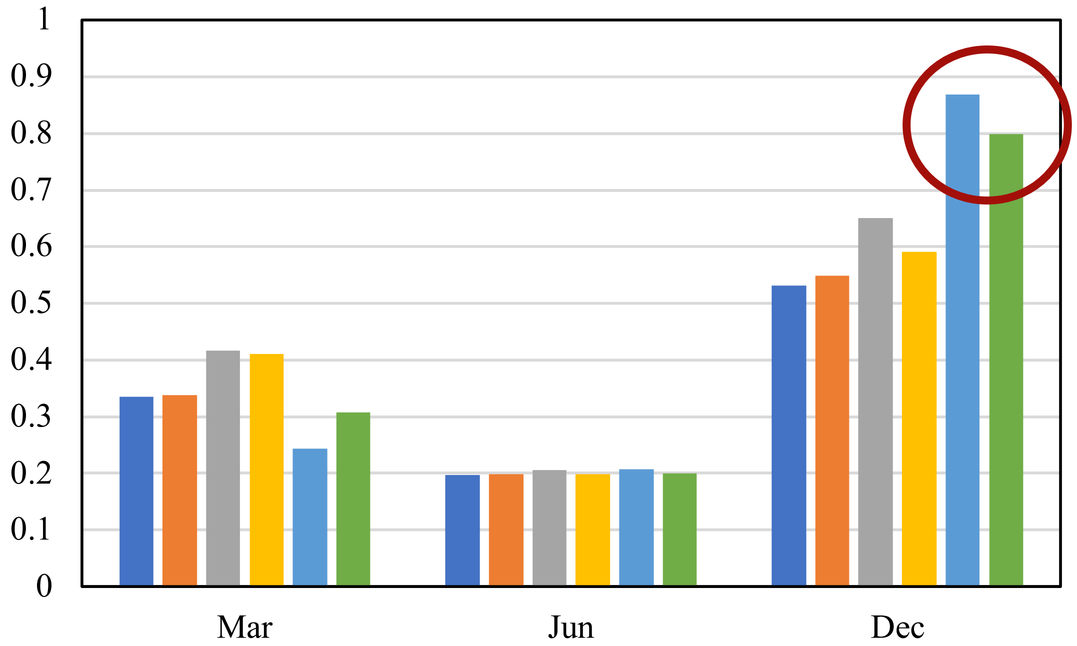


Transparent

Point in time glare calculation

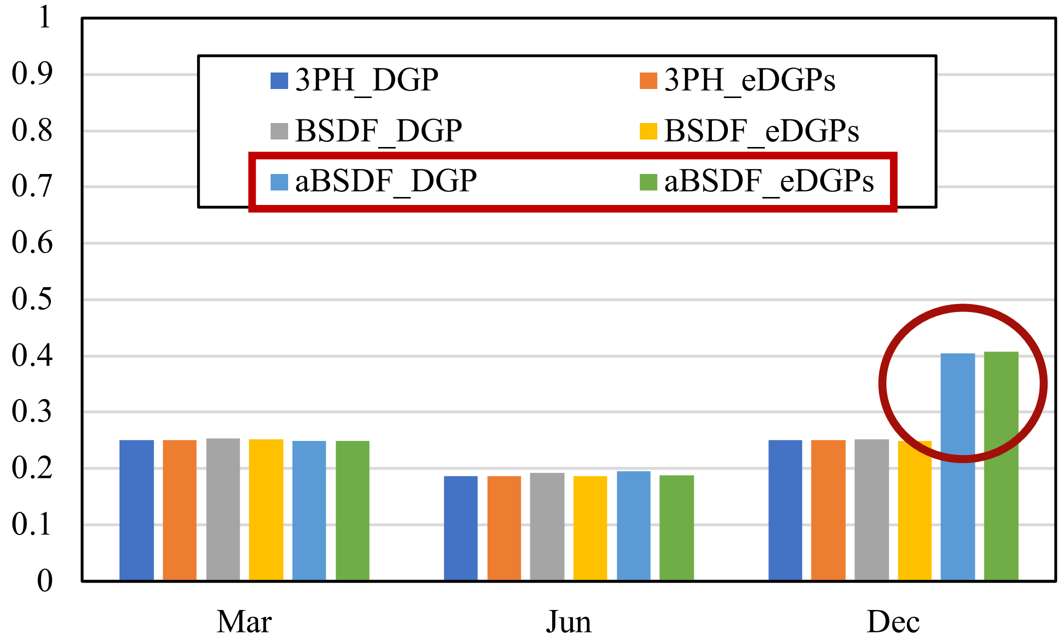


Translucent

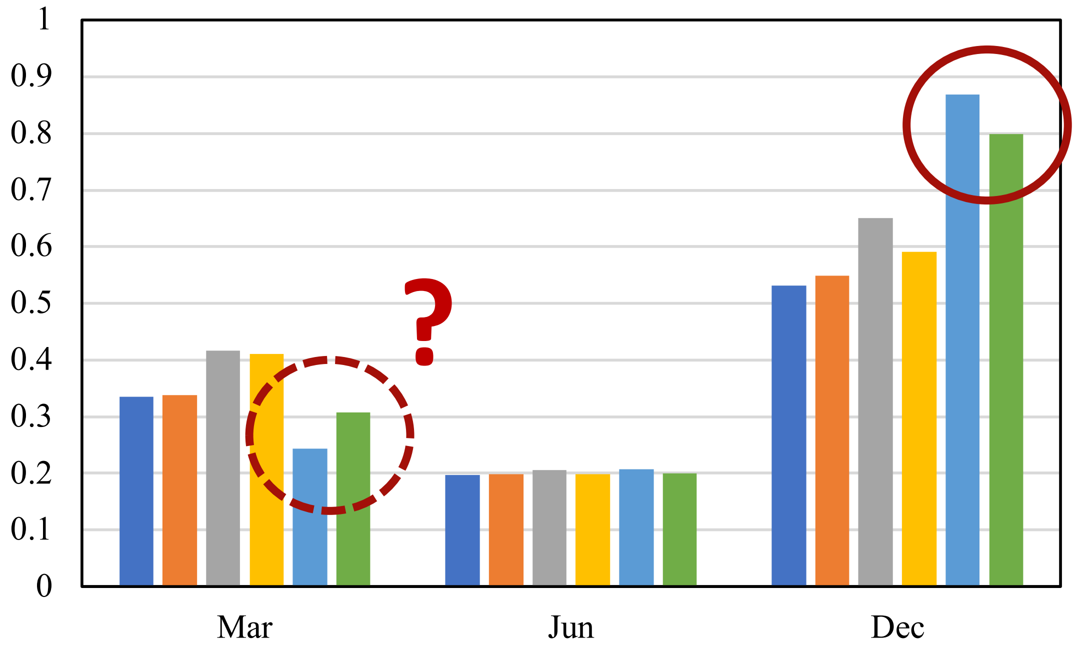


Transparent

Point in time glare calculation



Translucent



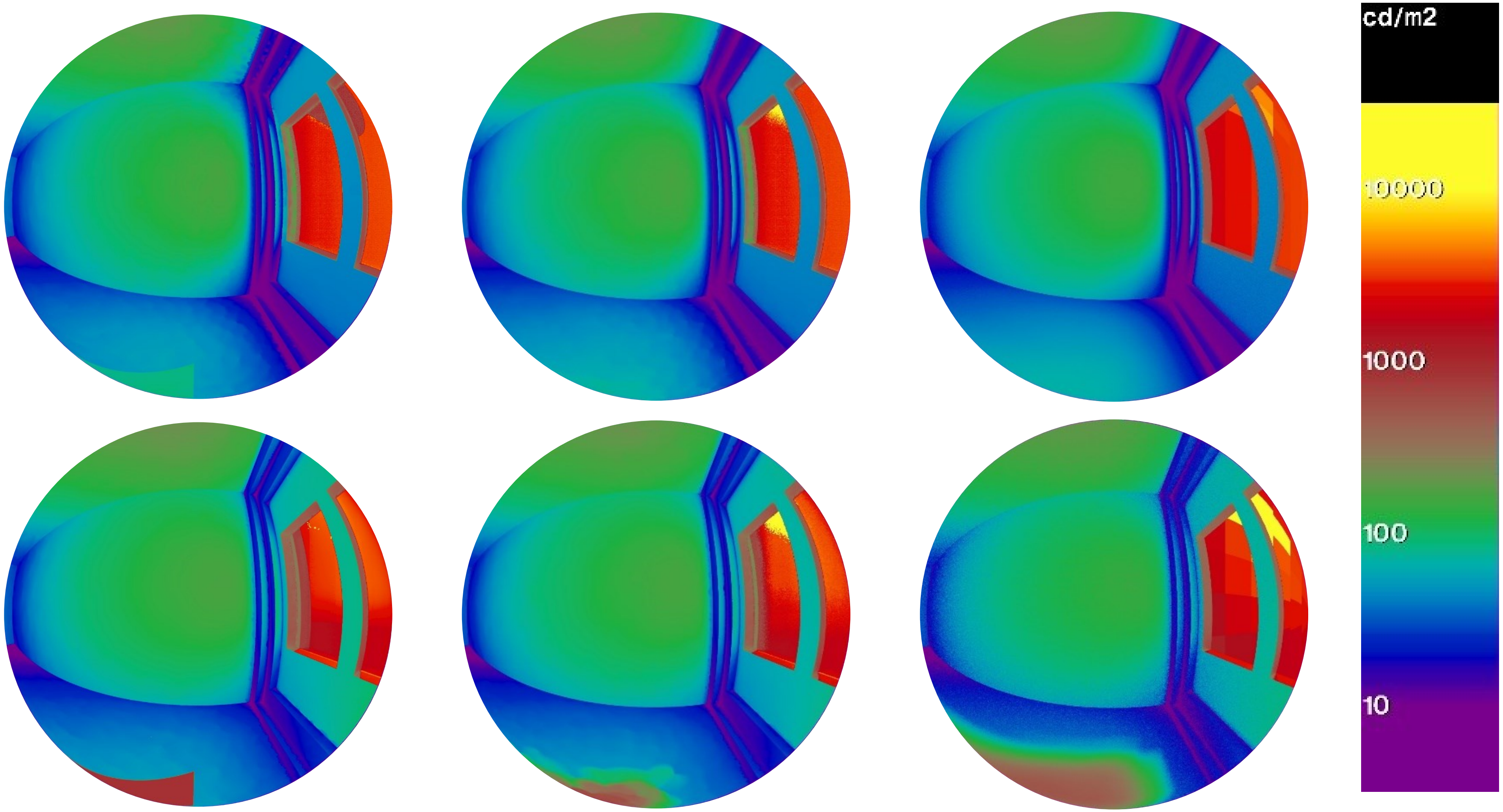
Transparent

Point in time luminance maps

aBSDF | BSDF | Three-phase image-based

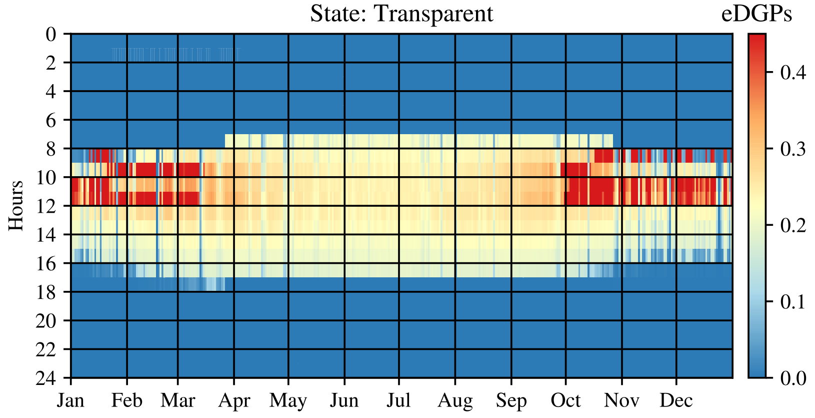
Translucent

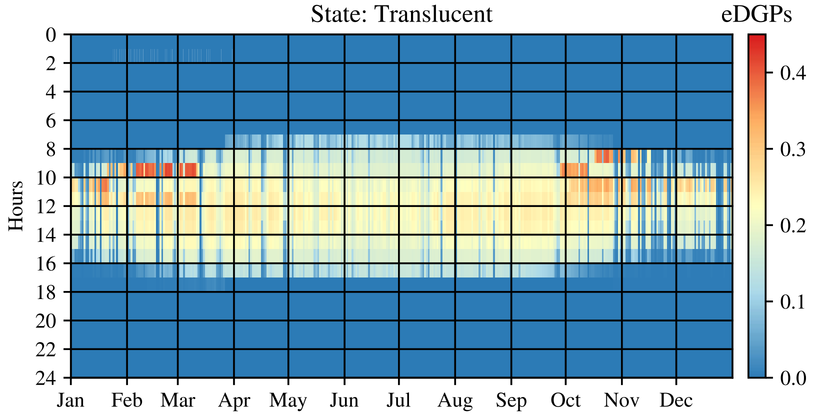
Transparent

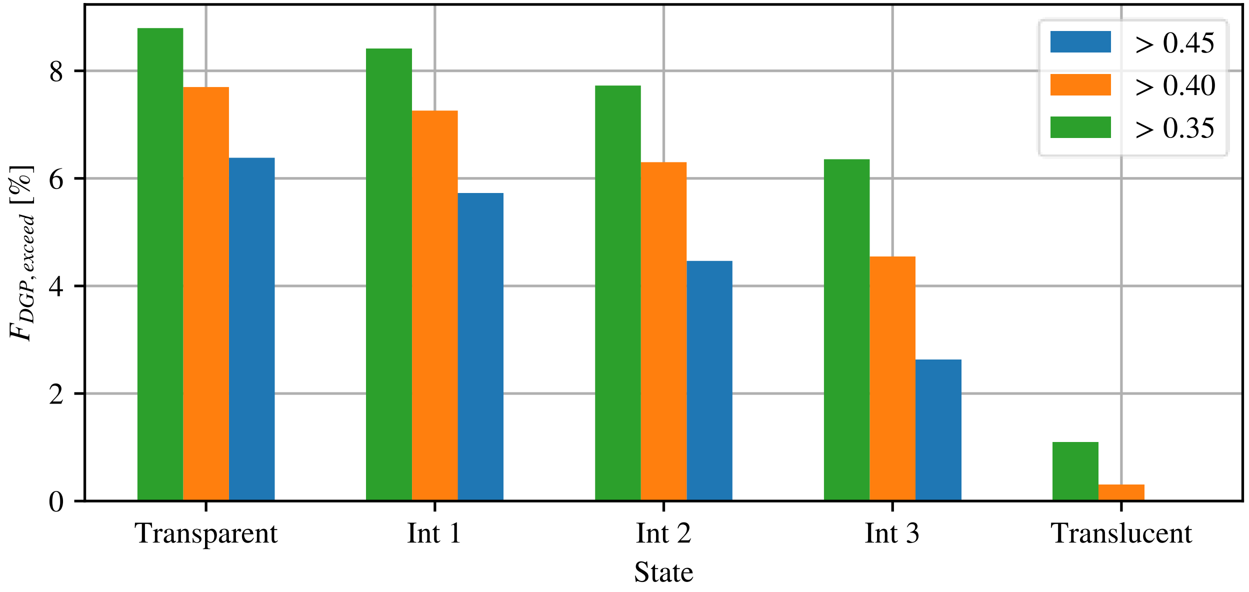


Annual glare calculation

- Glare generally **decreases** with translucency



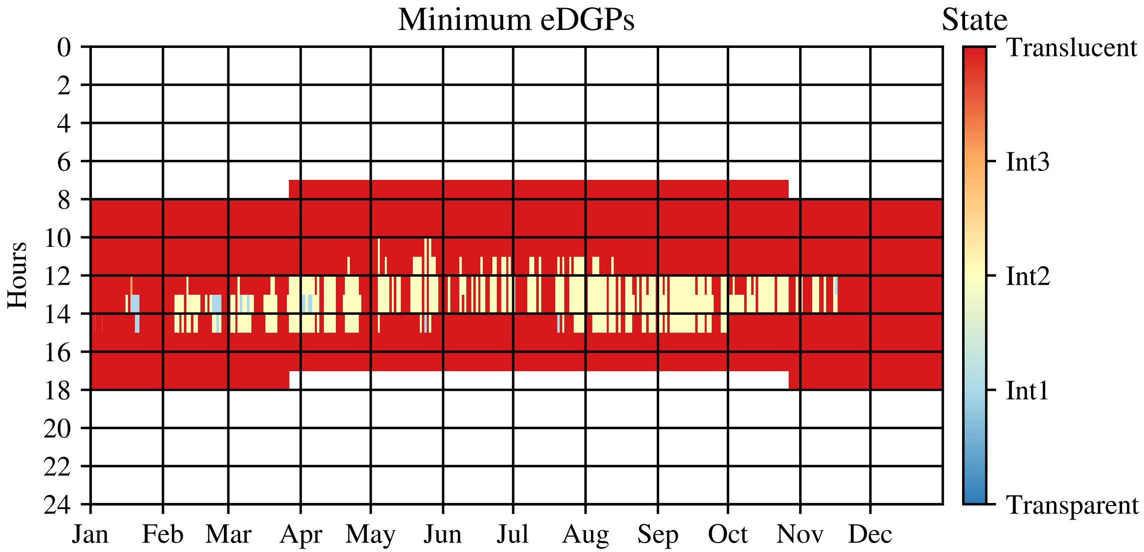


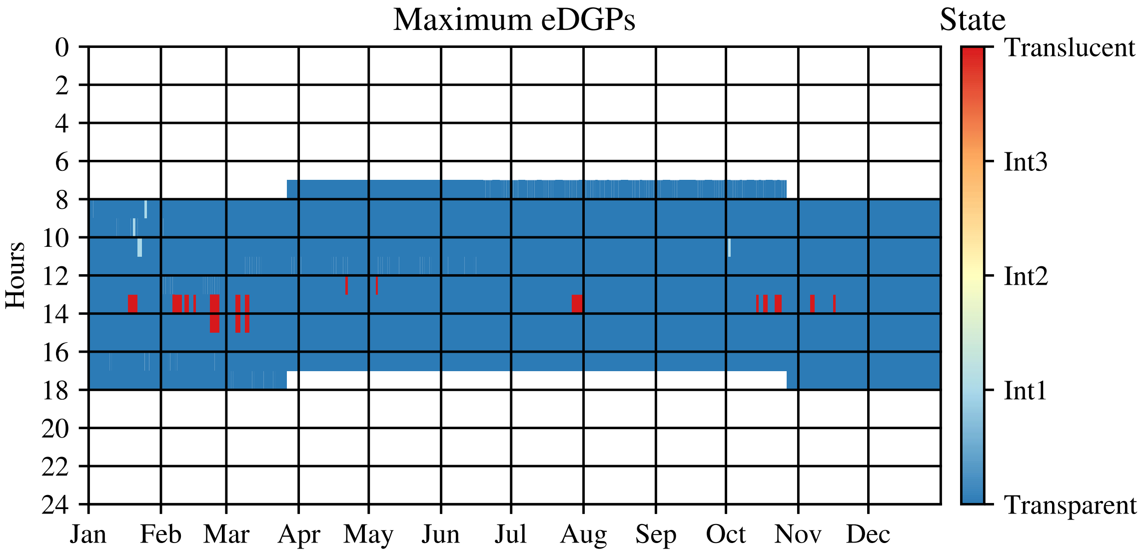


According to EN 17037:2022
Translucent state offers high glare protection
Int 3 medium glare protection
Int 2 minimum glare protection

Glare calculation

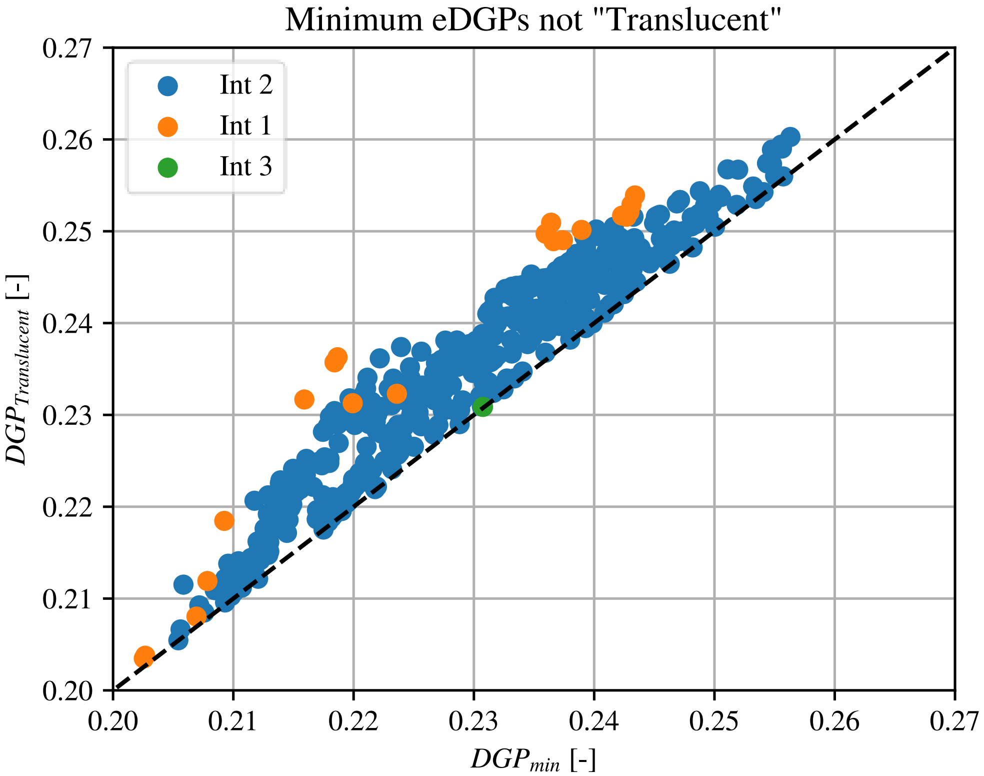
- Minimum glare not always with most translucent state
- Maximum glare not always with most transparent state

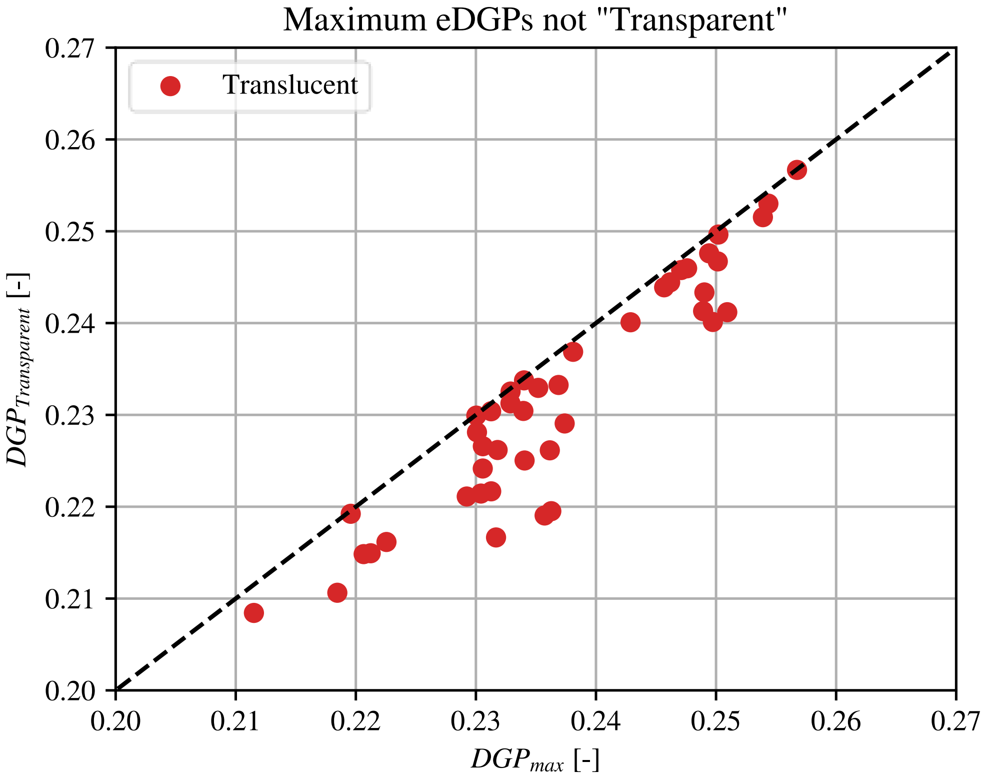




Glare calculation

- The difference in DGP is small
- Behaviour well inside imperceptible glare range





Conclusion

Conclusion

- Data-driven BSDF generation with *iso2klems*
- Comparison of glare calculation methods
- Counter intuitive PDLC glare behaviour revealed

Modelling and simulation of PDLC glazing in Radiance

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