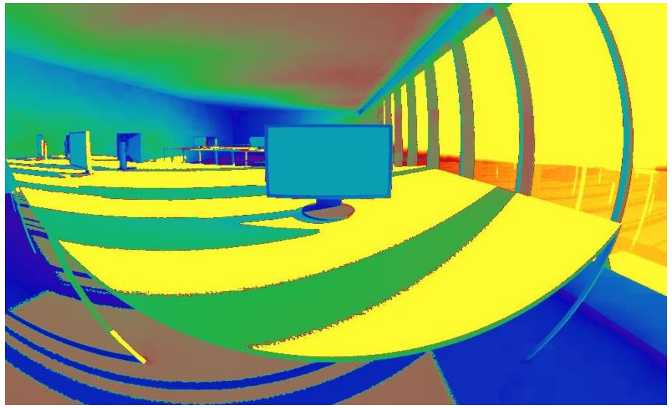




16th International
Radiance Workshop
Portland, Oregon

Daylighting performance of three dimensional textile

Speakers: **Andrea Zani & Giuseppe De Michele**

Authors: Andrea Zani, Giuseppe De Michele, Andrea G. Mainini, Alberto Speroni

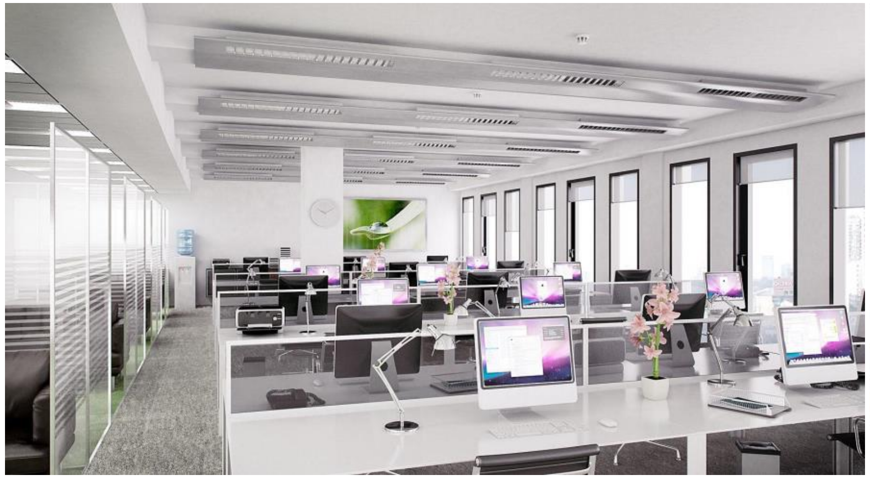
POLITECNICO MILANO 1863

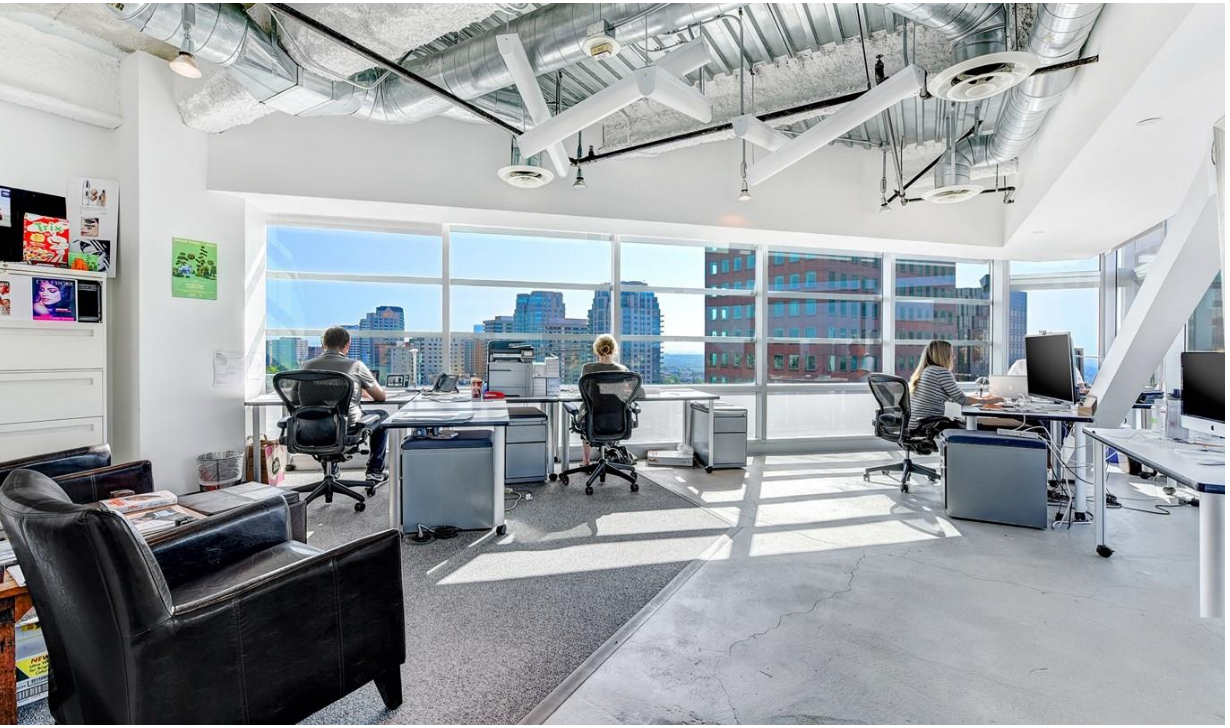
Berkeley UNIVERSITY OF CALIFORNIA

unibz

eurac research

Office and roller shade



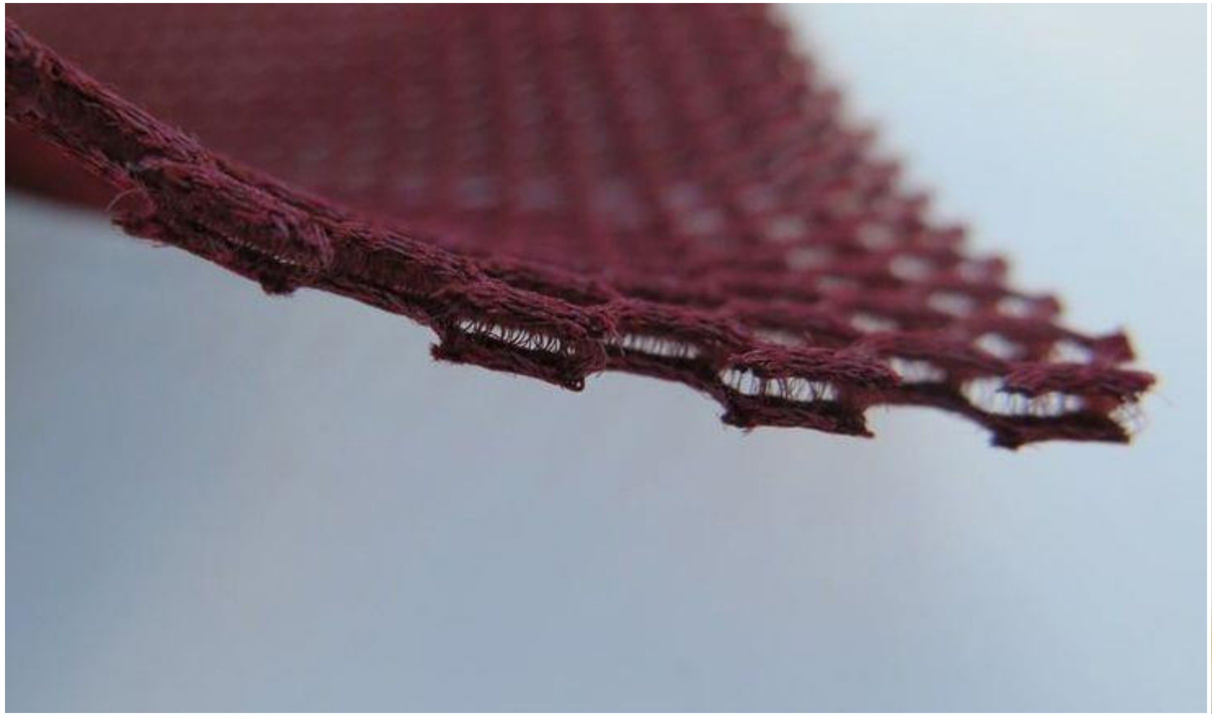

Problem statement

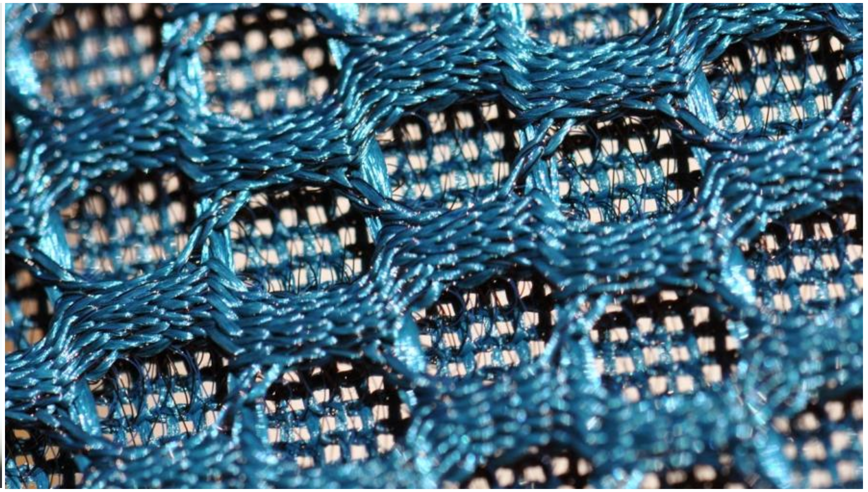
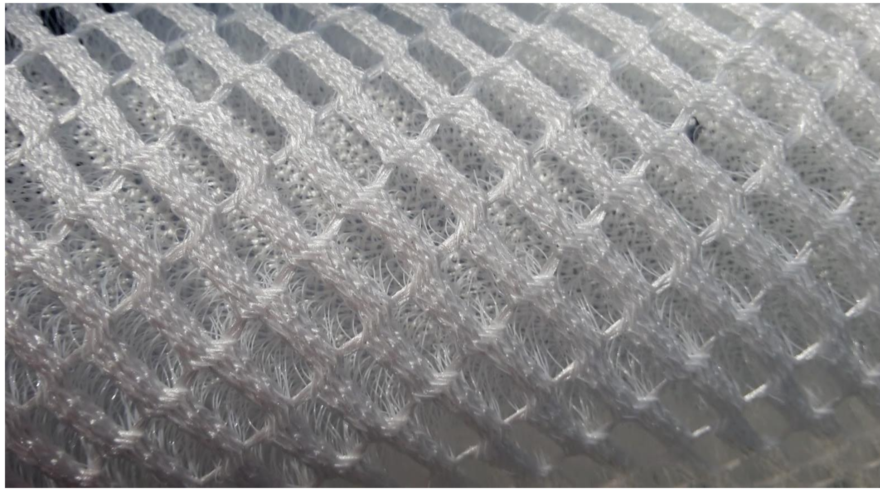
- Average illuminance level during the year
- Light distribution and uniformity in the space
- Visual connection with outdoor environment
- Not effective shading control strategy

The idea

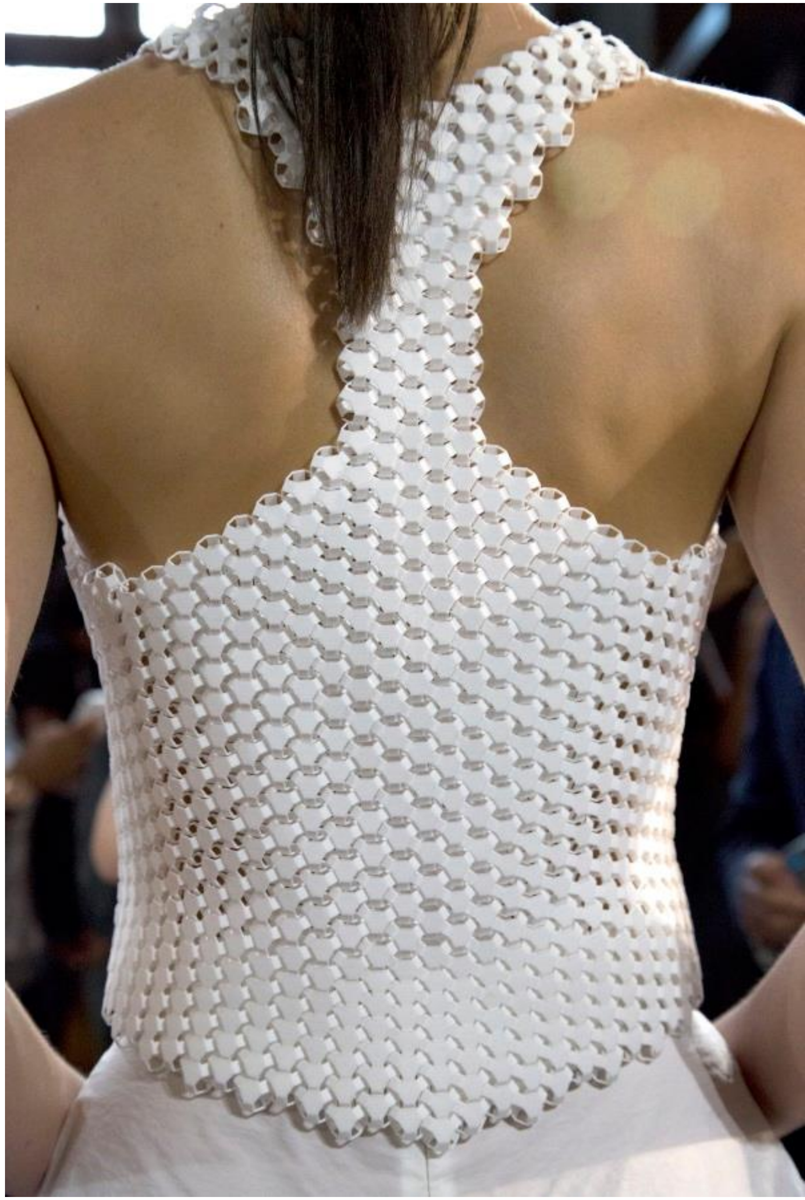
Poli, A. G. Mainini, R. Paolini, A. Speroni, L. Vercesi, M. Zinzi. Sviluppo di materiali e tecnologie per la riduzione degli effetti della radiazione solare. A. Implementazione delle prestazioni e nuovi prodotti per il controllo della radiazione solare e costruzione di un archivio cartaceo di prodotti innovativi. http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/edifici-pa/2012/rds-2013-156.pdf Corresponding Author: andreagiovanni.mainini@polimi.it

Three dimensional textile

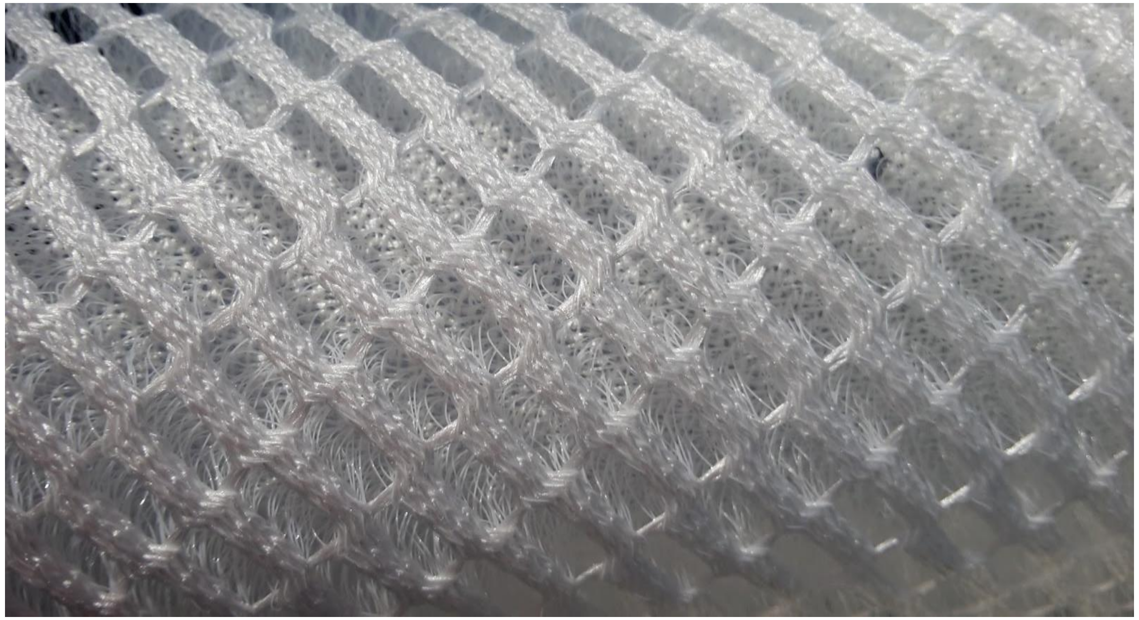
3D Textile - Field of application

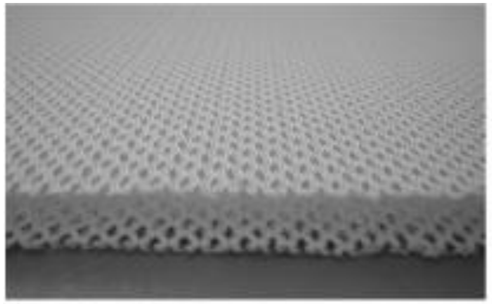


Objective

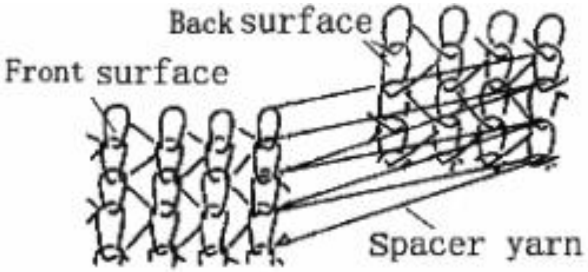
- Investigate the performance of 3D-warp knitted textile as roller blinds
- Define detailed model for 3D textile shading system
- Use a feasible and accurate method to simulate the complex system
- Assess the annual and point in time performance with different control strategies

3D-warp knitted textile



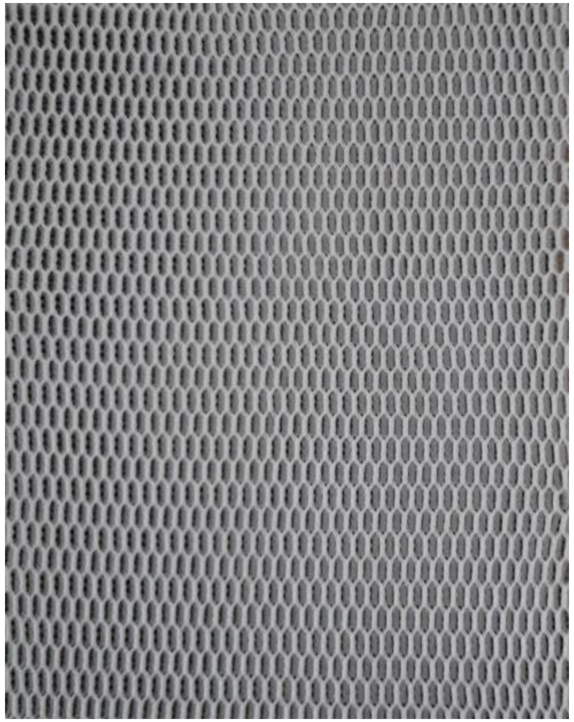


(a) Fabric sample

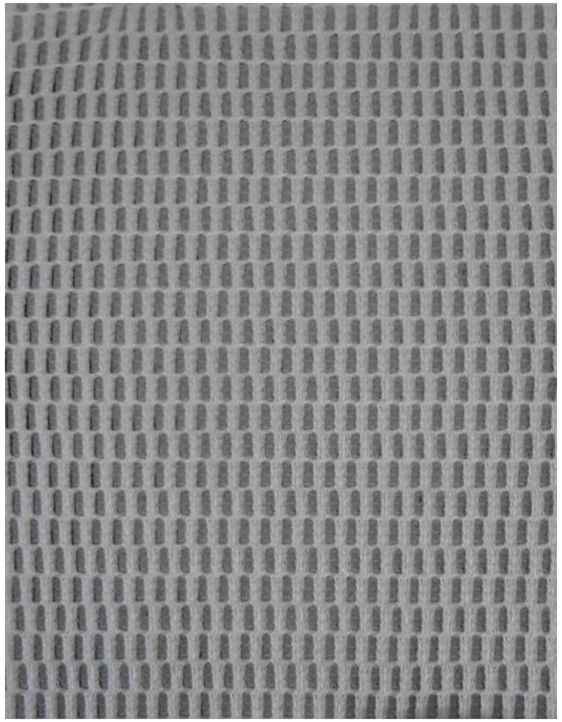


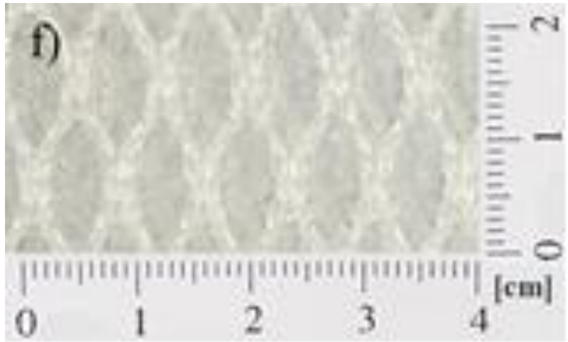
(b) Fabric diagram

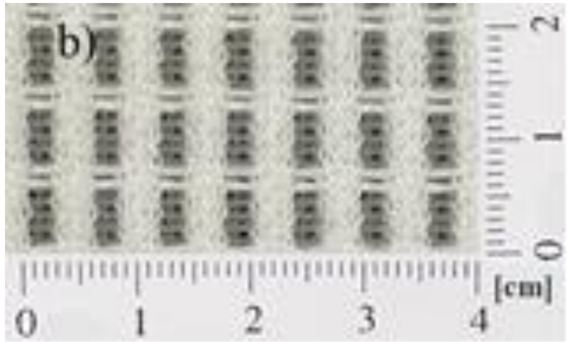
T1

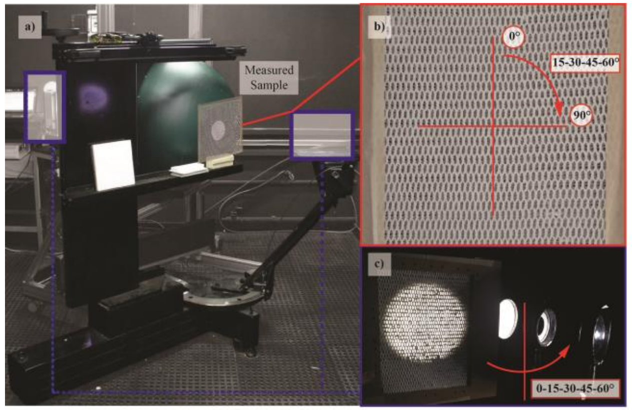


T2



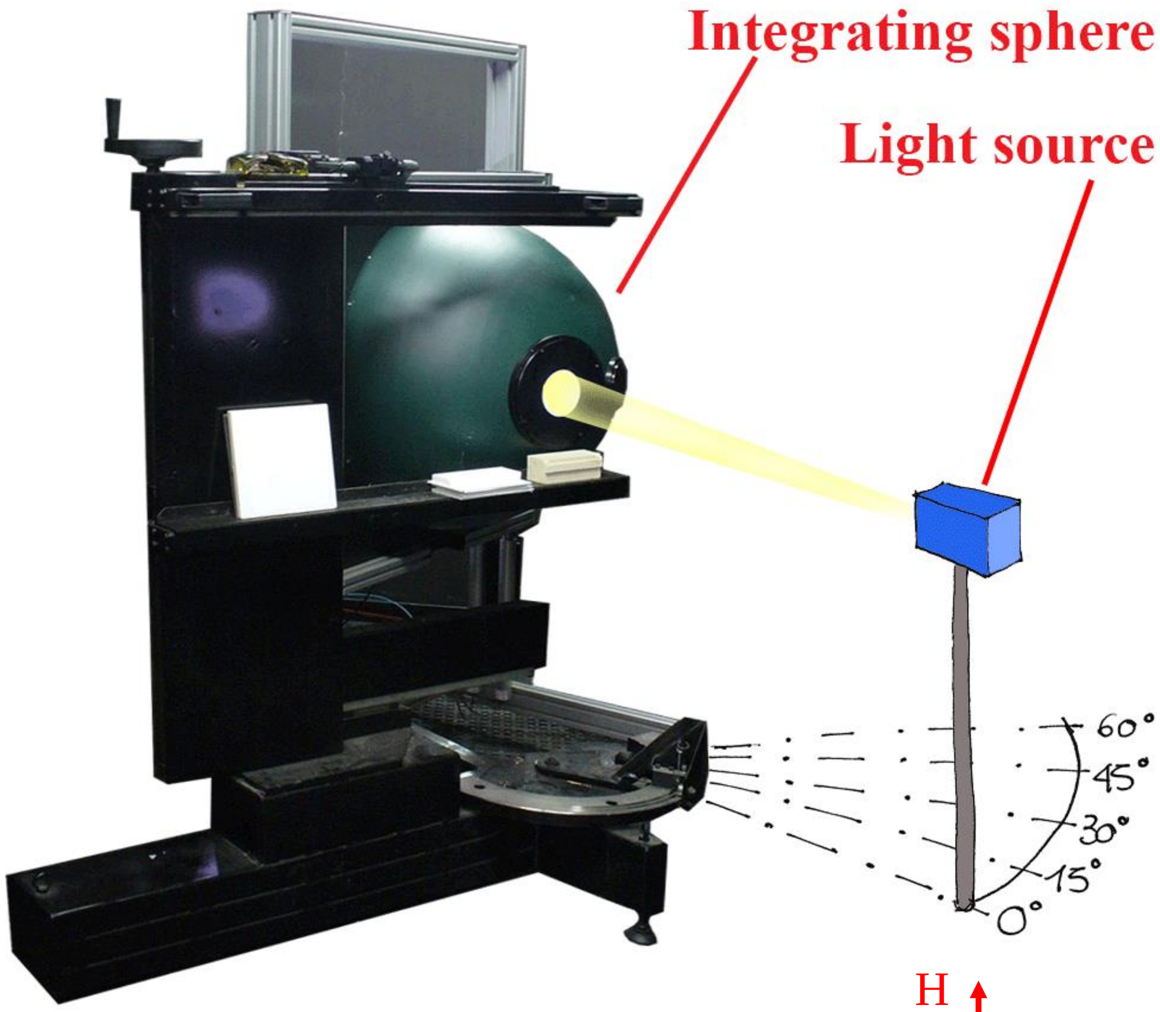


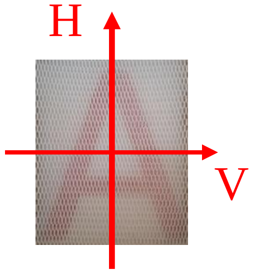


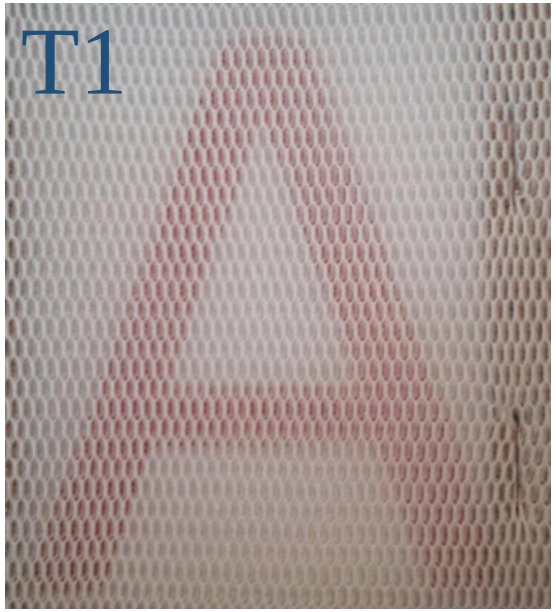


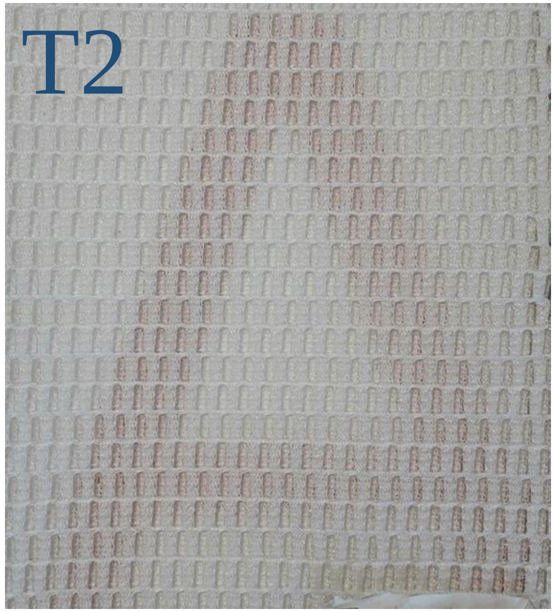
Measurements

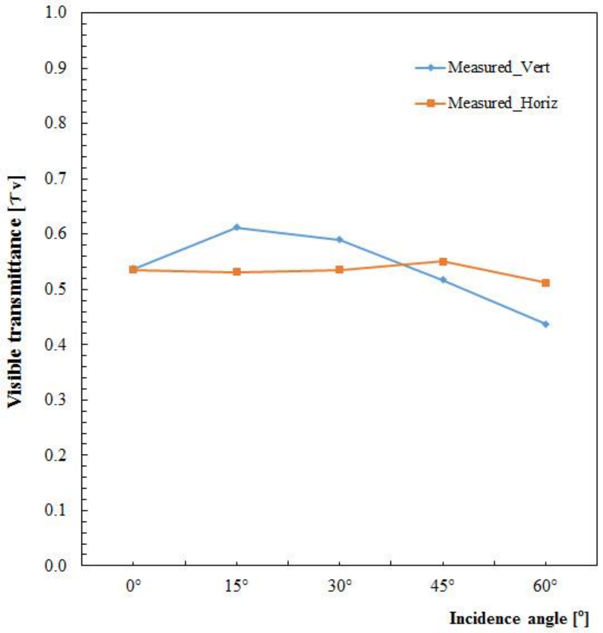
Angular transmittance

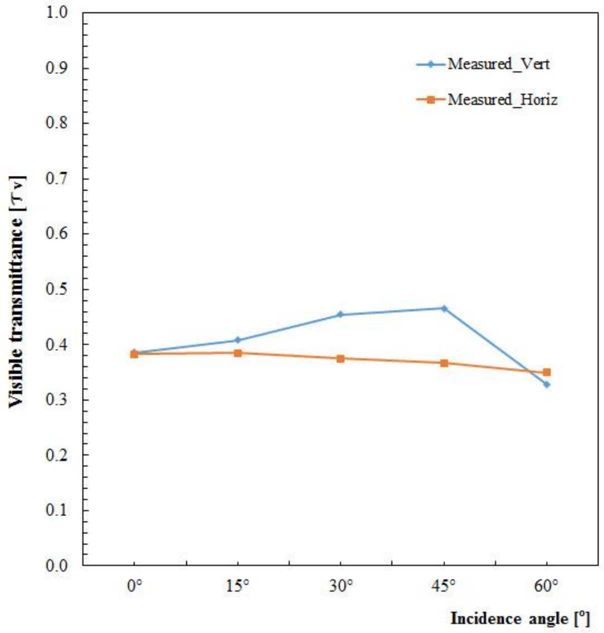




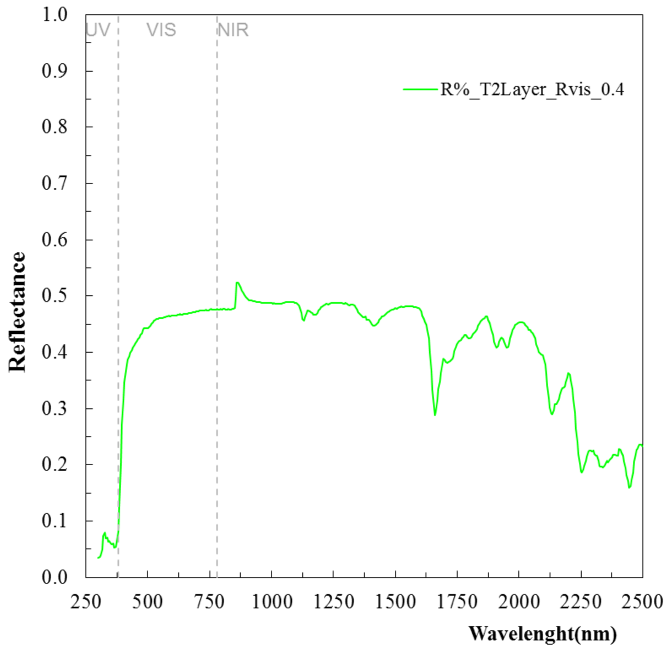


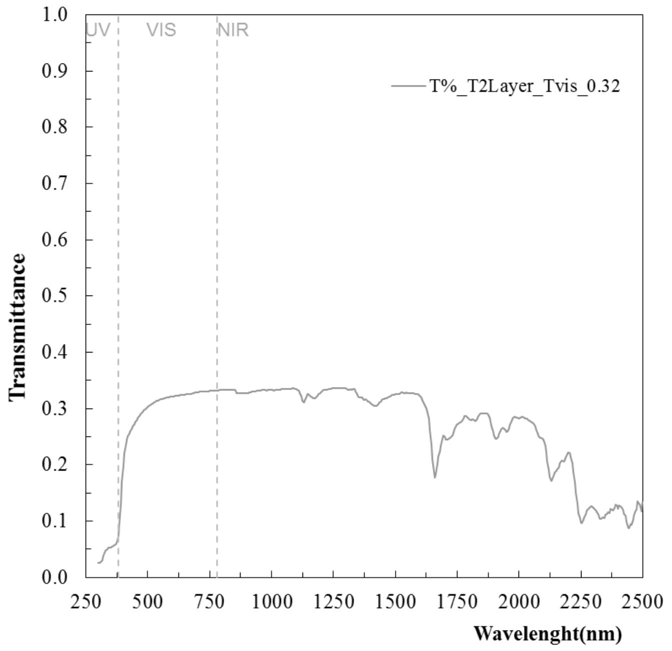




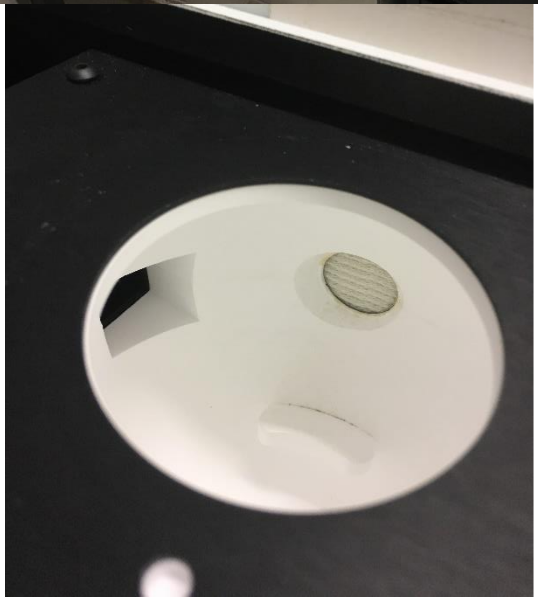


Spectral transmittance and reflectance

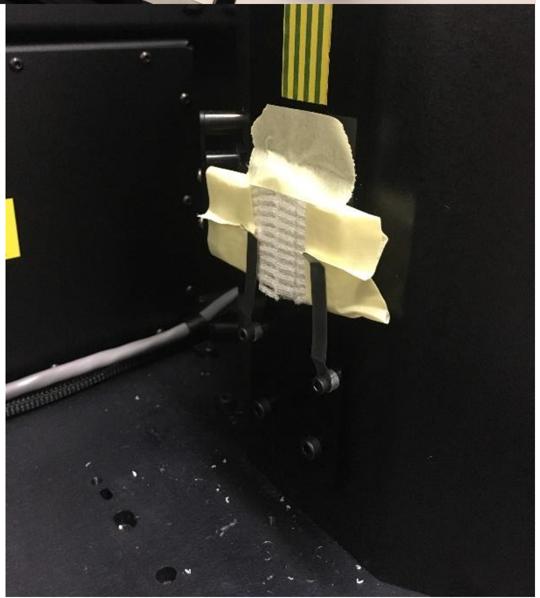




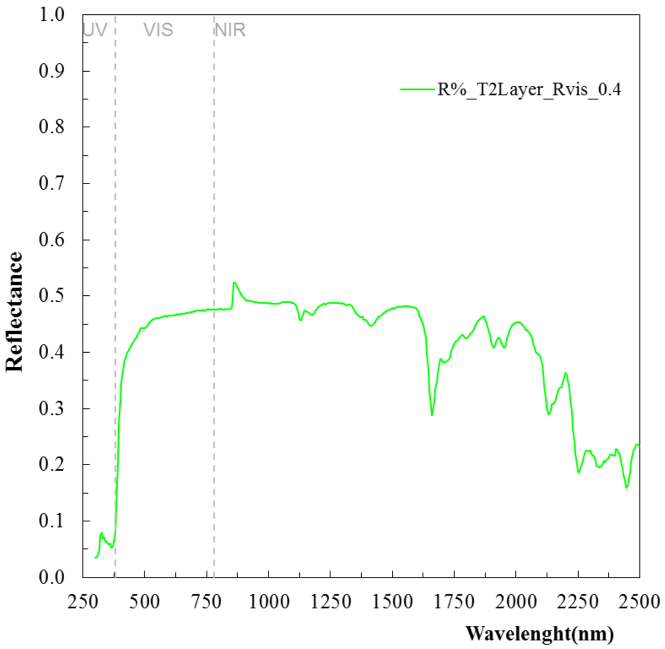
Reflectance

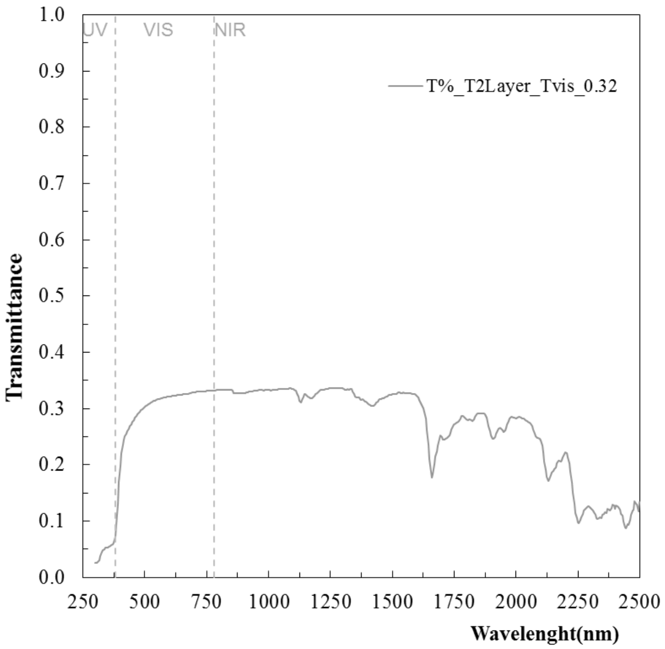


Transmittance

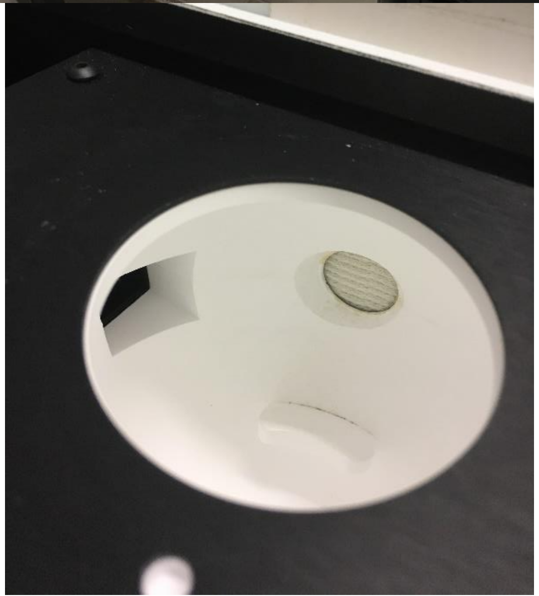


Spectral transmittance and reflectance

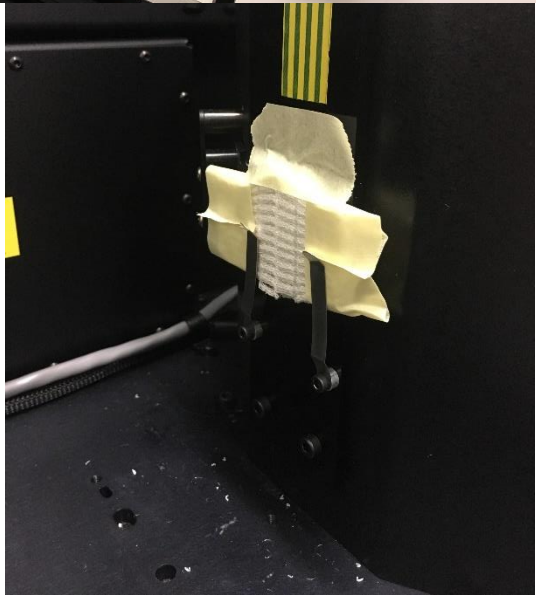




Reflectance

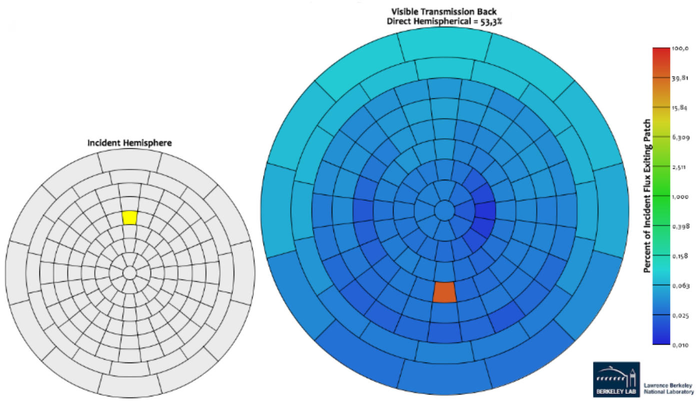


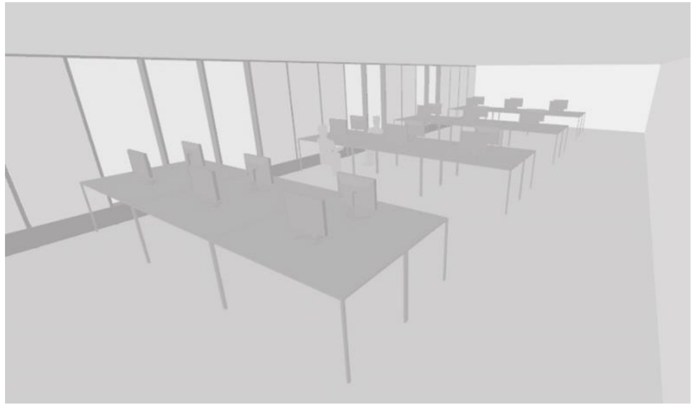
Transmittance

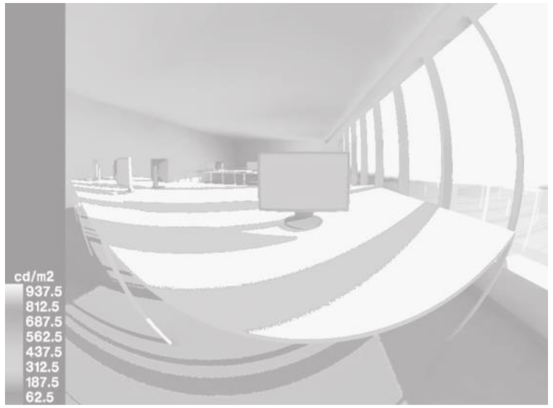


T2 Trans material

void trans T2
0
0
7 0.7 0.7 0.7 0.01 0 0.56 0


Incident Hemisphere
Visible Transmission Back
Direct Hemispherical = 53,3%
Percent of Incident Flux Exiting Patch

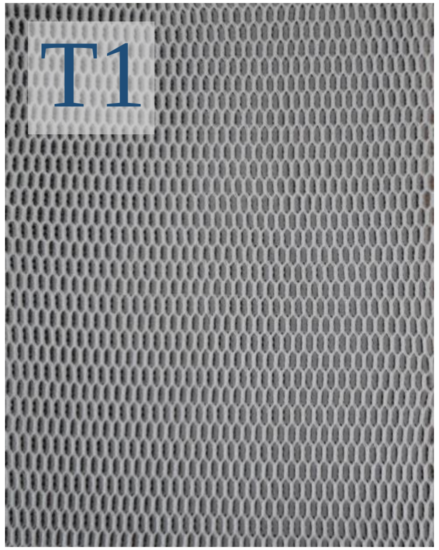


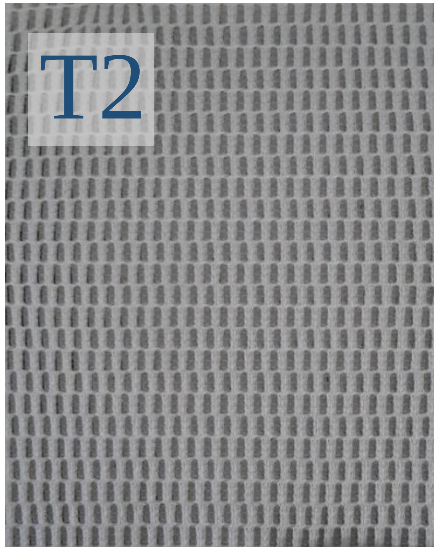

cd/m2
937.5
812.5
687.5
562.5
437.5
312.5
187.5
62.5

Modelling

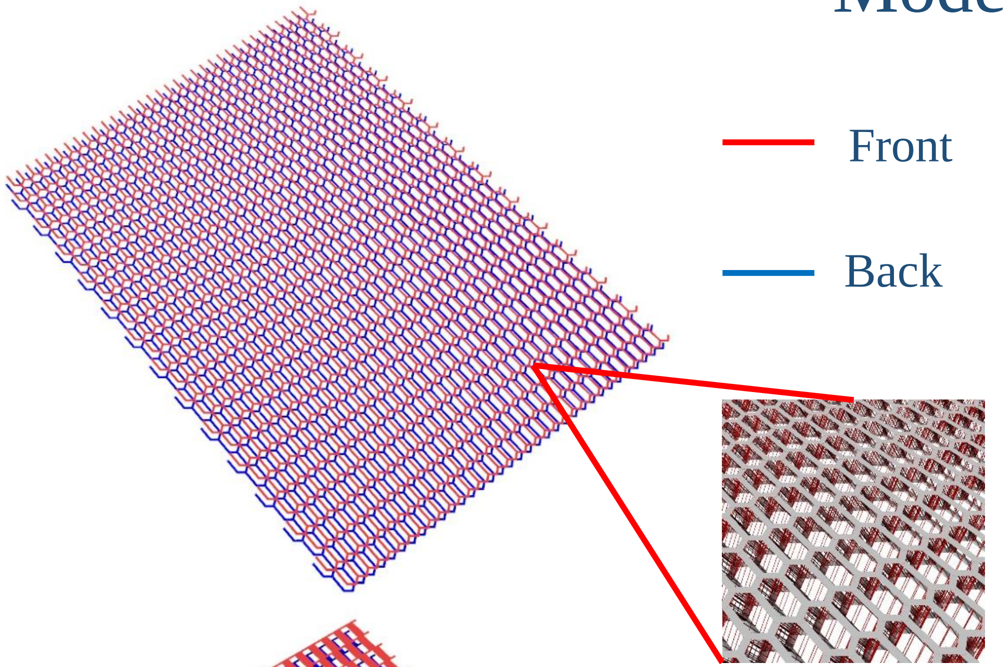
Bi-directional Scattering Distribution Function

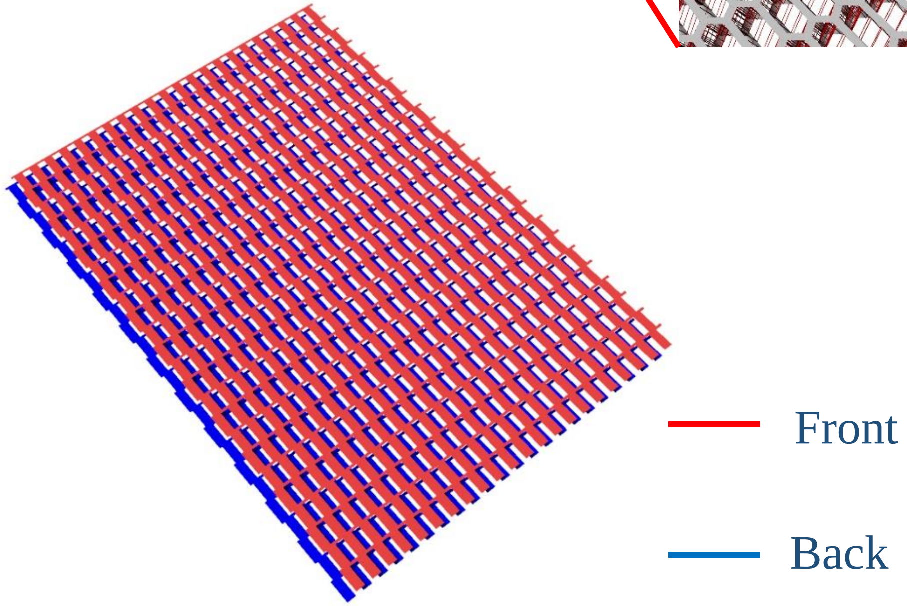
Model and material definition





50 x 70





Model dimension 50 x 70 cm

void plastic T1_Front & Back
0
0
5 0.85 0.85 0.85 0 0.05

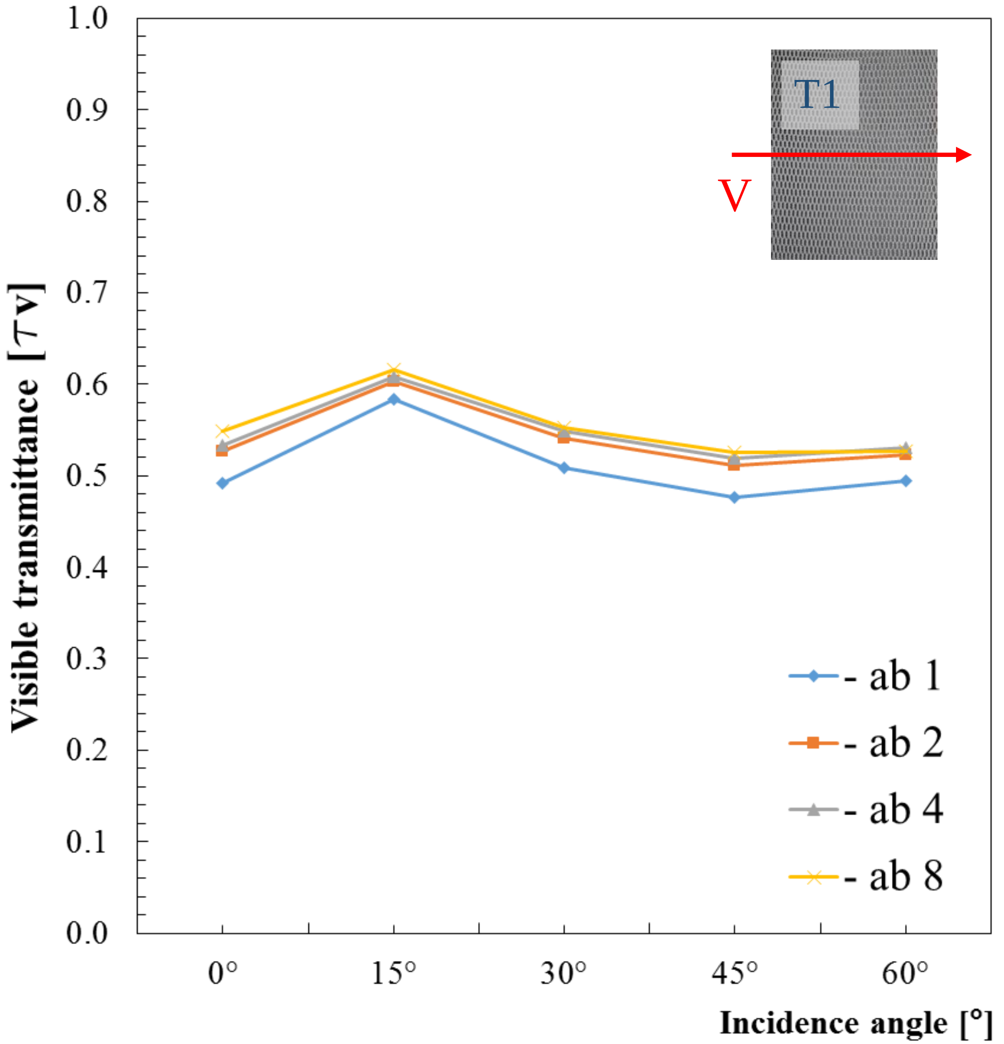
void plastic T1_Wires
0
0
5 0.85 0.85 0.85 0 0.05

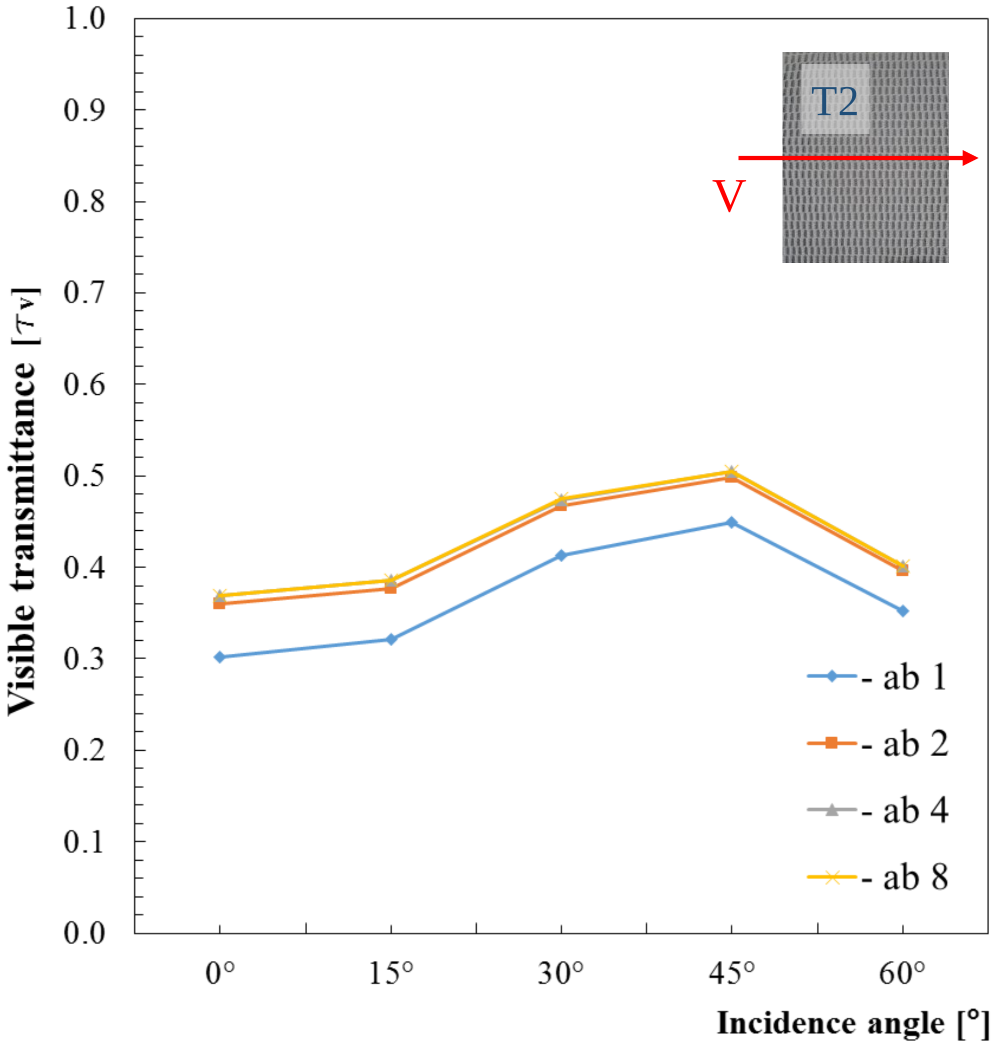
Model dimension 50 x 70 cm

void trans T2 Front & Back
0
0
7 0.7 0.7 0.7 0.01 0 0.56 0

Bi-directional Scattering Distribution Function

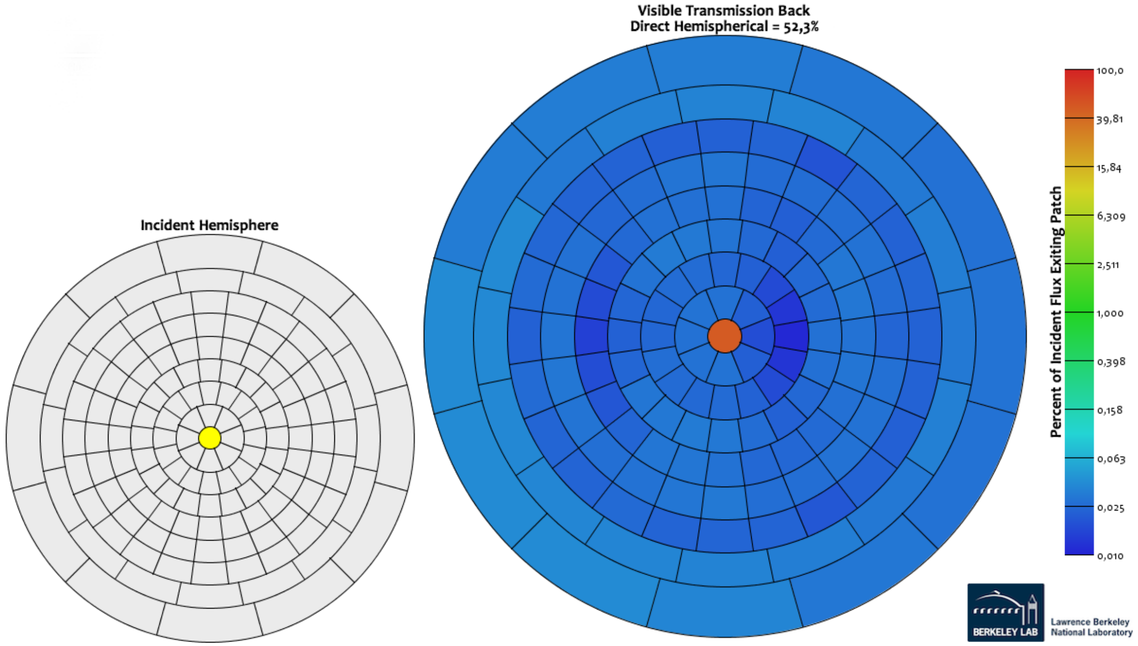
genBSDF settings

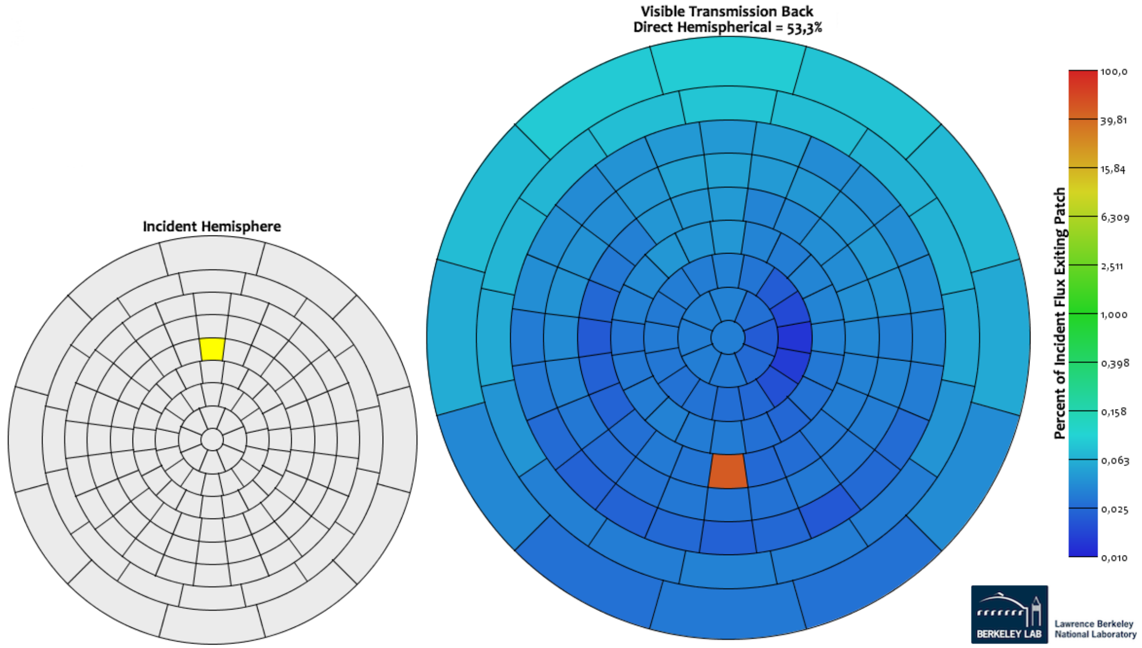


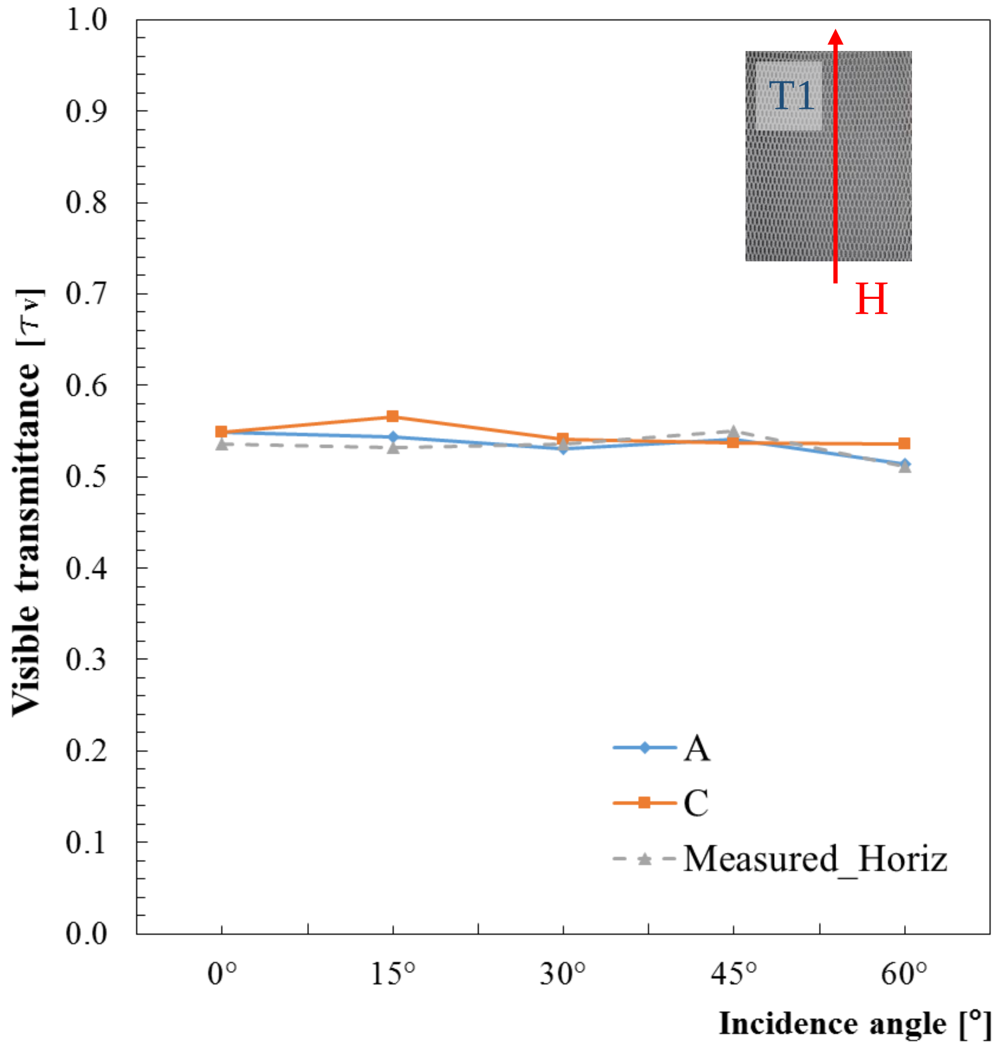


genBSDF -n 4 -c 4000 -dim 0.280 0.319 0.339 0.396 -0.018 0 +f +b -r '-ab 8' T1 & T2.rad > T1 & T2_bsdf.xml

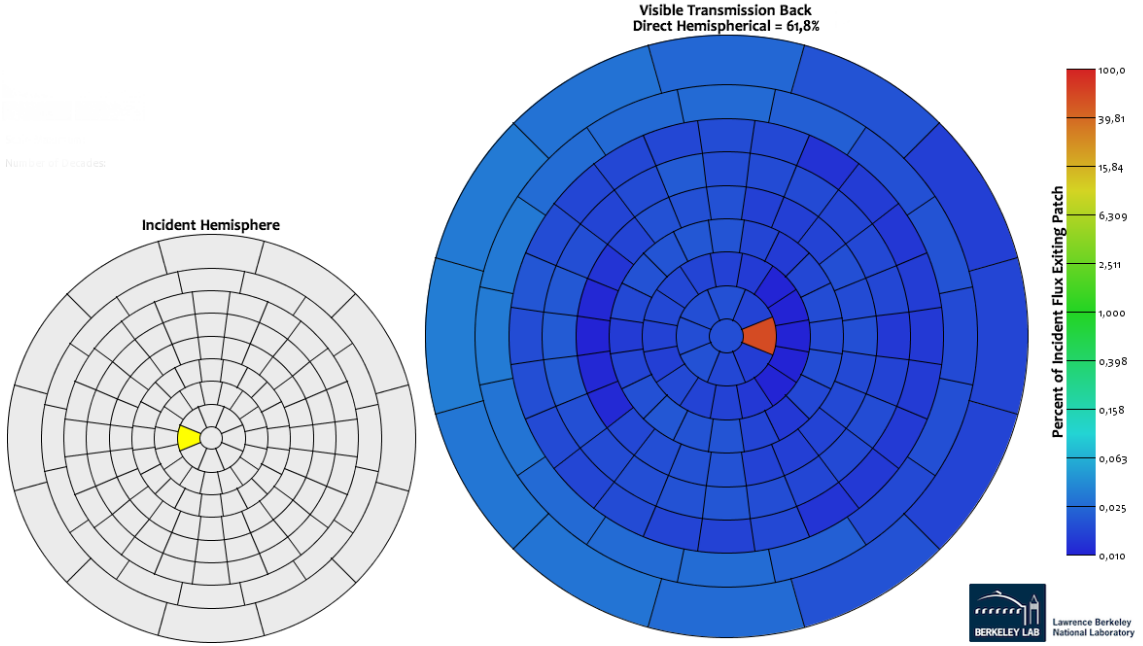
T1 - Bi-directional Scattering Distribution Function

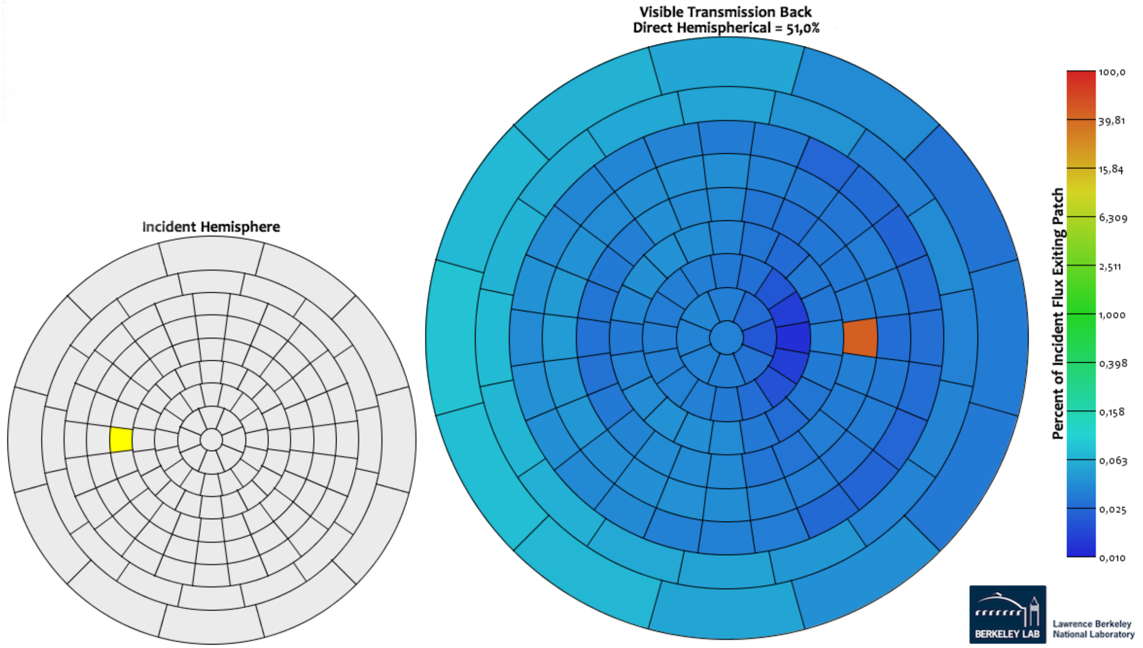


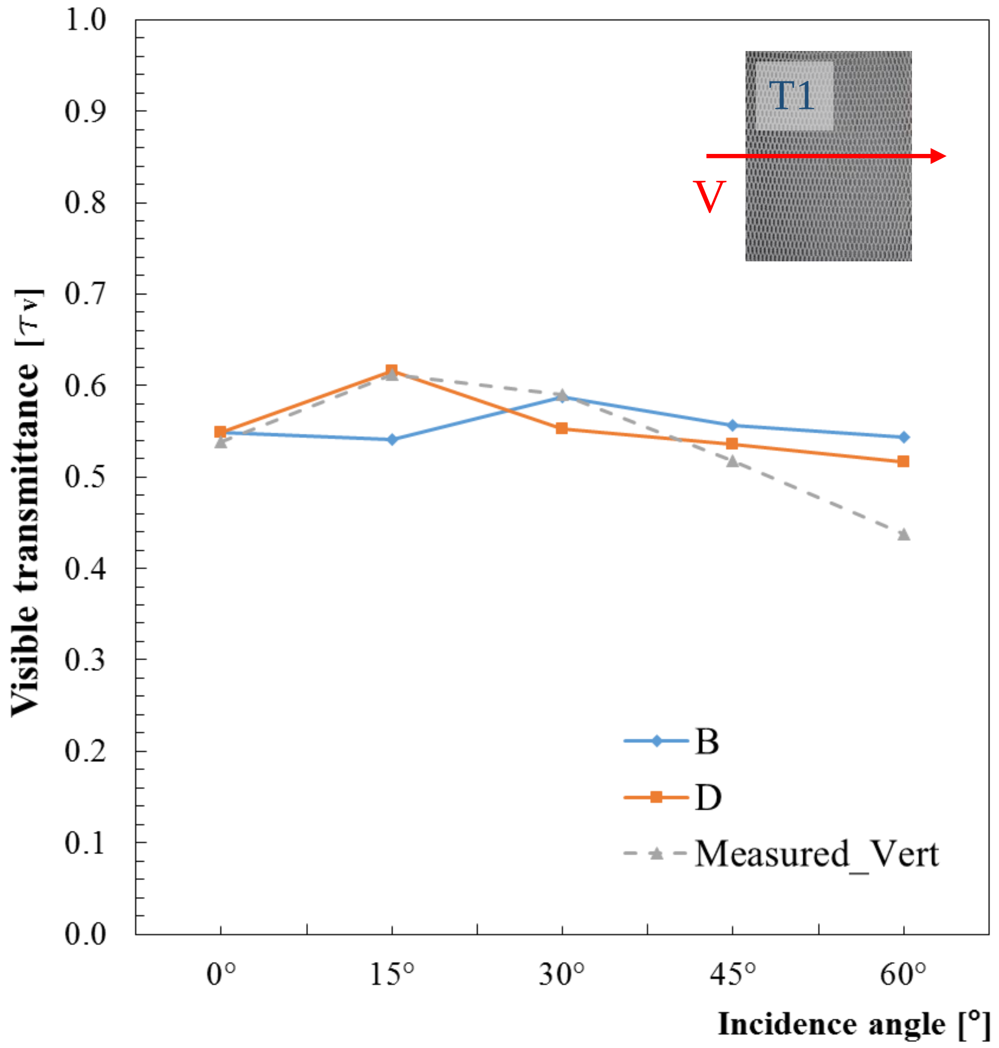




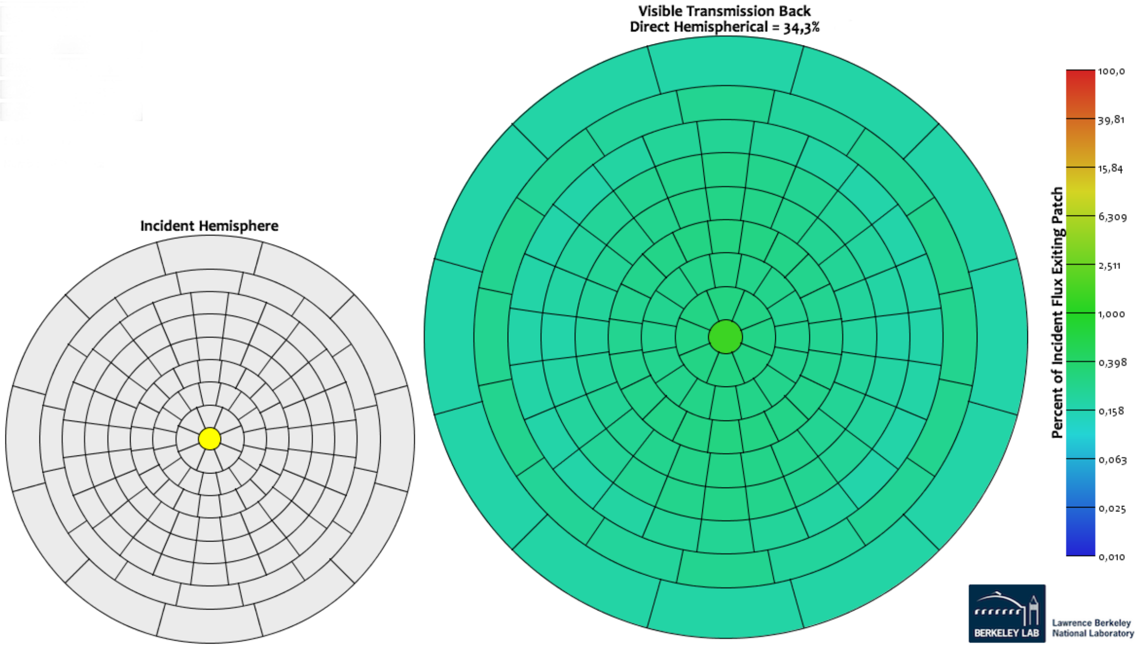
T1 - Bi-directional Scattering Distribution Function

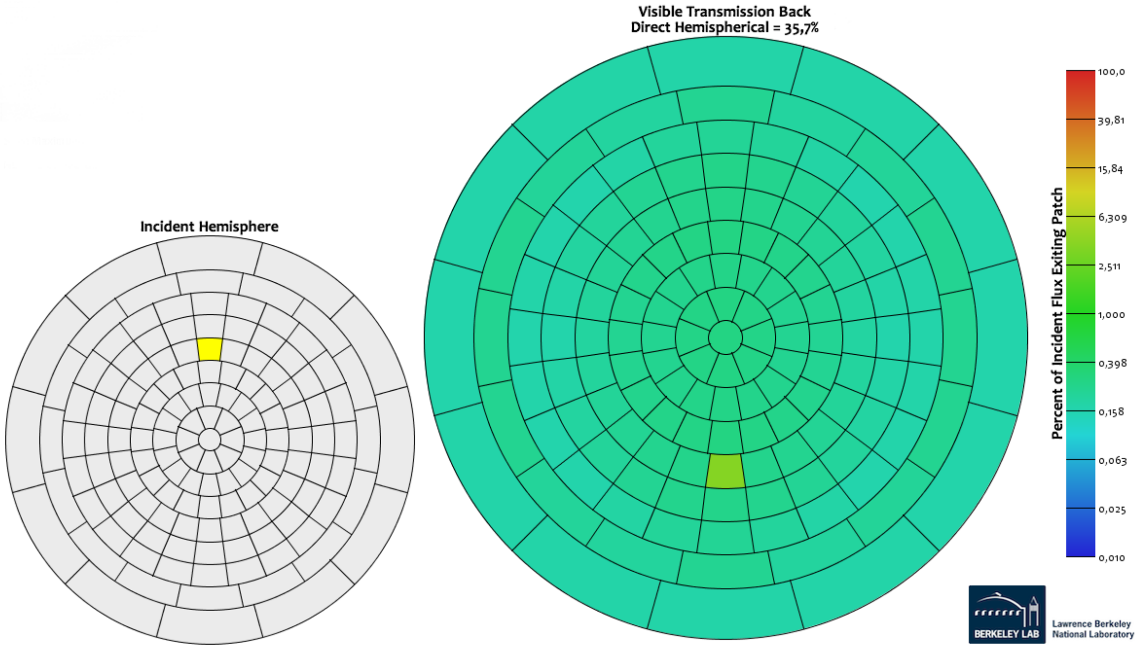


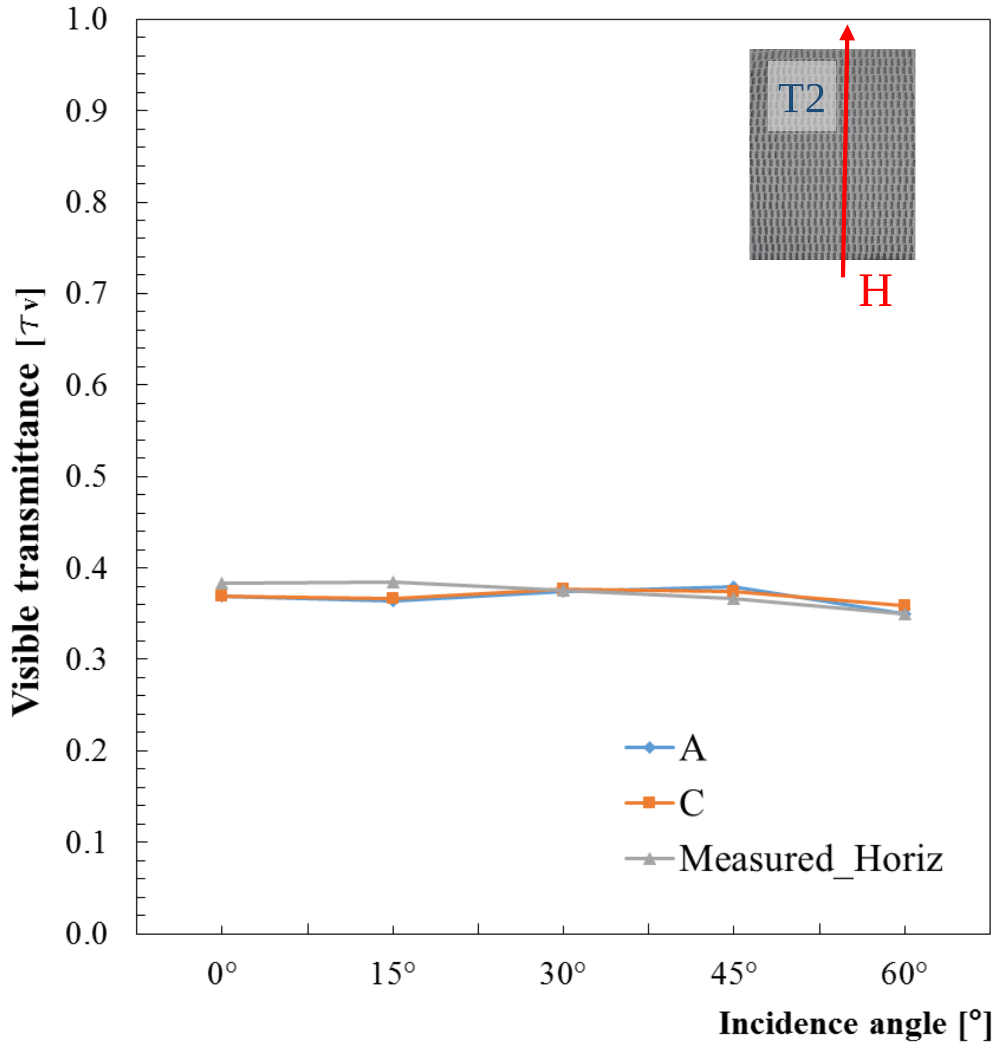




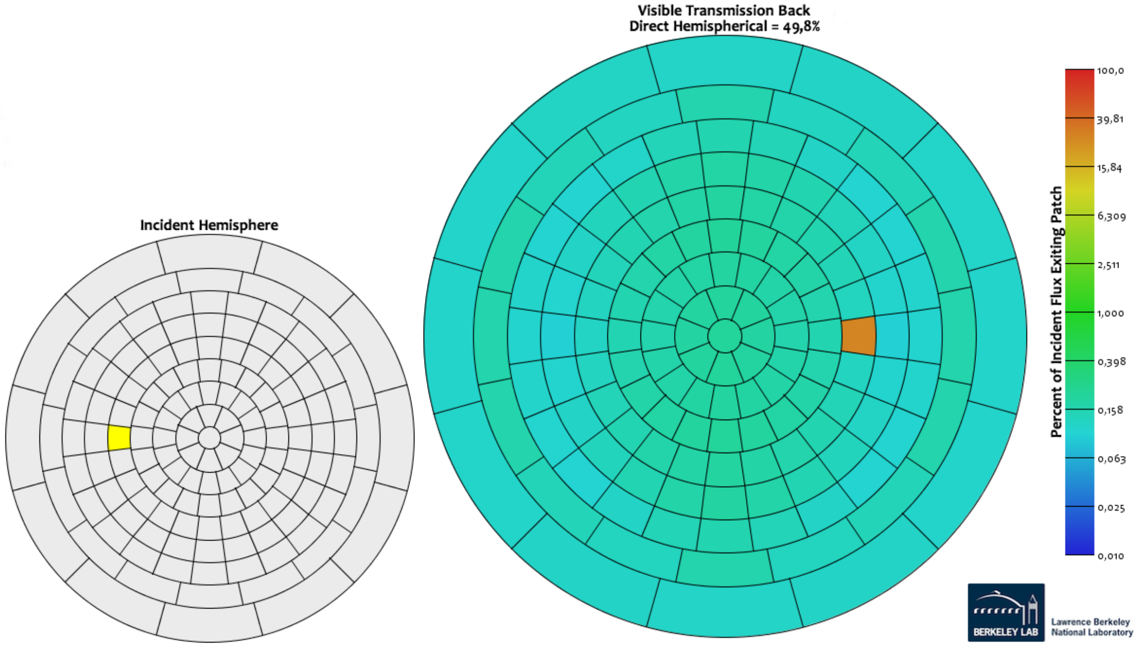
T2 - Bi-directional Scattering Distribution Function

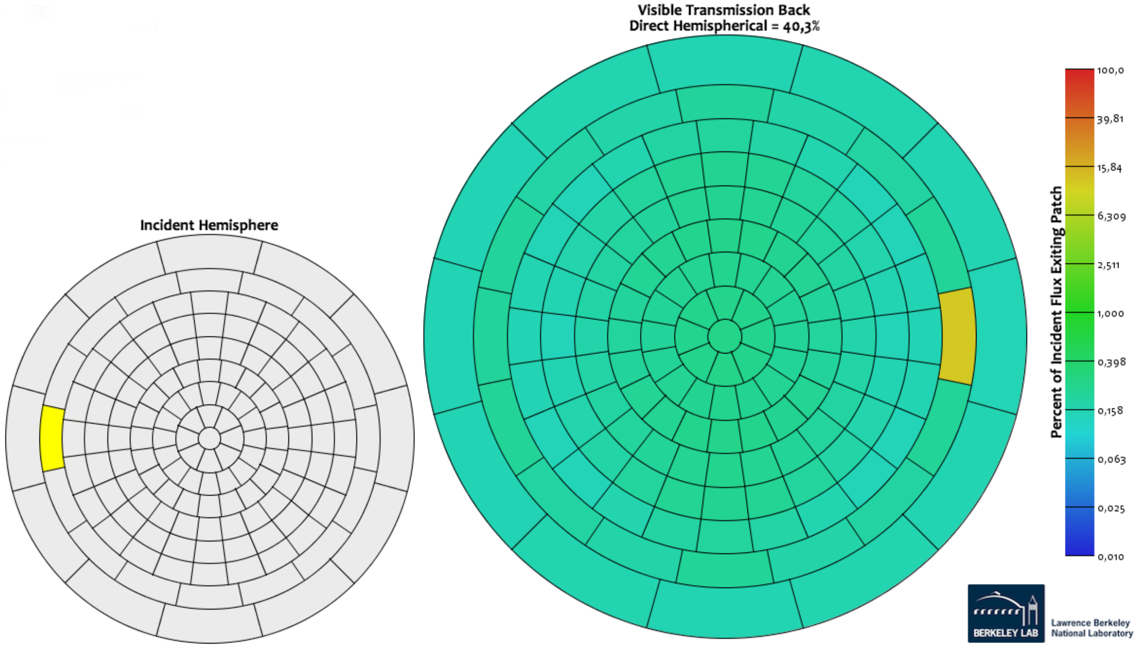


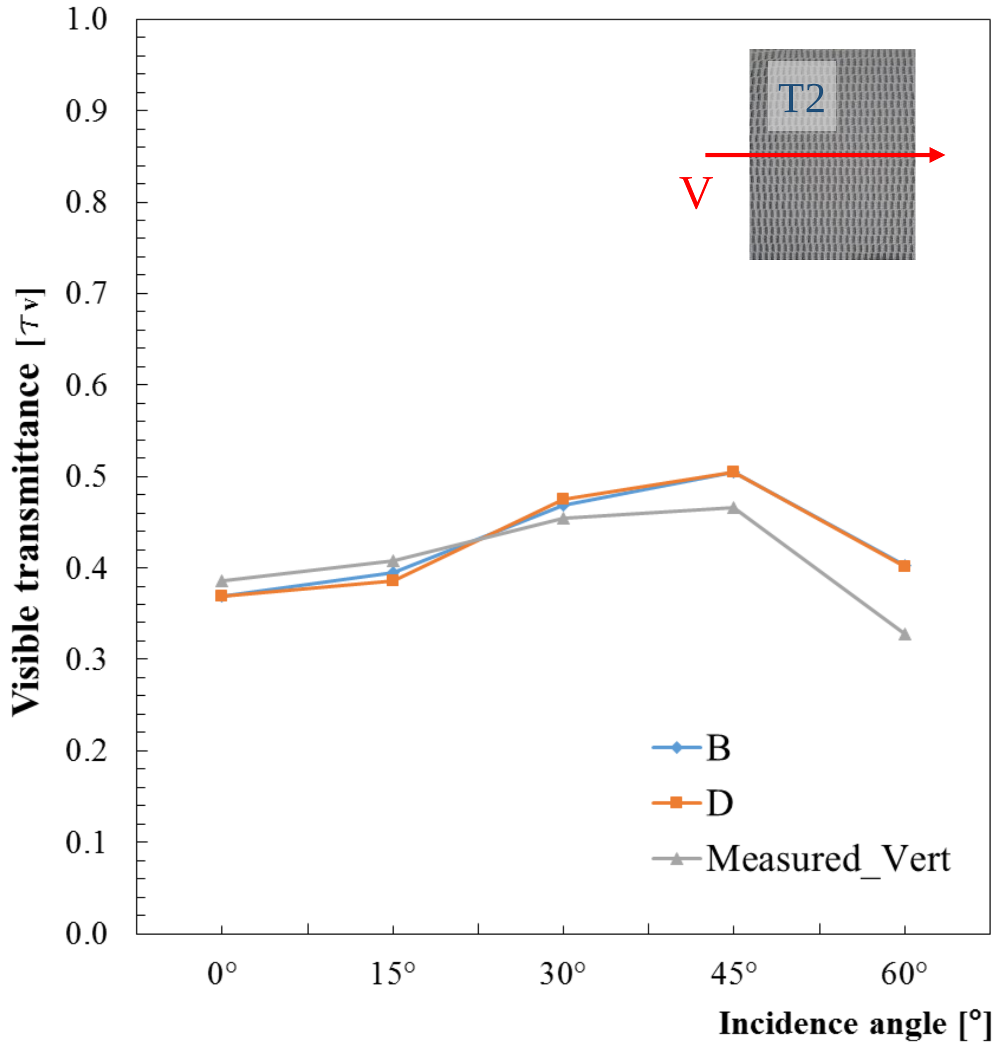




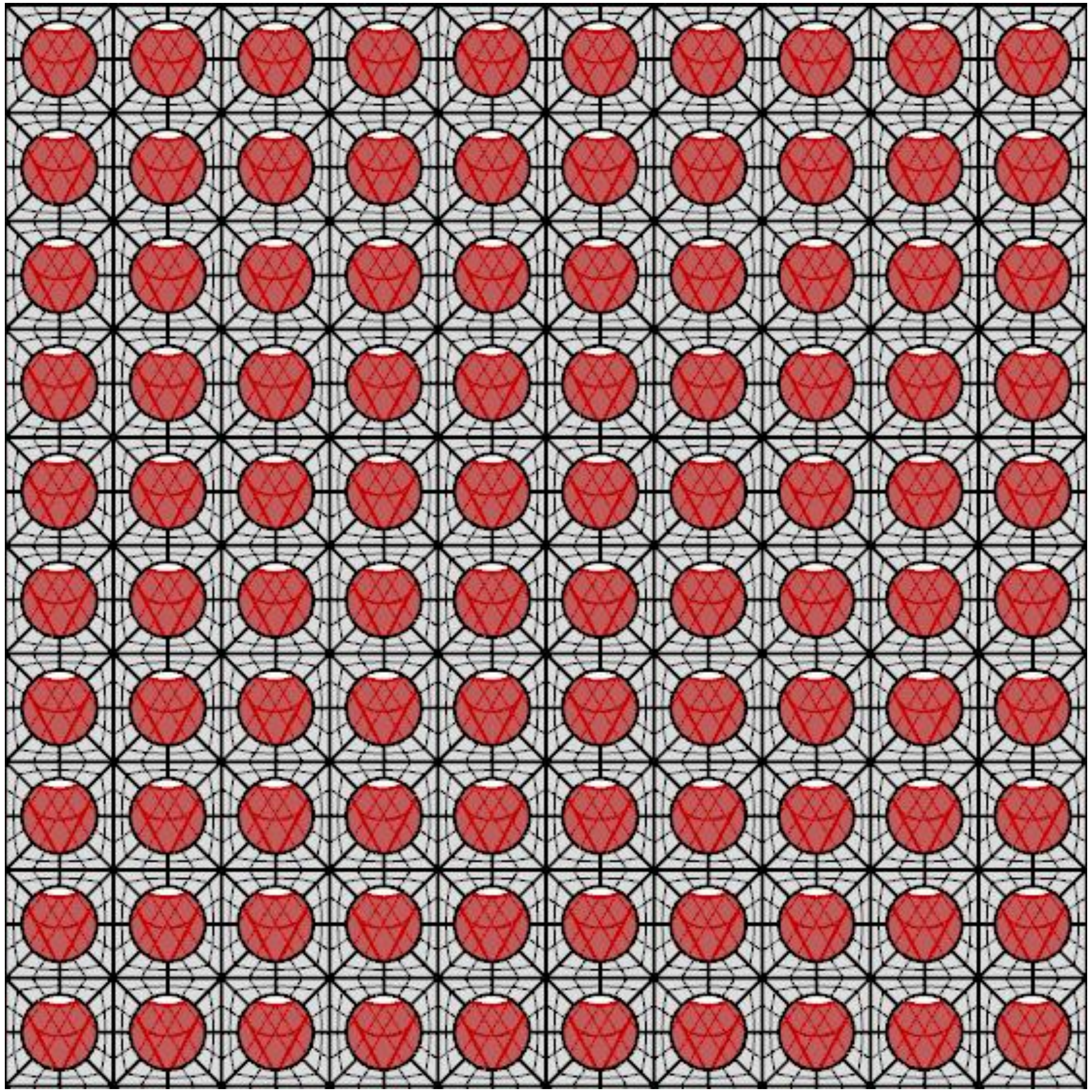
T2 - Bi-directional Scattering Distribution Function



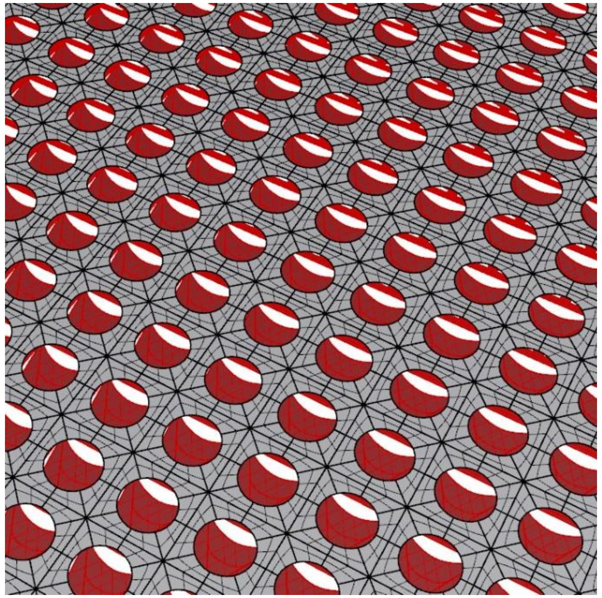


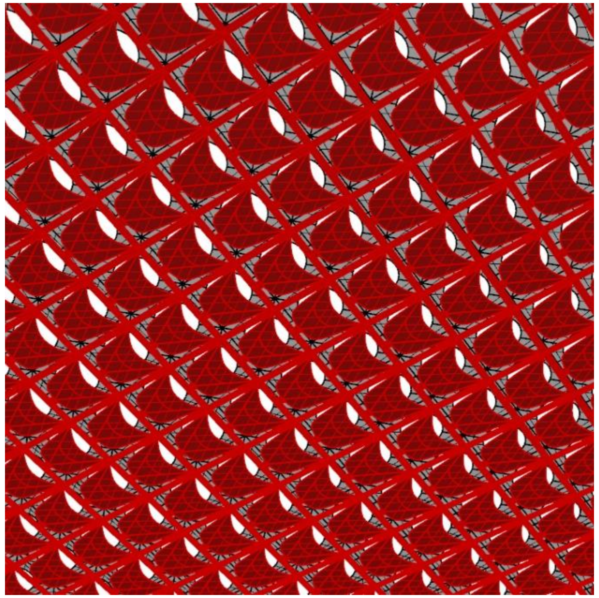


A new custom-made 3D textile

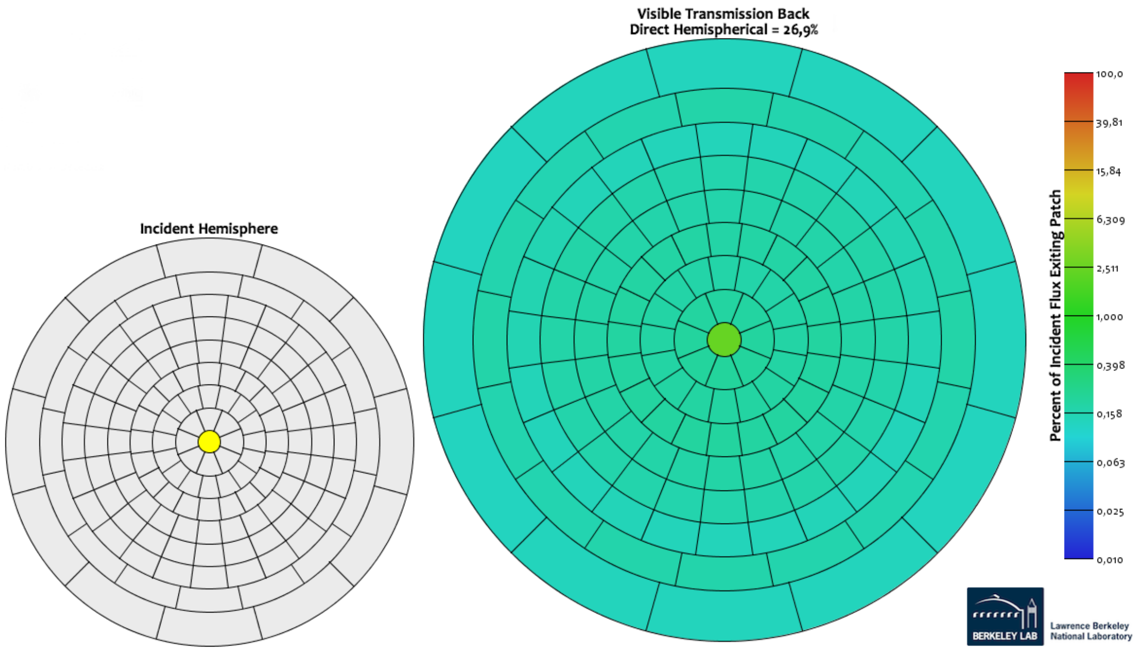


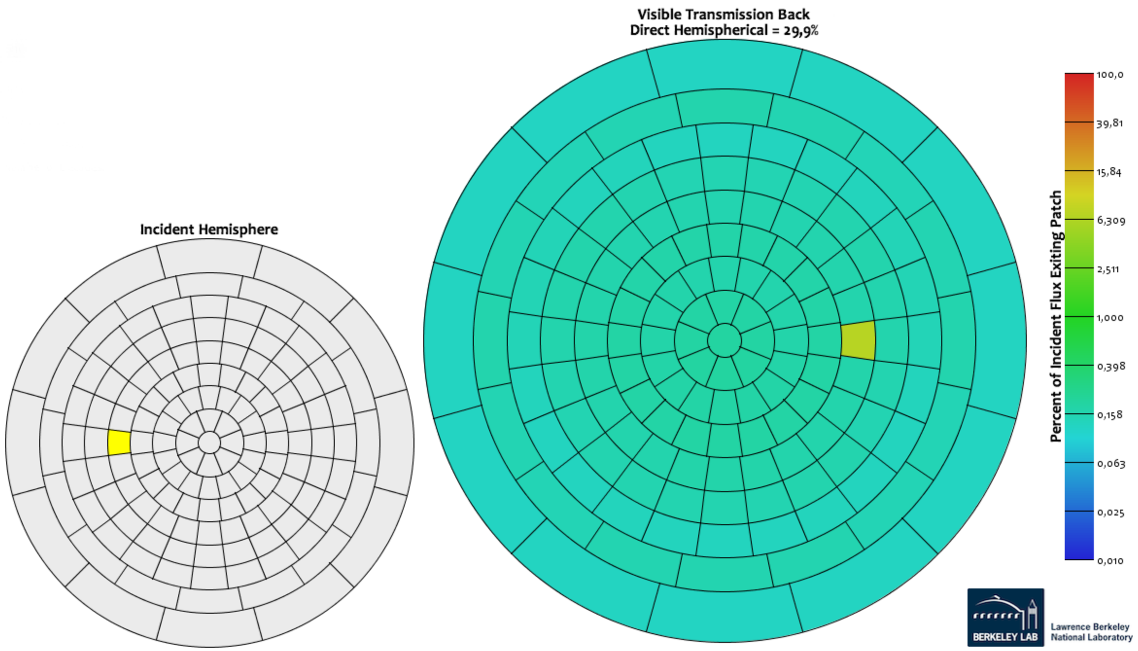
void trans TM
0
0
7 0.7 0.7 0.7 0 0 0.47 0

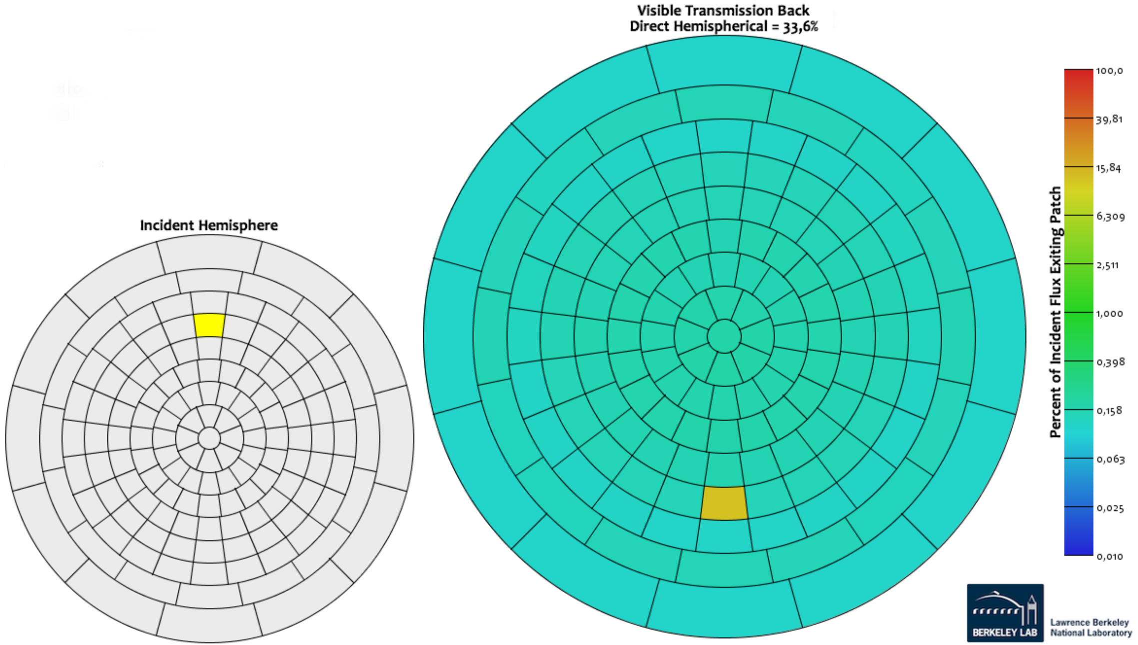


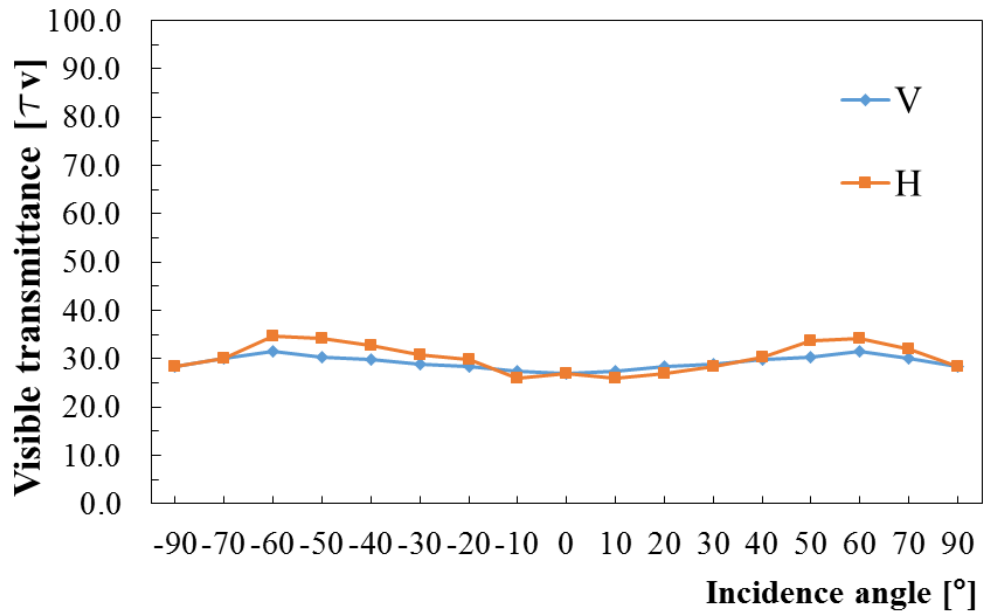


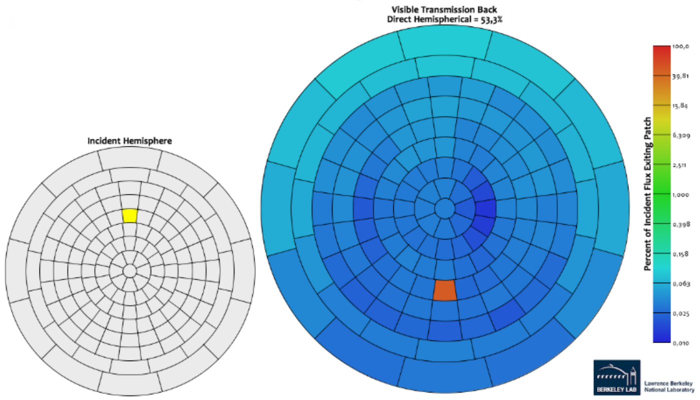
A new custom-made 3D textile

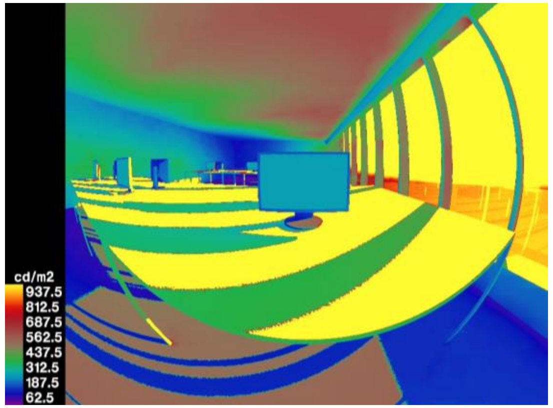








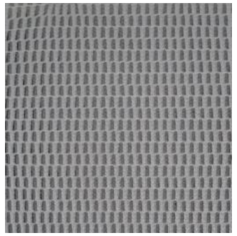
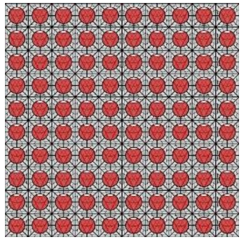




Simulations

Model

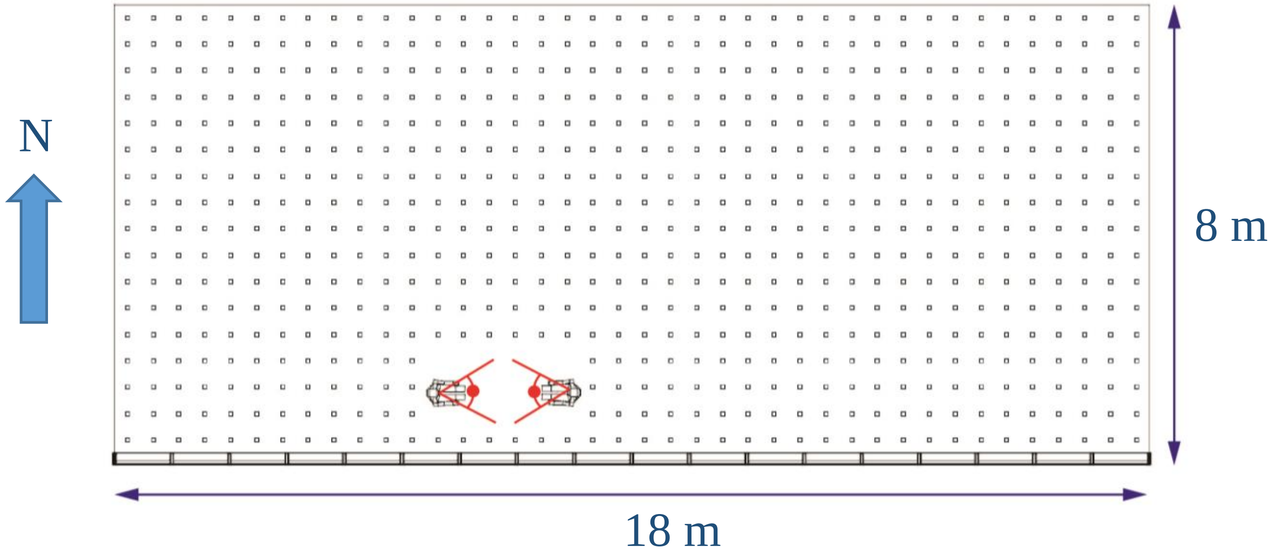
Case studies

	Glass - No Shade	void glass glazing 0 0 3 0.71 0.71 0.71
	Traditional Roller shade	void trans Roller_shade 0 0 7 0.87 0.87 0.87 0.000 0.000 0.25 0.05
	T2 - 3D Textile roller shade	void BSDF Roller_shade 6 0 Shade/T2_bsdf.xml 0 0 1 0 0
	TM - 3D Textile roller shade	void BSDF Roller_shade 6 0 Shade/TM_bsdf.xml 0 0 1 0 0

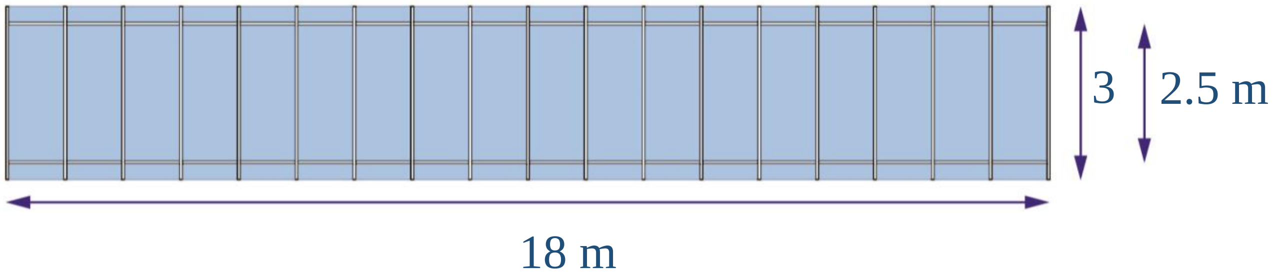
Model

Materials

	Reflectance	*Tvis*
Wall	0.5	
Floor	0.2	
Ceiling	0.8	
Furniture	0.5	
Frame	0.5	
Ground	0.3	
Glass		0.65



View position -vp 5.7 1.8 -vd 1 0 0 -vu 0 0 1
-vp 8 1.8 -vd -1 0 0 -vu 0 0 1



Sensor points 0 n0.45 0.8 0 0 1 (680 points)

Performances evaluation

Annual simulation - DA, UDI, sDA

- **rfluxmtx** through Daylight Coefficient Method

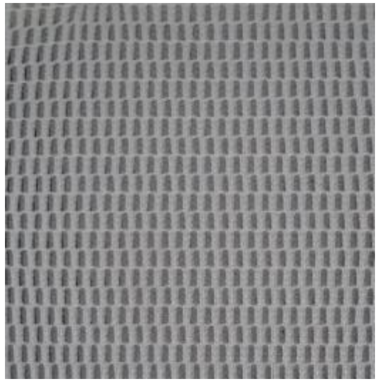
Control strategies

- Illuminance level
- Sun penetration depth

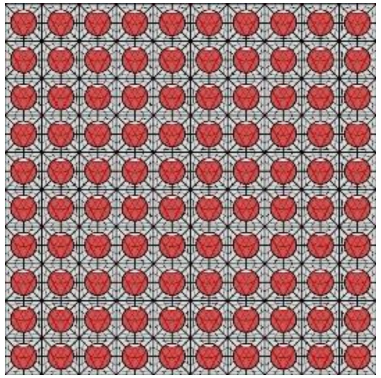
Point-in-time simulation - DGP

- **rpict** through rad

Roller shade



T2

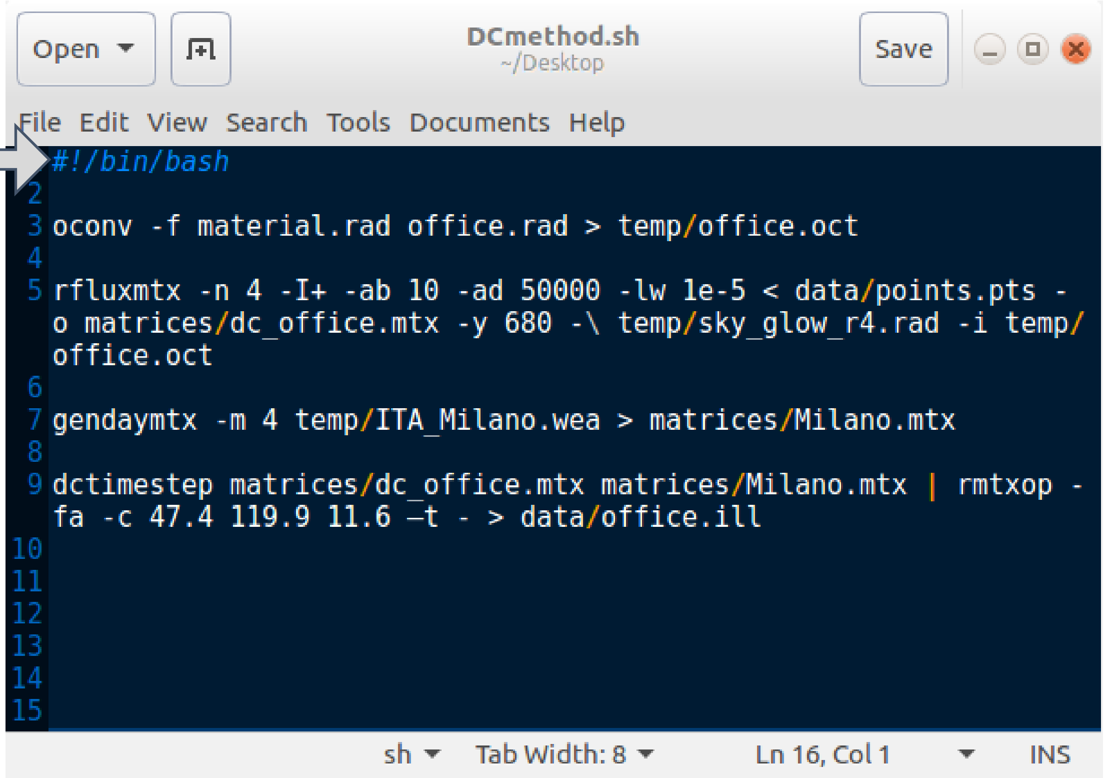


TM

Performances evaluation
Annual Simulation – DC method

DC-method procedure

```
oconv -f material.rad office.rad > temp/office.oct

rfluxmtx -n 4 -I+ -ab 10 -ad 50000 -lw 1e-5 <\
data/points.pts -o matrices/dc_office.mtx -y 680 -\
temp/sky_glow_r4.rad -i temp/office.oct

gendaymtx -m 4 temp/ITA_Milano.wea >\
matrices/Milano.mtx

dctimestep matrices/dc_office.mtx\
matrices/Milano.mtx | rmtxop -fa -c 47.4 119.9 11.6 –t\
- > data/office.ill
```




```
$ sh DCmethod.sh
```

Performances evaluation

Annual Simulation – DC method

Parametric analysis with bash

office.rad

office+rollershade.rad

office+T2_v02.rad

office+TM.rad

```
!xform objects/material.rad
!xform objects/ground.rad
!xform objects/forniture.rad | xform -t 0 .6 0
!xform objects/OpenOffice.rad

!xform objects/Roller_shadeTM.rad
```

Oconv + DC matrices

Sky matrix

dctimestep

```
#!/bin/bash

getUserName() {
        NAME=${1%.*}  # retain the part before the colon
        NAME=${NAME##*/}  # retain the part after the last slash
        echo $NAME
}

##########################################################################################

for Model in office*.rad; do
        radModel=$(getUserName ${Model})
        echo ${radModel}
        echo "Oconv running"
        oconv -f ${radModel}.rad > temp/${radModel}.oct
        echo "done!"

##########################################################################################

        echo "DC matrix calculation"

        dcopt="-I+ -ab 12 -ad 50000 -lw 1e-5"

        for pts in data/*.pts; do
                len=$(wc -l < "$pts")
                namePts=$(getUserName $pts)
                echo "matrix for ${namePts}"
                rfluxmtx -n 4 ${dcopt} < ${pts} -o matrices/${namePts}_${radModel}.dc -y ${len}
- temp/sky_glow1_r1.rad -i temp/${radModel}.oct
        done
        echo "done"
done

##########################################################################################

echo "Sky matrix generation"

weather="ITA_Milano"

m=4
for wea in temp/${weather}.wea; do
        weaName=$(getUserName $wea)
        echo ${weaName}
        gendaymtx -m ${m} ${wea} > matrices/m${m}_${weaName}.mtx
done
echo "done"

##########################################################################################

echo "dctimestep calculation"

for dc in matrices/*.dc; do
        for wea in matrices/*.mtx; do
                dcName=$(getUserName $dc)
                weaName=$(getUserName $wea)
                echo "${dcName}_${weaName}.dat running"
                dctimestep ${dc} ${wea} | rmtxop -fa -c 47.4 119.9 11.6 -t - > data/${dcName}_
${weaName}.dat

        done
done
echo "done"
```

Annual results

Office_NoShade.ill

Office+Roller_Shade_trans.ill

Office+shade_bsdfT2New.ill

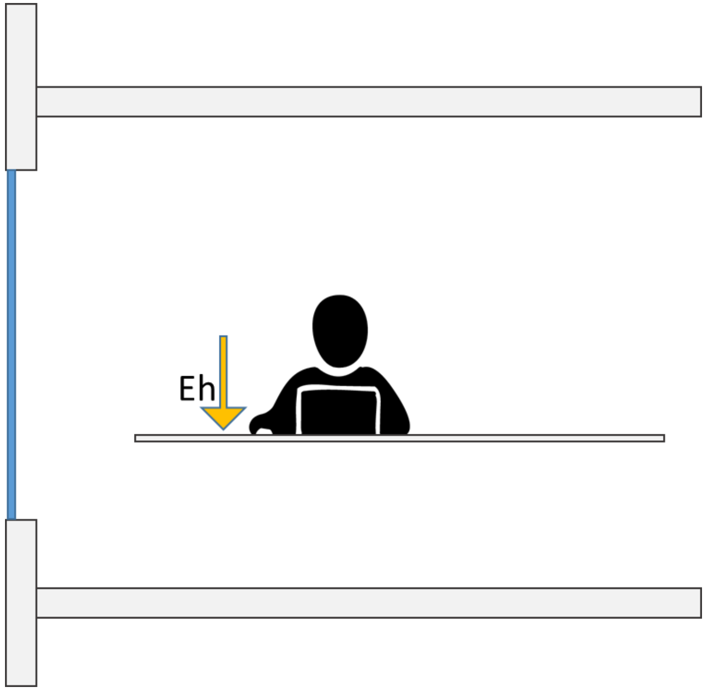
Office+shade_bsdfTM.ill

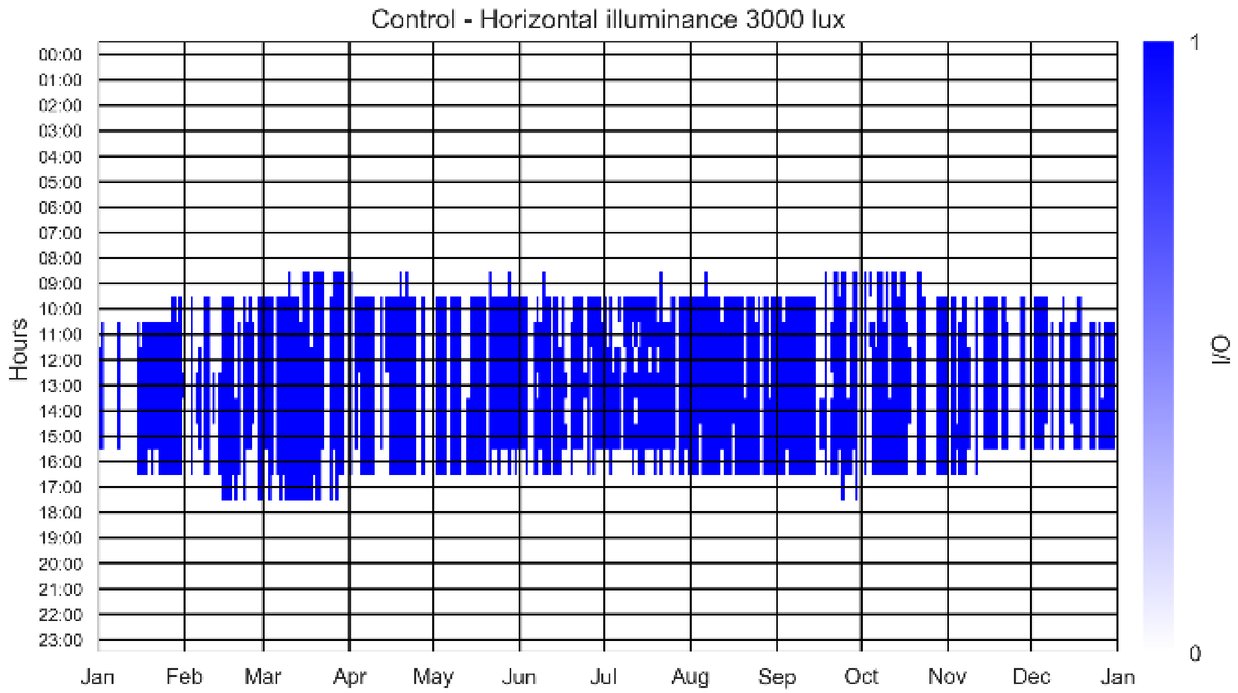
Performances evaluation

Shading control strategies

Horizontal illuminance

- Requires a first run of simulation
- Extract a sensor from the annual simulation with glass – 1.8 m away from the façade
- Shade is active if Eh > 3000 lux

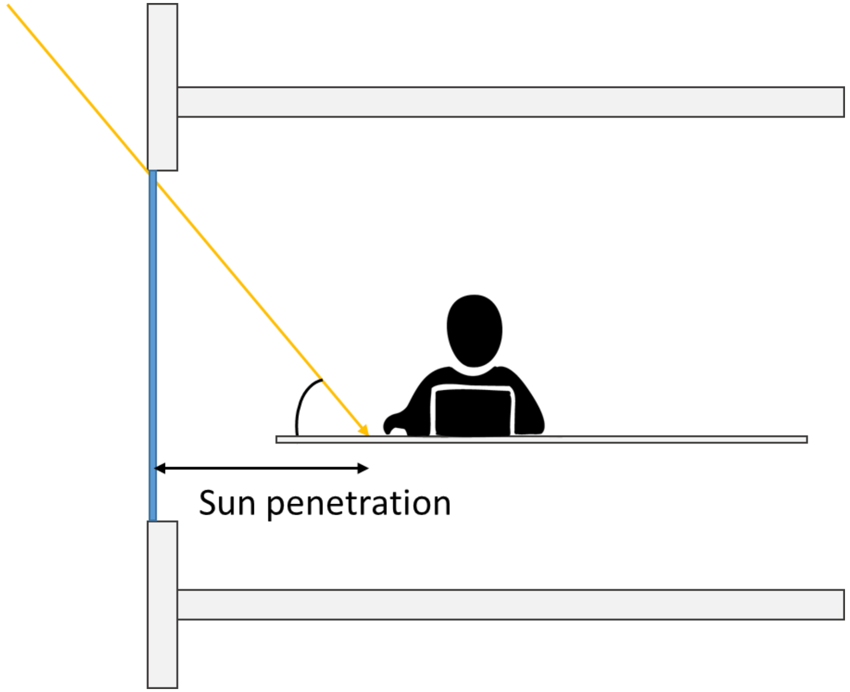


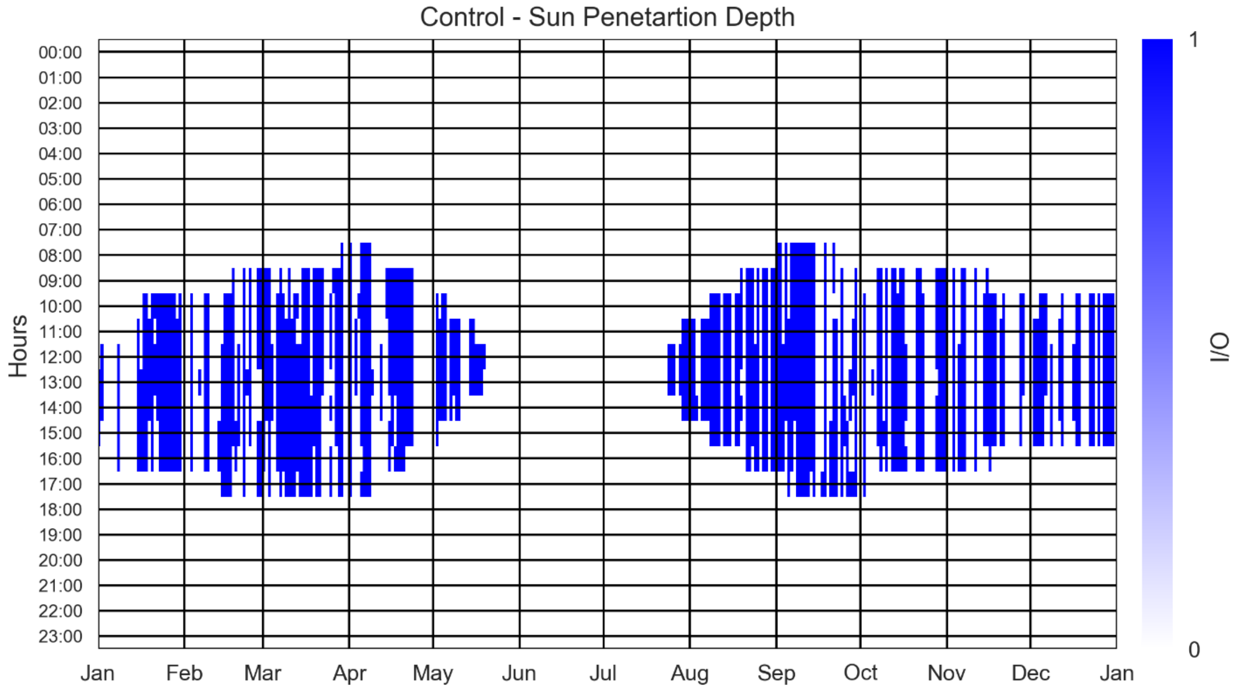


Performances evaluation
Shading control strategies

Sun Penetration Depth

- Based on sun angles analysis
- 1st condition: shade is active if the sun reaches the table - sun penetration > 0.9 m
- 2nd condition: Match statement 1 with the weather file - ratio total/diffuse hor. irr. > 1.5

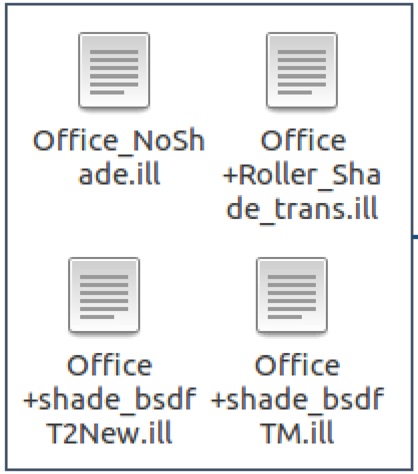




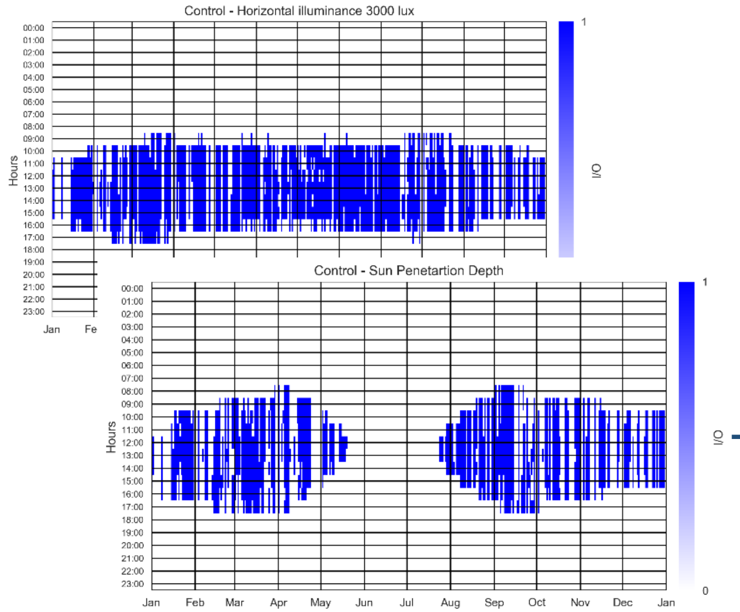
Performances evaluation

Post processing

Annual illuminance results



Control strategies

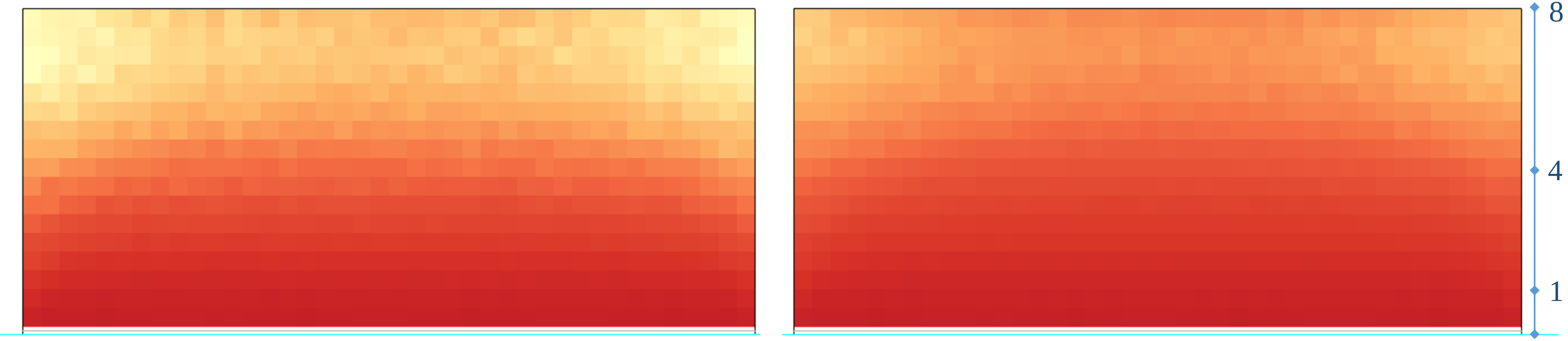



```
times = pd.date_range(start_time, end_time, freq="H")

noShade = pd.read_csv('Office_NOshade.dat',header = None, sep='\t', skiprows=7)
noShade.drop(noShade.columns[len(noShade.columns)-1], axis=1, inplace=True)

noShade.columns = ["Sensor_%i [lux]" % i for i in range(1,len(noShade.columns)+1)]

sensor = noShade["Sensor_310 [lux]"]

n = len( sensor )
noSh = np.empty(n)
Sh = np.empty(n)

for i in range(n):
    if sensor[i]>3000:
        IO = 1.
        OO = 0.
    else:
        IO = 0.
        OO = 1.
    Sh [i] = IO
    noSh [i] = OO

ctrl = pd.DataFrame(list(zip(Sh,noSh)))

noShadeIll = noShade.mul(ctrl[1], axis=0)

for of in glob.glob('Office+*.ill'):
    print(of)

    shade = pd.read_csv(of,header = None, sep='\t', skiprows=7)

    shade.drop(shade.columns[len(shade.columns)-1], axis=1, inplace=True
    shade.columns = ["Sensor_%i [lux]" % i for i in range(1,len(shade.co

    ShadeIll = shade.mul(ctrl[0], axis=0)

    illum = noShadeIll.add(ShadeIll)

    illum.to_csv("Eh_shadingControl_"+of, sep="\t", index=False)
```

Python+Panads

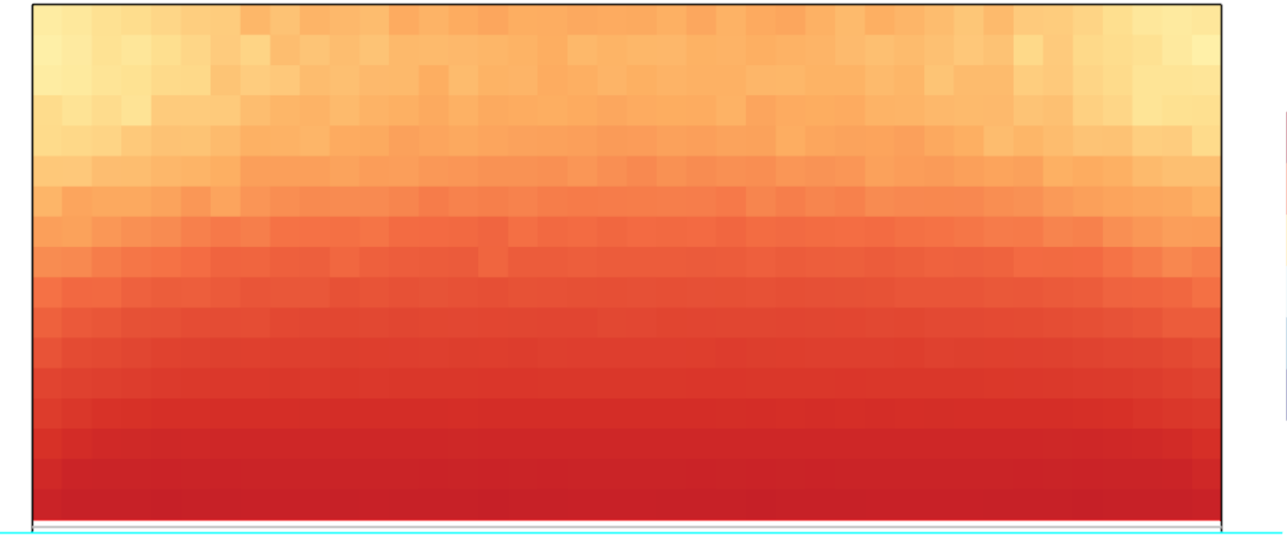
- Combined illuminance values
- CBDM indexes analysis

Daylight autonomy – Sun penetration control

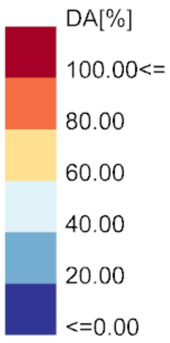


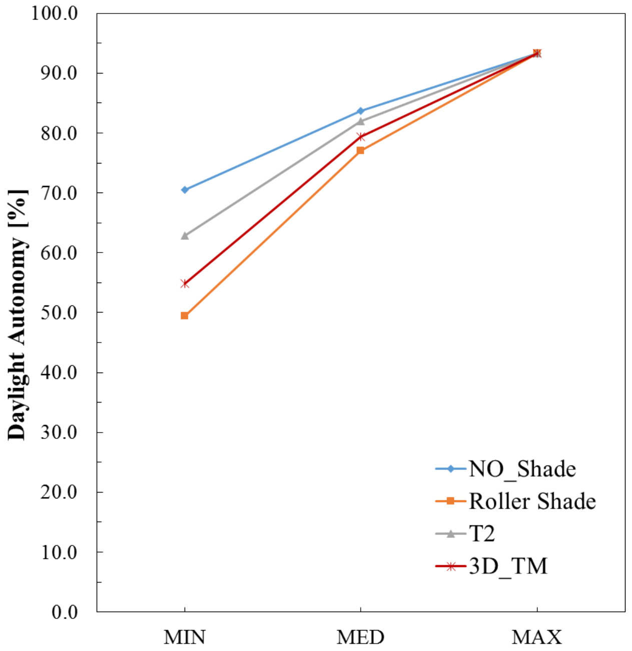
Roller Shade DA = 77.0% sDA = 99%

T2 DA = 81.9% sDA = 100%



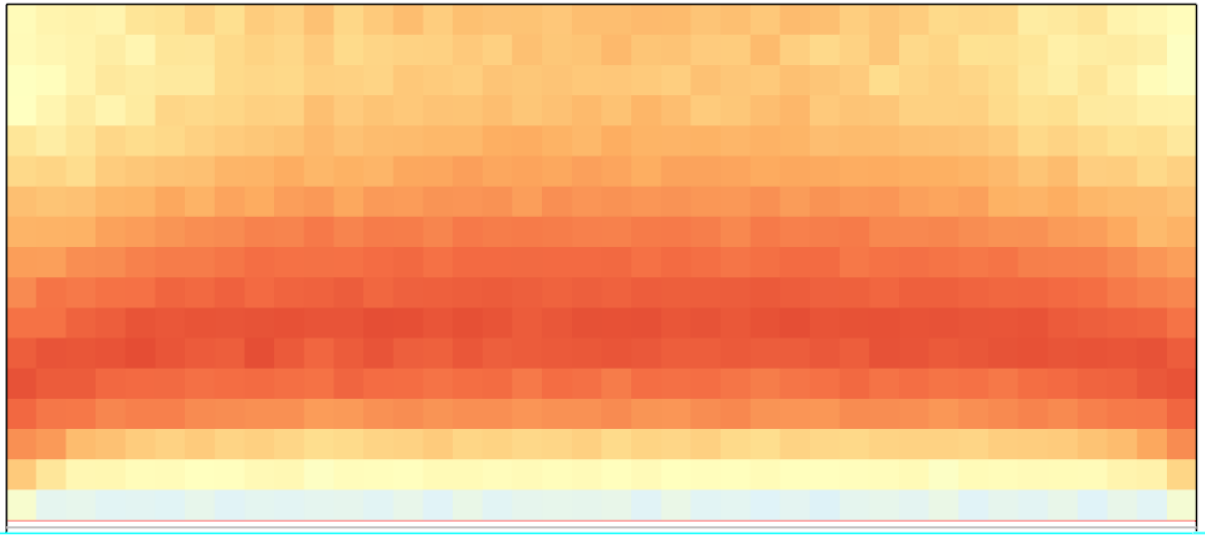
TM DA = 79.4% sDA = 100%



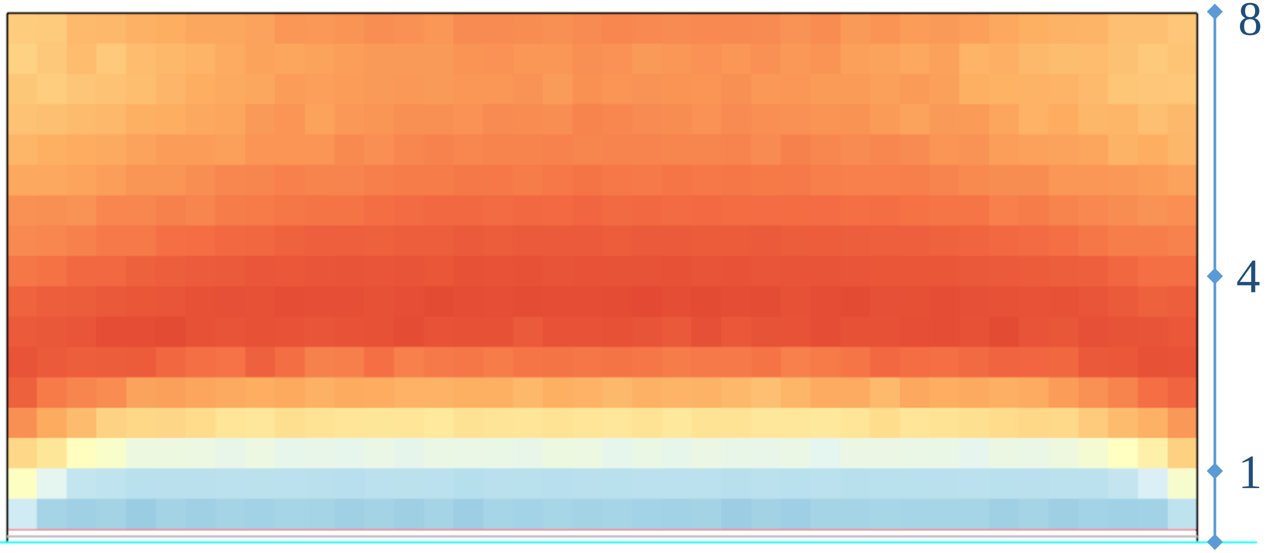


300<UDI<3000 – Sun penetration control

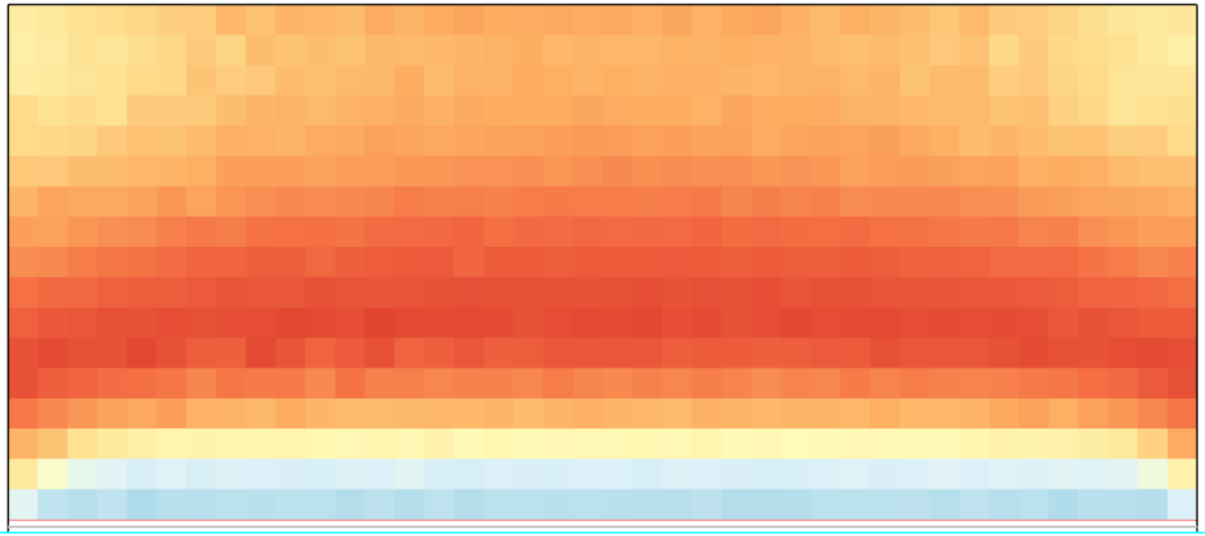
Results



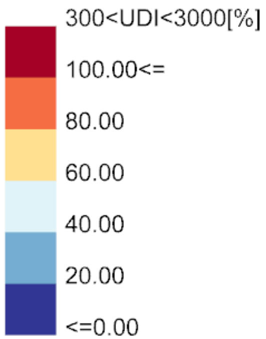
Roller Shade UDI = 68.5%

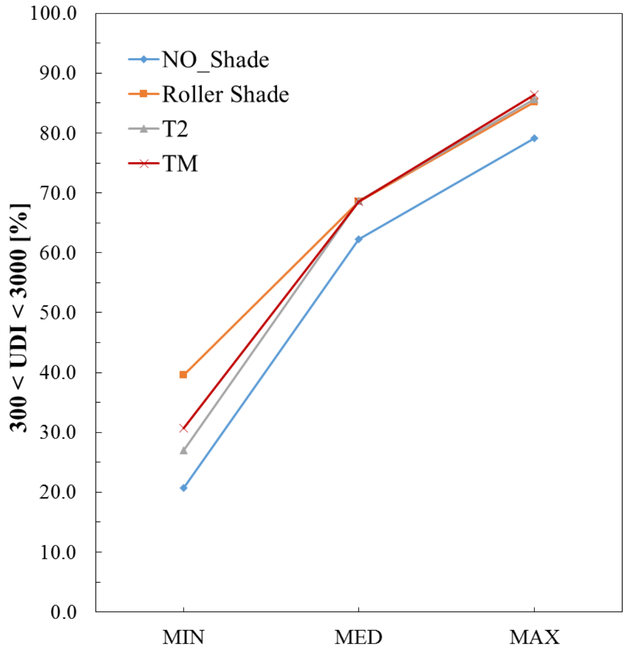


T2   UDI = 68.7%



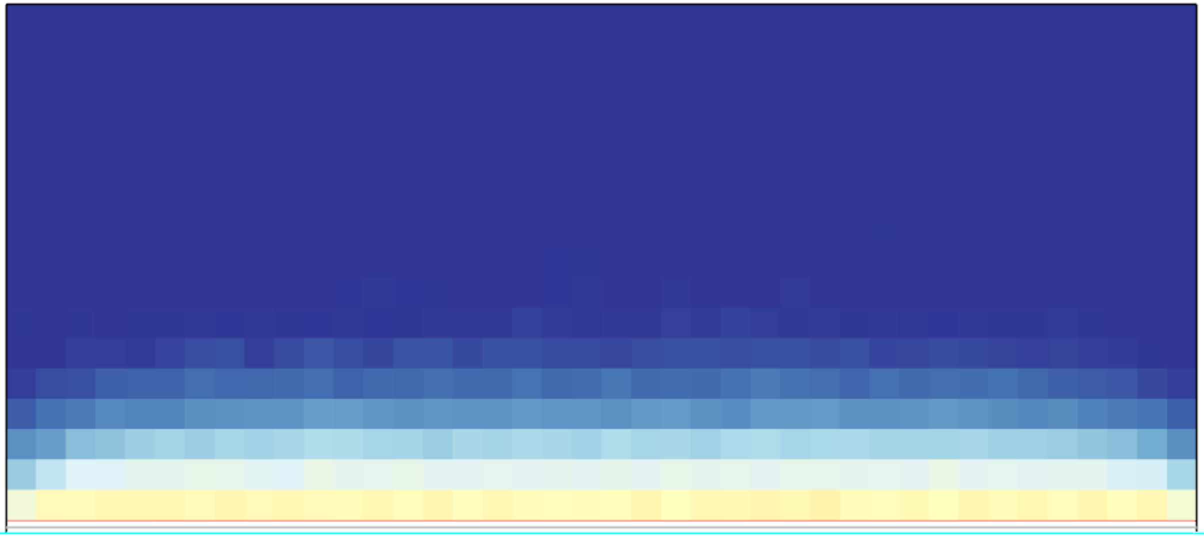
TM   UDI = 68.6%



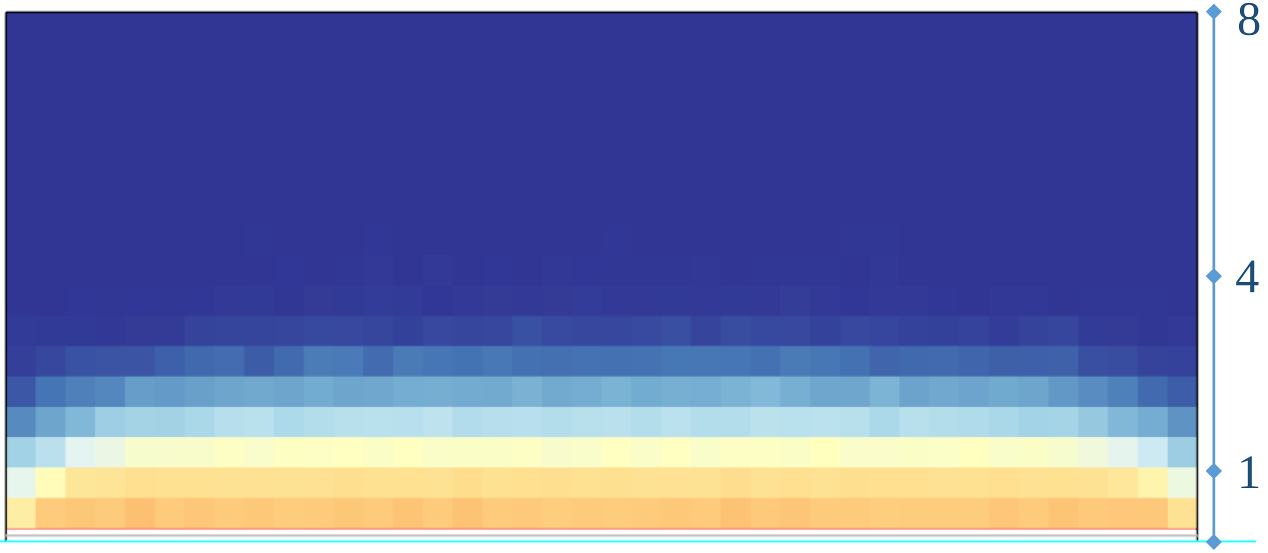


UDI>3000 – Sun penetration control

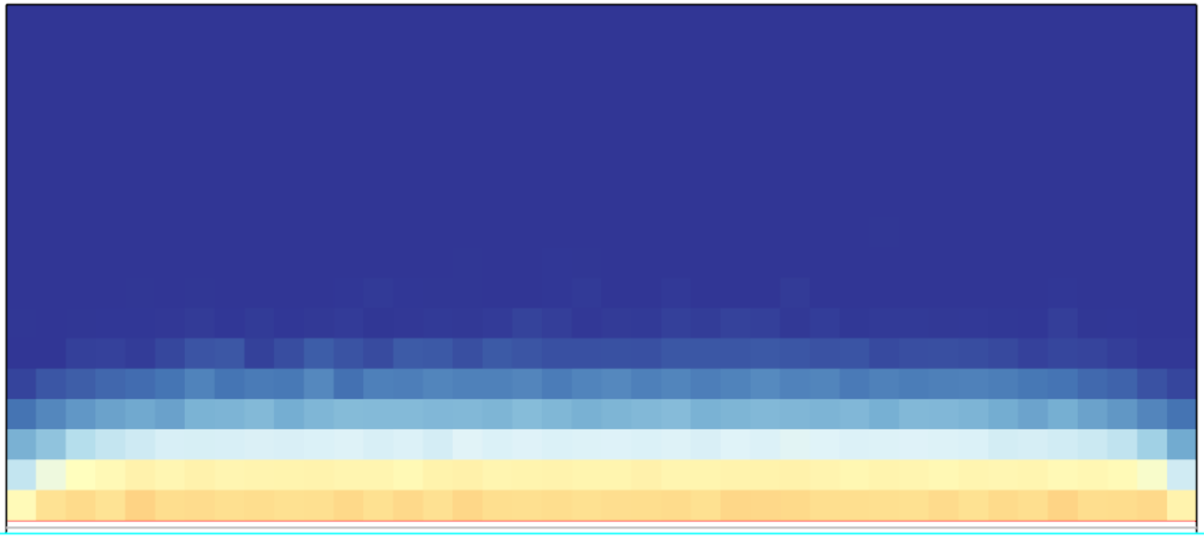
Results



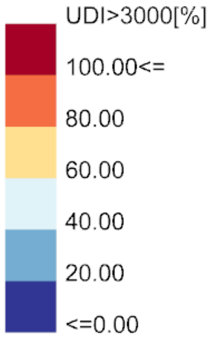
Roller Shade UDI = 8.5%

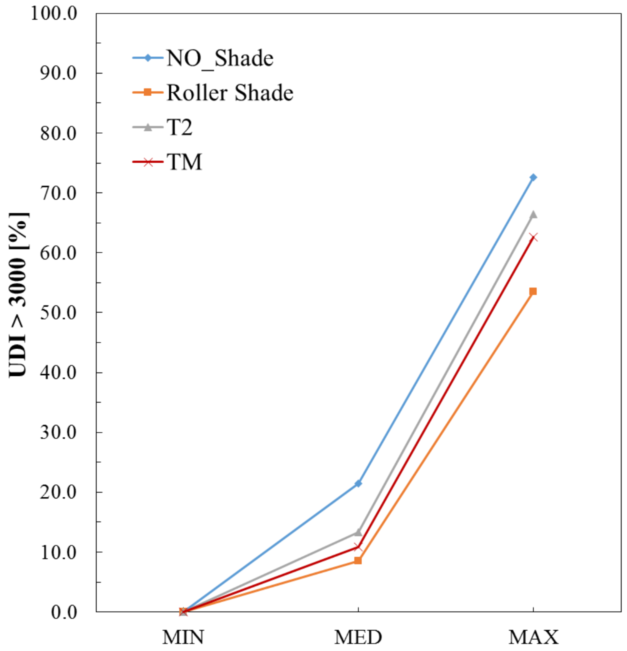


T2 UDI = 13.3%

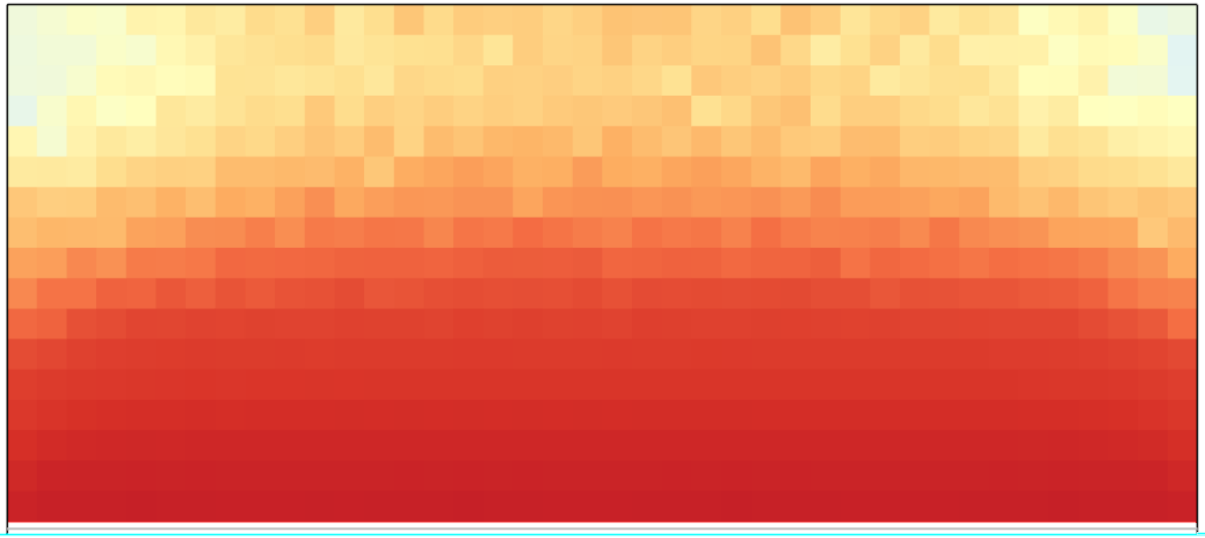


TM UDI = 10.8%

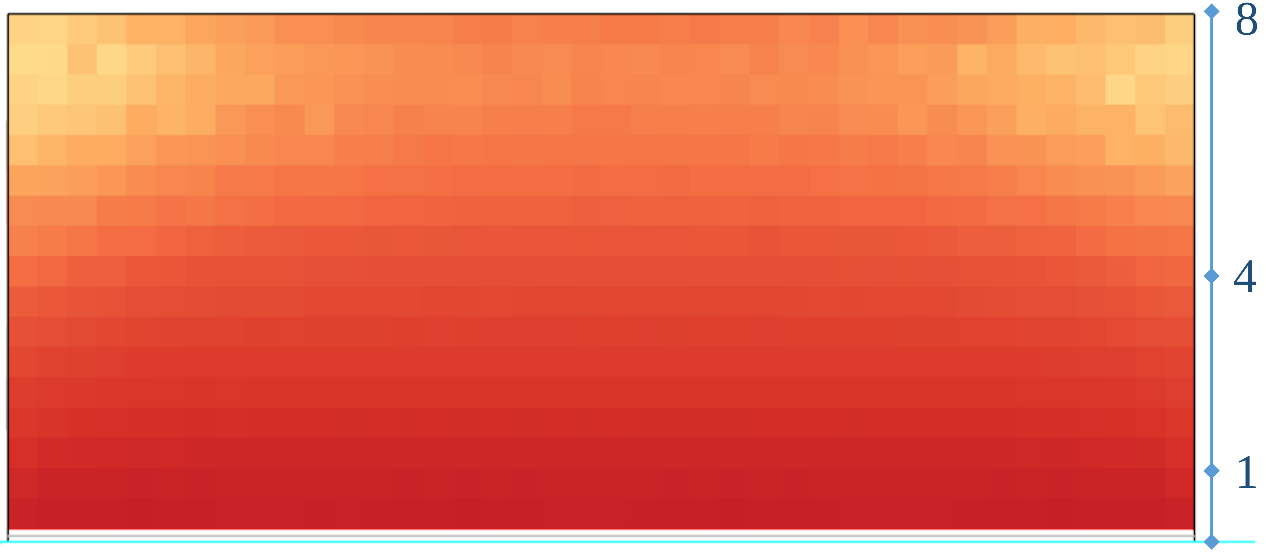




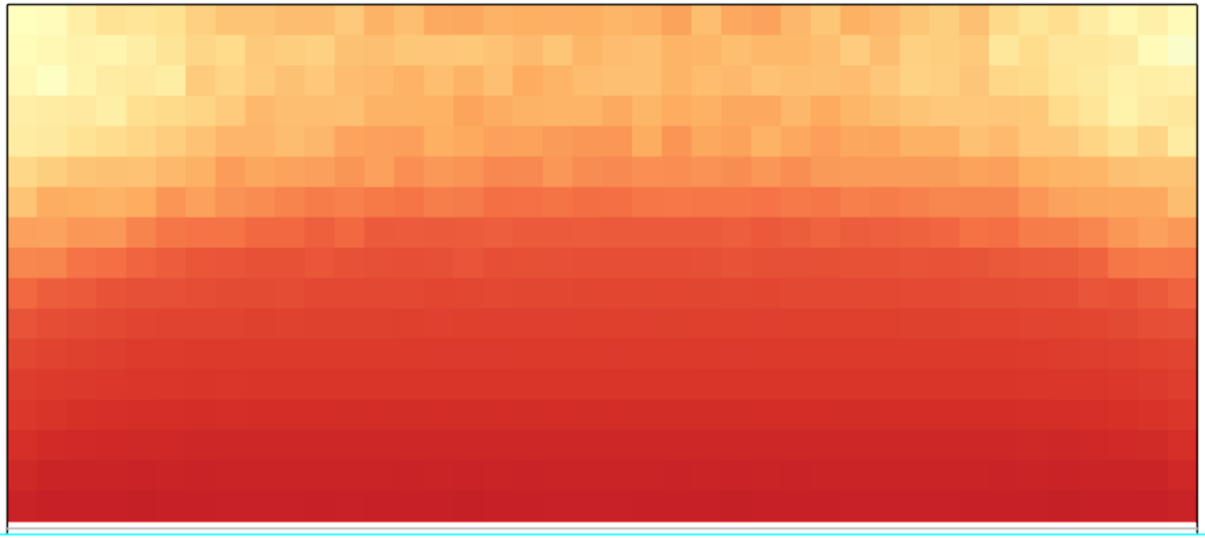
Daylight autonomy – Eh control



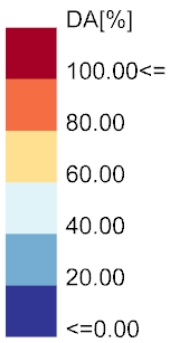
Roller Shade DA = 76.3% sDA = 96%

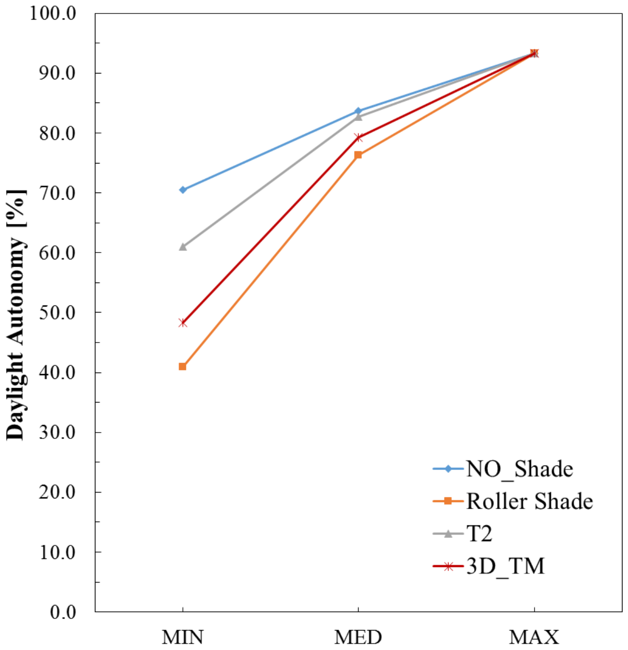


T2   DA = 82.7%   sDA = 100%

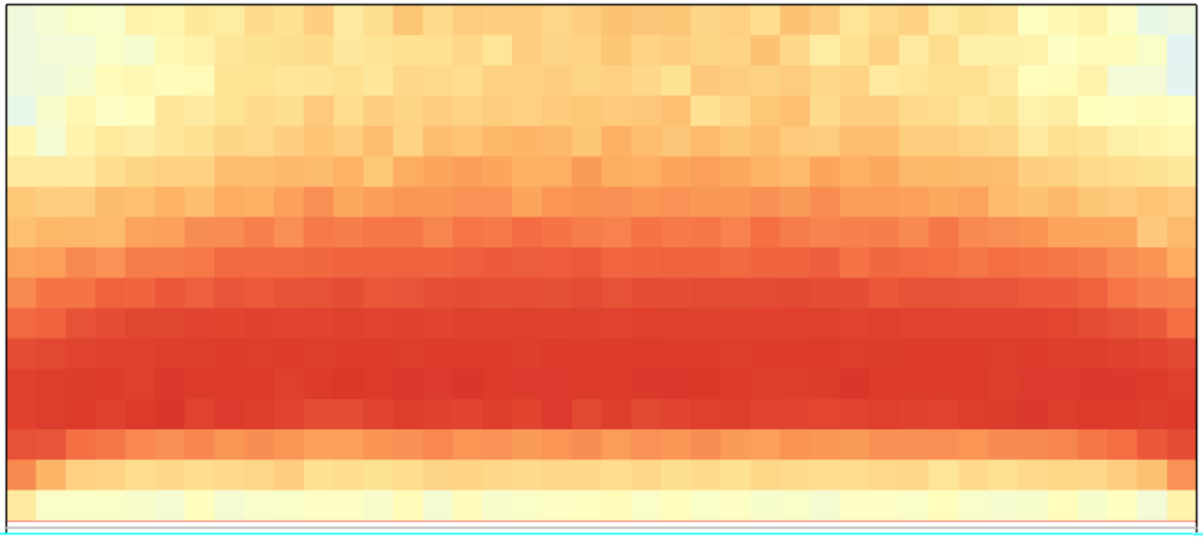


TM   DA = 79.3% sDA = 100%

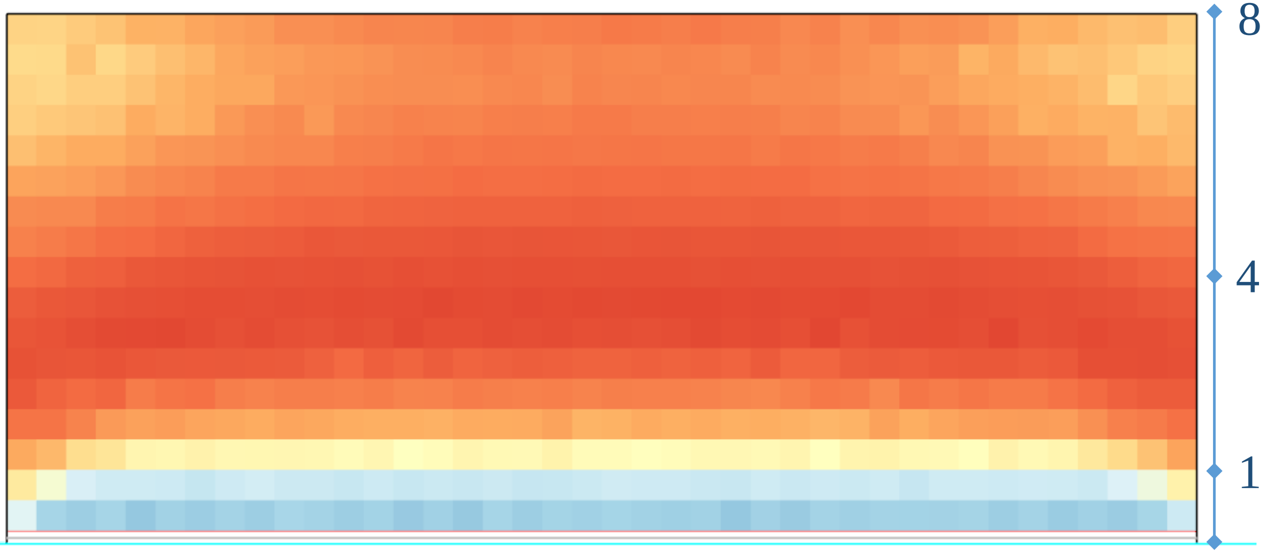




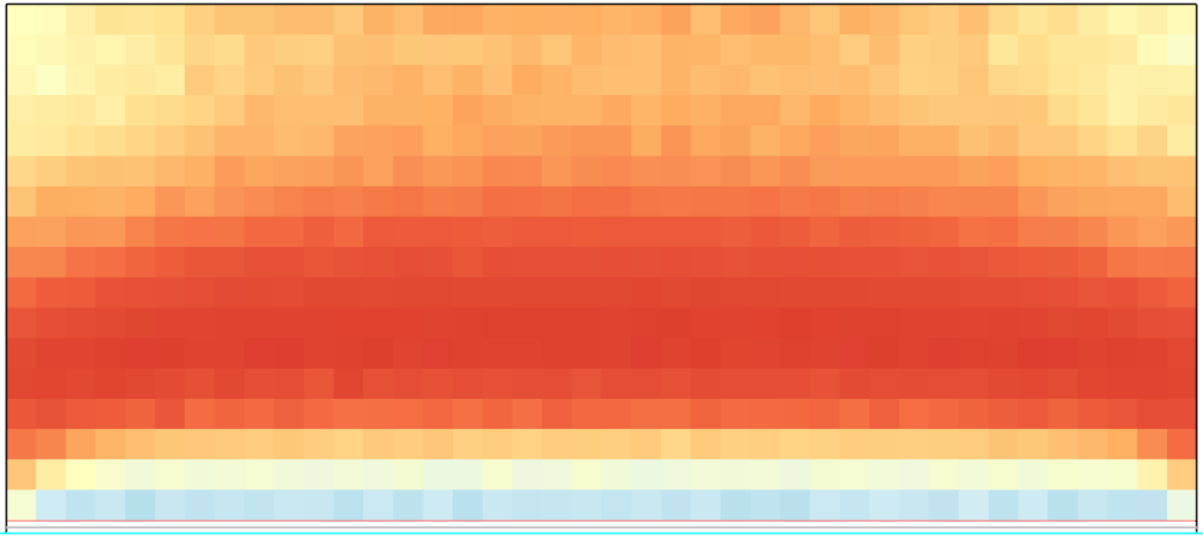
300<UDI<3000 – Eh control



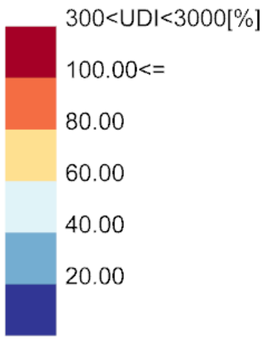
Roller Shade UDI = 70.8%

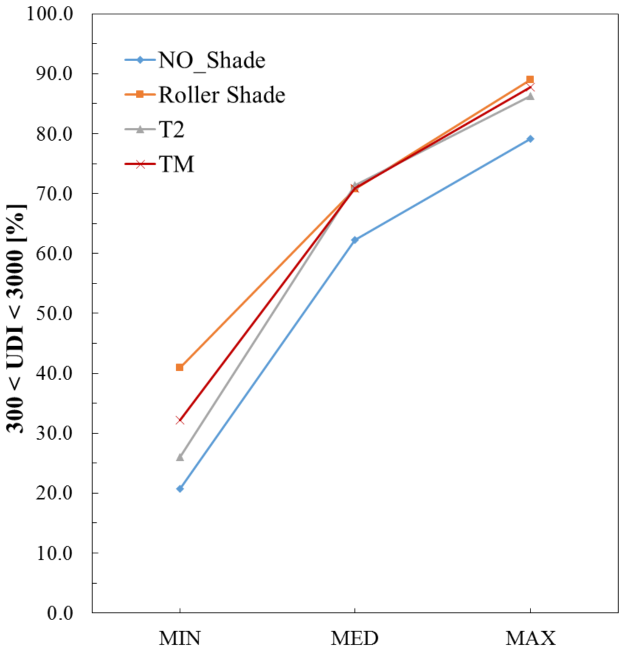


T2 UDI = 71.3%



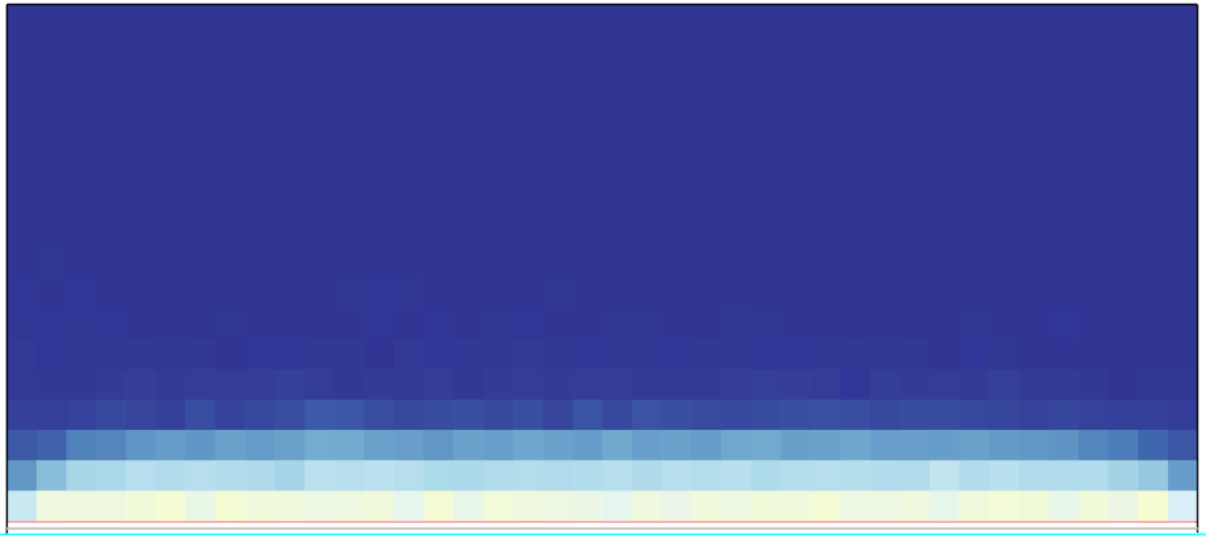
TM UDI = 71%



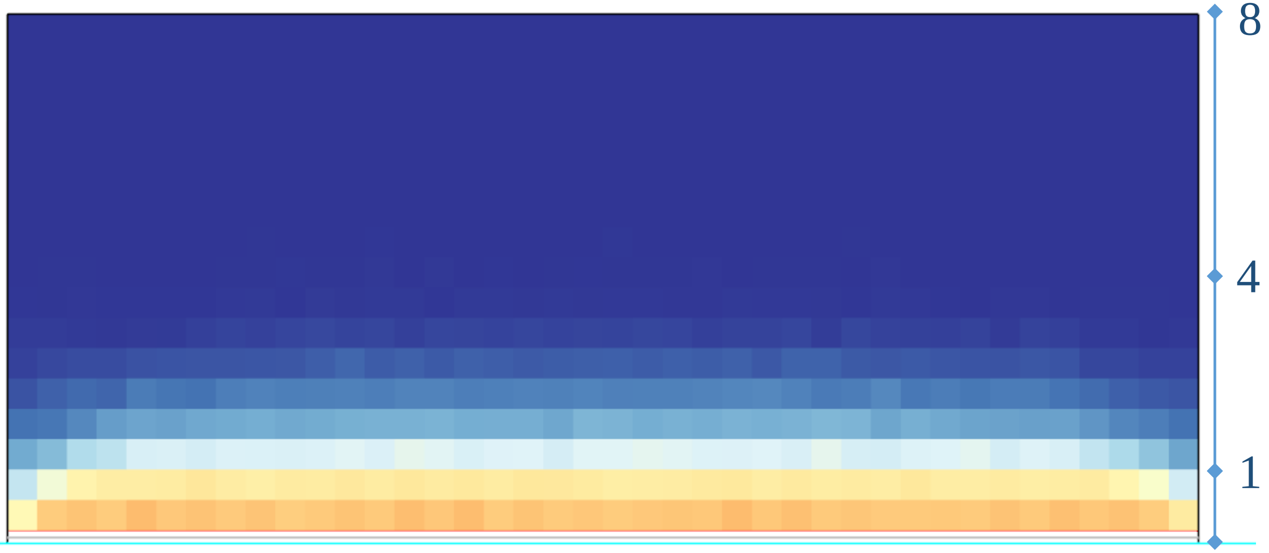


UDI>3000 – Eh control

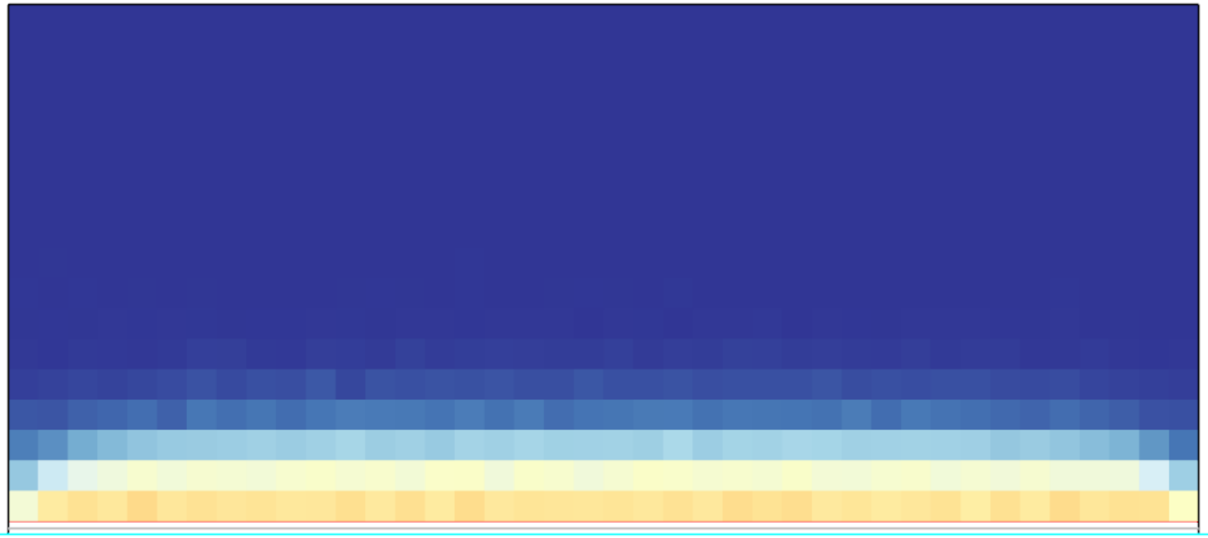
Results



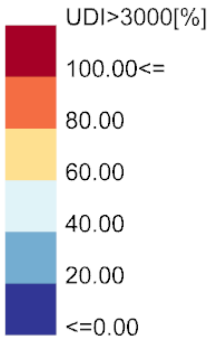
Roller Shade UDI = 5.6%

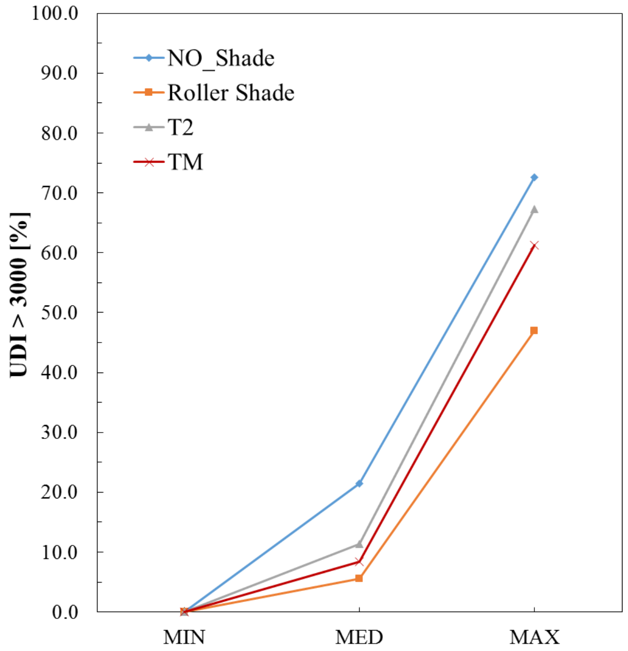


T2 UDI = 11.3%



TM UDI = 8.4%





Summary Results

NO STRATEGY CONTROL						
	DA 300	*UDI<100*	*100<UDI<300*	*300<UDI<3000*	*UDI>3000*	*sDA300*
NO_Shade	83.74	8.56	7.70	62.24	21.50	100%
Roller Shade	50.06	26.17	23.77	47.50	2.56	44%
T2	63.55	18.99	17.46	55.11	8.44	78%
3D_TM	55.89	22.97	21.14	50.48	5.42	54%

STRATEGY CONTROL Sun Penetration						
	DA 300	*UDI<100*	*100<UDI<300*	*300<UDI<3000*	*UDI>3000*	*sDA300*
NO_Shade	83.74	8.56	7.70	62.24	21.50	100%
Roller Shade	77.01	9.04	13.95	68.51	8.50	99%
T2	81.98	8.58	9.44	68.67	13.31	100%
3D_TM	79.39	8.76	11.84	68.58	10.82	100%

STRATEGY CONTROL Eh						
	DA 300	*UDI<100*	*100<UDI<300*	*300<UDI<3000*	*UDI>3000*	*sDA300*
NO_Shade	83.74	8.56	7.70	62.24	21.50	100%
Roller Shade	76.36	8.56	15.08	70.79	5.57	96%
T2	82.67	8.55	8.78	71.32	11.35	100%
3D_TM	79.31	8.55	12.14	70.92	8.39	100%

Performances evaluation

point-in-time simulation – rpict/rad

- Analysis over the standard days
  - 21st of March, June and December
  - 9:00-17:00 hours
- Perez sky + epw data
- Creation of the input*.rif file

Procedure to generate the sky file for the selected days

1. Extend the period of analysis
   14-30th March 9:00-17:00
   14-30th June 9:00-17:00
   14-30th December 9:00-17:00
2. Filter the clear hours on the epw
3. Average values of Direct Normal and Diffuse Horizontal Irr. -> gendaylit $M $D $h –W DN DH

Performances evaluation

point-in-time simulation – rpict/rad

- Creation of the input*.rif file

Select model and sky

Write and save the input *.rif file

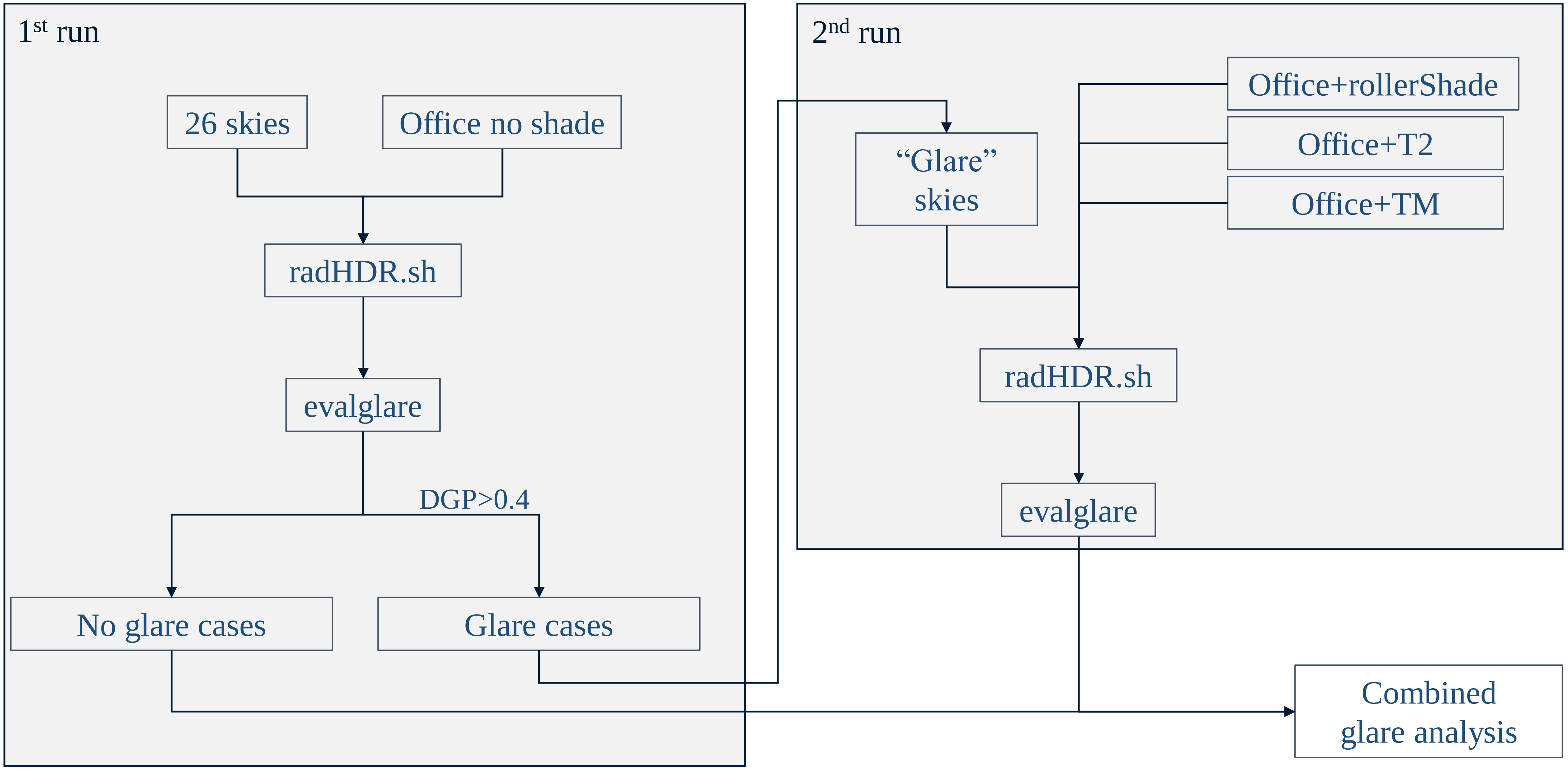
Run it with rad

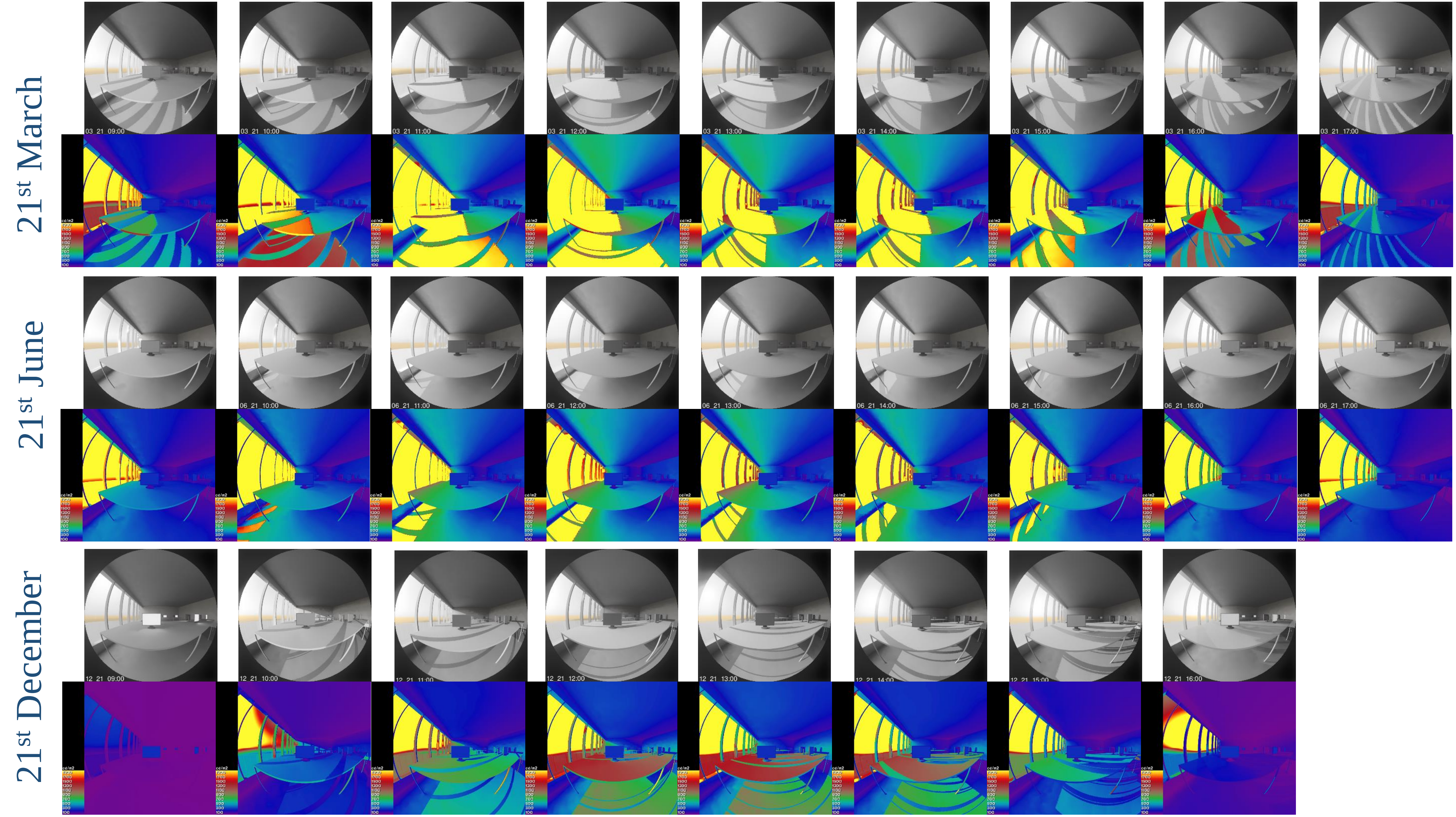
radHDR.sh

```
# generate the rif file for each model and each hour and run it

for radModel in office*; do
        mkdir images/${radModel}_vE
        mkdir rif/${radModel}_vE
        for date in temp/skies_vE/Perez_*.mat; do
                sky=$(getUserName ${date})

echo " Now running ${sky} for ${radModel}"

echo "
# Rad Input File
OCTREE= oct/${radModel}_${sky}_vE.oct
QUALITY= M
PENUMBRAS= TRUE
VARIABILITY= M
RESOLUTION= 600
INDIRECT= 4
ZONE= I 0 18 0 8 10 13


PICTURE= images/${radModel}_vE/${radModel}_${sky}
#RAWFILE= unf/office.unf
AMBFILE= amb/${radModel}_${sky}_vE.amb
materials= temp/skies/${sky}.mat
scene= ${radModel}.rad temp/skyDome.sky
view=vE -vf sensors_view/vE.vf

render= -ad 1024 -as 512 -aa .15 -lw 1e-5" > rif/${radModel}_vE/${radModel}_${sky}.rif


                rad -N 4 rif/${radModel}_vE/${radModel}_${sky}.rif


        done
done
```

Performances evaluation

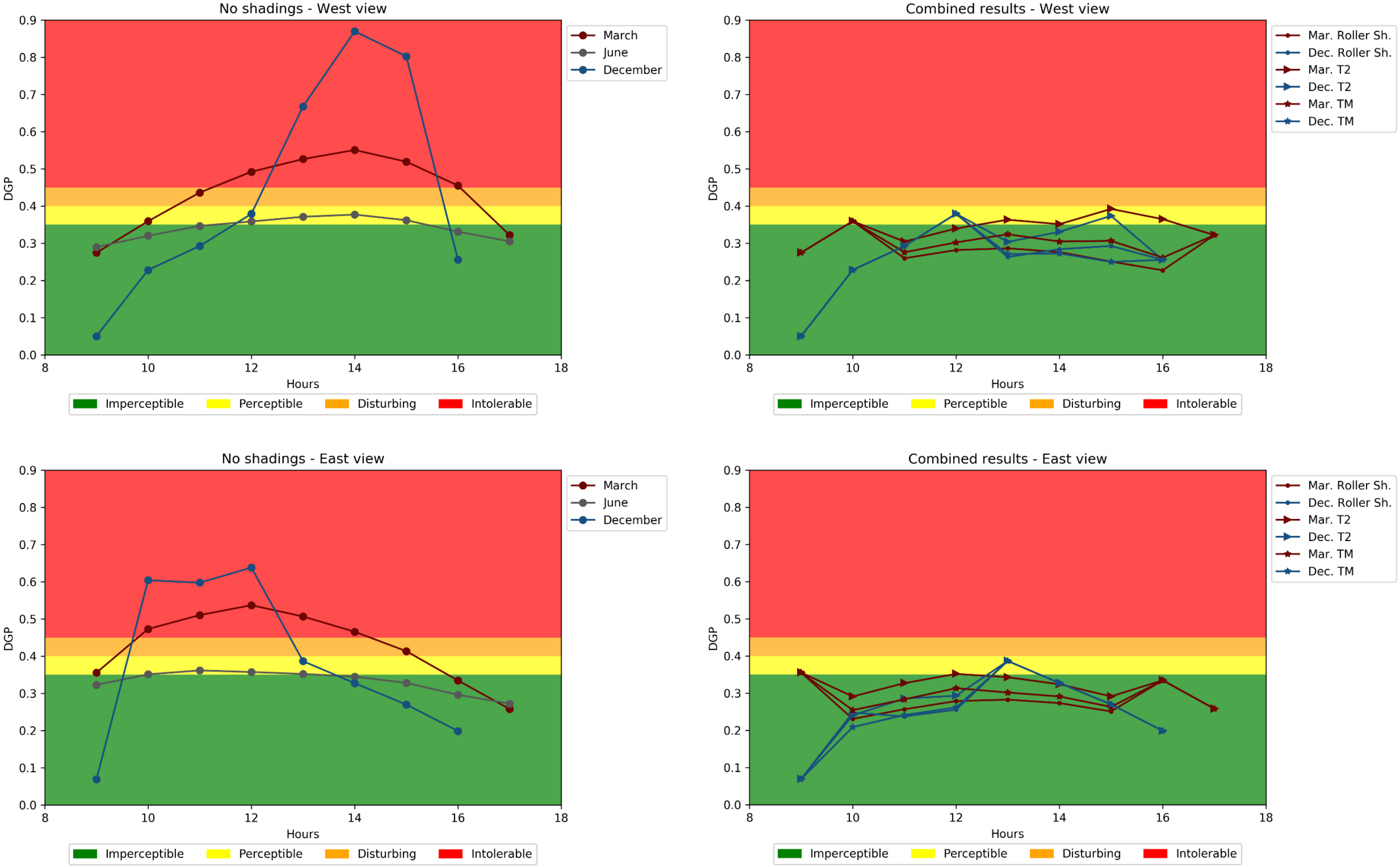
point-in-time simulation – rpict/rad



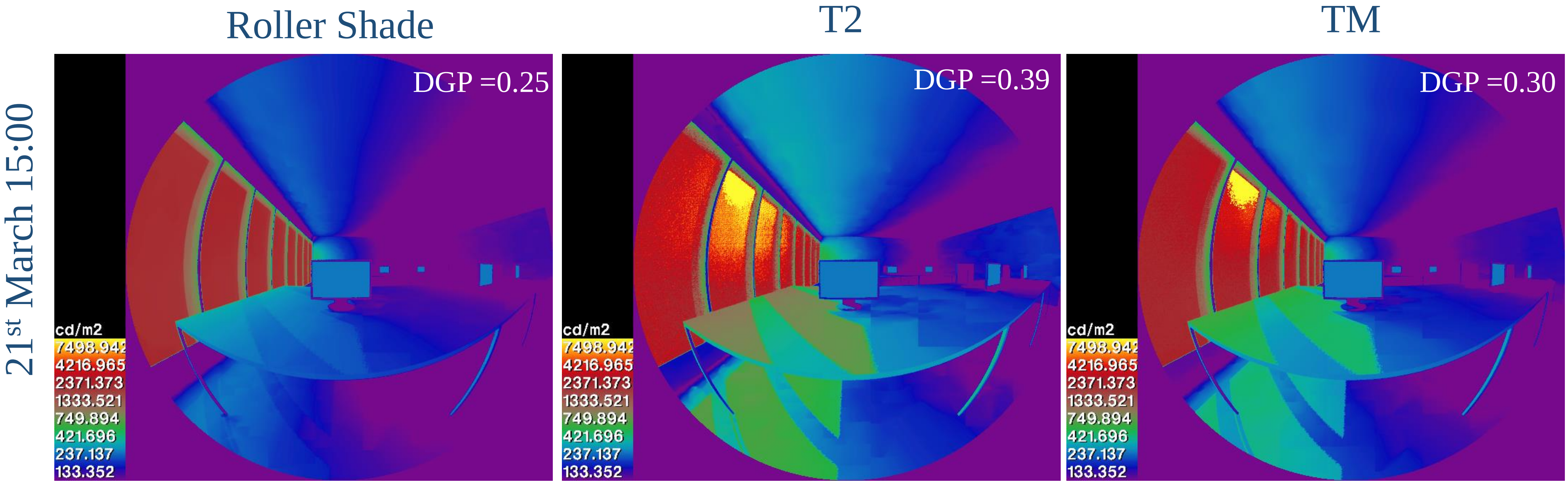

21st March
03_21_09:00
03_21_10:00
03_21_11:00
03_21_12:00
03_21_13:00
03_21_14:00
03_21_15:00
03_21_16:00
03_21_17:00
21st June
06_21_10:00
06_21_11:00
06_21_12:00
06_21_13:00
06_21_14:00
06_21_15:00
06_21_16:00
06_21_17:00
21st December
12_21_09:00
12_21_10:00
12_21_11:00
12_21_12:00
12_21_13:00
12_21_14:00
12_21_15:00
12_21_16:00

Results

DGP



No shadings - West view
Combined results - West view
No shadings - East view
Combined results - East view
DGP
Hours
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
8
10
12
14
16
18
March
June
December
Mar. Roller Sh.
Dec. Roller Sh.
Mar. T2
Dec. T2
Mar. TM
Dec. TM
Imperceptible
Perceptible
Disturbing
Intolerable



21st March 15:00
Roller Shade
T2
TM
DGP =0.25
DGP =0.39
DGP =0.30
cd/m2
7498.942
4216.965
2371.373
1333.521
749.894
421.696
237.137
133.352

Conclusion and improvements

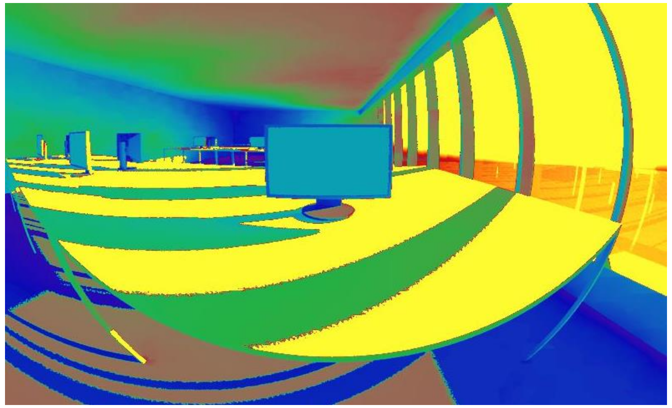
- Good fitting between measurements and model
- Improvement in annual daylight performance
- Good control of glare source over the year
- Optimized custom-made 3D textile can guarantee high performance

Conclusion and improvements

- Good fitting between measurements and model
- Improvement in annual daylight performance
- Good control of glare source over the year
- Optimized custom-made 3D textile can guarantee high performance

- Measured BSDF with photogoniometer
- Simulate the fabric surface with BRTDfunc
- Annual glare analysis
- 5-phase method with incorporated geometry





16th International Radiance Workshop
Portland, Oregon

Thank you for your attention
… any questions?

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