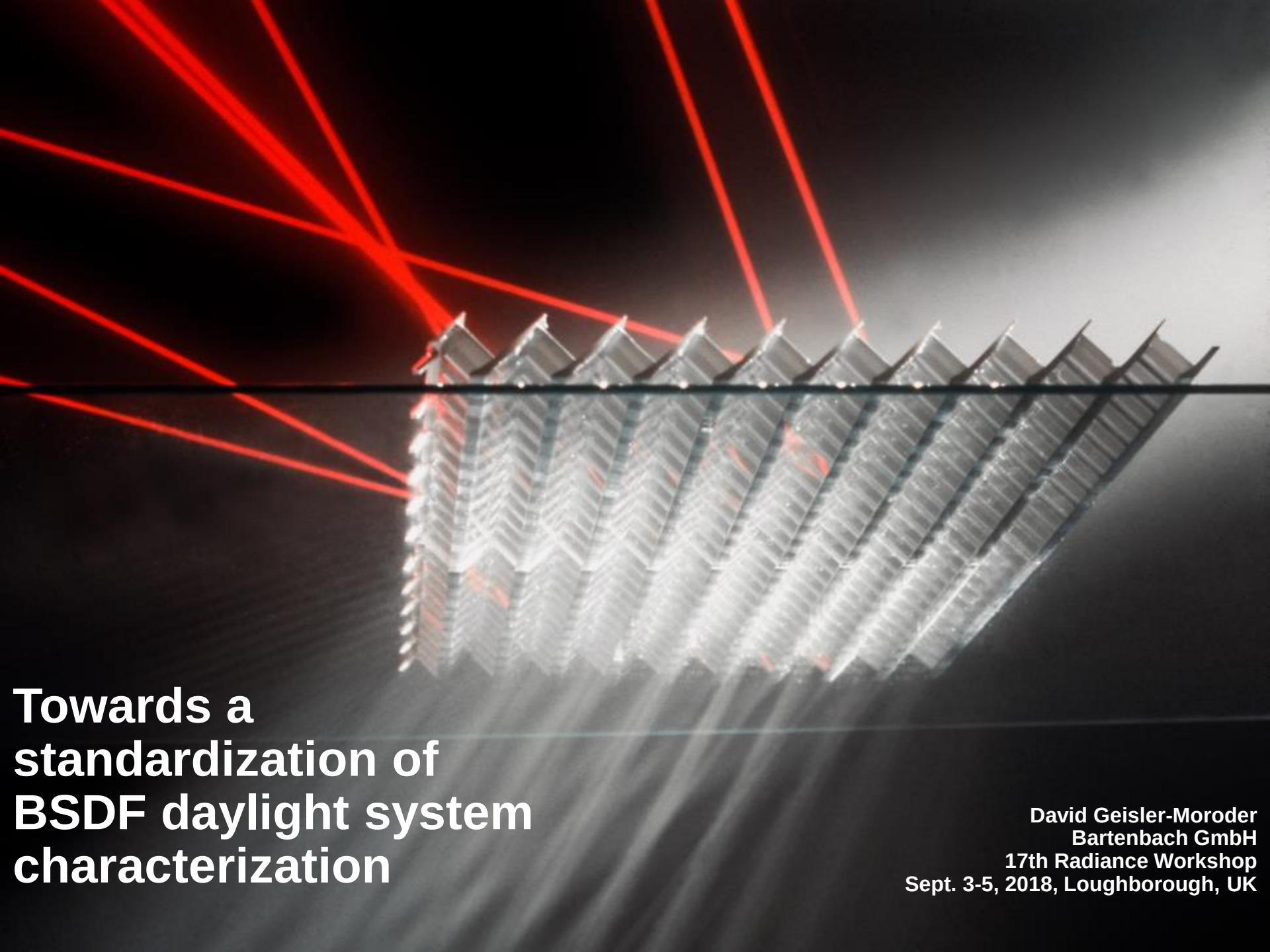


Towards a standardization of BSDF daylight system characterization

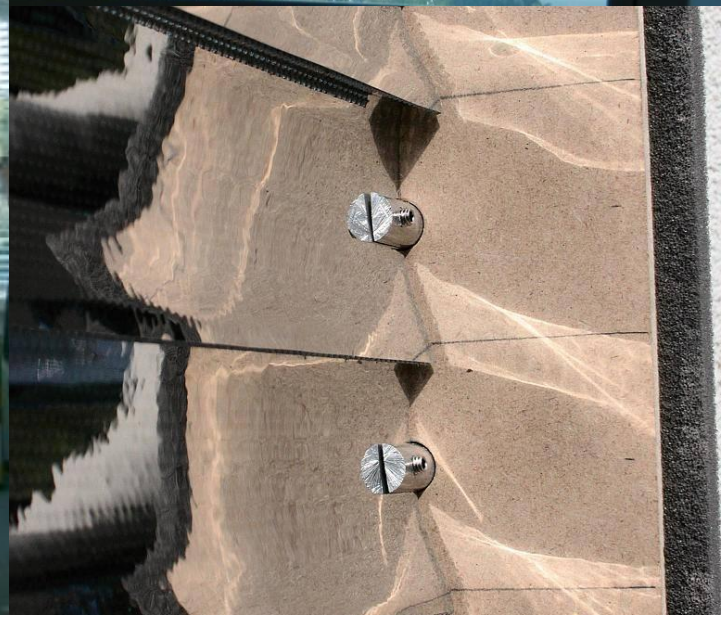
David Geisler-Moroder
Bartenbach GmbH
17th Radiance Workshop
Sept. 3-5, 2018, Loughborough, UK

Library Augsburg, Germany

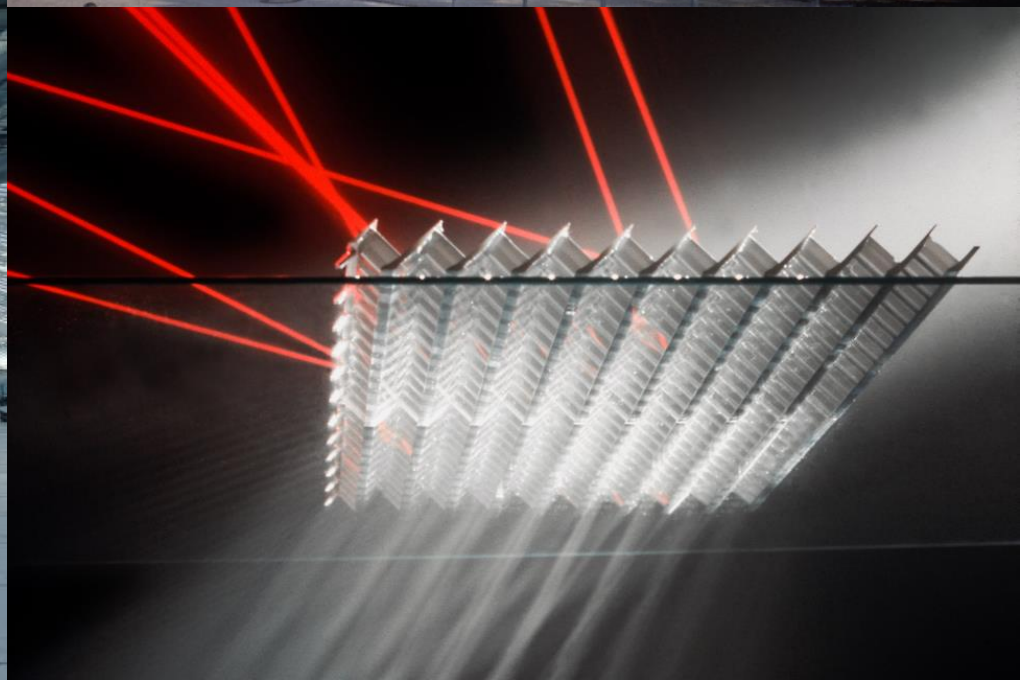
Bayerische Bauindustrie, Munich, Germany

Genzyme Headquarters, Cambridge, MA, USA

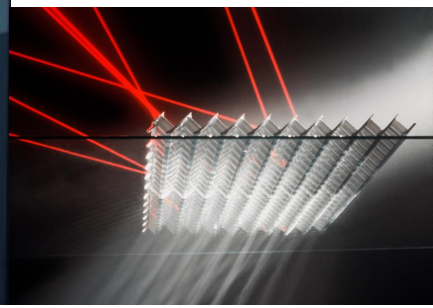
durlum, Schopfheim, Germany



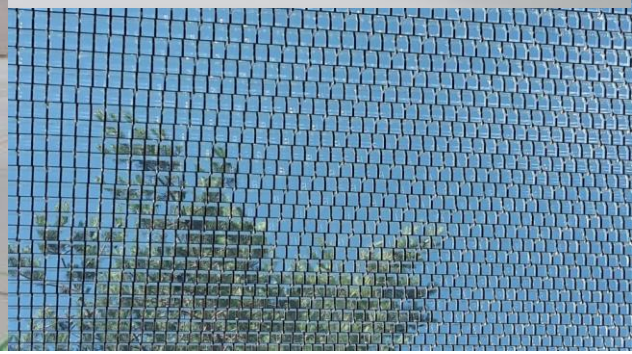
Designcenter, Linz, Austria



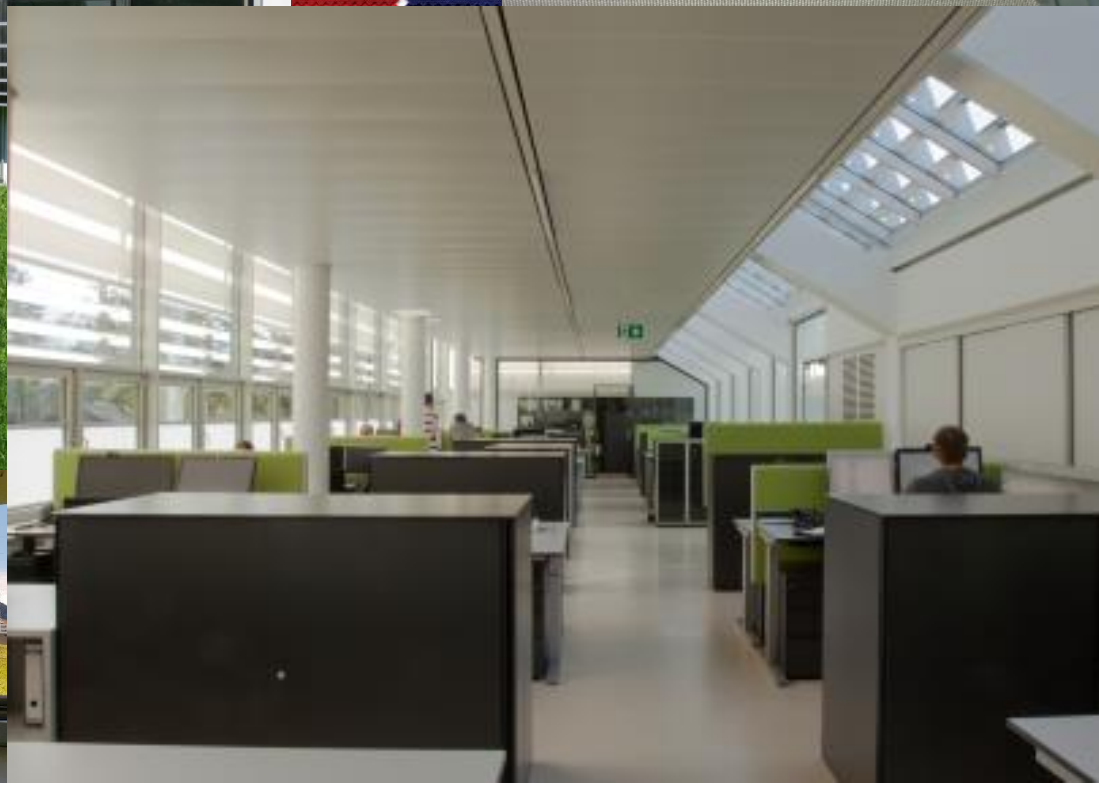
Airport Zurich, Switzerland



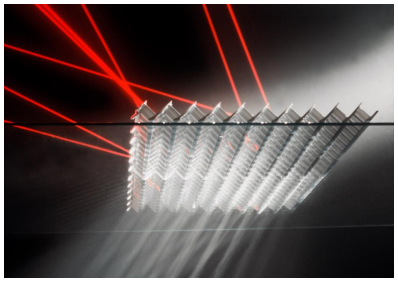
Sports Hall Clervaux, Luxembourg

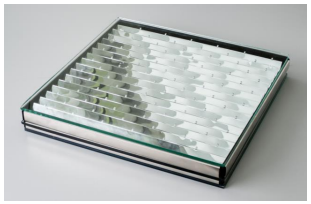


Bartenbach R&D office, Aldrans, Austria



Problem



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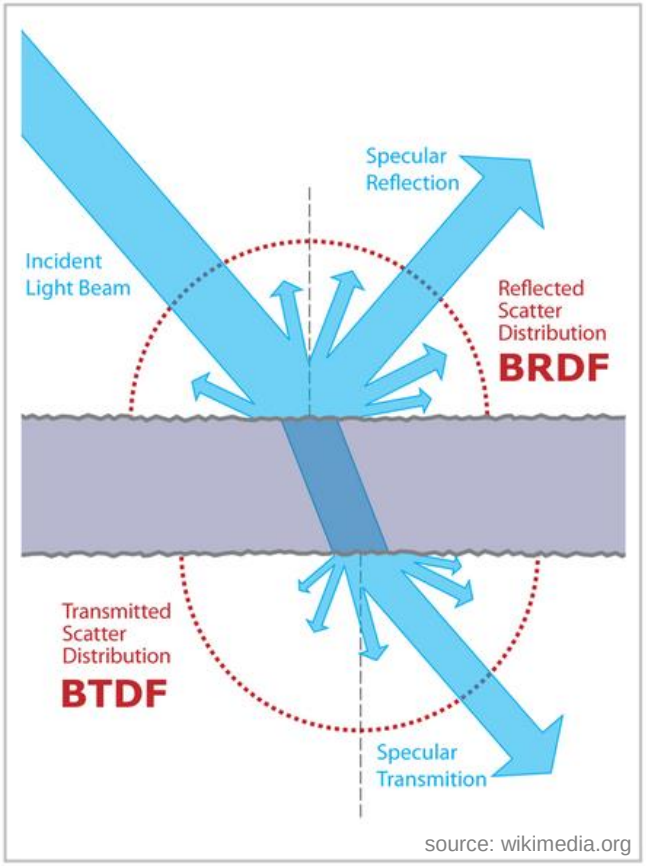

Specular
Reflection
Incident
Light Beam
Reflected
Scatter
Distribution
BRDF
Transmitted
Scatter
Distribution
BTDF
Specular
Transmition
source: wikimedia.org

BSDF basics

BRDF, BTDF, BSDF?

B **bidirectional**

R **reflection**

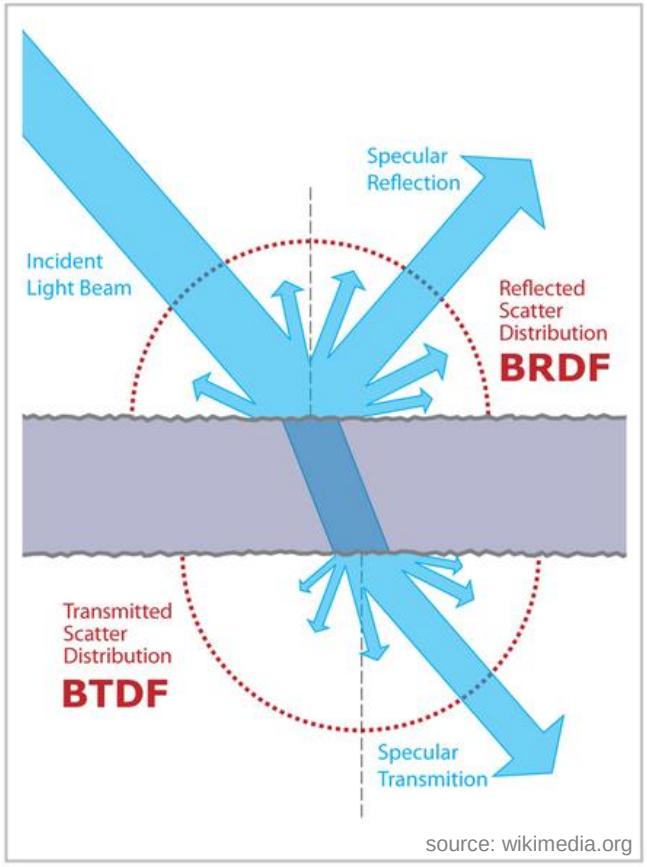
T **transmission**

S **scattering**

DF **distribution function**

„BSDF = BRDF + BTDF“

We are talking about data-driven BSDFs!

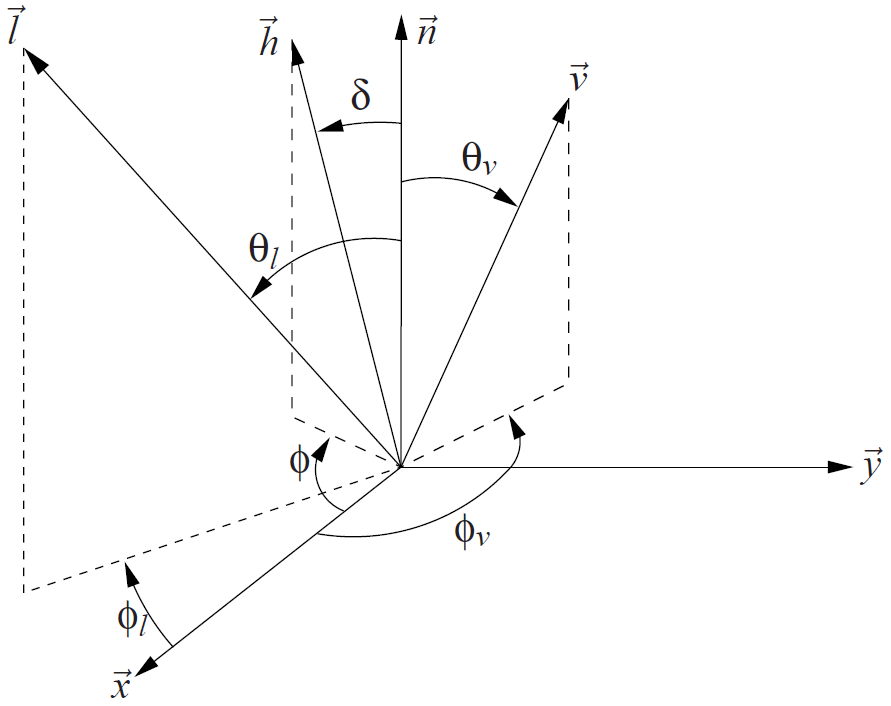


BSDF basics

rendering equation

$$L_v(\theta_v,\phi_v) = \int_0^{2\pi}\int_0^{\pi/2} L_l(\theta_l,\phi_l)\, f(\theta_l,\phi_l;\theta_v,\phi_v)\cos\theta_l \sin\theta_l \, d\theta_l \, d\phi_l$$

(θ_l,φ_l)	light source direction
(θ_v,φ_v)	view point direction
$f(\theta_l,\varphi_l;\theta_v,\varphi_v)$	BSDF
$L_l(\theta_l,\varphi_l)$	radiance from light source direction
$L_v(\theta_v,\varphi_v)$	radiance to view point direction



BSDF basics

physical plausibility

1. Helmholtz reciprocity

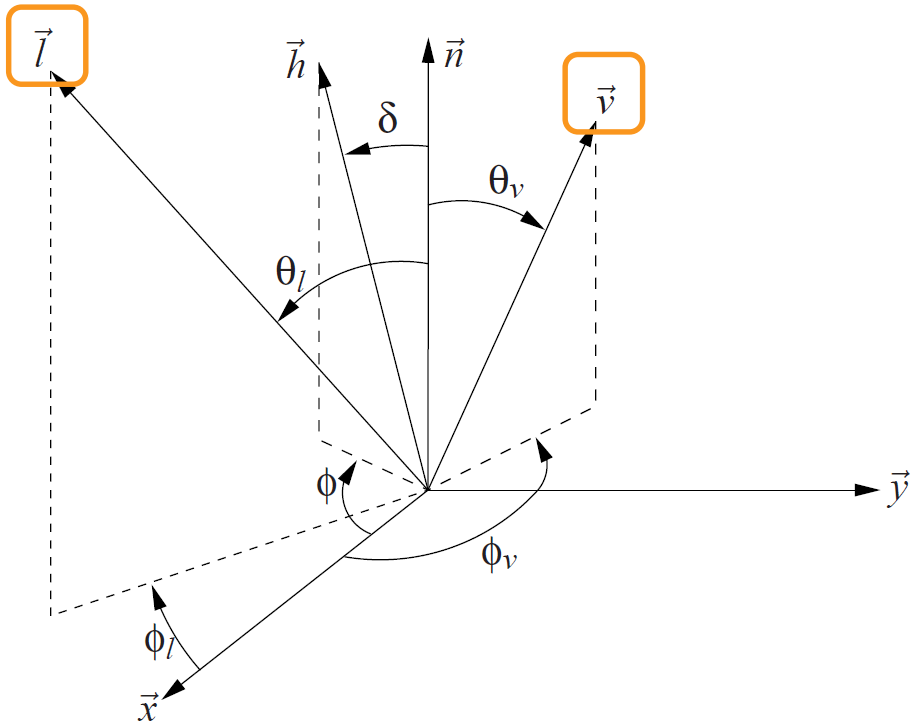
$f(\theta_l,\varphi_l;\theta_v,\varphi_v) = f(\theta_v,\varphi_v;\theta_l,\varphi_l)$

2. energy balance

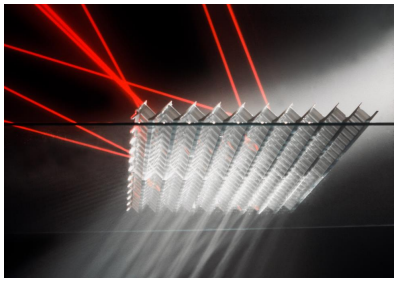
albedo

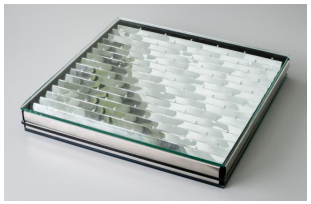
$$a(\theta_l,\phi_l) = \int_0^{2\pi}\int_0^{\pi/2} f(\theta_l,\phi_l;\theta_v,\phi_v)\cos\theta_v \sin\theta_v d\theta_v d\phi_v$$

bounded by 1



Problem



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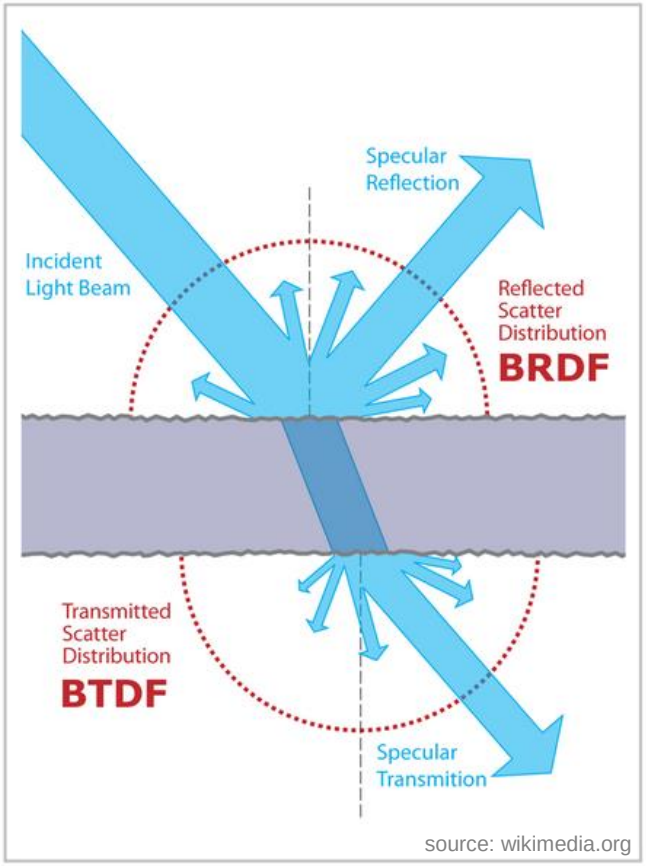
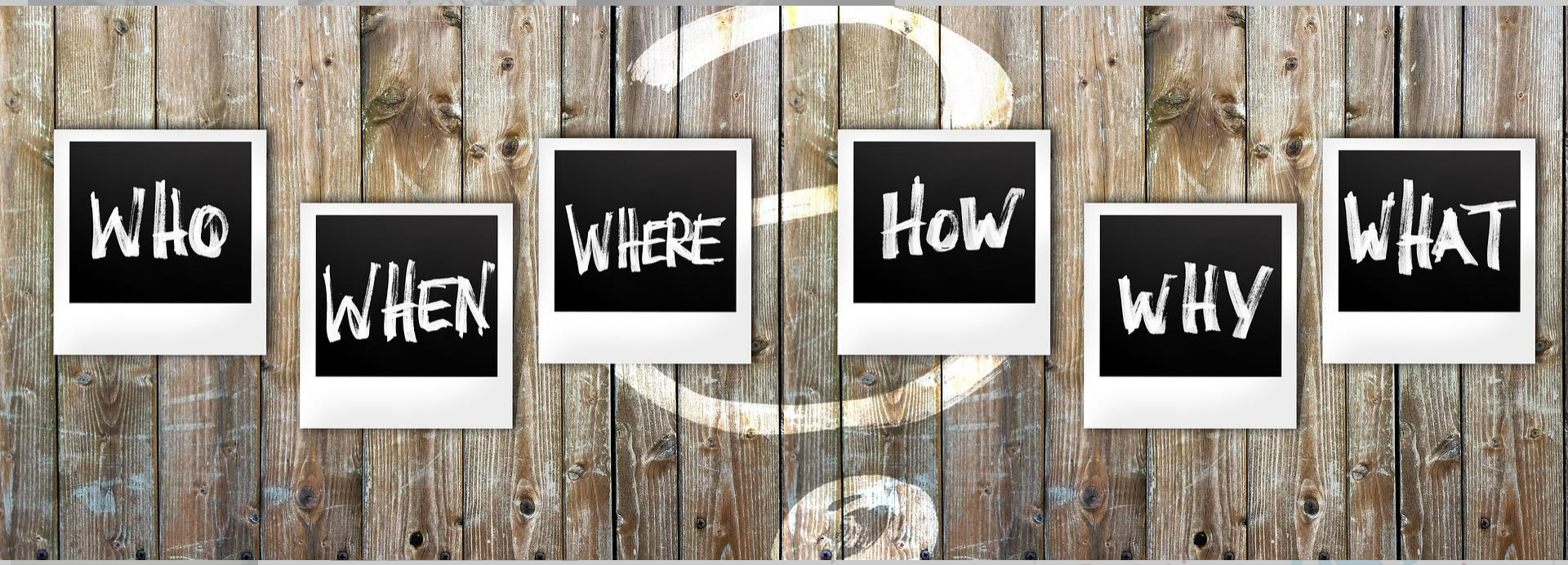
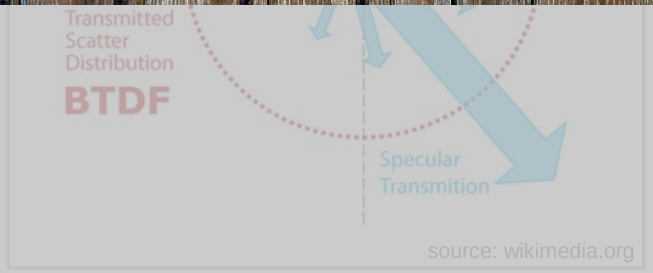

Specular
Reflection
Incident
Light Beam
Reflected
Scatter
Distribution
BRDF
Transmitted
Scatter
Distribution
BTDF
Specular
Transmition
source: wikimedia.org

Problem


WHO
WHEN
WHERE
HOW
WHY
WHAT


Transmitted
Scatter
Distribution
BTDF
Specular
Transmition
source: wikimedia.org

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Fraunhofer ISE
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BERKELEY LAB

Bartenbach
research & development

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN

Fraunhofer IBP
Fraunhofer-Institut für Bauphysik IBP

… industry asks
… developing daylighting systems

… RADIANCE! (or other daylighting software)

… guide manufacturers

That‘s the question.

IEA SHC Task 61 / Annex 77

IEA Task / Annex Proposal

Integrated solutions for daylight and electric lighting

From component to user centered system efficiency

Task organizer: 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

IEA SHC Task 61 / Annex 77

Subtask C: Design Support for Practitioners

Objective:

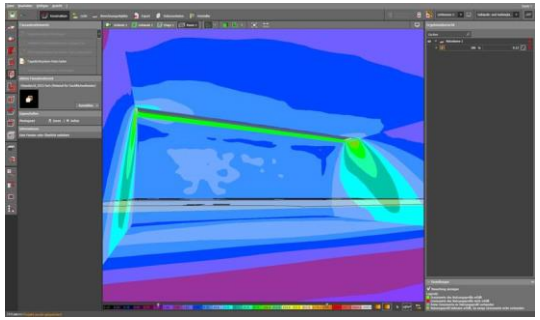
Focus on the application of technical innovations in the field of integrated lighting solutions in practitioners' workflows. Bring findings onto the desktops of designers by integration into widely used software tools, standards and codes, and design guidelines.

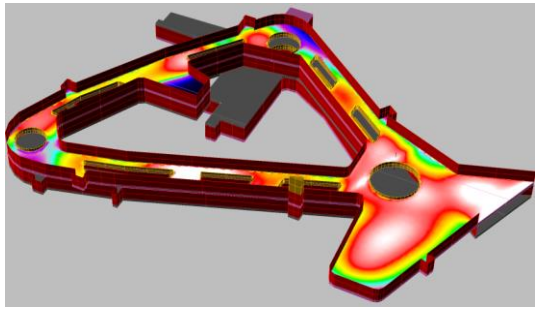
C.1
Review of state of the art design workflows

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





IEA SHC Task 61 / Annex 77

Subtask C1: Review of state of the art workflows

Objectives:

- Document currently used tools
- List current features of common lighting design software
- Depict main pitfalls in the design process
- Show best practice examples

Results:

- Documentation of established workflows and methods
- Documentation of open issues to be addressed in simulation tools

RELUX®
light simulation tools

RADSITE | radiance-online.org

AGi32
lighting software
by Lighting Analysts

DALEC
Building Energy under Control

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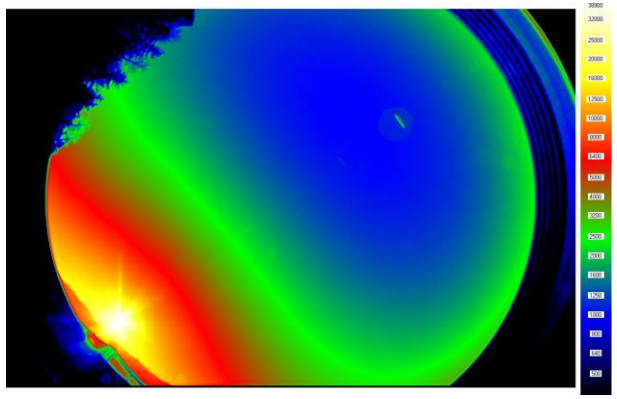


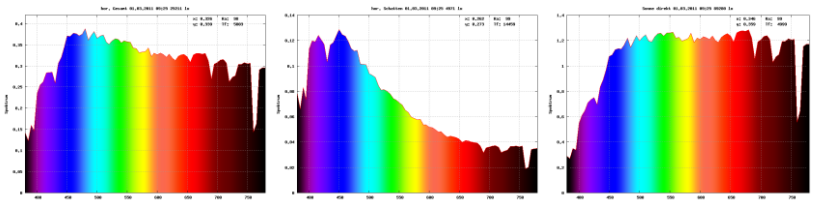
Subtask C3: Spectral sky models for advanced daylight simulations

Objectives:

- Review existing spectral sky models
- Analyze recent developments in daylight simulation methods
- Derive approximations from reduced color information

Results:

- Spectral sky model
- Algorithms to derive spectral evaluations from reduced spectral data



IEA SHC Task 61 / Annex 77

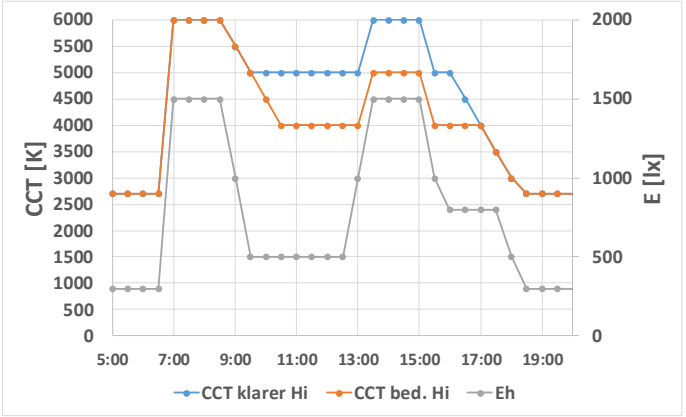
Subtask C4: Hourly rating methods for integrated solutions

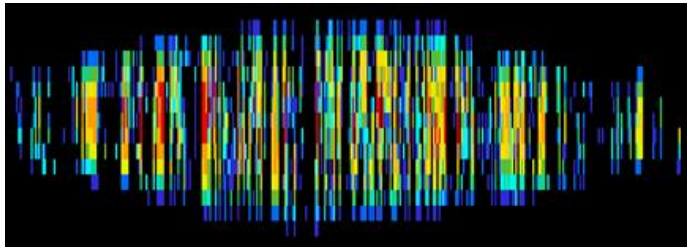
Objectives:

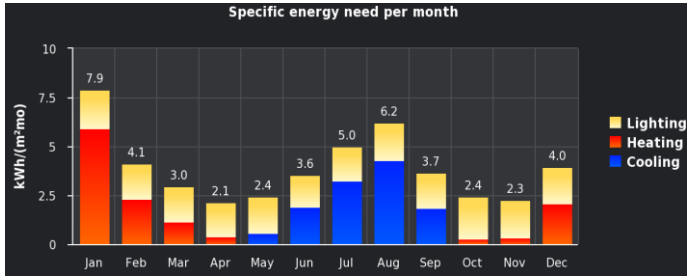
- Review existing rating models and document open issues
- Elaborate user-centered integral performance assessment for lighting solutions in terms of energetic, photometric and non-visual effects

Results:

- Generic hourly rating model for performance evaluation of integral lighting solutions





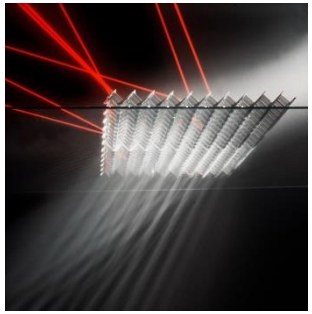


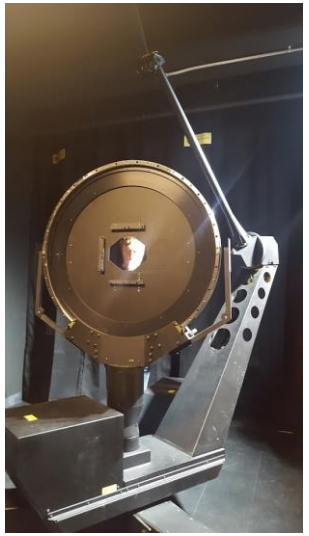
IEA SHC Task 61 / Annex 77

Subtask 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

IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Simulation**
  - **genBSDF**
    part of the RADIANCE software package
  - **WINDOW**
    LBNL software for calculation of total window thermal performance indices
  - **commercial software** (e.g. LucidShape, ASAP, LightTools, TracePro, …), need to create own „patch – illumination“ and conversion from ray file to patches
  - …

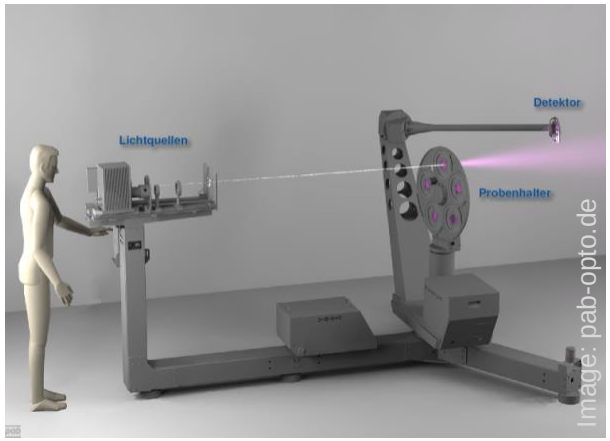
IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Measurement (1)**

Scanning goniophotometer



IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Measurement (2)**

CCD based goniophotometer

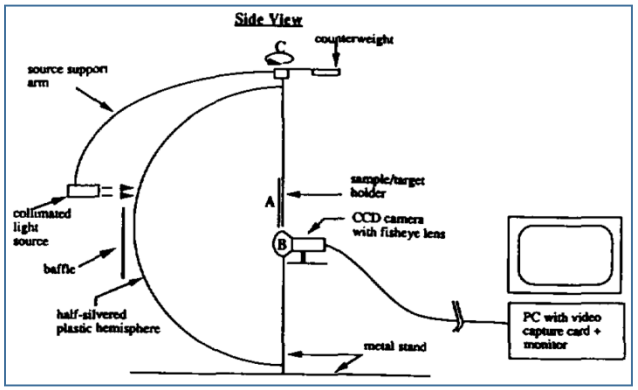


Image: G. Ward 1992

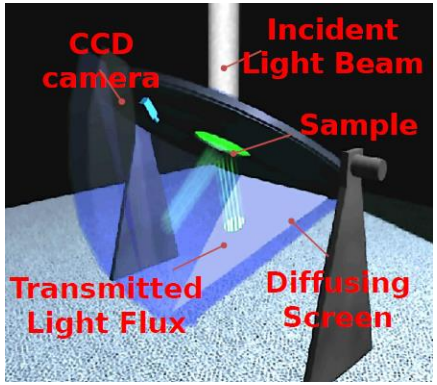


Image: J.Kämpf 2011

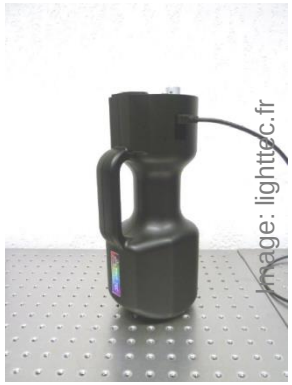


Image: lighttec.fr

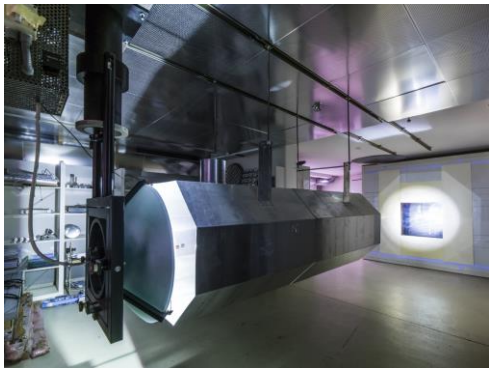
IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Measurement (3)**

Direct-hemispherical transmission



IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Data formats**
  - **XML file format**
    definition of data discretization in header
    data blocks interpreted by software
    accordingly

```
<?xml version="1.0" encoding="UTF-8"?>
<WindowElement xmlns="http://windows.lbl.gov" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        <WindowElementType>System</WindowElementType>
        <Optical>
                <Layer>
                <Material>
                        <Name>DALEC_UL_00deg_1u2panes</Name>
                        <Manufacturer>Bartenbach</Manufacturer>
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                        <DeviceType>Integral</DeviceType>
                        </Material>
                <DataDefinition>
                        <IncidentDataStructure>Columns</IncidentDataStructure>
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                        <AngleBasisName>LBNL/Klems Full</AngleBasisName>
                                <AngleBasisBlock>
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                                <UpperTheta>5</UpperTheta>
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                                <ThetaBounds>
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                                </ThetaBounds>
                                </AngleBasisBlock>
```

  - **Established data formats**

name	input resolution	output resolution	currently used by software
WINDOW6	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

IEA SHC Task 61 / Annex 77

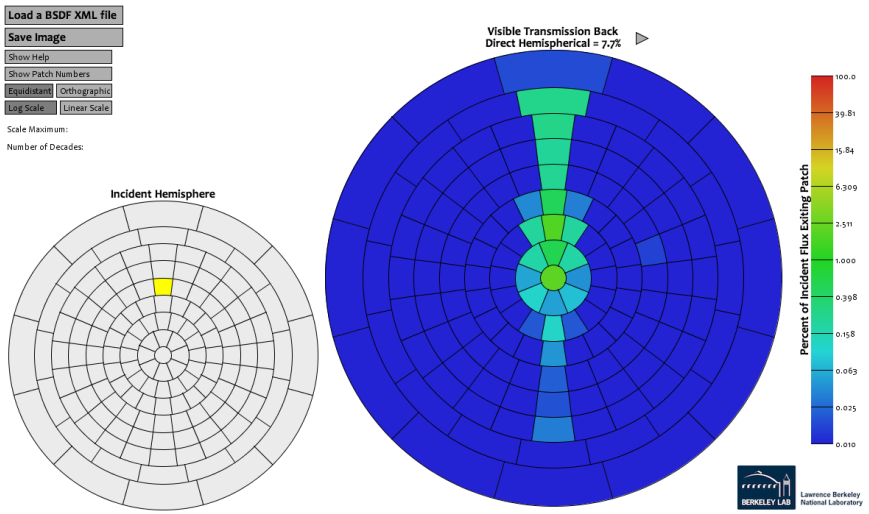
Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Data formats (1)**

Klems patches

- subdivision of hemisphere into 145 patches
- approx. equal illuminance from each patch if luminance is constant in hemisphere



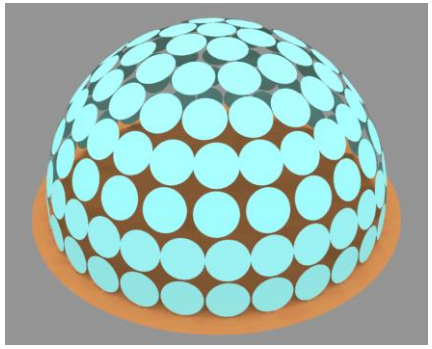
- 9 θ ranges: {0°-5°, 5°-15°, 15°-25°, 25°-35°, 35°-45°, 45°-55°, 55°-65°, 65°-75°, 75°-90°}
- φ subdivisions per θ range: {1, 8, 16, 20, 24, 24, 24, 16, 12}
- average solid angle 2π/145 = 0.0433 sr, i.e. cone with 2 x 6.73° apex angle

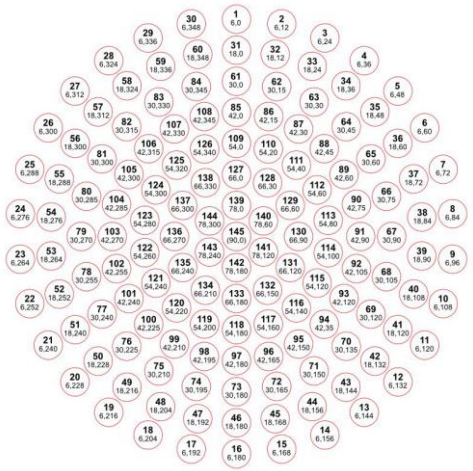
IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Data formats (2)**





Tregenza patches (CIE 108-1994)

- subdivision of hemisphere into 145 patches
- approx. equal solid angle for 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

IEA SHC Task 61 / Annex 77

Subtask C2: Standardization of BSDF daylight system characterization

State-of-the-art review

- **Data formats (3)**

Variable resolution BSDFs

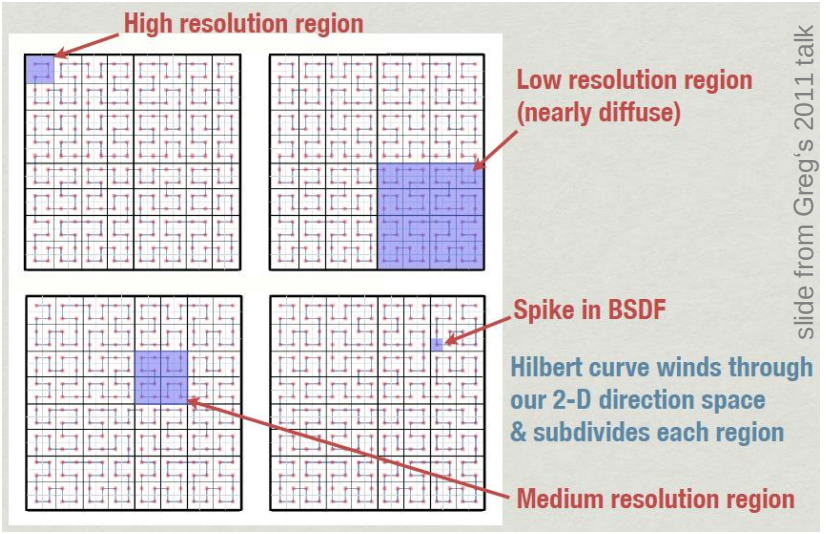
- **idea:** **high resolution for spikey regions**
  low resolution for smooth regions

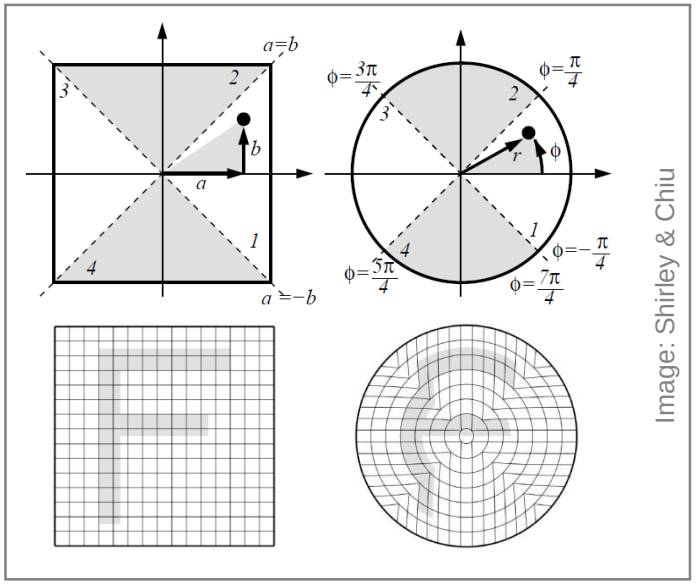
- based on Shirley-Chiu-mapping
  (preserves fractional area, i.e. projected solid angle)

- maximum dimensions in 4D $2^{2n} \times 2^{2n}$
  ($n = 4 / 5 / 6$: $256^2 / 1024^2 / 4096^2$)

+ efficient data structure
  (ideal diffuse reflector needs 1 value $\{1/\pi\}$)

– no matrix structure (daylight coefficient approach)





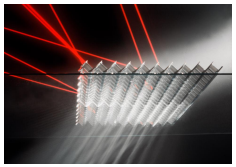
IEA SHC Task 61 / Annex 77

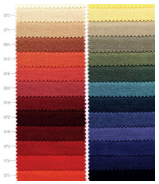
Subtask C2: Standardization of BSDF daylight system characterization

BSDF requirements

System typologies

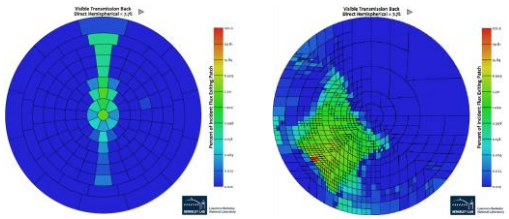
- Clear glass / films
- Blinds
- Fabrics
- Redirecting structures
- …





Resolutions

- Klems patches
- IEA21 / Tregenza patches (CIE 108-1994)
- Variable resolution BSDFs (Shirley-Chiu mapping, tensor trees)
- …



Ratings

- Luminous flux
- Interior illuminances
- Glare evaluations
- Luminances
- Visualizations
- …

Φ

E

DGP

DGI

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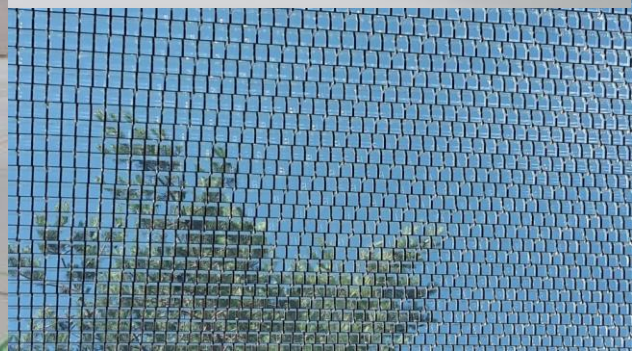
IEA SHC Task 61 / Annex 77

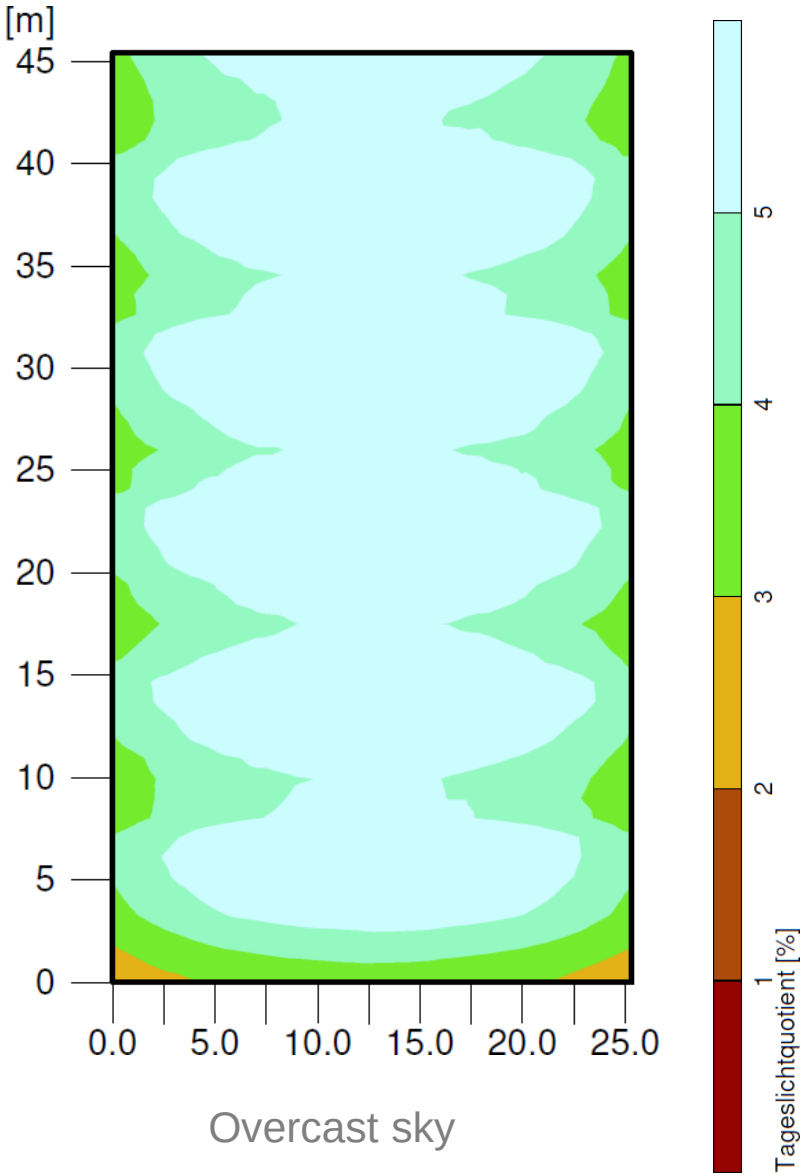
Current Tasks

- Review of state of the art design workflows
- Standardization of BSDF daylight system characterization

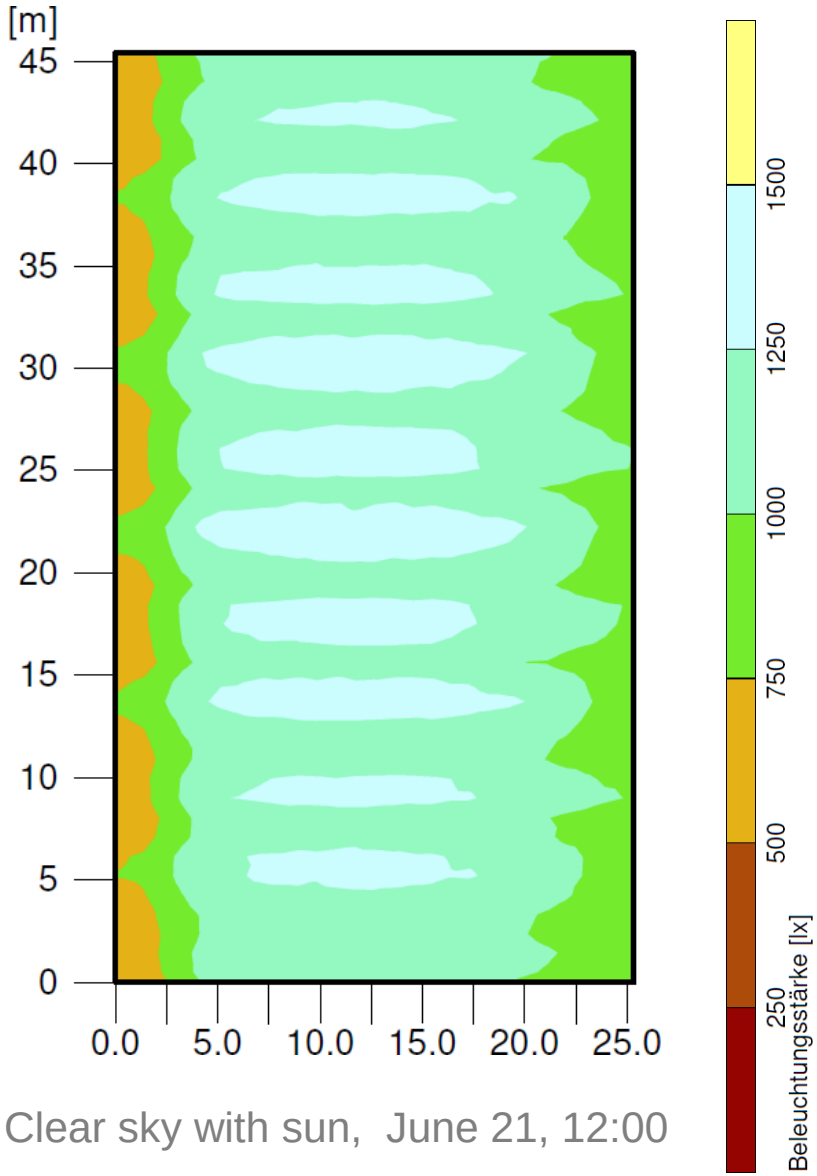
Sports Hall Clervaux, Luxembourg



Sports Hall Clervaux, Luxembourg

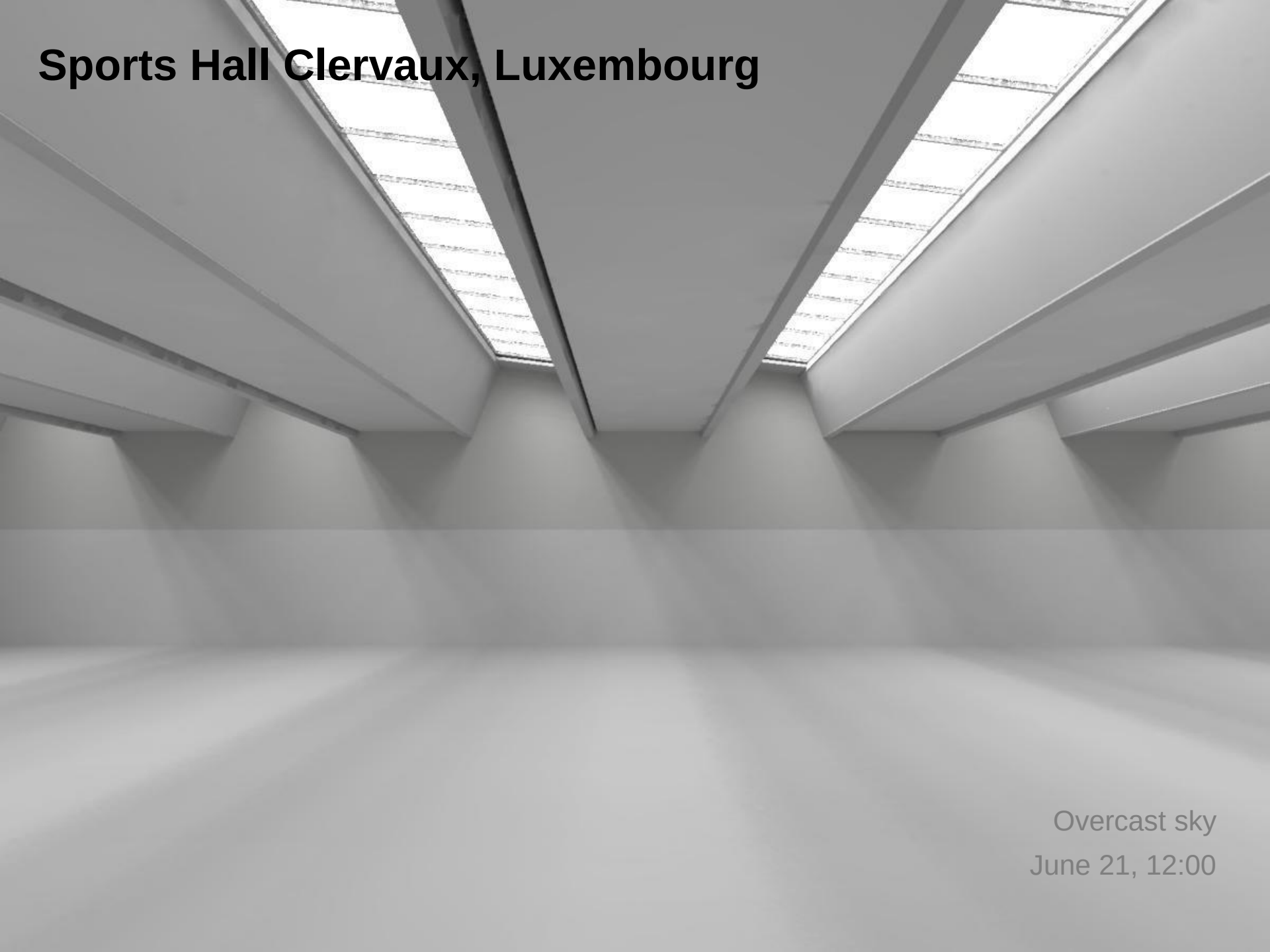


Overcast sky



Clear sky with sun, June 21, 12:00

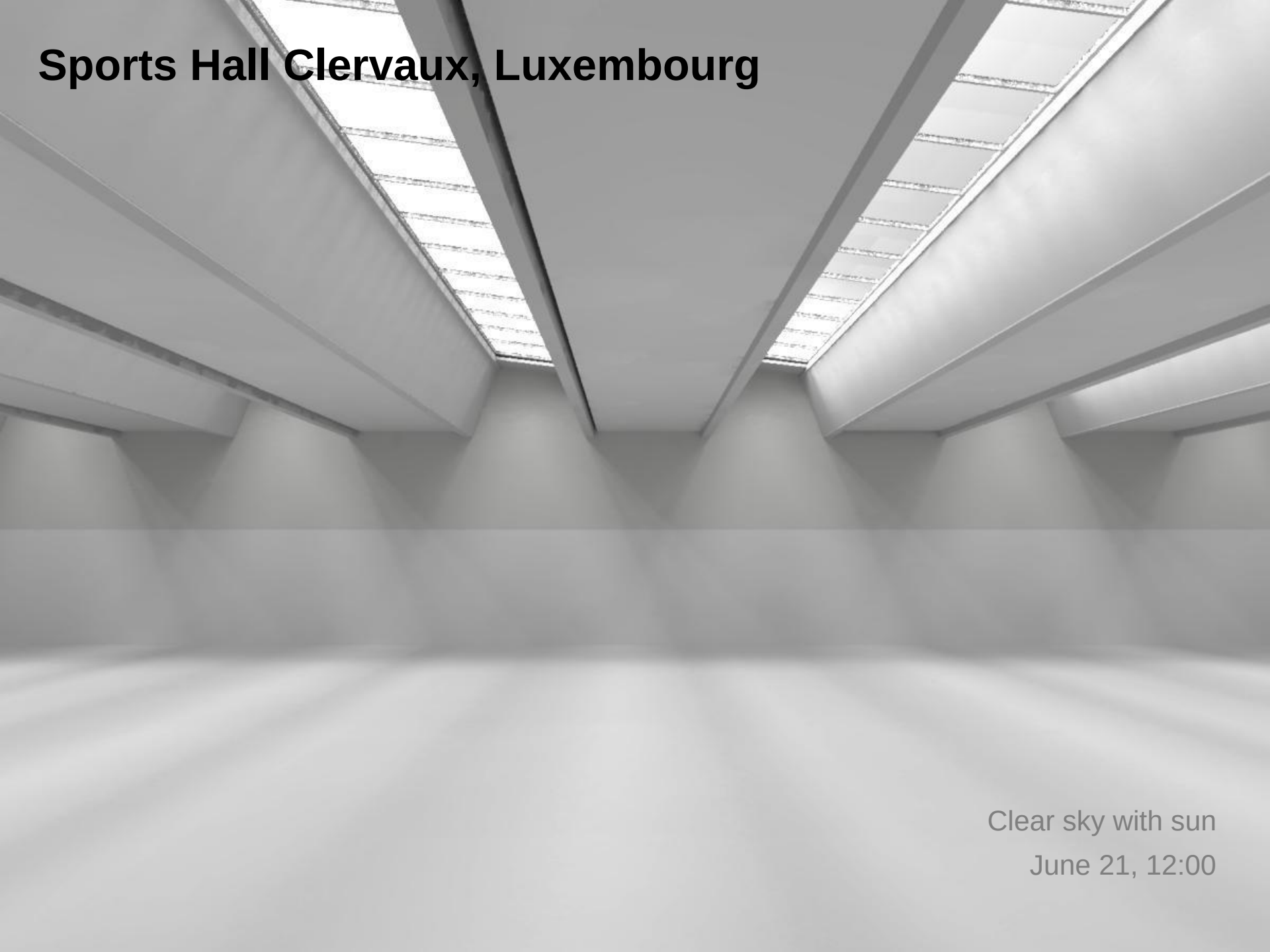
Sports Hall Clervaux, Luxembourg



Overcast sky

June 21, 12:00

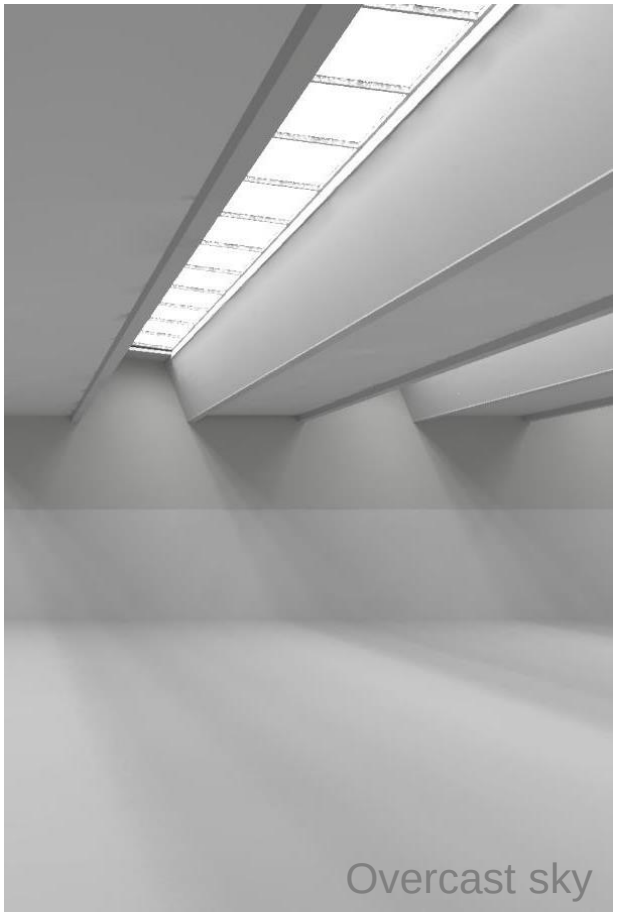
Sports Hall Clervaux, Luxembourg

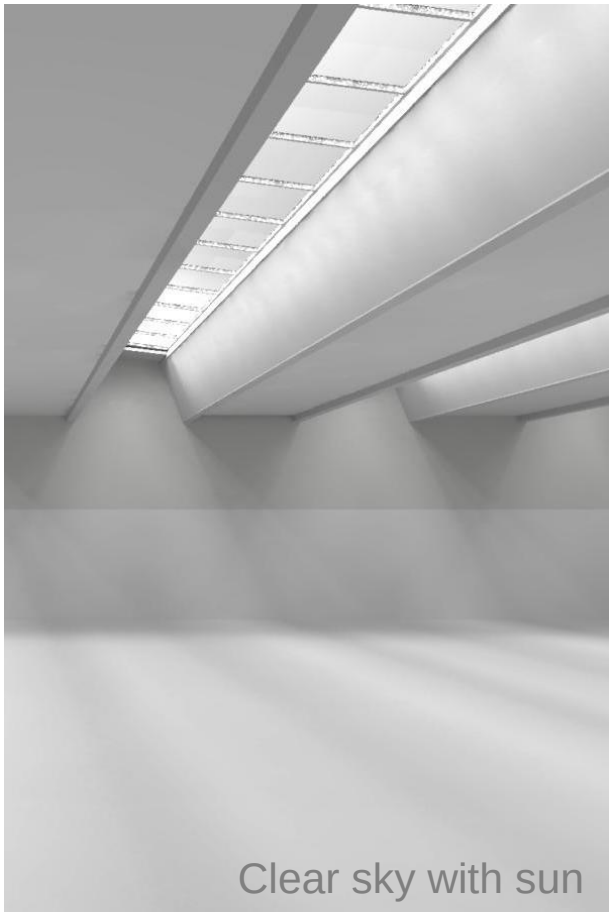


Clear sky with sun

June 21, 12:00

Sports Hall Clervaux, Luxembourg





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