BSDF Daylight System Characterization – Sensitivity and Requirements to Resolution

David Geisler-Moroder
Bartenbach GmbH

18th International Radiance Workshop
New York City
21-23 August 2019

- founded 1976 (Prof. Dr. h.c. Ing. Christian Bartenbach)
- Independent from manufacturers
- 90 employees (ca. 40 lighting design , 25 R&D)
- Locations: Aldrans, Austria
- more than 10.000 projects worldwide

DAYLIGHTING DESIGN

COMPLETE LIGHTING SOLUTIONS

MATERIALS CONSULTATION

ARTIFICIAL LIGHTING DESIGN

RESEARCH & DEVELOPMENT

MODEL BUILDING & VISUALISATION

OUR RANGE OF SERVICES

Tailored to suit your needs

ARTIFICIAL LIGHTING DESIGN
COMPLETE LIGHTING SOLUTIONS

ARTIFICIAL LIGHTING
DAYLIGHTING DESIGN
MODEL BUILDING & VISUALISATION

ARTIFICIAL LIGHTING
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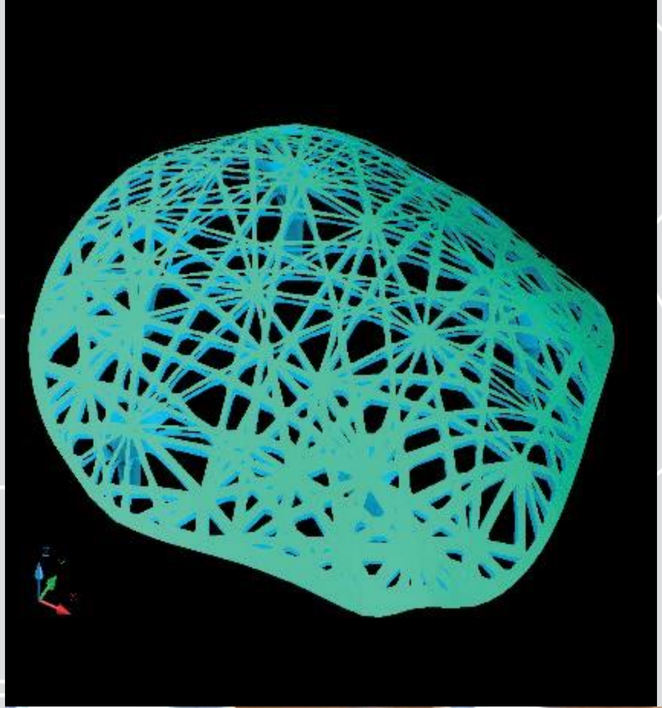
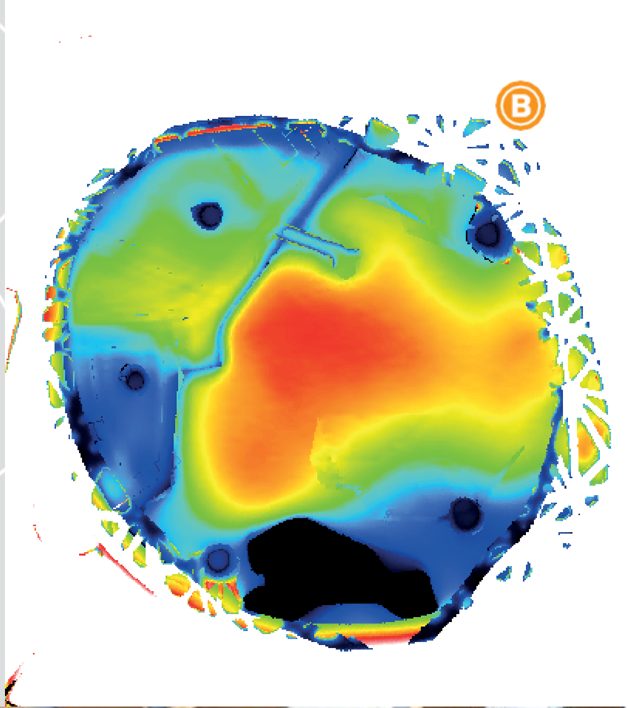
RESEARCH & DEVELOPMENT

- The visual effects of light
- The biological effects of light
- The therapeutic effects of light
- Project-specific product development
- The development of innovative product solutions for architectural use
- Daylight simulation for complex building structures





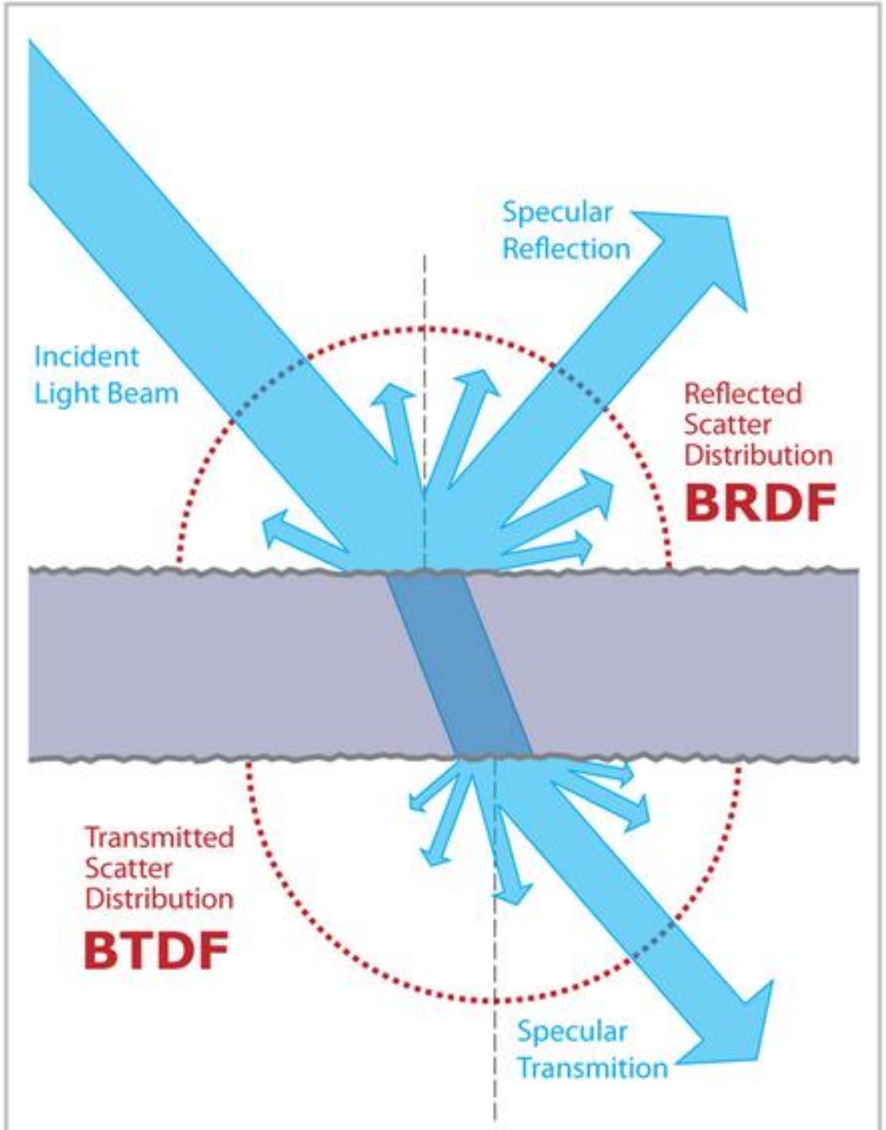
BSDFs

BSDF? BTDF + BRDF!

BSDF bidirectional scattering distribution function

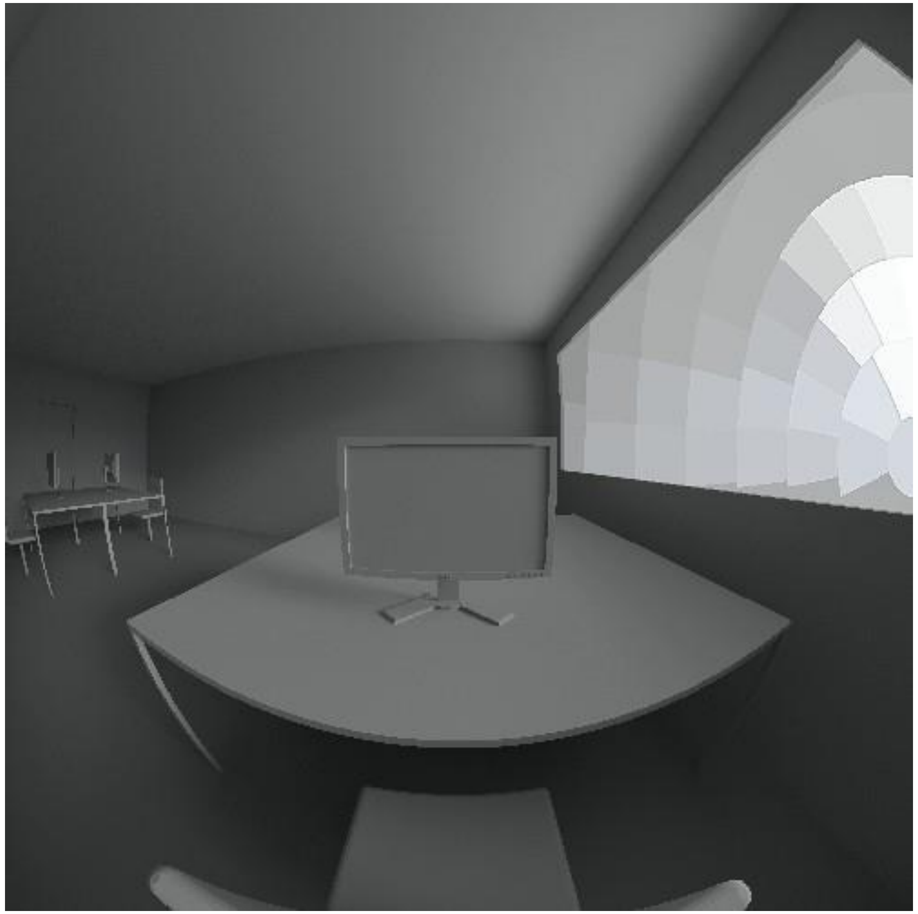
BRDF bidirectional reflection distribution function

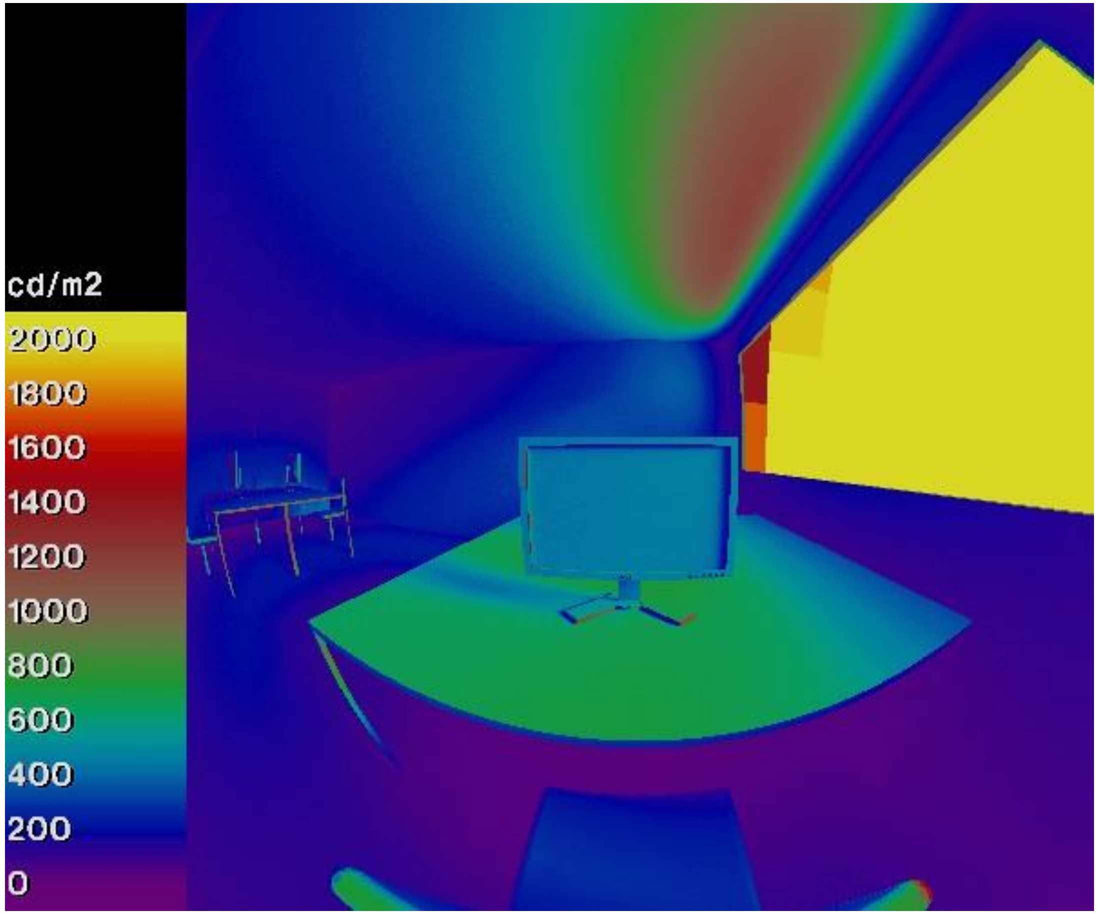
BTDF bidirectional transmission distribution function



source: wikimedia.org

BSDFs

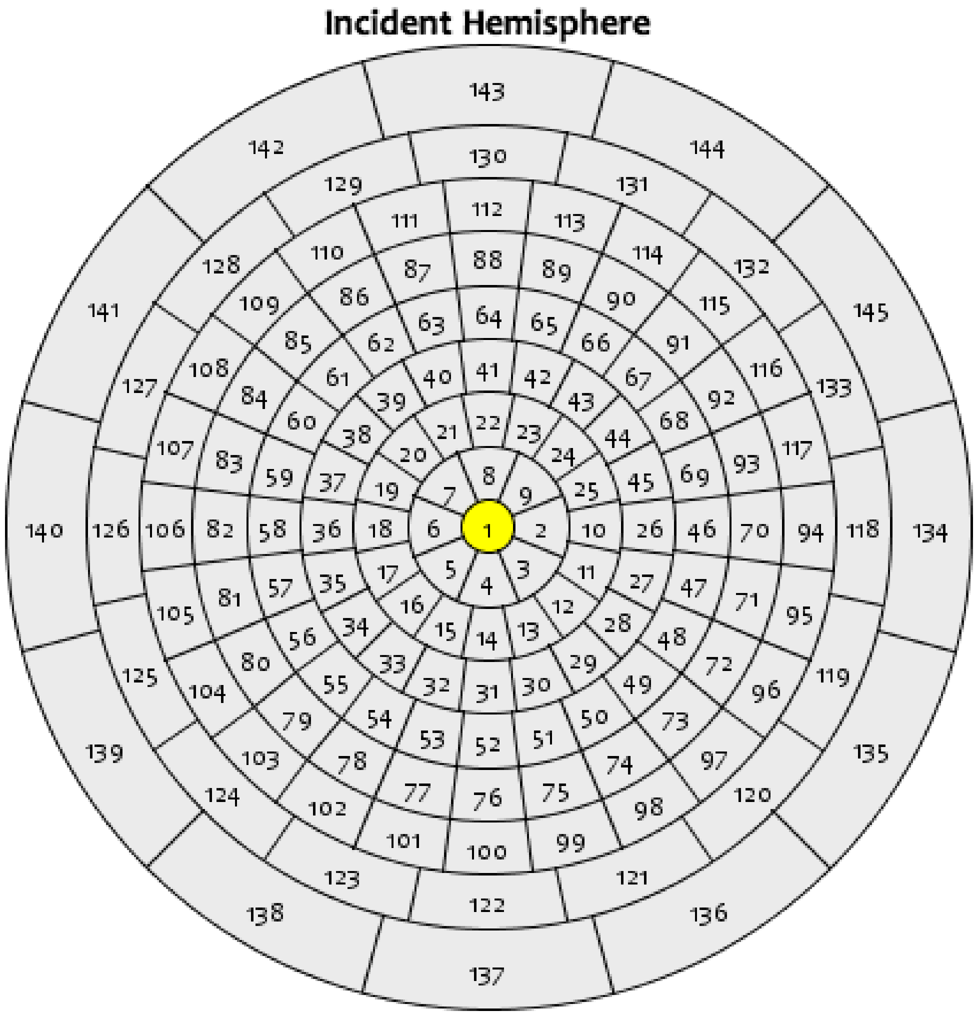




BSDF – Discretizations

Klems‘ discretization

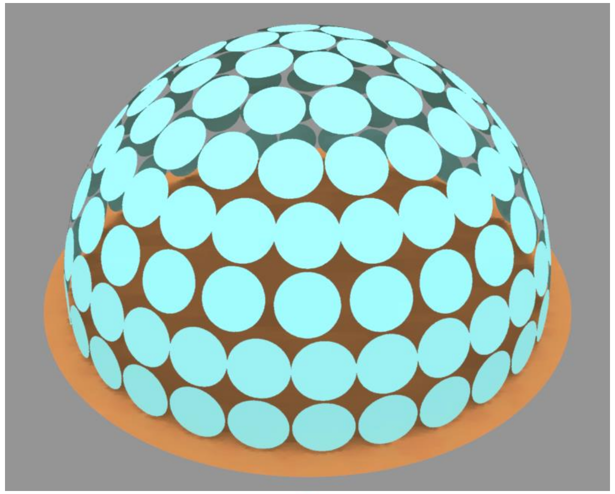
- subdivision of hemisphere into 145 patches
- approx. equal illuminance from each patch if luminance is constant in hemisphere
- 9 θ ranges {0°-5°, 5°-15°, 15°-25°, 25°-35°, 35°-45°, 45°-55°, 55°-65°, 65°-75°, 75°-90°}
- φ subdivisions per θ range {1, 8, 16, 20, 24, 24, 24, 16, 12}
- average solid angle 2π/145 = 0.0433 sr, i.e. cone with 2 x 6.73° apex angle [2π*(1-cos(α/2)) = 2π/145]

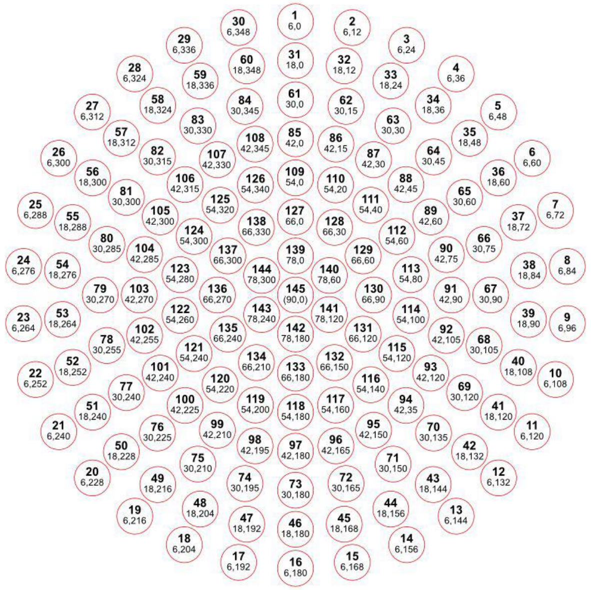


BSDF – Discretizations

Tregenza scheme (CIE 108-1994)

- subdivision of hemisphere into 145 patches
- approx. equal solid angles foz each patch
- 8 θ ranges {0°-6°, 6°-18°, 18°-30°, 30°-42°, 42°-54°,
  54°-66°, 66°-78°, 78°-90°}
- φ subdivisions per θ range
  {1, 6, 12, 18, 24, 24, 30, 30}
- average solid angle 2π/145 = 0.0433 sr,
  i.e. cone with 2 x 6.73° apex angle [2π*(1-cos(α/2)) = 2π/145]

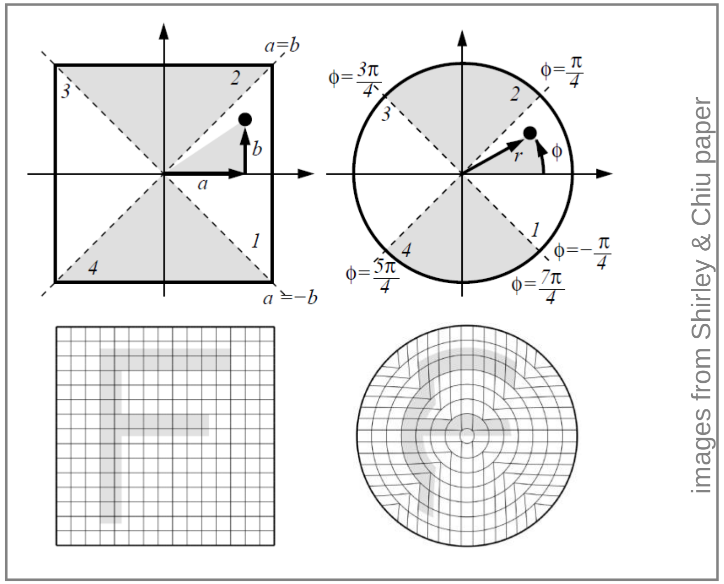


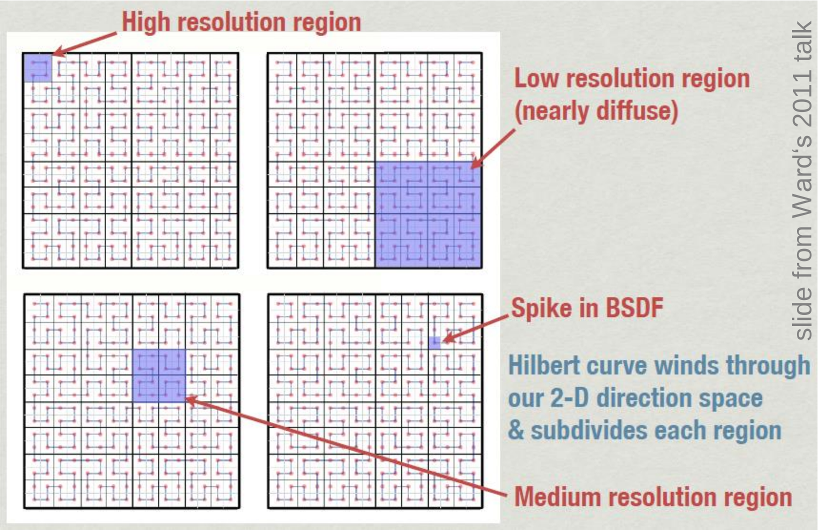


BSDF – Discretizations

Variable resolution („tensor tree“)

- idea: high resolution for spikey regions
  low resolution for smooth regions
- based on Shirley-Chiu-mapping
  (preserves fractional area, i.e. projected solid angle)
- maximum dimensions in 4D 2^{2n} x 2^{2n}
  (n = 4 / 5 / 6: 256^2 / 1024^2 / 4096^2)
- + efficient data structure (ideal diffuse reflector needs 1 value {1/π})
- – no matrix structure (needed for daylight coefficient approach)





BSDF – Data format

XML file format

- definition of data discretization in header
- data blocks interpreted by software accordingly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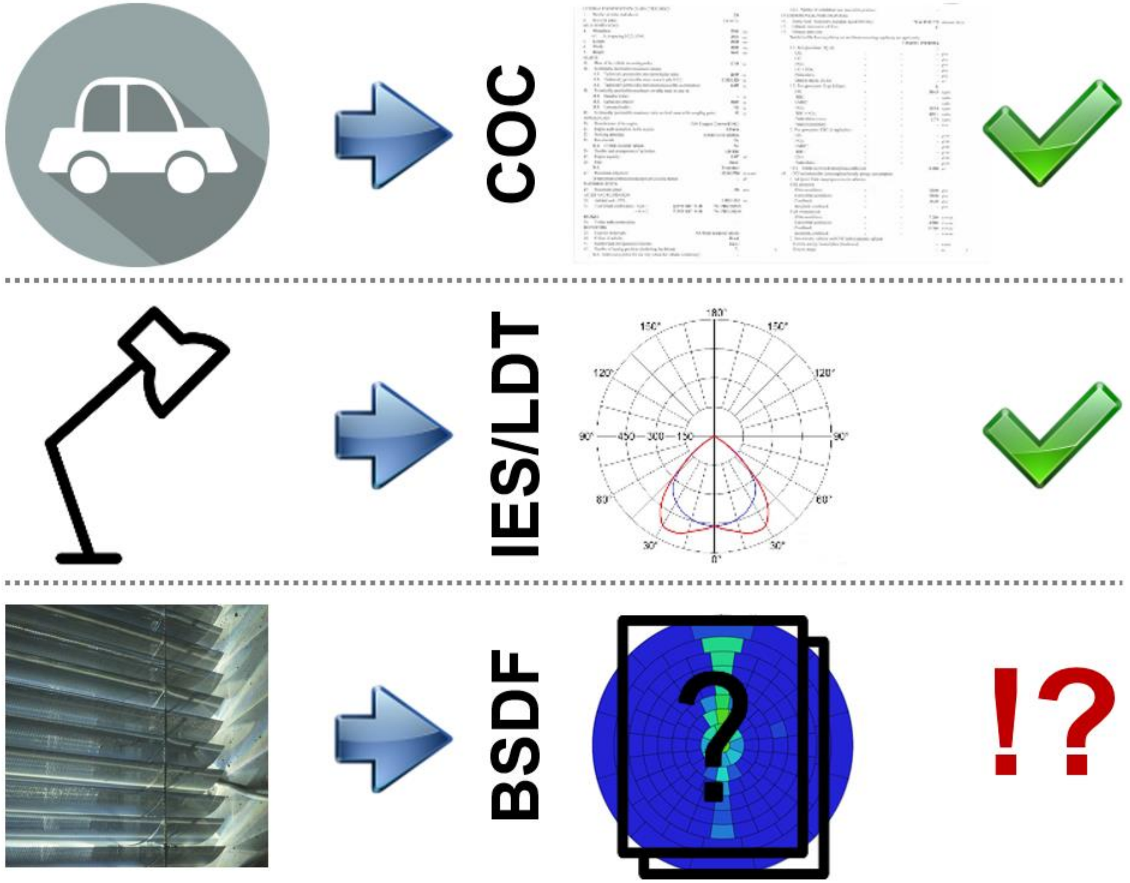
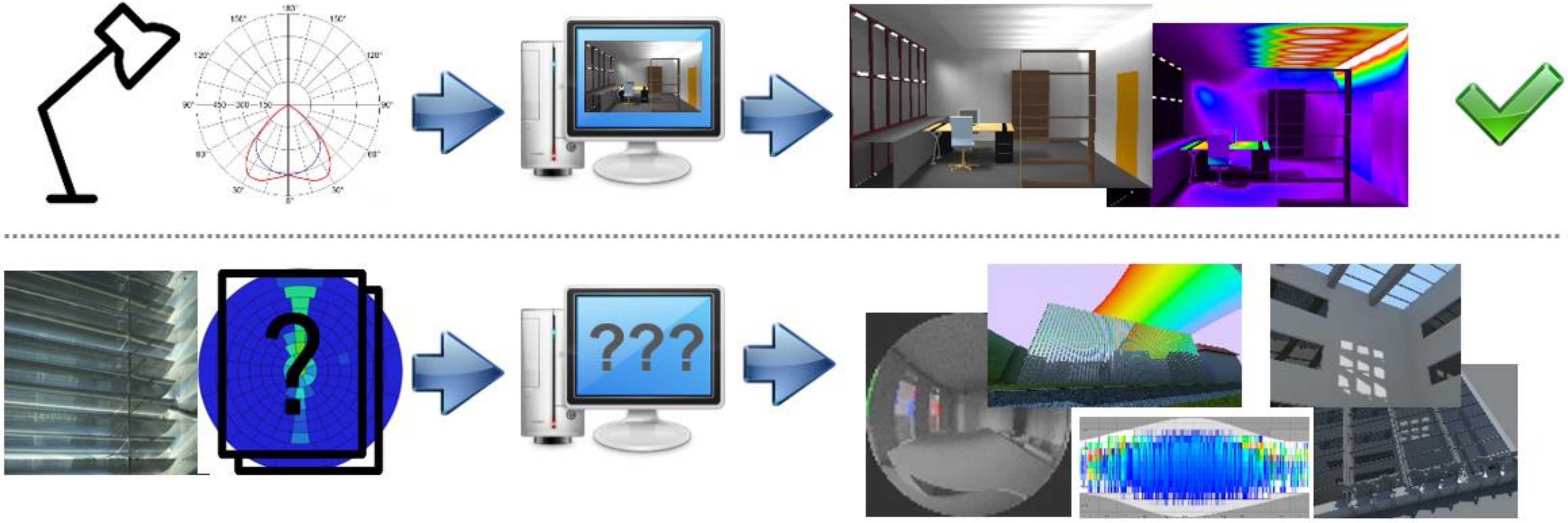
Established data formats

name	input resolution	output resolution	currently used by software
WINDOW6 standard basis	Klems (145)	Klems (145)	WINDOW7, Relux, Radiance
IEA 21	Tregenza (145)	5deg full, i.e. 5°x5° (1297)	Relux, Radiance, Dialux*
Shirley-Chiu	variable (limitation through data size)	variable (limitation through data size)	Radiance

BSDF – Standardization?



BSDF – Standardization?



IEA SHC Task 61 / EBC Annex 77

Integrated solutions for daylight and electric lighting

From component to user centered system efficiency

Operating Agent: J. de Boer, Germany

Subtask A

B. Matusiak, Norway

User Perspective, Requirements

Subtask B

M. Fontoynont, Denmark

Integration and optimization of daylight and electric lighting

Subtask C

D. Geisler-Moroder, Austria

Design support for practioners

(Tools, Standards, Guidelines)

Subtask D

N. Gentile, Sweden

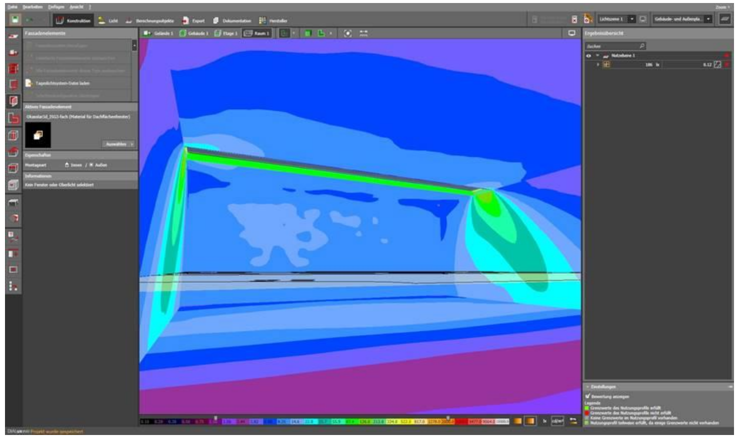
W. Osterhaus, Denmark

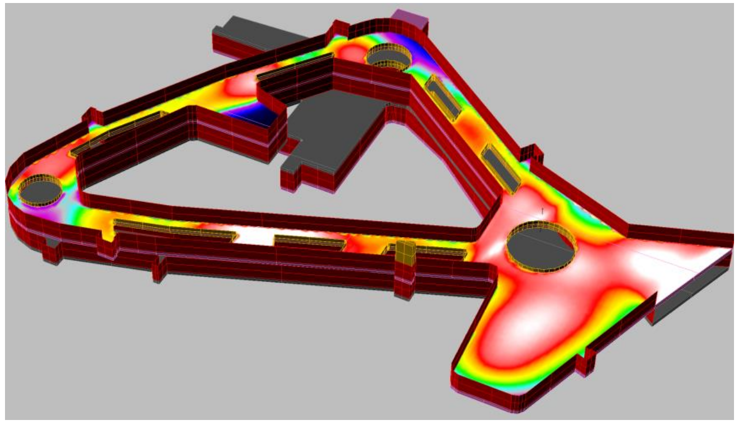
Lab and field study performance tracking

Joint Working Group

- Evaluation method for integrated lighting solutions
- Virtual reality (VR) based Decision Guide

Subtask C: Design Support for Practitioners





Objective

Focus on the application of technical innovations in the field of integrated lighting solutions in practitioners' workflows. Bring findings onto the desktops of designers by integration into widely used software tools, standards and codes, and design guidelines.

C.1 Review of state of the art design workflows

C.2 Standardization of BSDF daylight system characterization

C.3 Spectral sky models for advanced daylight simulations

C.4 Hourly rating method for integrated solutions

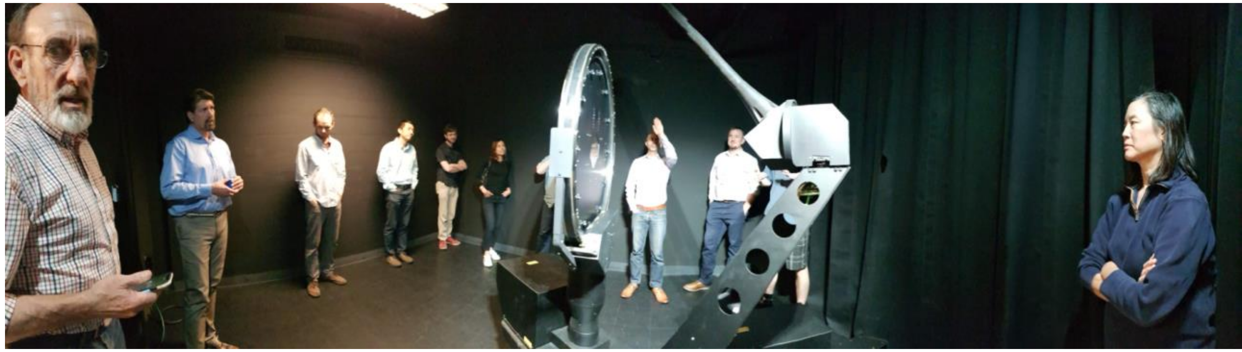
C2: Standardization of BSDF daylight system characterization

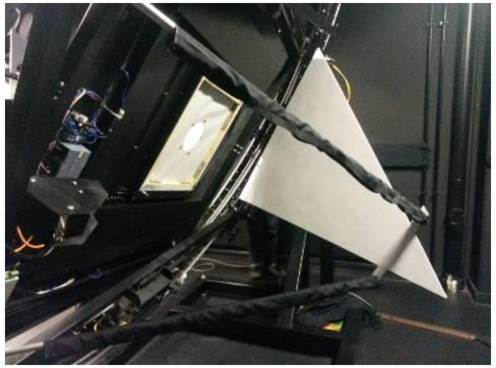
Objectives

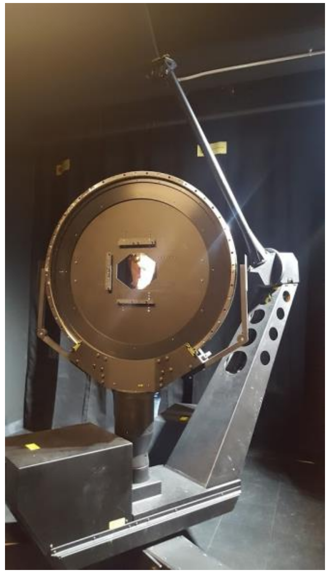
- Collect existing procedures
- Analyze requirements and necessary resolutions for BSDF data
- Elaborate BSDF generation specifications
- Define uniform BSDF data format
- Merge and extend existing BSDF databases
- Derive simplified ratings based on BSDFs

Results

- Specification of BSDF generation routines
- Pre-normative work for BSDF daylight system characterization
- Labeling scheme







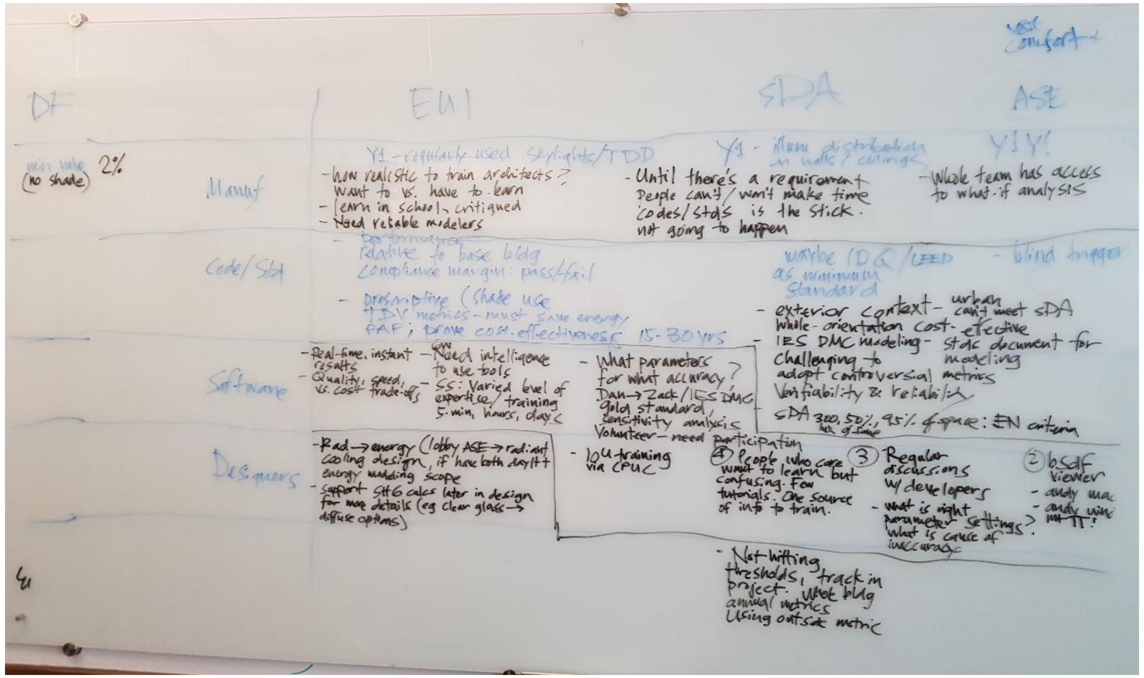
LBNL activities towards US standard

Ongoing work on BSDF topics

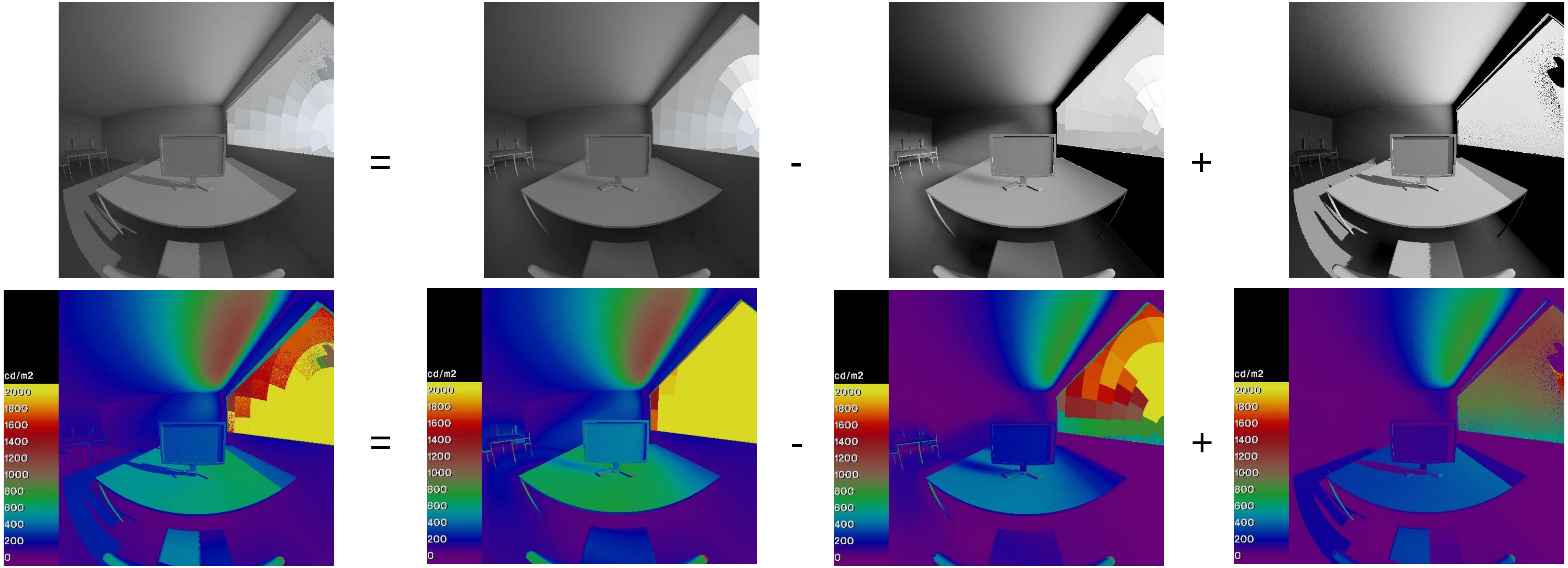
- BSDF generation toolchain
- Validation and testing
- Simplified models for system groups
- US standardization
- …

Workshop June 2019

- Software developers
- Manufacturers
- Codes & Standards representatives
- Researchers
- Designers



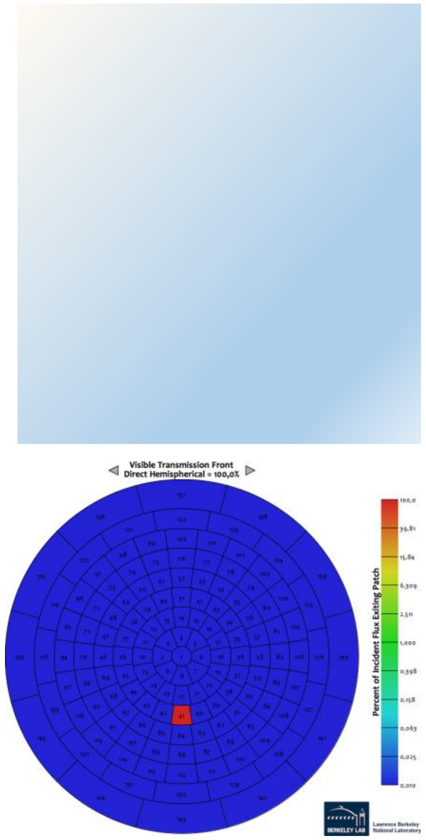
Five-Phase Method



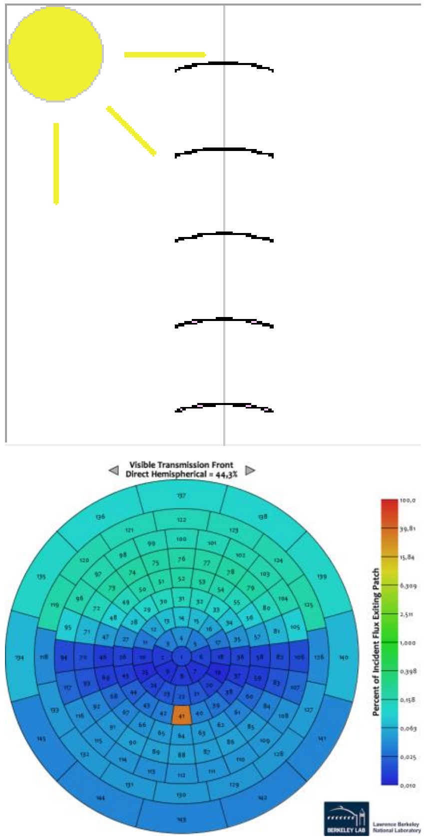
Five-Phase-Method | Three-Phase-Method | Three-Phase direct | accurate direct (tt 5)

Sensitivity Analysis

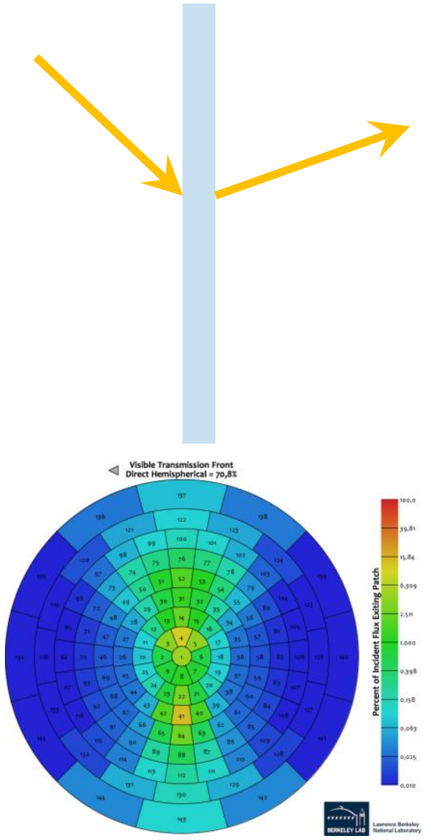
Systems



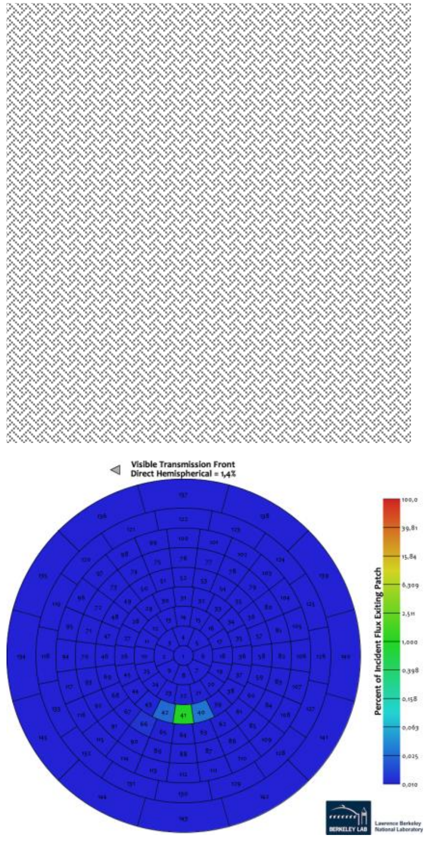
Glazing



Blinds, 00 deg tilt

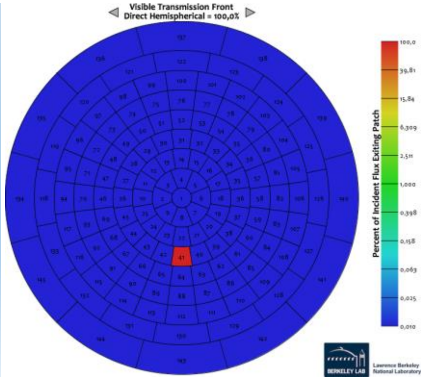


Daylight redirecting film



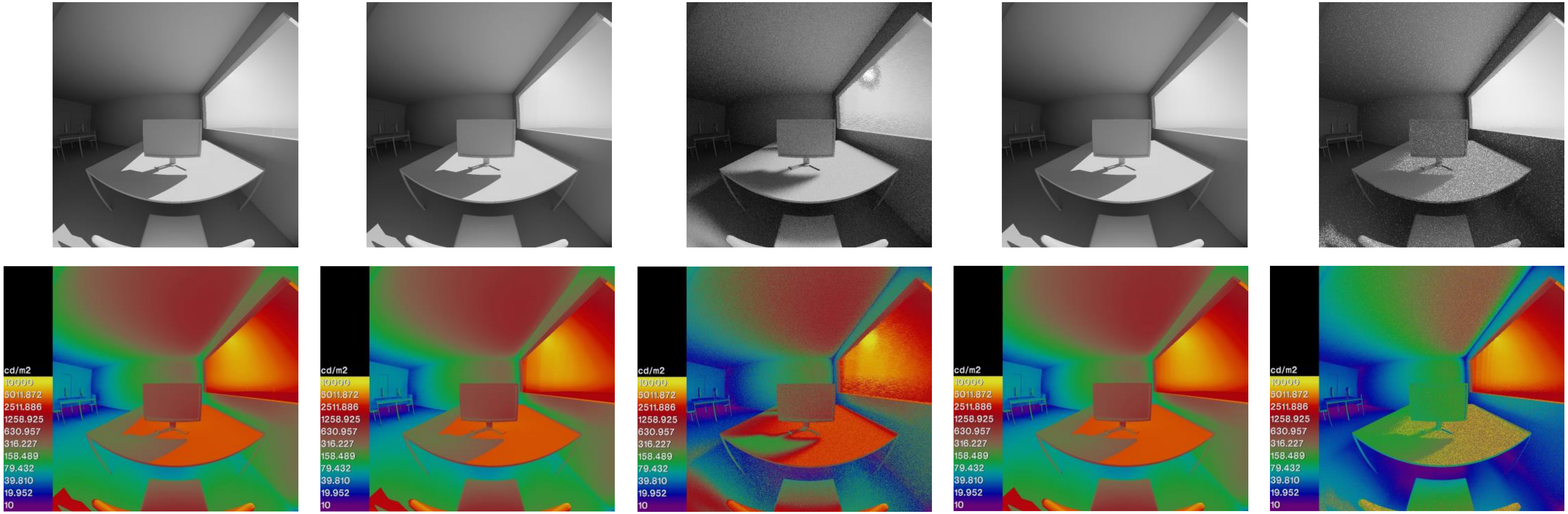
Fabric

Sensitivity Analysis



Glazing

CIE Sunny Sky
21 March, 10am
Innsbruck, Austria (47.3N / 11.4E)



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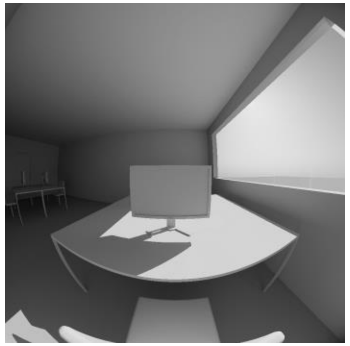
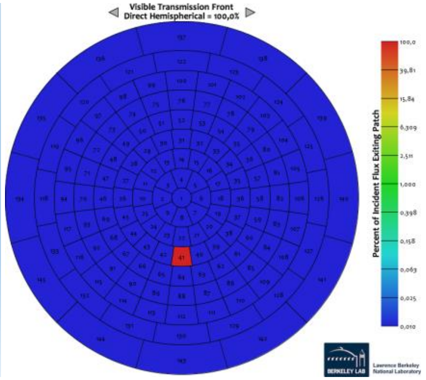
DGP 1.00	DGP 1.00	DGP 1.00	DGP 1.00	DGP 1.00

Sensitivity Analysis





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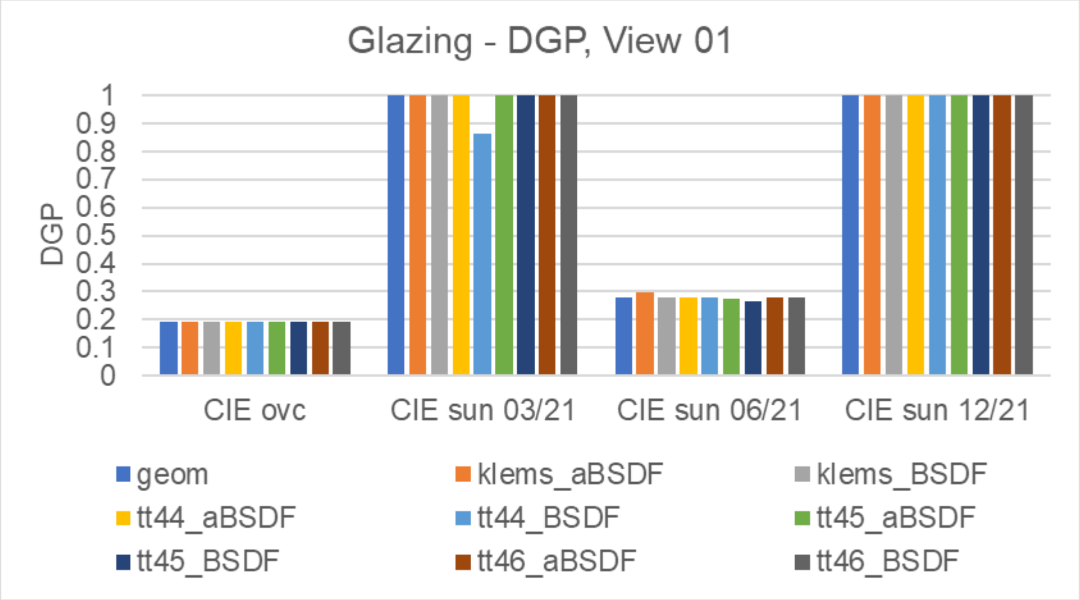
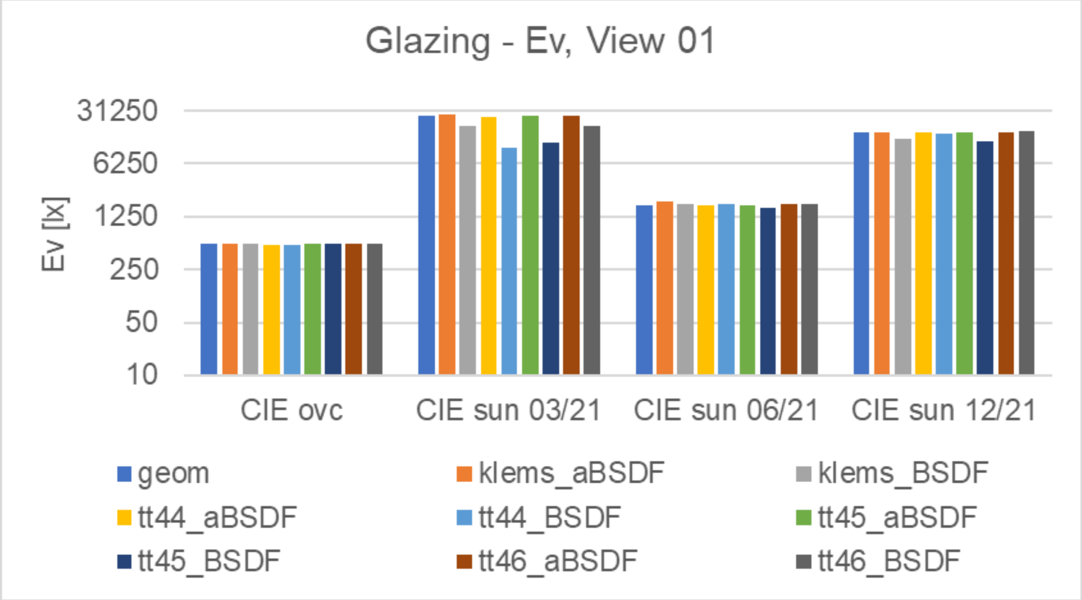
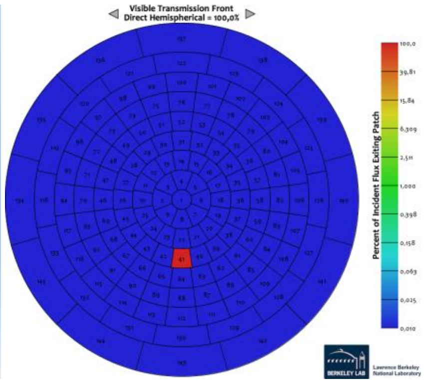




Sensitivity Analysis



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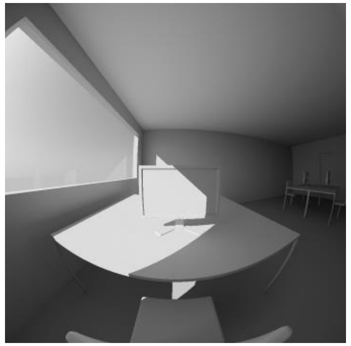

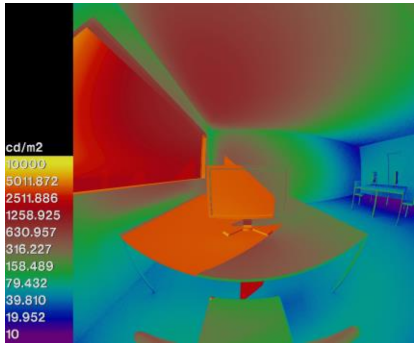

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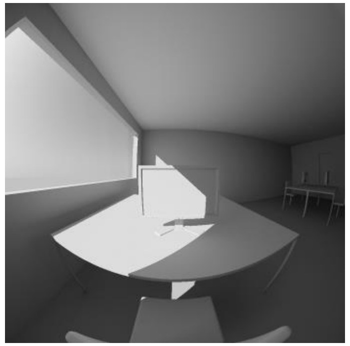

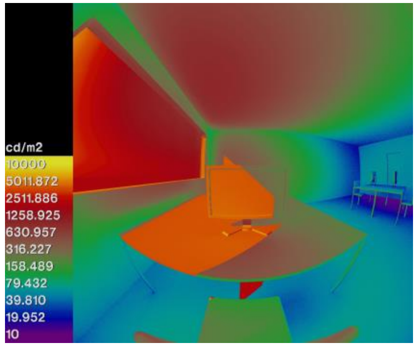

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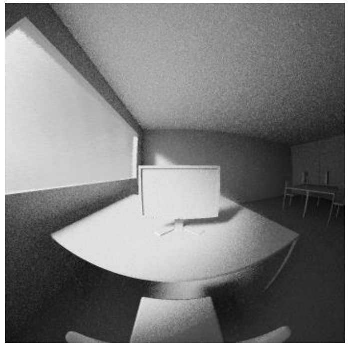

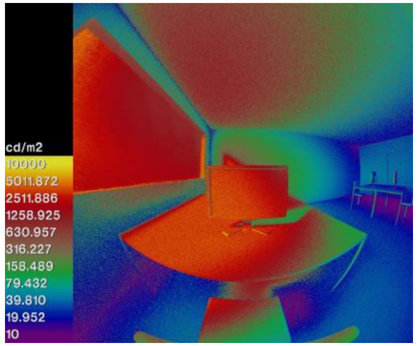

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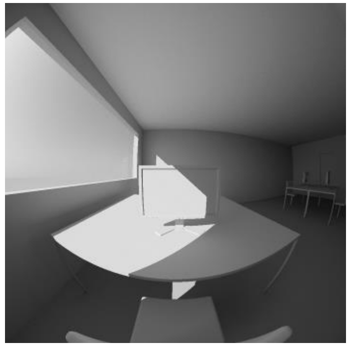

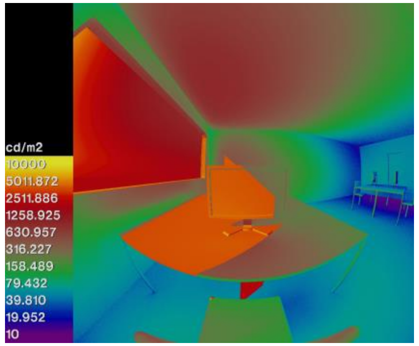

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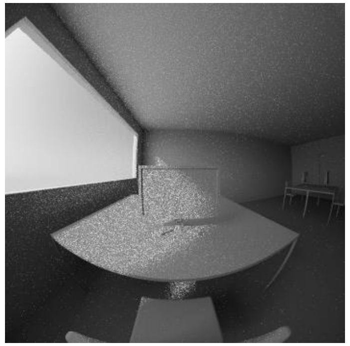

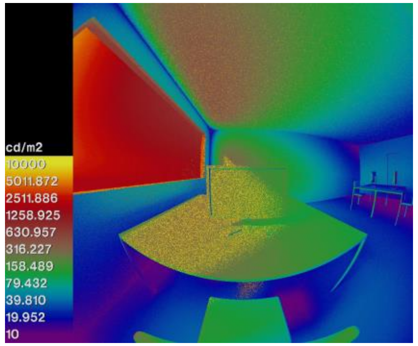

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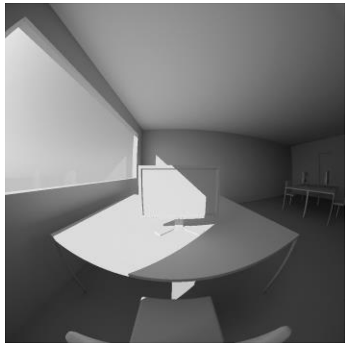
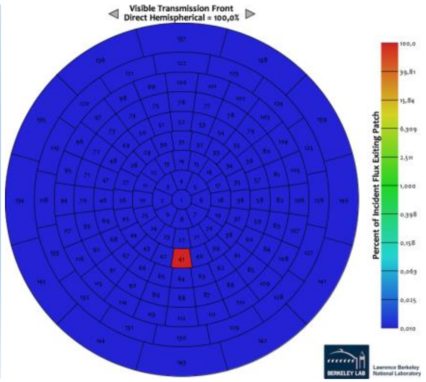
Sensitivity Analysis





Glazing

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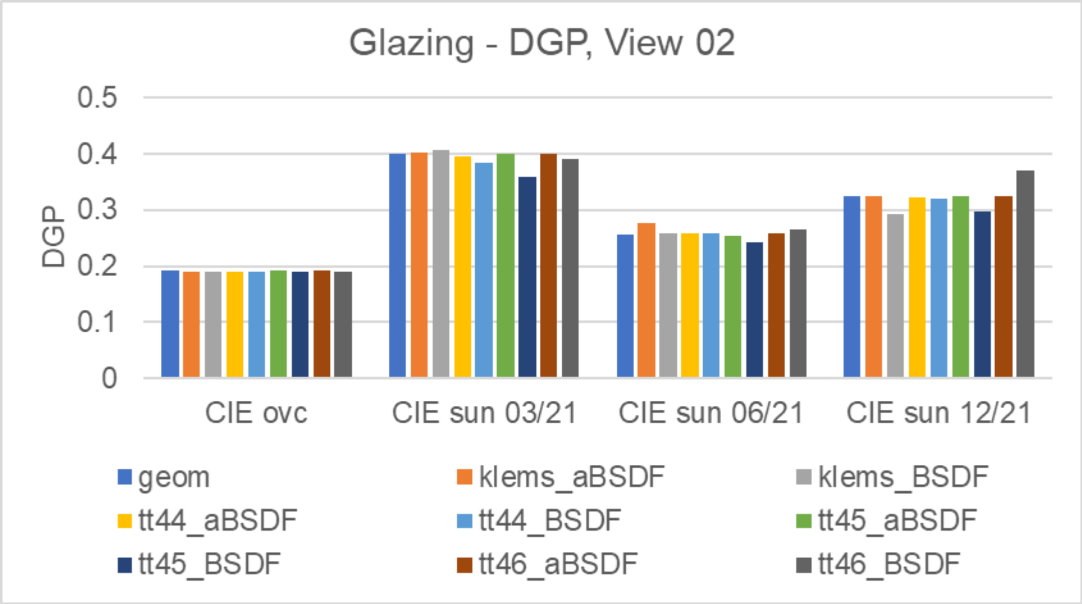
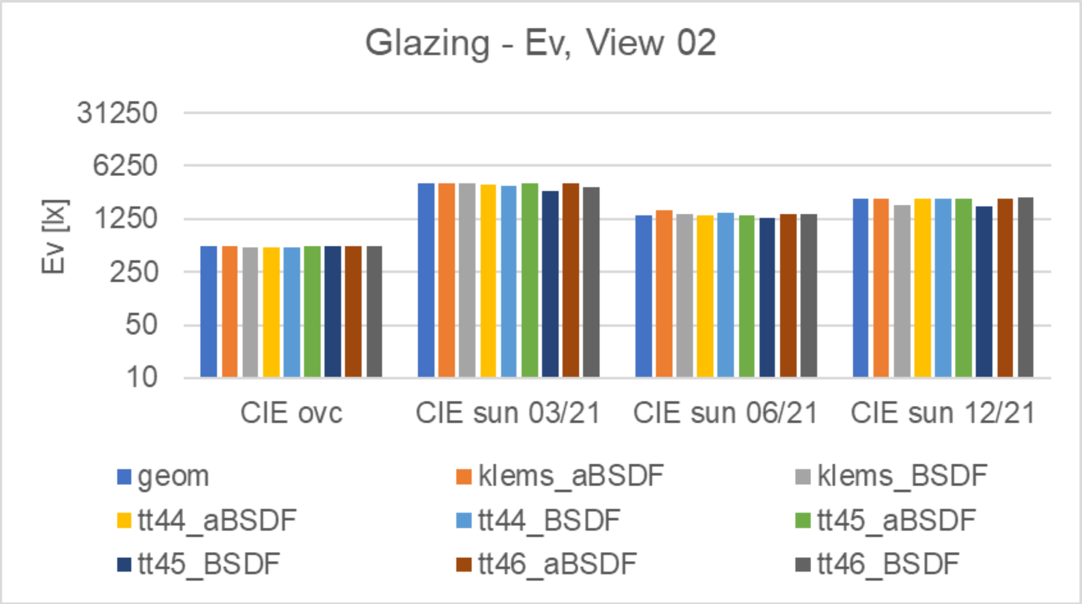
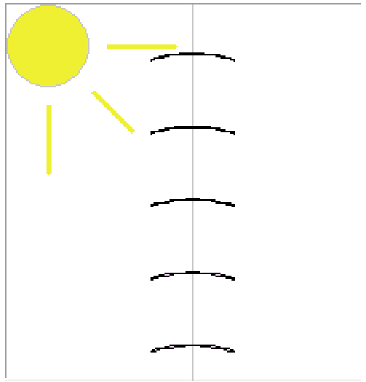
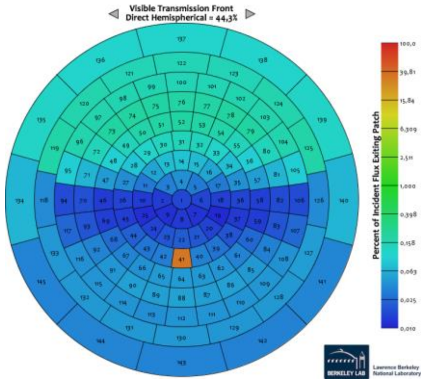
21 March, 10am
Innsbruck, Austria (47.3N / 11.4E)





Sensitivity Analysis





Blinds, 00deg tilt

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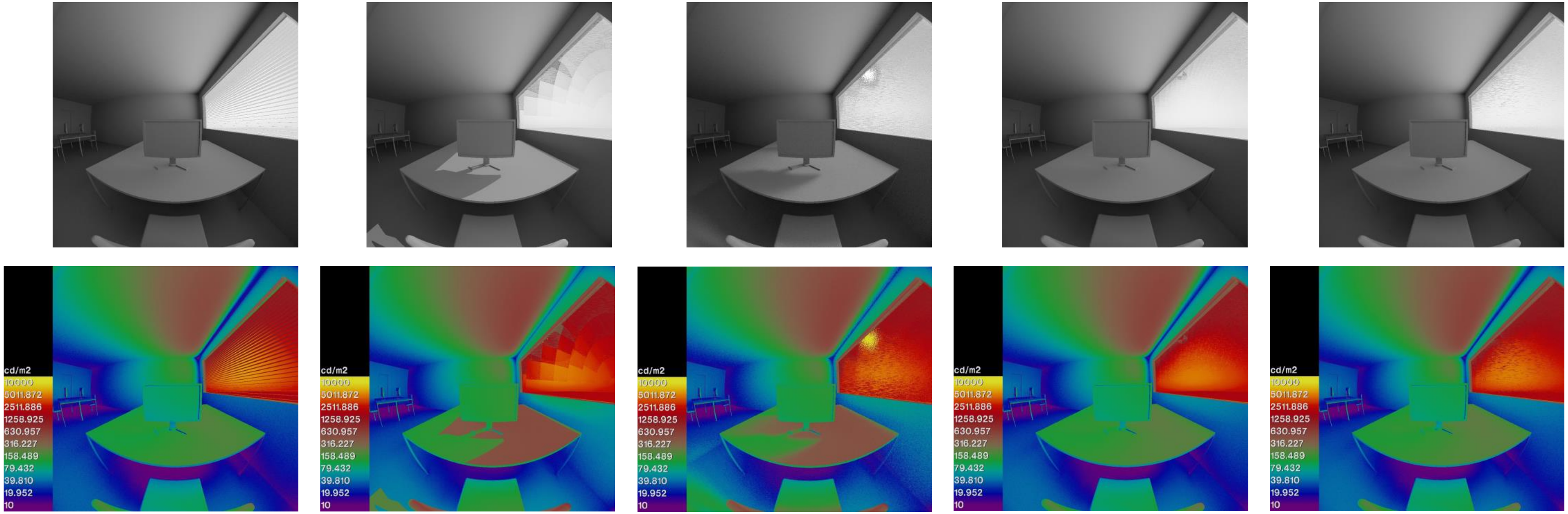

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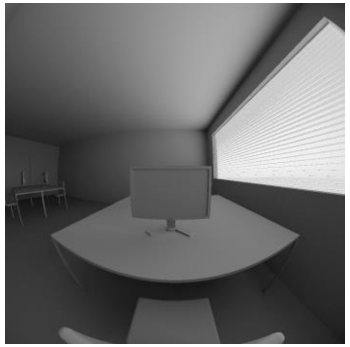
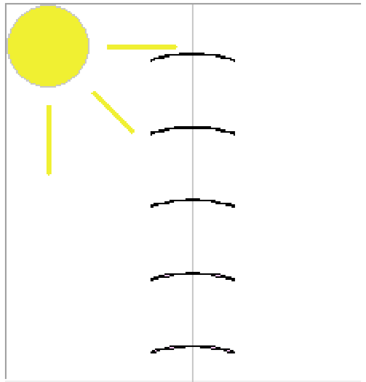
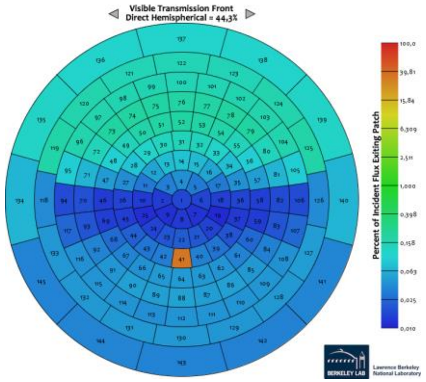
Sensitivity Analysis







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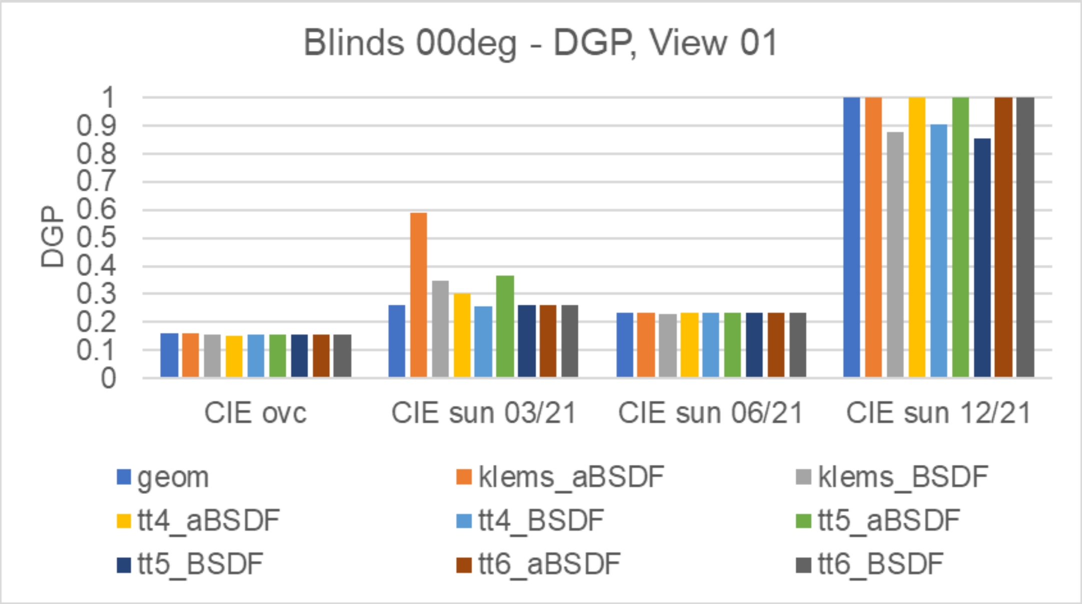

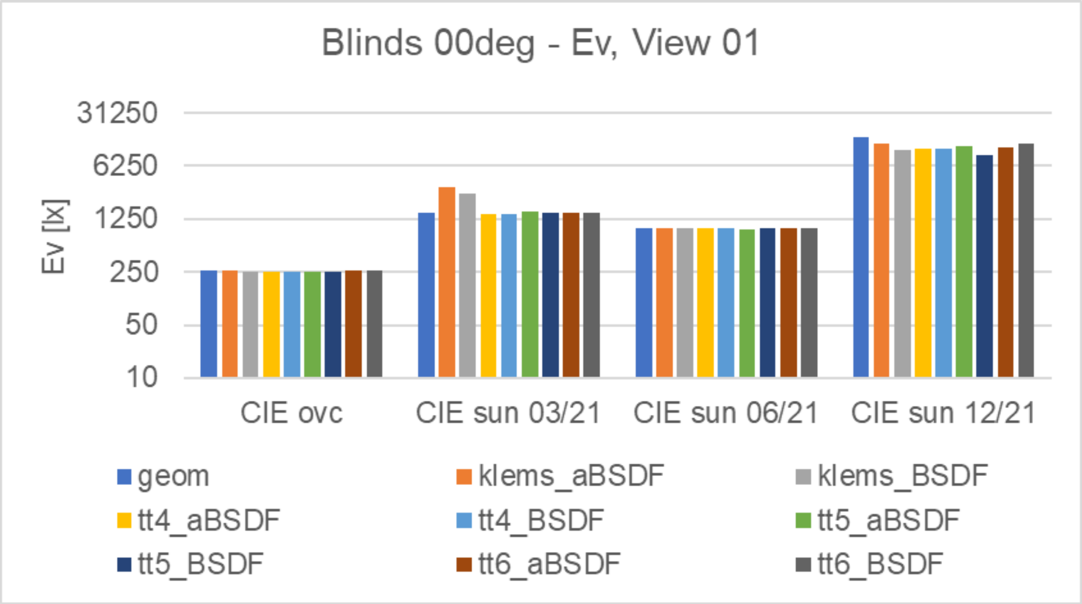

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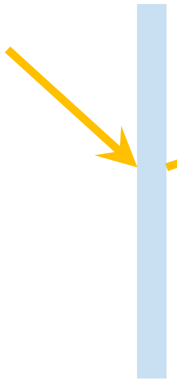
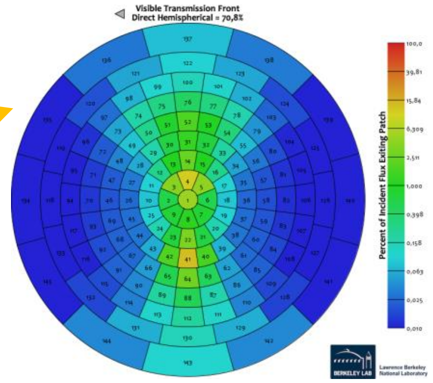
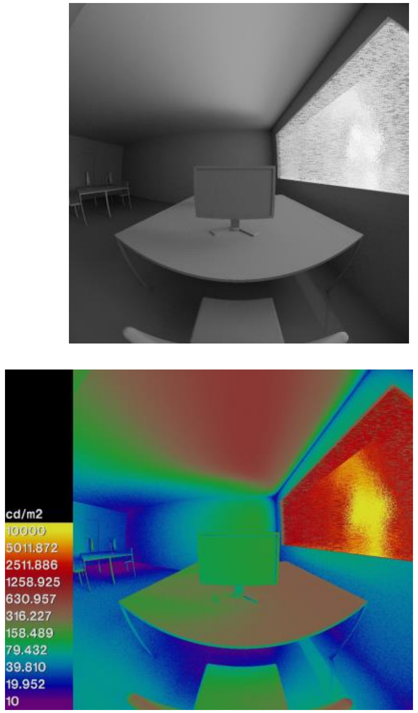


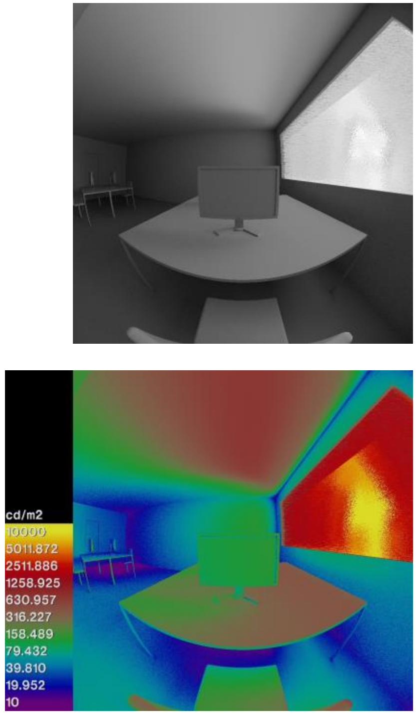


Daylight redirecting film

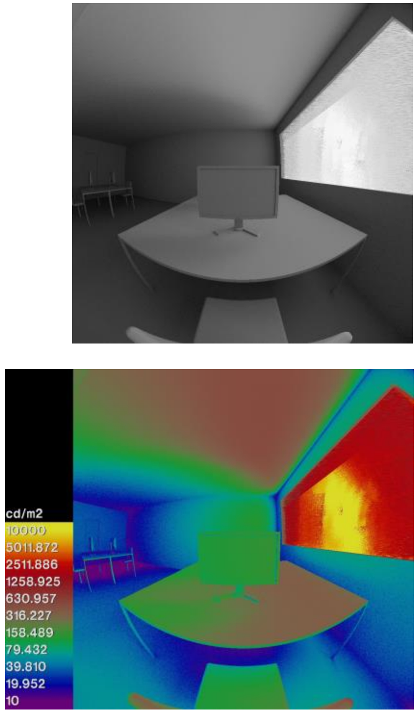
CIE Sunny Sky
21 June, 10am
Innsbruck, Austria (47.3N / 11.4E)



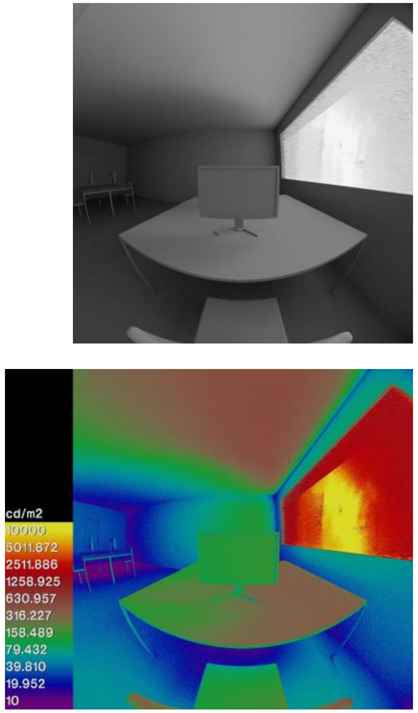
Klems aBSDF
Ev 2090 lx
DGP 0.30



Klems BSDF
Ev 2180 lx
DGP 0.30

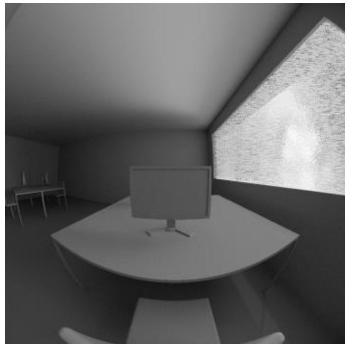


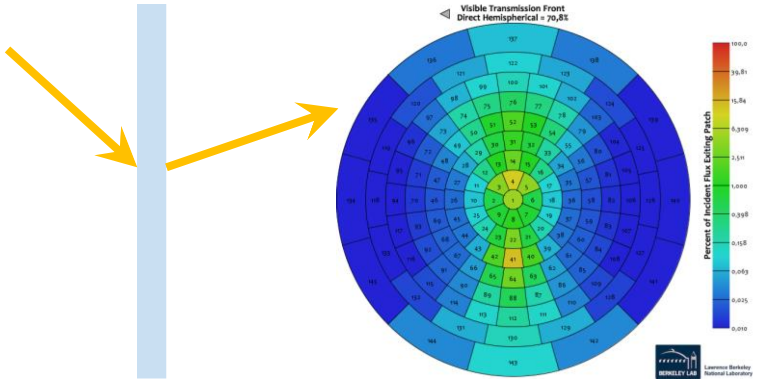
tt46 aBSDF
Ev 2650 lx
DGP 0.33



tt46 BSDF
Ev 2660 lx
DGP 0.33

Sensitivity Analysis





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21 June, 10am
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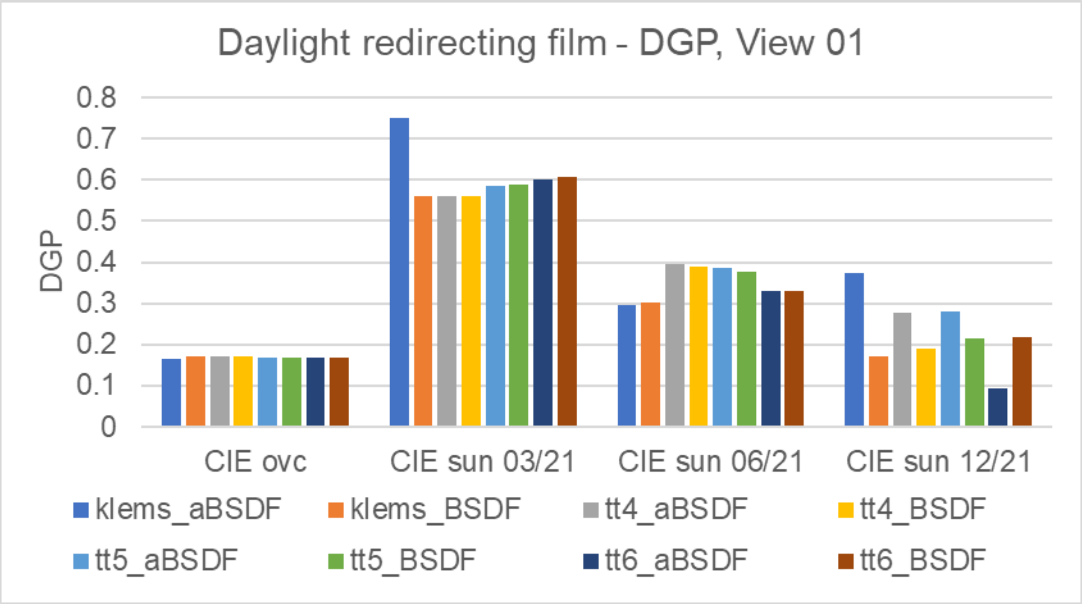
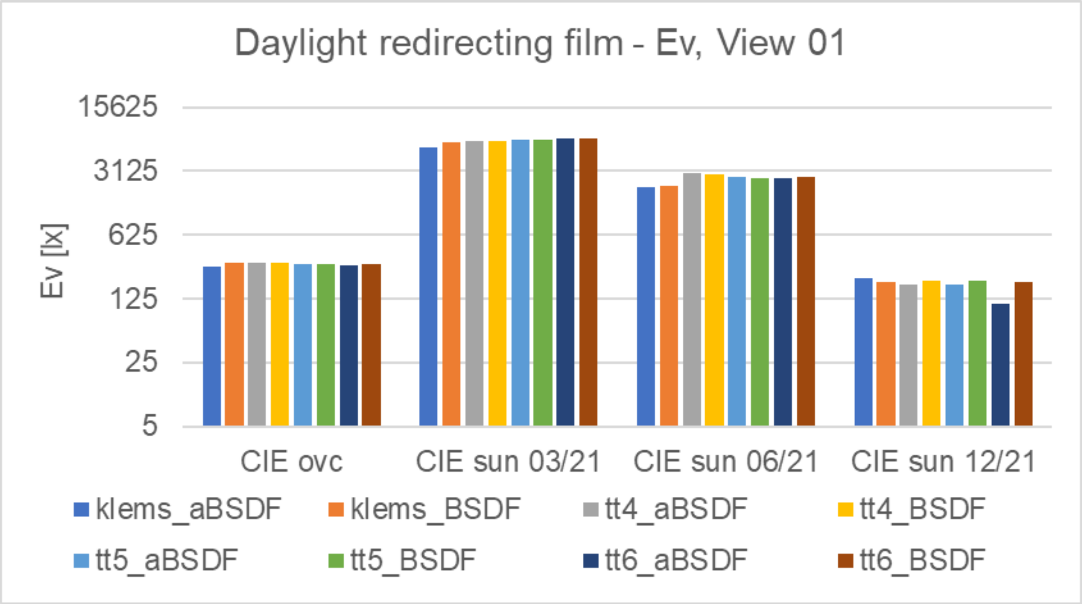
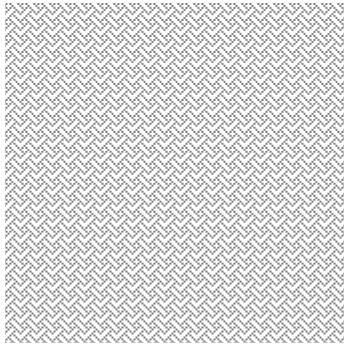
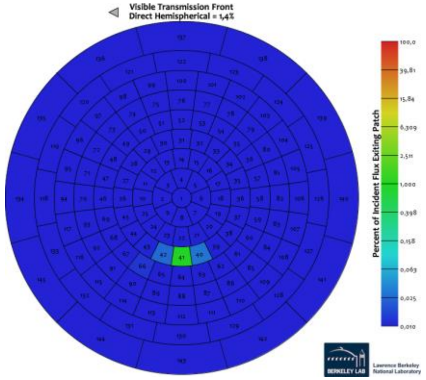




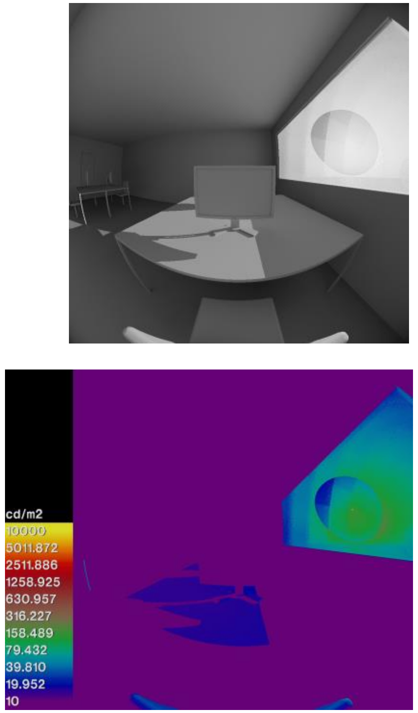
Sensitivity Analysis



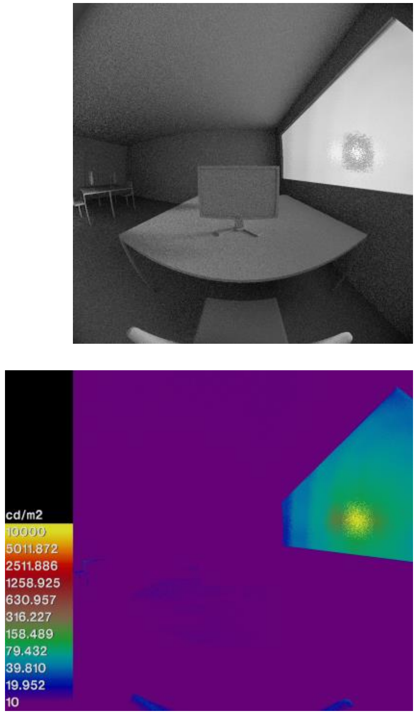


Fabric

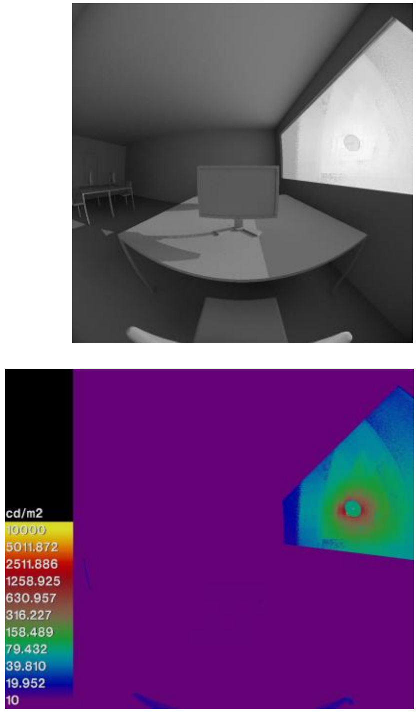
CIE Sunny Sky
21 December, 10am
Innsbruck, Austria (47.3N / 11.4E)



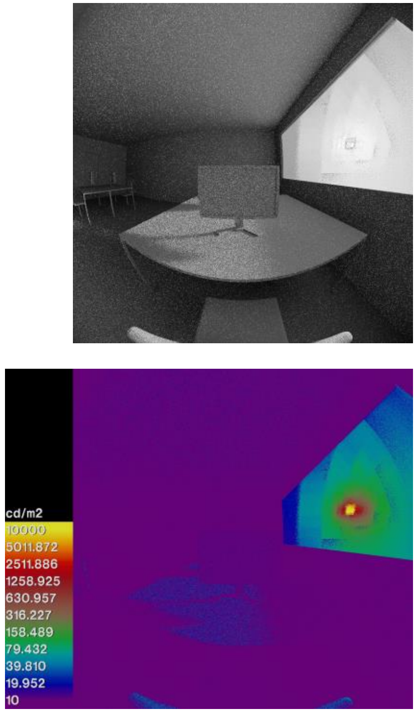
Klems aBSDF
Ev 213 lx
DGP 0.37



Klems BSDF
Ev 191 lx
DGP 0.17

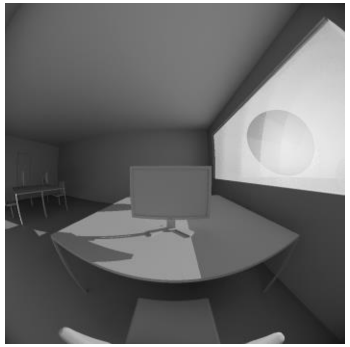


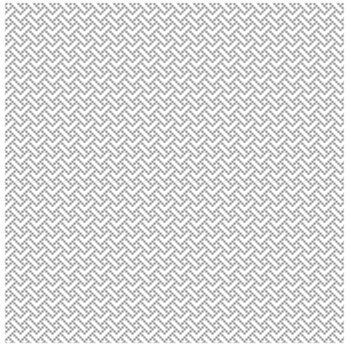
tt46 aBSDF
Ev 109 lx
DGP 0.09

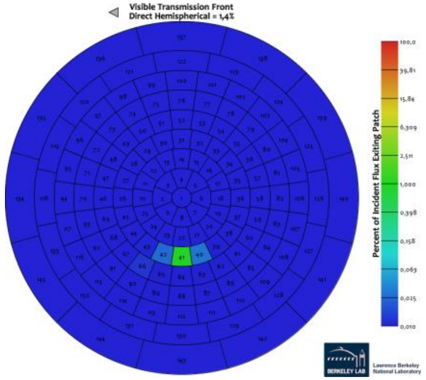


tt46 BSDF
Ev 193 lx
DGP 0.22

Sensitivity Analysis







Fabric

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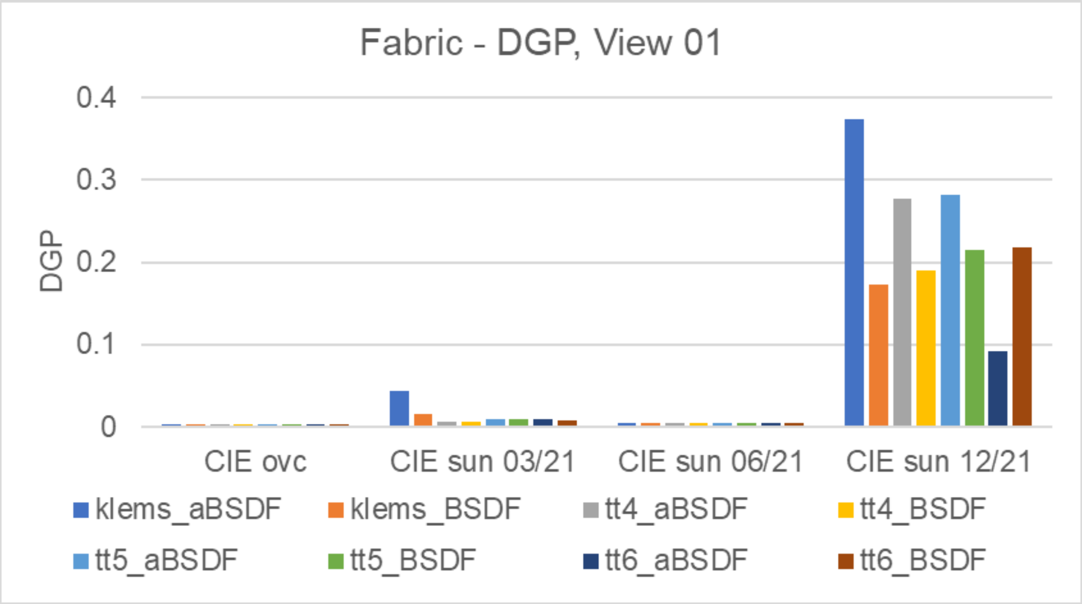
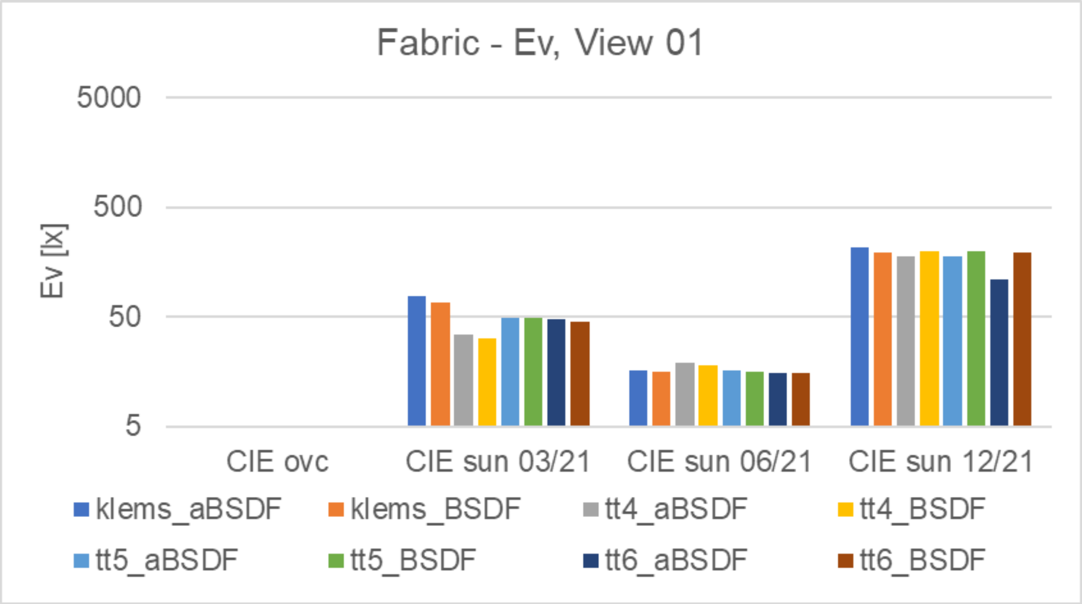




M.Sc. thesis – Mikkel Pedersen & Frederik Rasmussen

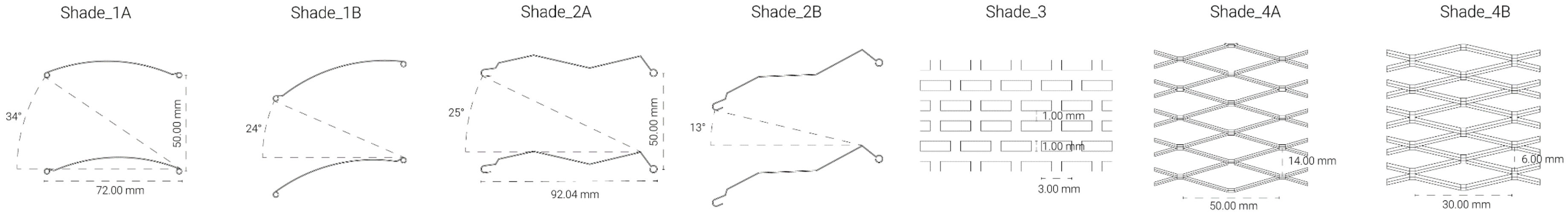
A Sensitivity Analysis on the Effect of BSDF Resolutions for Solar Shading Devices Coupled with Practical Measurements

Supervisors: Associate Professor, Mandana Sarey Khanie
Professor, Jørn Toftum
Dipl. –ing. dr. David Geisler-Moroder

Background

- Case

- Shading systems



- Daylight metrics

Daylight Autonomy (DA), continuous Daylight Autonomy (cDA), Useful Daylight Illuminance (UDI)

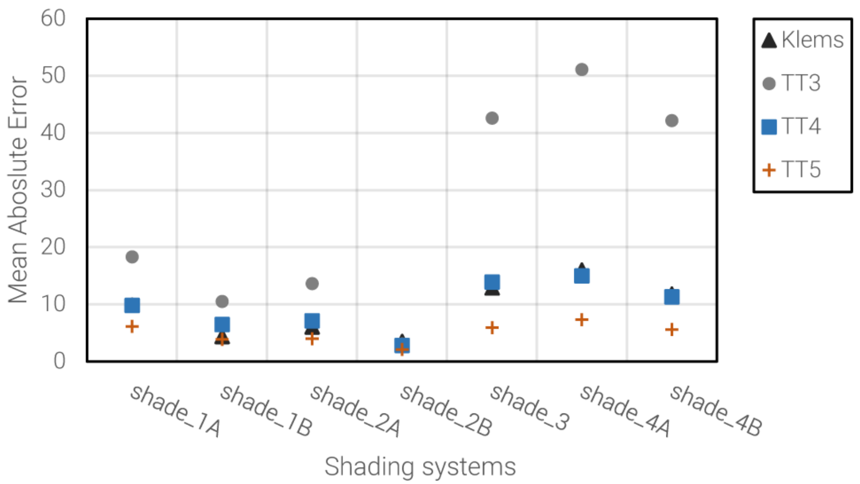
Illuminance

Daylight Glare Probability (DGP), Unified Glare Rating (UGR)

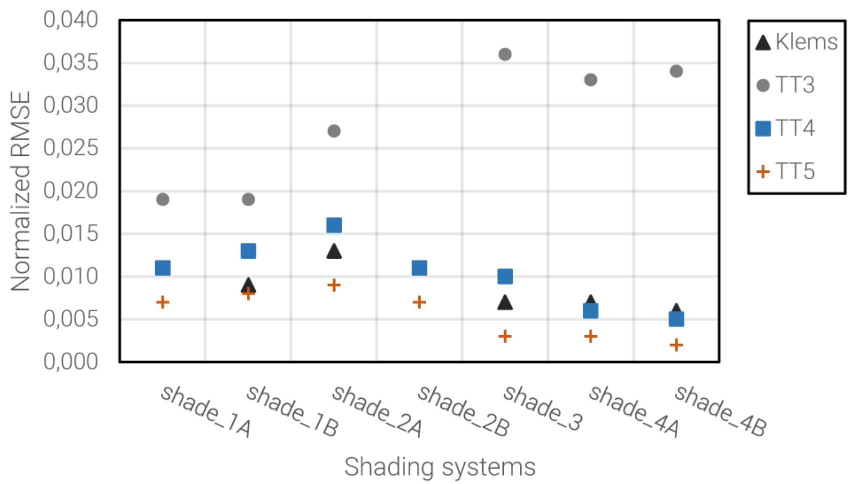
- Background
- Simulation study – Annual
- Simulation study – point-in-time
- Field study
- Conclusion

Simulation study

- annual climate-based for illuminance



Mean Absolute Error - Compared in regards to Illuminance



Normalized RMSE - Compared in regards to Illuminance

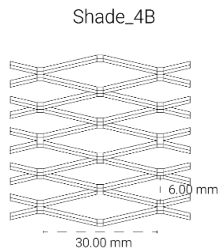
Simulation study

- annual climate-based remarks

- Little to no difference between the BSDF resolutions compared to TT6, when evaluating Daylight Metrics (DA, cDA, UDI) and Shading Systems.
- Comparisons made from illuminance values show the highest deviations using TT3 for shading systems, 3, 4A and 4B.
- The BSDF resolution have less influence on cDA due to the partial credit system.
- The lower limit in UDI makes for the BSDF resolutions to affect the result.

Simulation study

- point-in-time climate-based



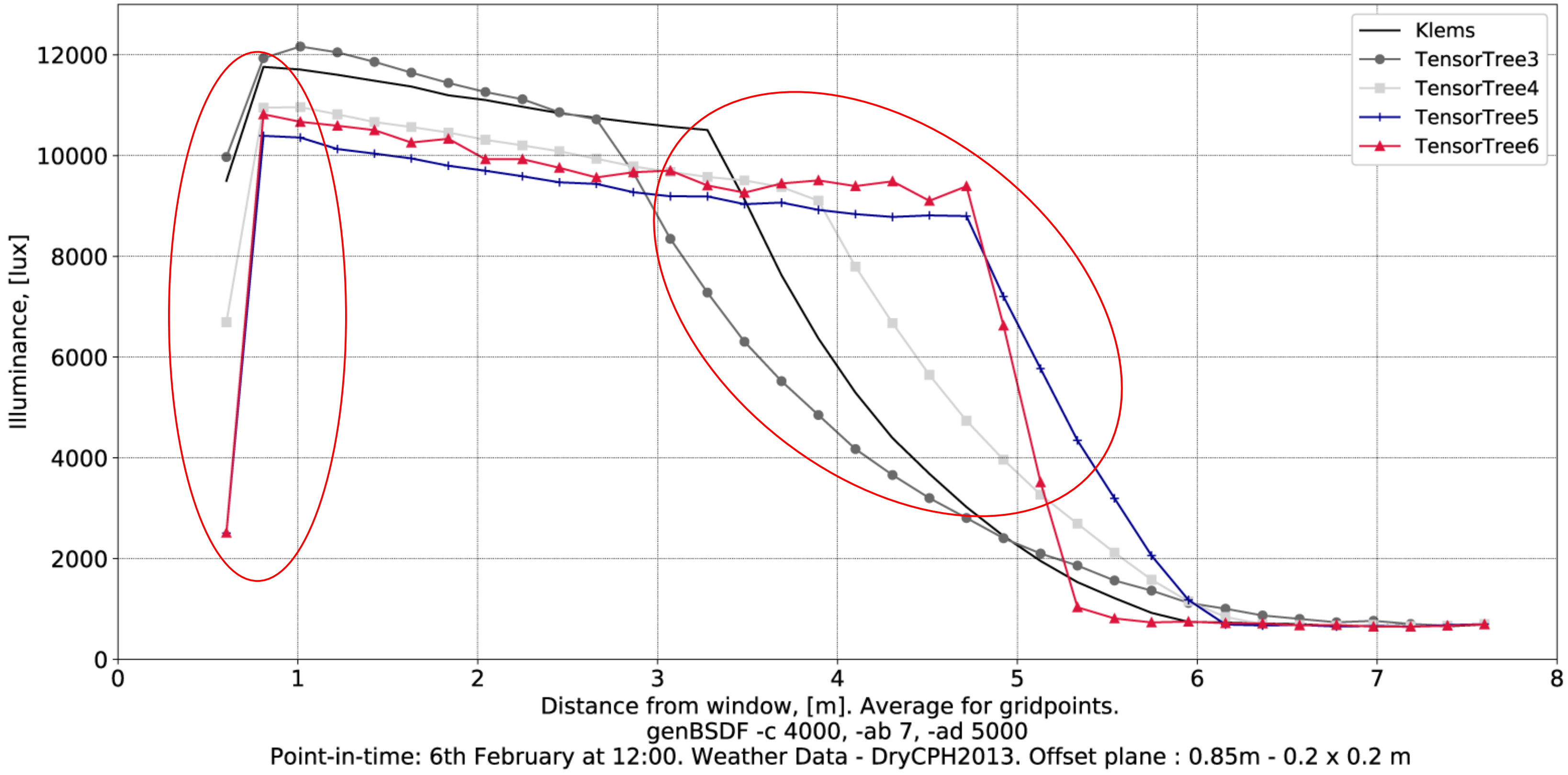


Figure 8.21.: Average illuminance [lux] for grid points in a distance from the window [m] - Shading system - 4B.

Work in progress

System characterization

BSDF

Other characterization ($\tau(\alpha)$, τ_{n-n}, τ_{n-h}, …)

Measurement only

Simulation only

Measurement of base material and simulation of system

Klems / Tregenza-IEA21 / Tensor tree (3/4/5/6/7/…)

Venetian blinds

BSDF

- BSDF measurement of base material (if not provided)
- Software conversion to full high-res BSDF (pabopto2bsdf, bsdf2ttree), Tensor tree 5

OR

- derive analytical model of material (depends on material)
- 3D geometry set-up
- genBSDF for BSDF of full sys

- measurement of $\tau(\alpha)$ for cross-check

- Klems
- Tregenza-IEA21
- Tensor tree 6/7 (anisotropic)

Other characterization

- $\tau(\alpha)$ (includes τ_{n-n} and τ_{n-h})

Work in progress

Venetian blinds

Task	Simulation method	System characterization / BSDF
Daylight Factor	Raytracing possibly mkillum continuous sky model	(a) Geometry (b) Low-res BSDF
Point-in-time illuminance for overcast / sunny sky	Raytracing continuous sky model	(a) Geometry (b) Low-res BSDF
Point-in-time glare metric for overcast / sunny sky	Raytracing peak extraction continuous sky model	(a) High-res BSDF (tt6/7) (b) Low-res BSDF (with peak extraction)
Point-in-time rendering for overcast / sunny sky	Raytracing peak extraction continuous sky model	(a) High-res BSDF (tt6/7) (b) Low-res BSDF if peak extraction
Annual illuminance metric	DC-method or 3-PM	Low-res BSDF
Annual glare metric	5-PM peak extraction	Low-res BSDF and (a) Geometry or (b) high-res BSDF (tt6/7) or (c) low-res BSDF only if PE

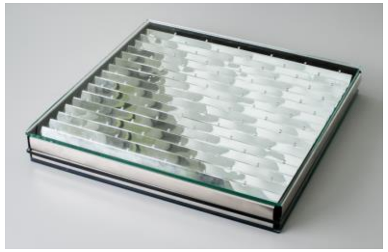
Work in
progress

Aim

The „right“ system data for

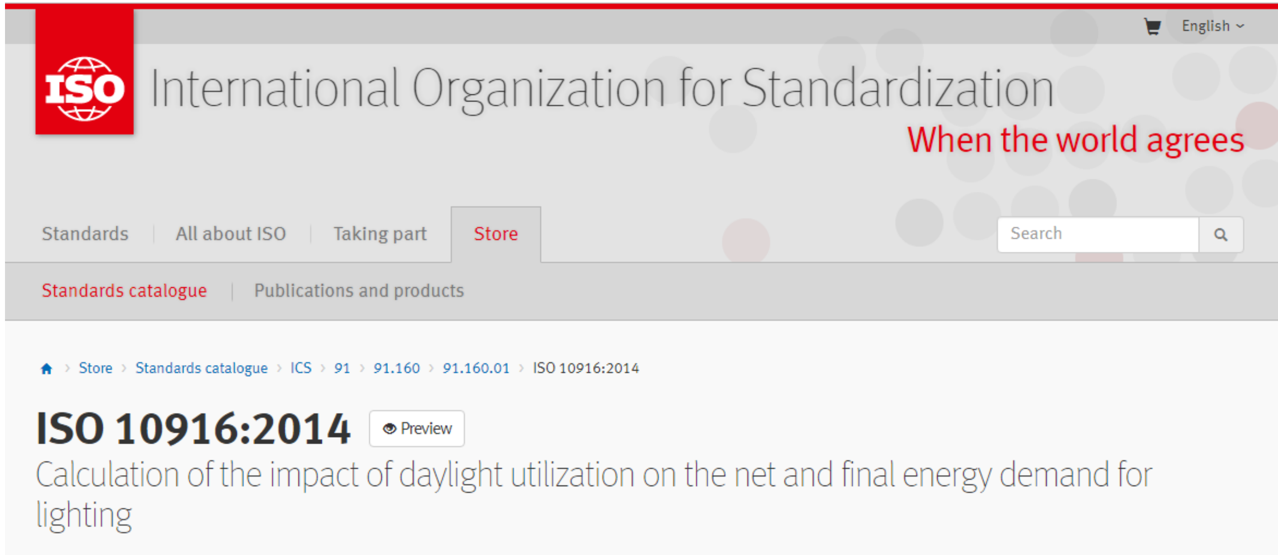
- Transparent systems[1]
- Woven shades
- Venetian blinds
- Specular blinds / grids
- Micro-/Nano-structured systems
- Prisms, LCPs

[1] Clear / electrochromic glazing, films



Work in progress

Standardization of BSDF daylight system characterization



Working items

- Information on BSDF basics
- Specification of BSDF resolutions
- Data format(s)
- Specification of BSDF requirements for
  - Classes of daylight systems (glazing, blinds, fabrics, redirecting films,)
  - Applications / metrics (illuminance, luminance/glare, solar gain; point-in-time, annual)
  - Appropriate BSDF resolutions (low-res … high-res)
- Information on BSDF generation procedures
  - Measurement devices and post-processing procedures
  - Simulation routines

Acknowledgments

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„IEA SHC Task 61 / EBC Annex 77"
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Austrian Research Promotion Agency FFG
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Federal Ministry Republic of Austria Digital and Economic Affairs

Federal Ministry Republic of Austria Transport, Innovation and Technology

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

FFG