Adapting genBSDF for custom fenestration measurement

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Bidirectional Scattering Distribution Functions

What Is a BSDF?

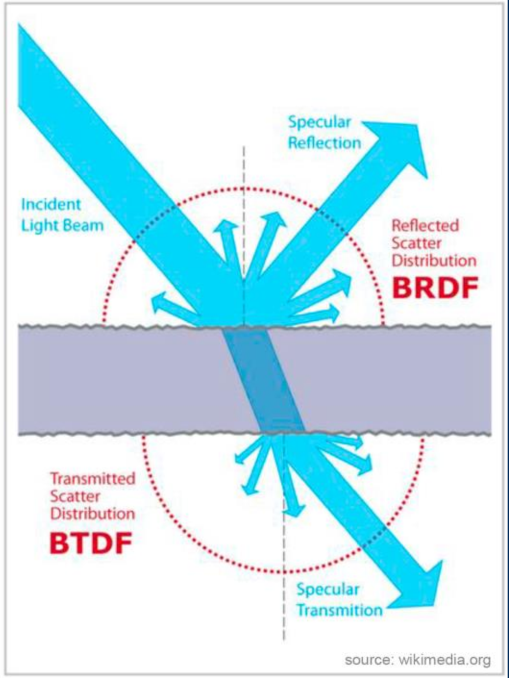
- “BSDF” stands for “Bidirectional Scattering Distribution Function” (BRDF + BTDF)
- Describes how light scatters off a surface
- Incl. wavelength, a 5-dimensional scalar function
  - unitless ratio of outgoing radiance over incoming irradiance (1/steradian)

Greg Ward, Freibourg 2010
“Calculating and Applying BSDFs in Radiance”

BSDFs

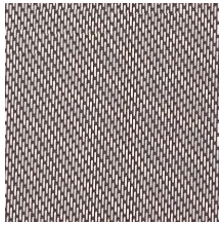
BSDF? BTDF + BRDF!

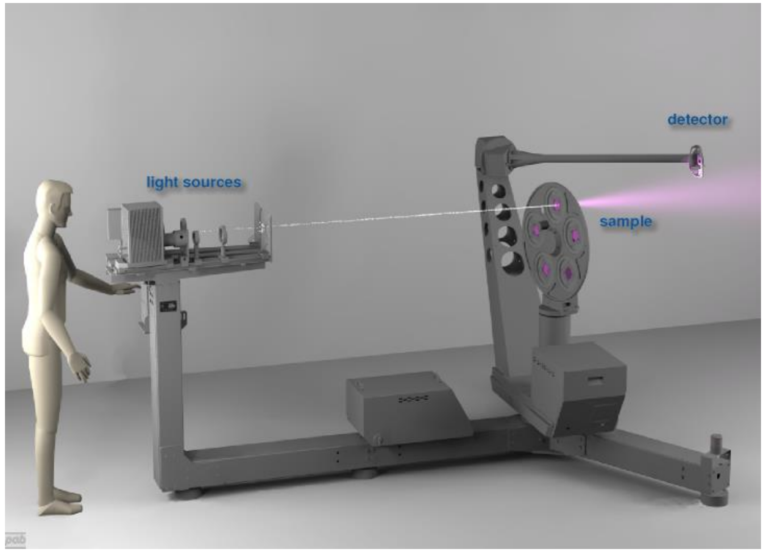
BSDF	bidirectional scattering distribution function
BRDF	bidirectional reflection distribution function
BTDF	bidirectional transmission distribution function



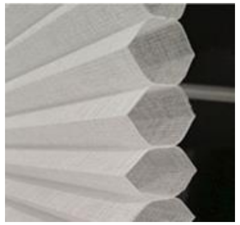
David Geisler-Moroder, New York 2019
“BSDF Daylight System Characterization”

Some common approaches for generating BSDF





(L x B x H) > 6m x 4m x 2.7m



```
genBSDF [ -c Nsamp ] [ -t{3|4} Nlog2 ][ {+|-}C ][ {+|-}a ][ {+|-}forward ][ {+|-}backward ][ {+|-}mgf ][ {+|-}geom unit ][ -dim Xmin Xmax Ymin Ymax Zmin Zmax ] [ geom .. ]
```

Fachgebiet gebäude* systeme technik

The WIPANO „KLEMS“ project | Oct. 2021 – Sep. 2023

BMWi Fördermaßnahme
WIPANO – „Wissens- und Technologietransfer durch Patente und Normen“

Projektantrag **„KLEMS“**
„Entwicklung einer Prüfnorm zur Bestimmung der winkelabhängigen solaren Strahlungstransmission von Bauteilen“

PtJ Projektträger Jülich Forschungszentrum Jülich

Einreicher: Fraunhofer-Center für Silizium-Photovoltaik CSP
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und Dr. Charlotte Pfau
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Projektpartner: Technische Universität Kaiserslautern
Prof. Dr.-Ing. Sabine Hoffmann

Wavelabs Solar Metrology Systems GmbH
Dr. Sascha Esefelder

Verein Deutscher Ingenieure e.V. (VDI)
Dipl.-Ing. Björn Düchting

Assoziierte Partner: WAREMA Renkhoff SE, Ulrich Lang
GMB Glasmanufaktur Brandenburg GmbH, Dr. Carsten Horch

Gesamtkosten/Fördermittel: 797.845 € / 638640 €

Geplante Projektlaufzeit: 01.08.2021 – 31.07.2023

Fraunhofer CSP · Technische Universität Kaiserslautern · WAVELABS · VDI · warema · GMB

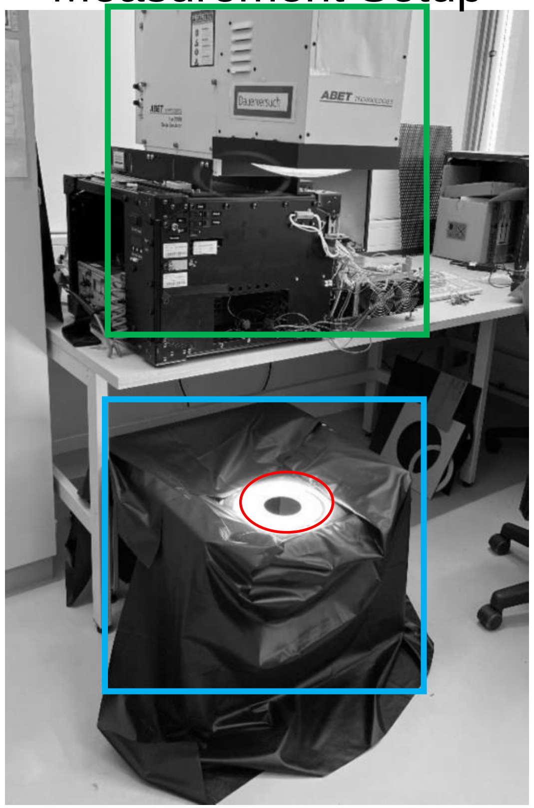
“Knowledge and Technology Transfer through Patents and Standards”

“Development of a testing standard for determining the angle-dependent solar radiation transmission of components.”

Fraunhofer CSP	Instrumentation, Research
RPTU	Simulations, Research
WAVELABS	Sun simulator, light sources
VDI	Coordination on the standard (VDI EE 2068)
warema, GMB	Industry partners

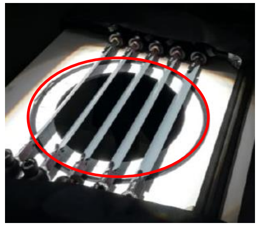
The transmittance measurement setup developed by Fraunhofer CSP

Measurement Setup



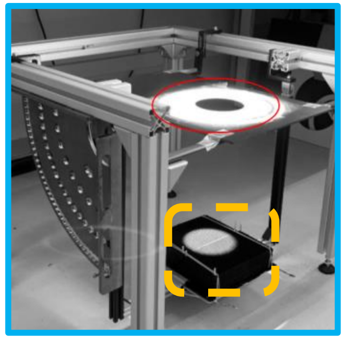
(L x B x H) < 0.5m x 0.5m x 1m

Sample

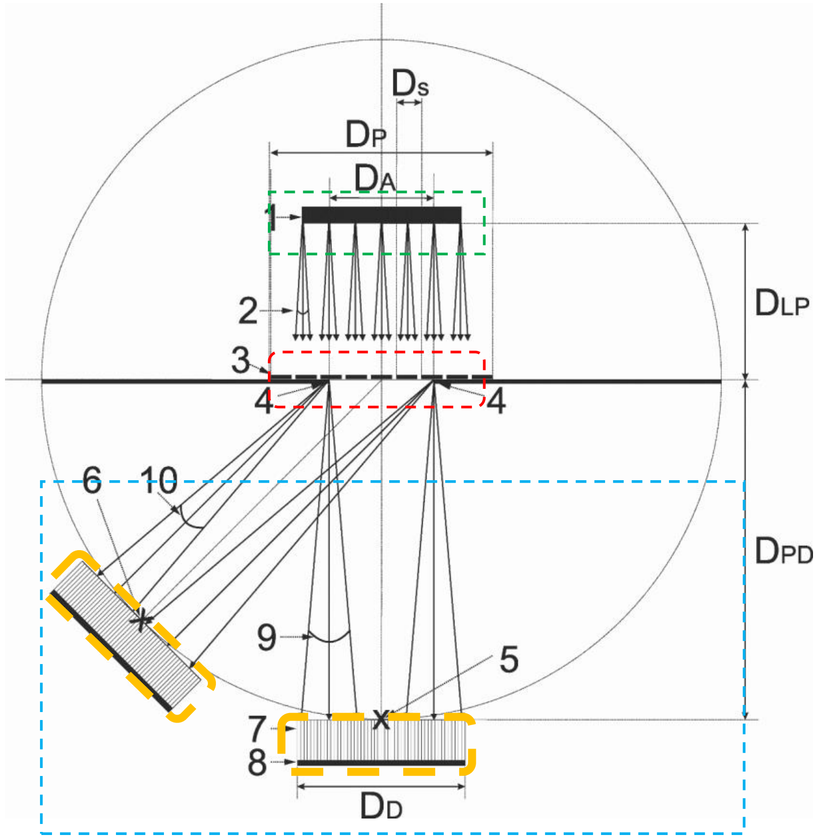


Aperture ~ 0.1m x 0.1m

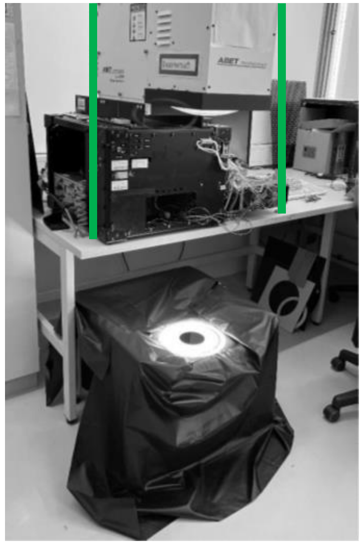
Goniometer

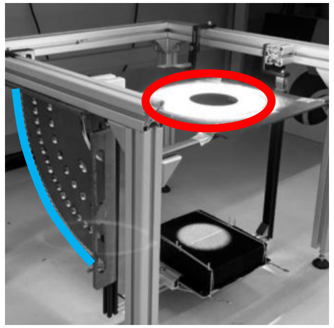


Radius < 0.3m



The prototypical setup is intended to measure **transmittance** across a ¼ hemisphere





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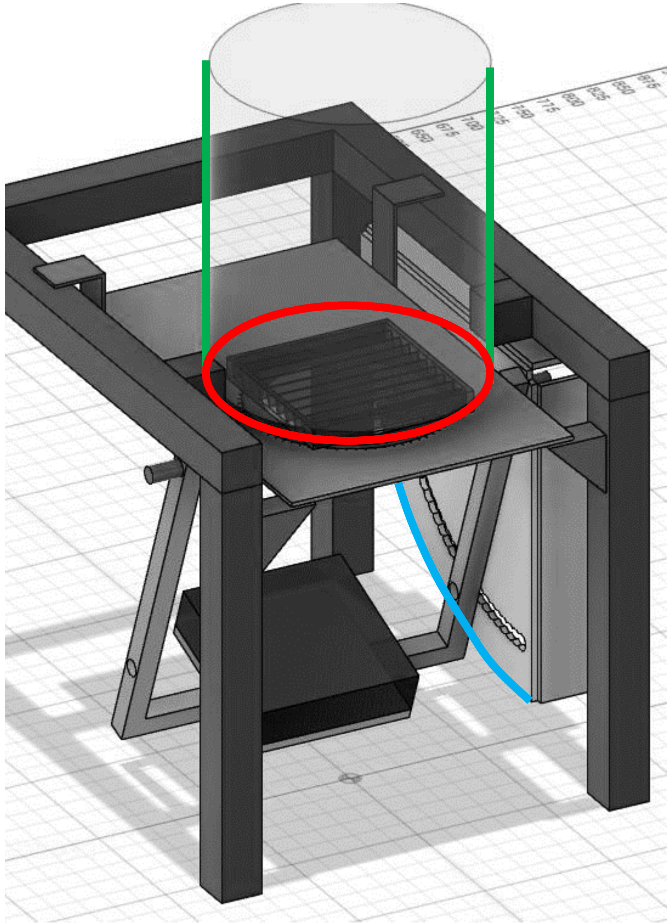

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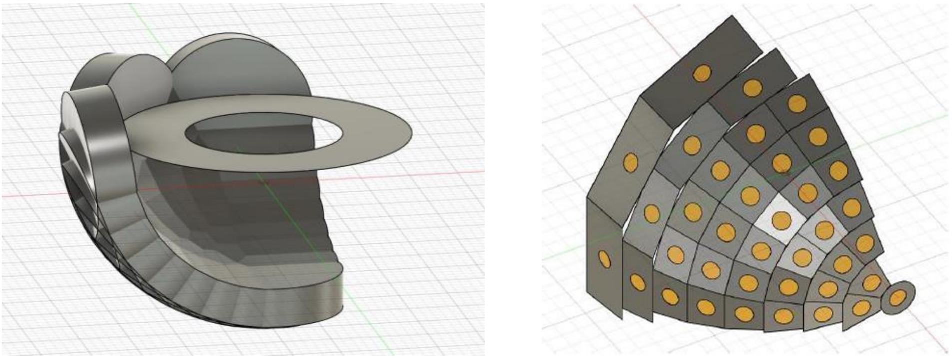

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Φ: Azimuthal measurements through sample rotation

θ: Vertical measurements through goniometer

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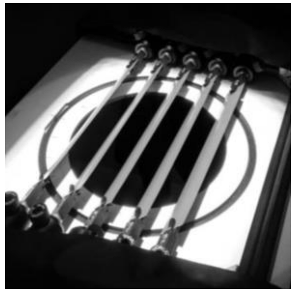
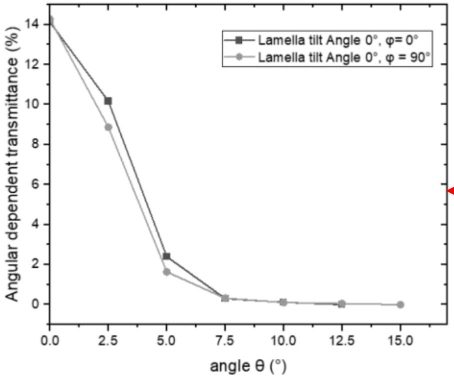
Goal: *Validate* the measured transmittances with Radiance

“Empirical validation should in principle compare a 'true' model, based on measurements obtained from physical experiments, with simulated results from a mathematical model implemented in a program.”

Jensen, Søren Østergaard. "Validation of building energy simulation programs: a methodology." Energy and buildings 22.2 (1995): 133-144).



© Fraunhofer CSP




```
genBSDF sample < rays > . . . . .
rcontrib -M mod oct < rays > ....
rfluxmtx send rec oct < rays > ..
```

?

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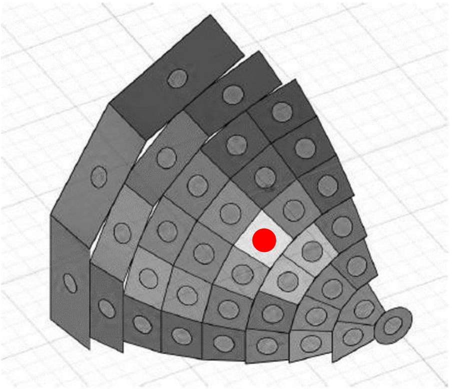
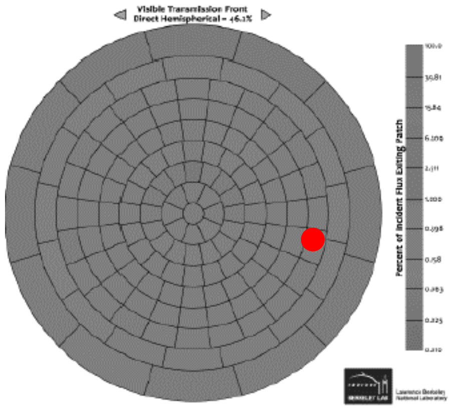
Adapting genBSDF – Attempt 1: Modifying the measurement basis



Measured positions
© Fraunhofer CSP



Klems basis

```
print RADSCN '#@rfluxmtx ' . ($tensortree ? "h=-sc$ns\n" : "h=-kf\n");
```

genBSDF.pl

```
char            *kfullfn = "klems_full.cal";
char            *khalffn = "klems_half.cal";
char            *kquarterfn = "klems_quarter.cal";
```

rfluxmtx.c

```
kpola(r) : select(r, 5, 15, 25, 35, 45, 55, 65, 75, 90);
knaz(r) : select(r, 1, 8, 16, 20, 24, 24, 24, 16, 12);
kaccum(r) : if(r-.5, knaz(r) + kaccum(r-1), 0);

Nkbins : kaccum(knaz(0));

kbin(Nx,Ny,Nz,Ux,Uy,Uz) = kbin2(Acos(-Dx*Nx-Dy*Ny
```

klems_full.cal

```
calfn = kfullfn; kfullfn = NULL;
binf = "kbin";
nbins = "Nkbins";
```

rfluxmtx.c

(The position of the dots are representative only)

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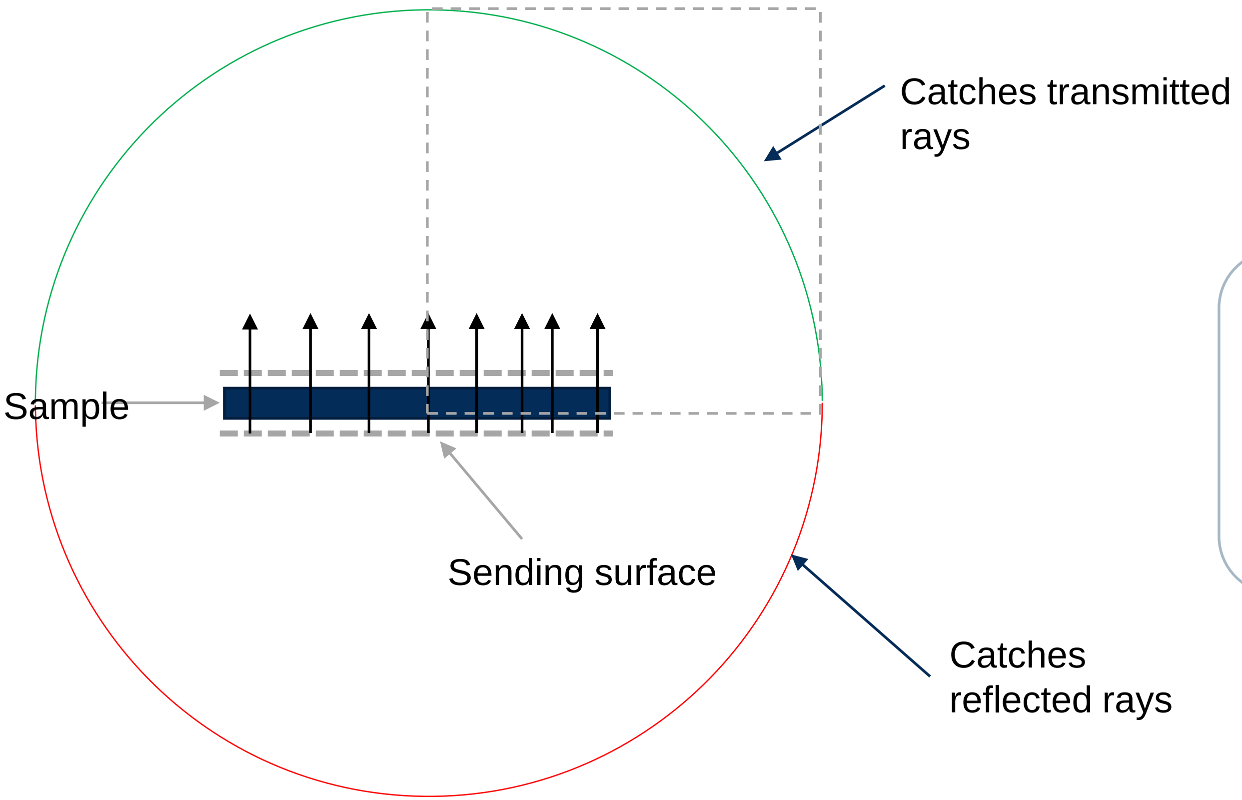
Adapting genBSDF – Attempt 1: Extract a subset of the output of genBSDF



Schematic representation of genBSDF

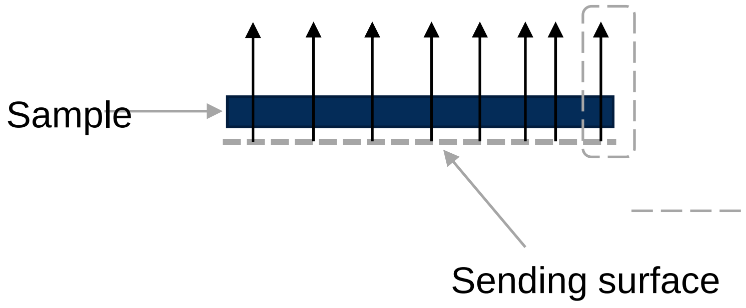
Attempt 1 in summary

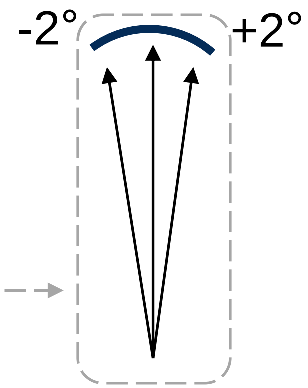
#1: Modify the angular basis in the .cal file.

#2: Run genBSDF

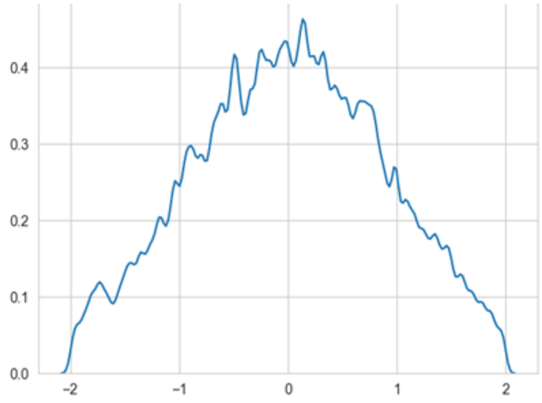
#3: Extract transmittance for quarter hemisphere

Practical Considerations: An “imperfect” light source

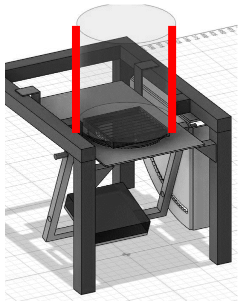




Angular Divergence



Sample Distribution



The parallel light source has an angular divergence.
Divergence follows a roughly Gaussian distribution.
At any angle of incidence, the rays diverge by ~ ±2° to ±4°

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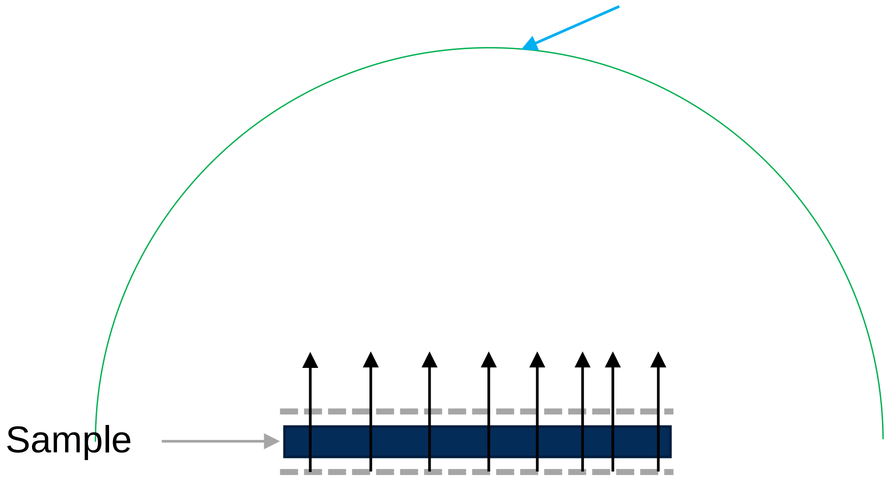
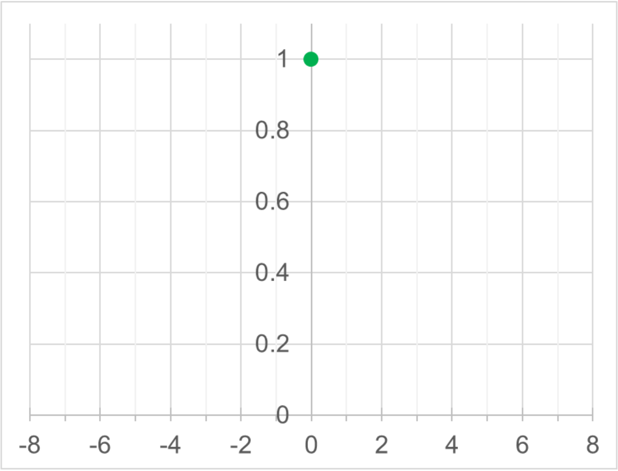
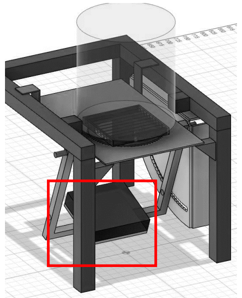
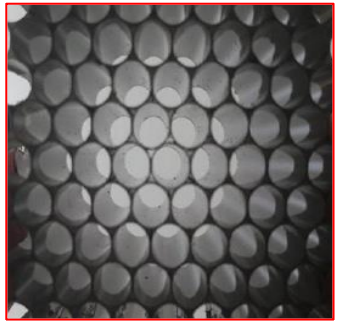
Practical Considerations: A detector with variable angular sensitivity (e.g. θ = 0°, Φ =0°)

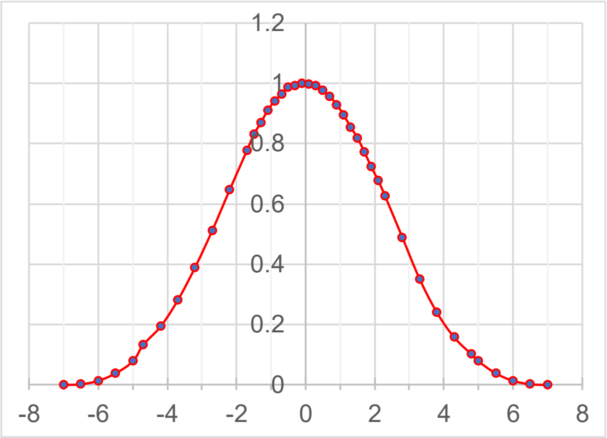




Ideal (genBSDF)







Measurement setup

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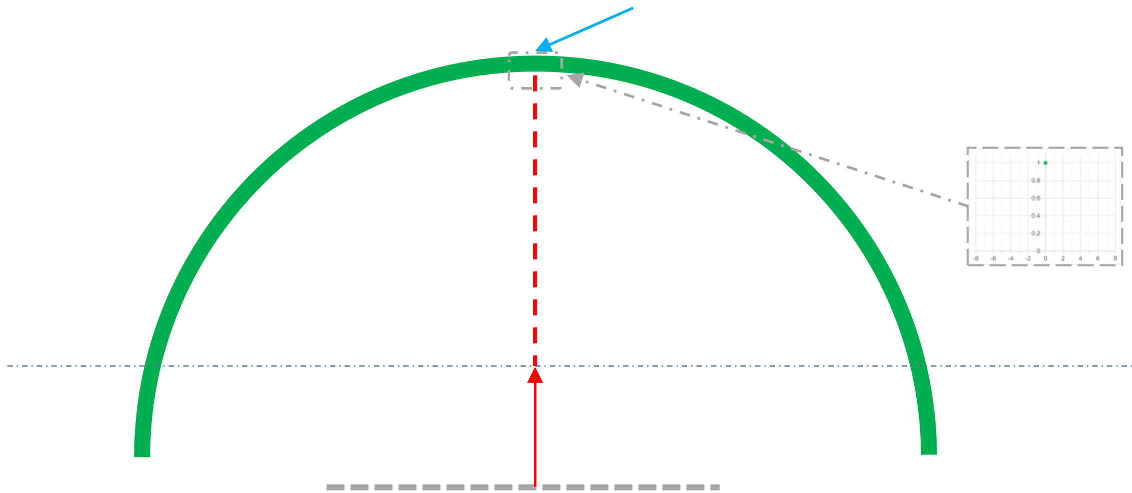
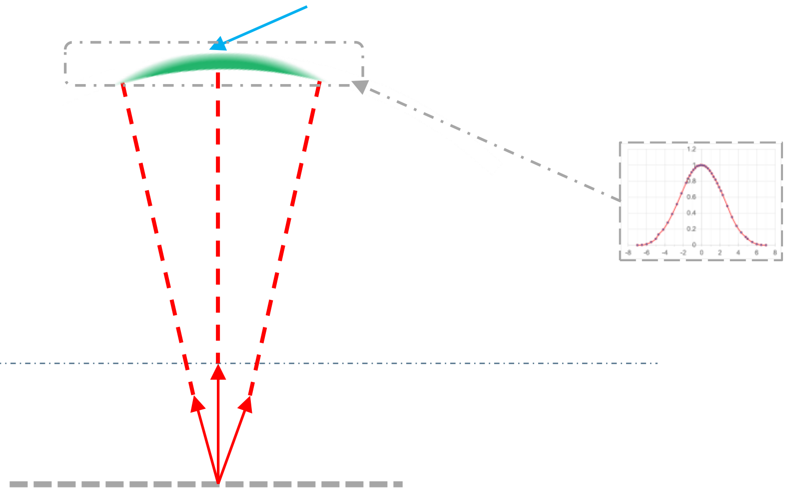
Implications: Example1 | No sample, Normal incidence, Measurement at θ = 0°, Φ =0°

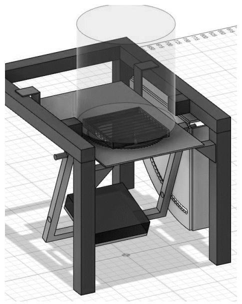
Transmittance = 100%



genBSDF

Transmittance < 100%





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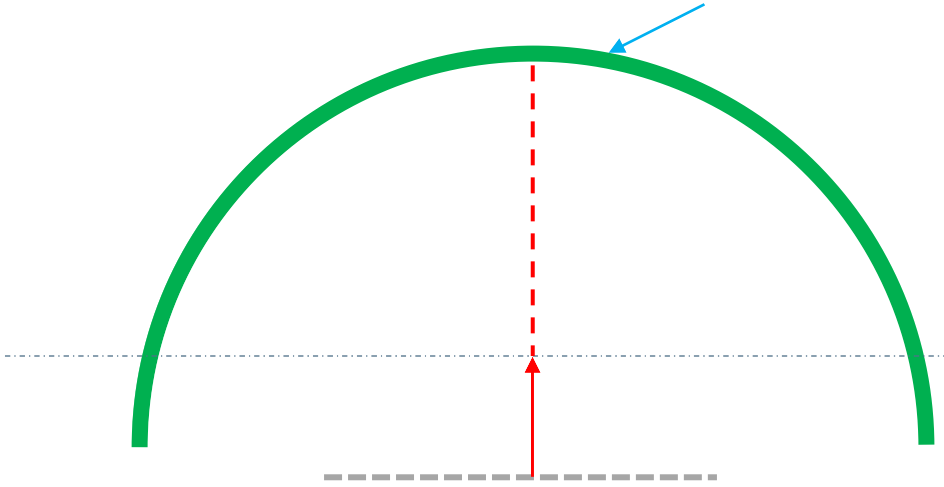
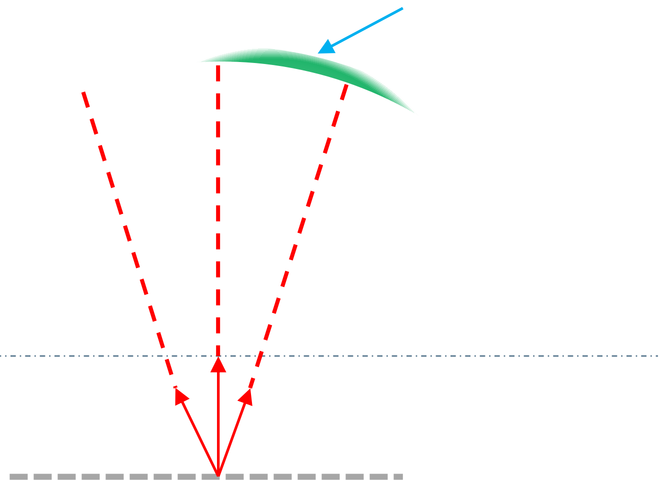
Implications: Example2 | No sample, Normal incidence, Measurement at θ = 2.5°, Φ =0°

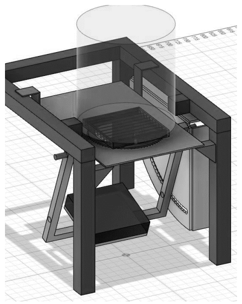
Transmittance = 0%



genBSDF

Transmittance > 0%





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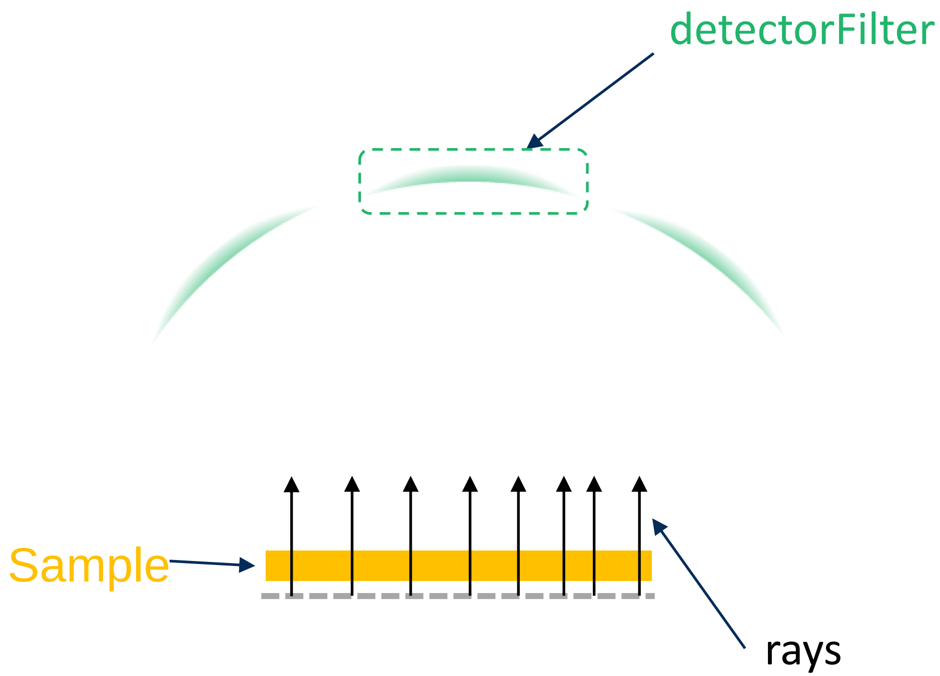
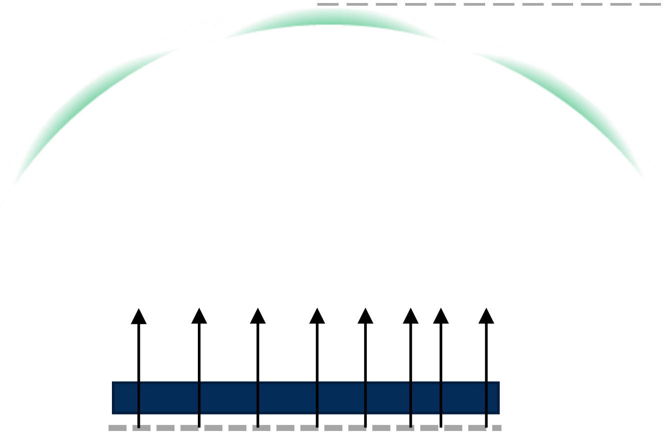
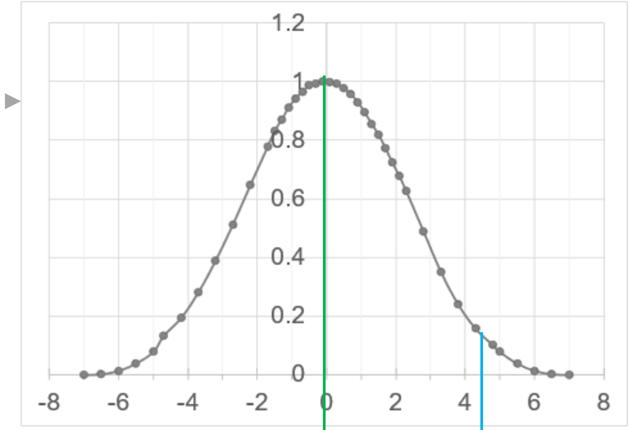
Adapting genBSDF – Attempt 2: A custom transmittance measurement system

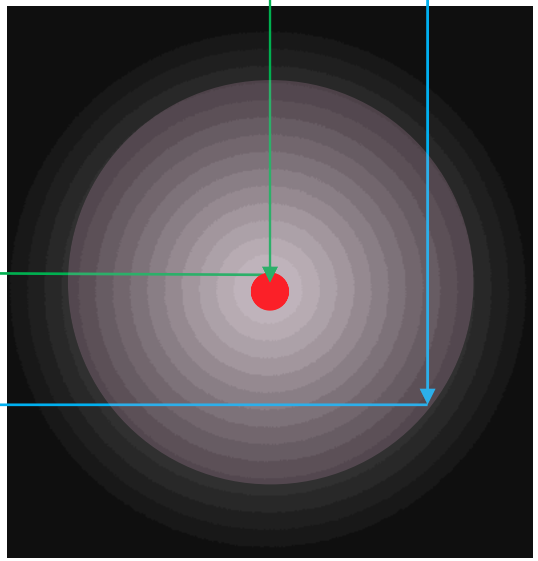



```
rcontrib
      -V+
      -o %sdetectorfilter.dat
      -M detectorFilterList
      octree
      < rays
```

Modeling the detector and angle filter and detector using *glow* and *source*



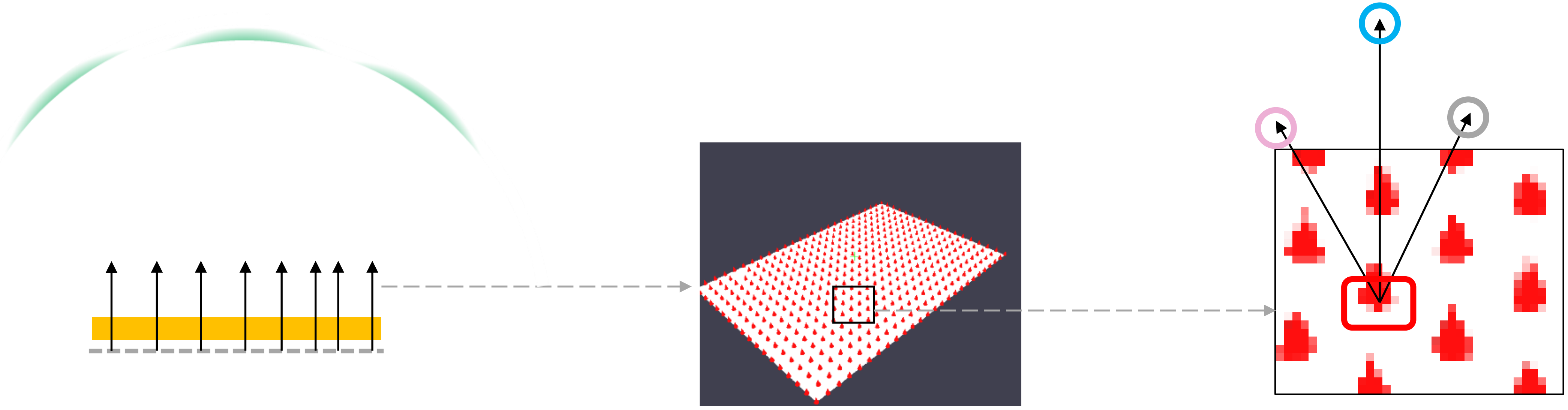




```
void glow det01 0 0 4 0.99 0.99 0.99
        det01 source src1 0 0 4 0 0 1 2
                --------

void glow det_N 0 0 4 0.15 0.15 0.15
        det_N source srcN 0 0 4 0 0 1 16
```

Modeling the light source as divergent rays from every origin point



$x \quad y \quad z \quad x_{vec01} \quad y_{vec01} \quad z_{vec01}$

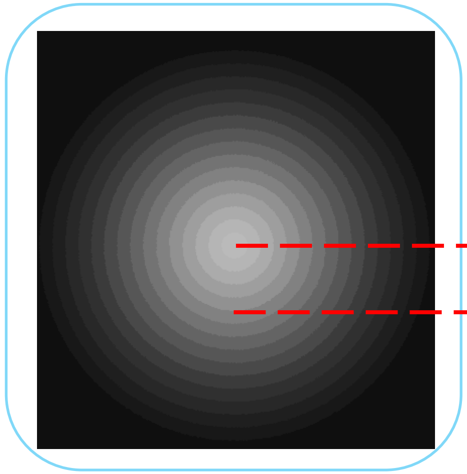
$x \quad y \quad z \quad x_{vec02} \quad y_{vec02} \quad z_{vec02}$

\- - - - - - - - - - - -

$x \quad y \quad z \quad x_{vecNN} \quad y_{vecNN} \quad z_{vecNN}$

Deriving transmittance from the simulation result

```
rcontrib -V+ -o %sdetectorfilter.dat
-M detectorFilterMat octree < rays
```



A_1 (column of m values):

9.923691e-01
0.000000e+00
9.923711e-01
0.000000e+00
0.000000e+00
9.923689e-01
9.923729e-01

A_3 (column of m values):

0.000000e+00
8.318529e-01
0.000000e+00
0.000000e+00
8.318478e-01
0.000000e+00
0.000000e+00

Transmittance = $\text{mean}(A_1 + A_2 \ldots \ldots .. A_n)$

n = Total number of detector filters

m = Total number of rays

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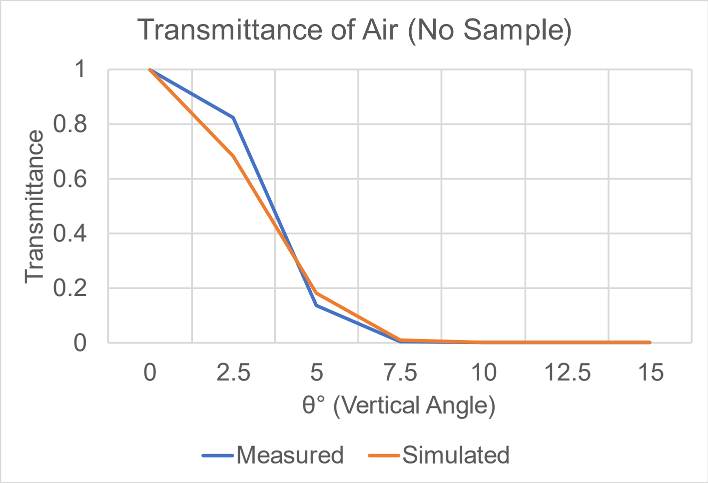
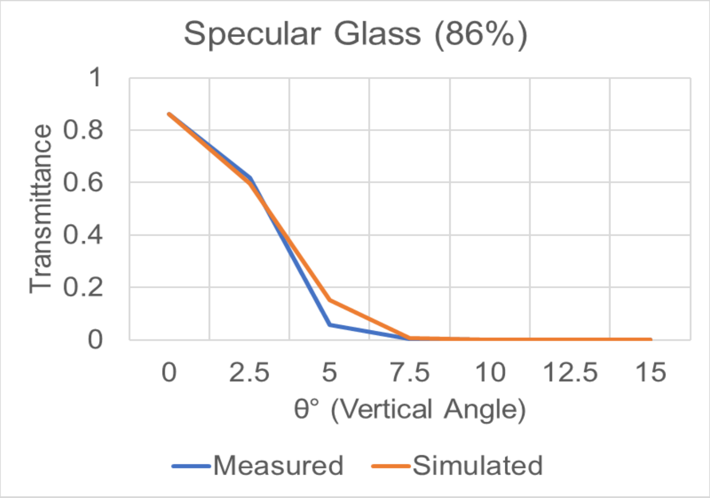
RPTU

Simulation with no sample and simple glass at normal incidence | Correction factor




```
trans=calcTransmission(deviceFile,theta=90-theta,phi=phi)
if not transCorrFact:
    transCorrFact=1/trans
transCorr=transCorrFact*trans
```

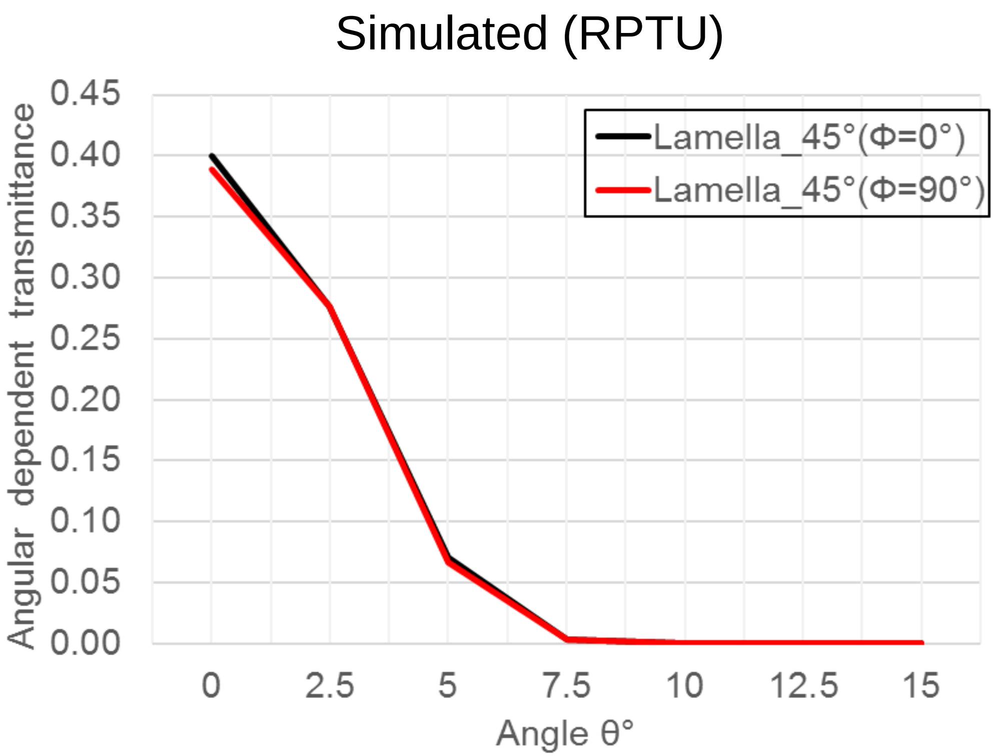
transCorrFact sets transmittance at normal incidence to 1.0 (100%)

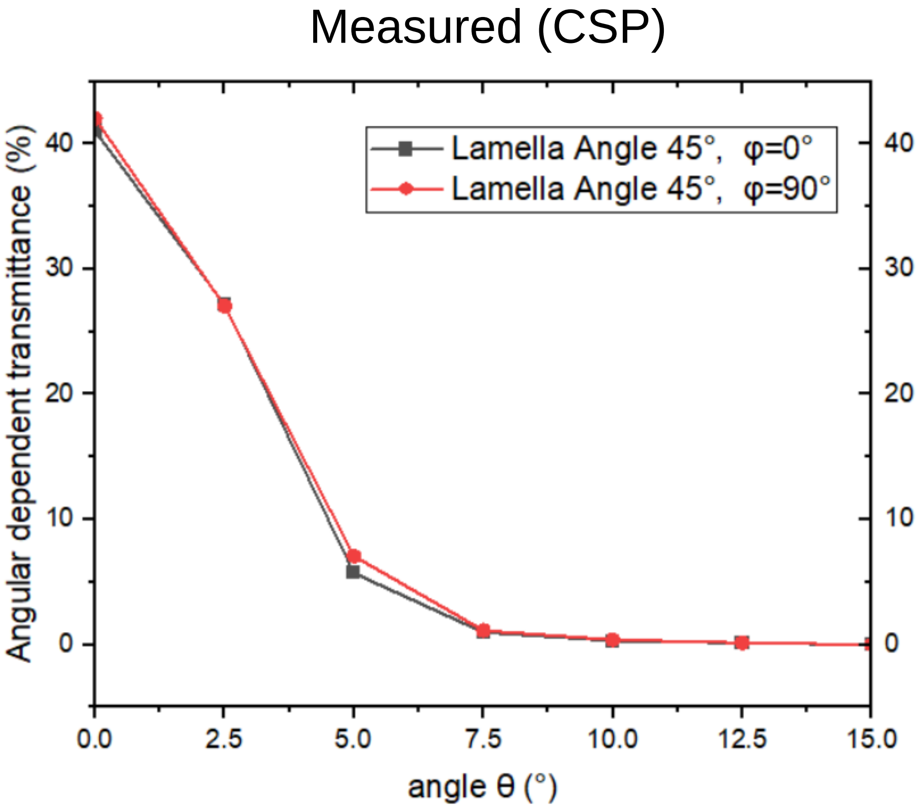


Uses the same correction factor as derived for Air (No Sample)

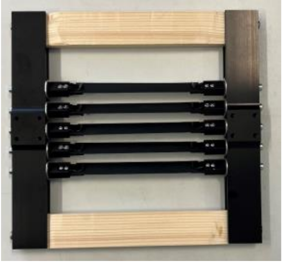
Need to check if the same correction factor can be used for all values of (θ ,Φ).

Simulation with lamella blinds (black, opaque, diffusing) at 45° tilt





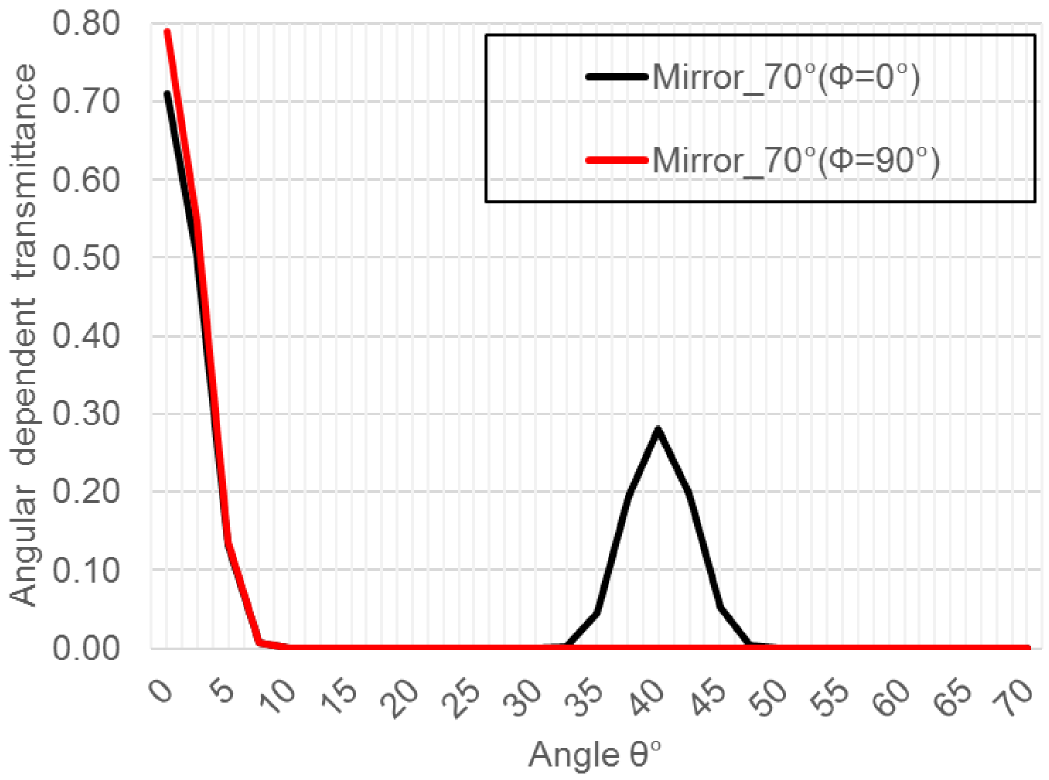
Φ = 0°



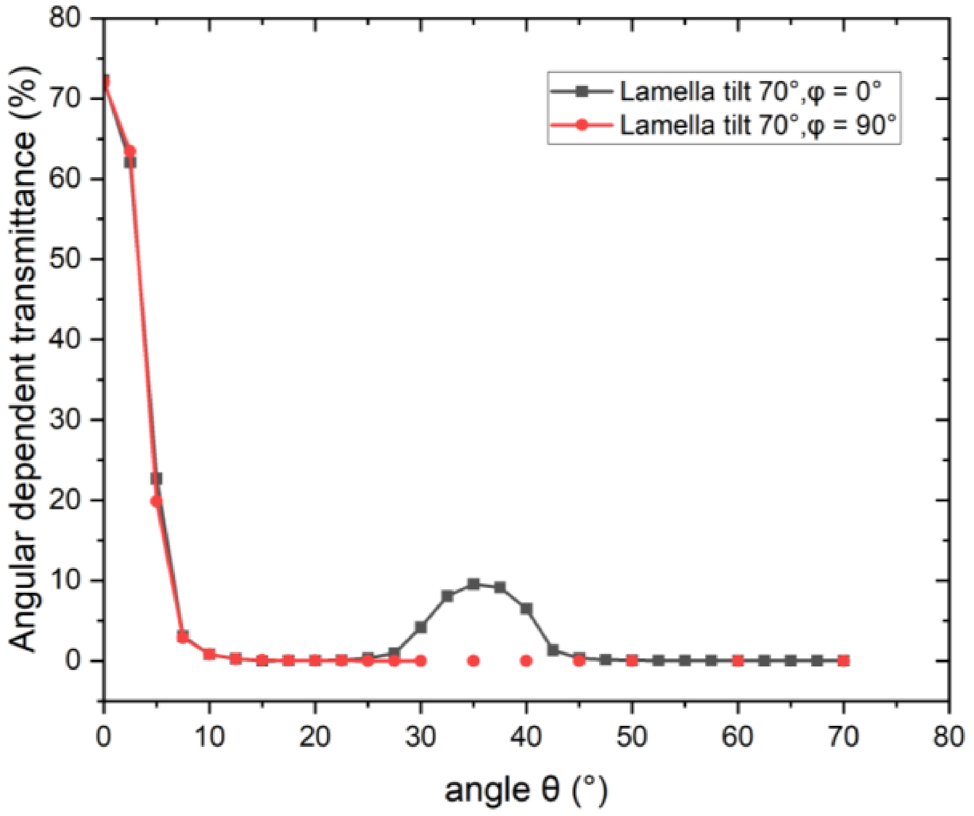
Φ = 90°

Simulation with lamella blinds (mirror, specular) at 70° tilt

Simulated (RPTU)



Measured (CSP)



Φ = 0°

Φ = 90°

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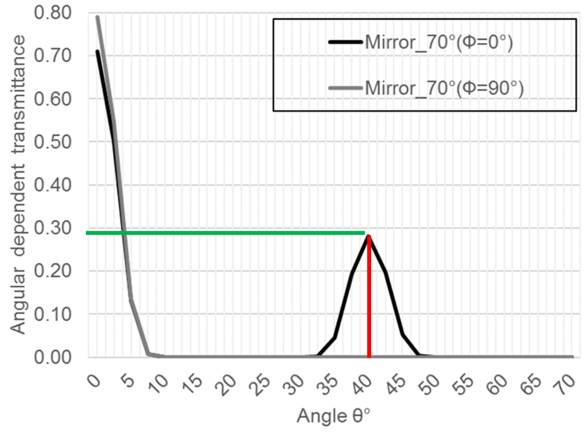
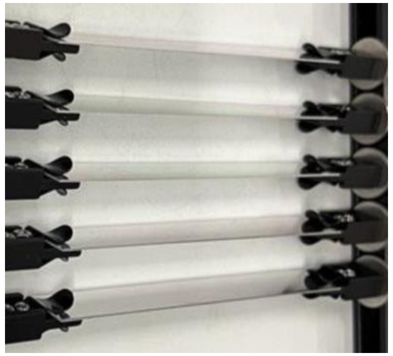
Probable reasons for difference in simulated vs measured values for mirror lamella blinds





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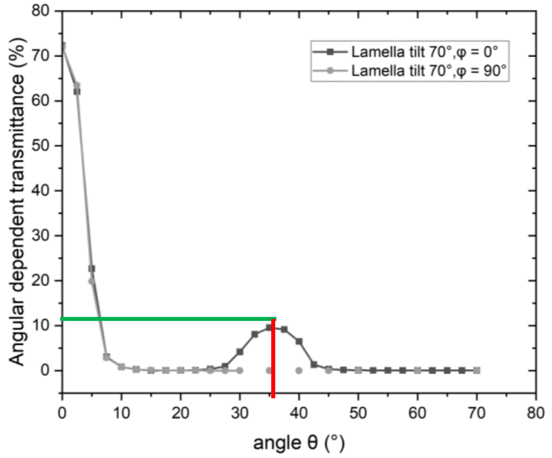
"The light reflected from the lamellas is re-captured peak at a theta of around 35°. (theory peak should be at 40° ,but tilt angle of ±5° may vary due to lamella twisting)"



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"Only 10% light is captured at 35° as peak, because the reflected light is not homogeneous:

- mirrors are not 100% reflective
- lamellas tilt angle may vary by ±5° (twisting)"

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Ongoing work

Improvements to the simulation model after one-to-one comparison with measurements.

Measurements and simulations with additional samples.

Comparison with genBSDF results.

Documentation of instrumentation and simulation in a standard (VDI-EE 2068)

Thank you.

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