Optical and thermal characteristics of solar shading and how they can be measured/determined

Results from the ICON project between LBNL and Fraunhofer ISE

Helen Rose Wilson, Fraunhofer ISE

Jacob Jonsson, LBNL

ES-SO Webinar
Fraunhofer ISE, Freiburg

23rd February, 2022

www.ise.Fraunhofer.de

© Fraunhofer ISE

ICON

BERKELEY LAB ENERGY TECHNOLOGIES AREA

Fraunhofer ISE

Solar shading and glazing components in the (European) „big picture“

- The European Performance of Buildings Directive sets ambitious guidelines to ensure that the building sector contributes to the energy transformation
- It is currently being implemented at the European national level in national laws and building codes
- The role of solar shading, together with glazing, has been recognised
- We need solar shading to balance different types of functionality, e.g.
  - Daylighting provision vs solar heat gain control.
  - Daylighting provision vs glare protection.


Venetian blind system mounted in the Köln Triangle building in Cologne

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Quantifying the effect of solar shading on energy consumption, daylighting and glare in buildings – and the need for measured optical data

- Optical and thermal properties of solar envelope components are needed as a reliable basis for further calculations relevant to building performance
- This performance has often been based on optical properties measured at normal incidence
- Even accurate measurement of light-scattering or light-redirecting materials at normal incidence

  (τ_n-h, τ_n-n, ρ_n-h) is challenging.
- Angle-selective shading and fenestration systems require optical properties measured at least at oblique incidence

  - τ_n-h, τ_n-n, ρ_n-h are not enough !

Venetian blind system mounted in the Köln Triangle building in Cologne

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

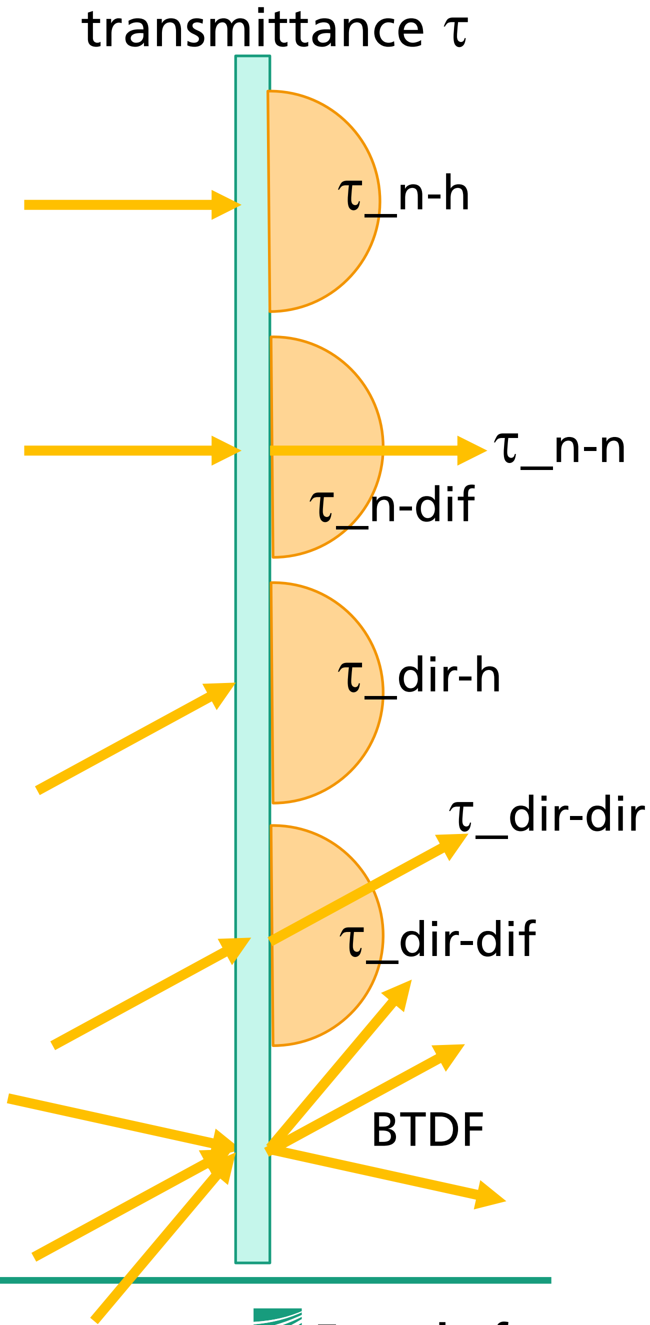
A hierarchy of spatial resolution for optical properties
- transmittance τ and reflectance ρ

Incidence direction	Exit directions	Qualifier	Symbol
Normal	Hemispherical	Normal-hemispherical	τ_n-h, ρ_n-h
Normal	Normal or diffuse	Normal-normal or normal-diffuse	τ_n-n, τ_n-dif ρ_n-n, ρ_n-dif
Direct (varying both θ and ϕ)	hemispherical	Direct-hemispherical	τ_dir-h, ρ_dir-h
Direct (varying both θ and ϕ)	Direct or diffuse	Direct-direct or direct-diffuse	τ_dir-dir, τ_dir-dif ρ_dir-dir, ρ_dir-dif
Direct (varying both θ and ϕ)	Direct (varying both θ and ϕ)	Bidirectional	BSDF, BTDF, BRDF*

*Bidirectional scattering distribution function BSDF

Bidirectional transmittance distribution function BTDF

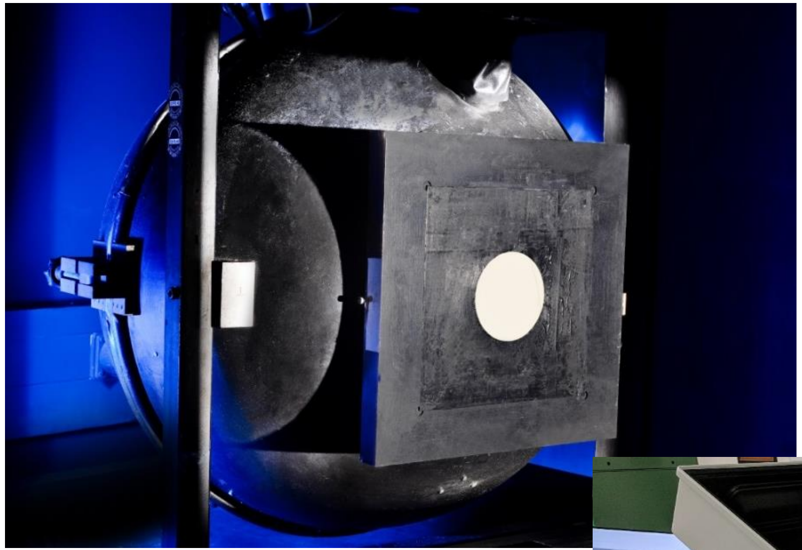
Bidirectional reflectance distribution function BRDF



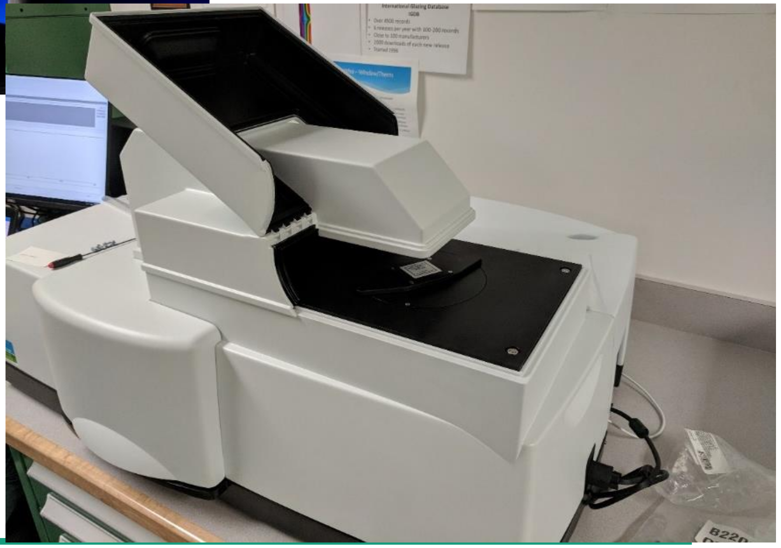
© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Integrating-sphere measurements of normal-hemispherical transmittance and reflectance of light-scattering glass panes according to modified NFRC standards

- An NFRC inter-laboratory comparison with 12 labs and 6 light-scattering glass samples applied **integrating spheres** with **large entrance apertures**
- Previous situation: Measured transmittance up to 0.10 too low!



"TAUWIN" integrating sphere at Fraunhofer ISE



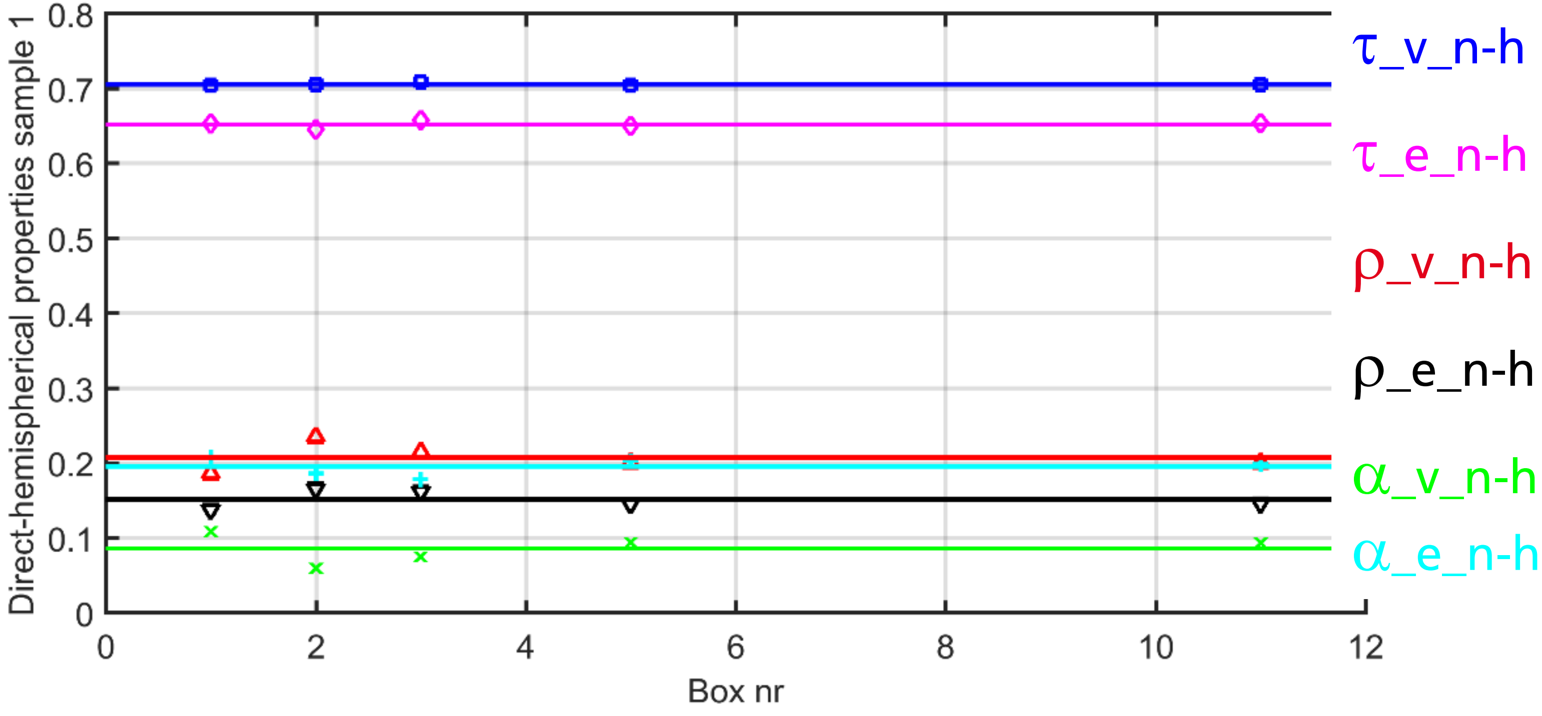
Commercial spectrophoto-meter with new integrating sphere at LBNL

Measured light-scattering laminated glass sample

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Integrating-sphere measurements of normal-hemispherical transmittance and reflectance of light-scattering glass panes according to modified NFRC standards

- An NFRC inter-laboratory comparison with 12 labs and 6 light-scattering glass samples applied **integrating spheres** with **large entrance apertures**
- Normal-hemispherical values now within ± 0.02



Measured light-scattering glass laminate

With room lighting

Without room lighting

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

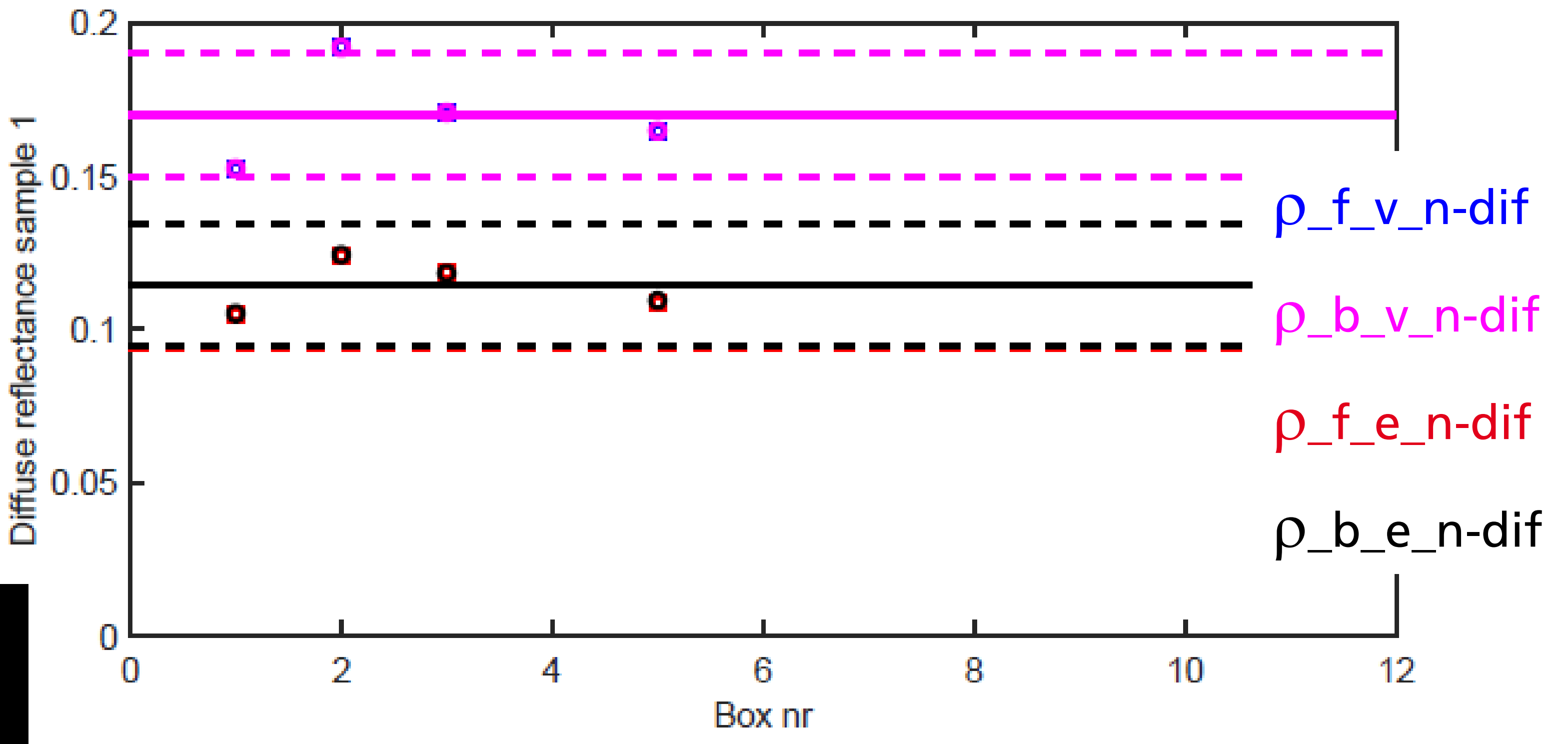
Integrating-sphere measurements of normal-normal and normal-diffuse components of light-scattering glass panes according to modified NFRC standards, modelled on EN 14500

- Slightly poorer agreement for the normal-normal and normal-diffuse components,
  within 0.03 for transmittance and 0.04 for reflectance
- Well-known that sphere geometry influences the measured value for the normal-diffuse measured value

Measured light-scattering glass laminate

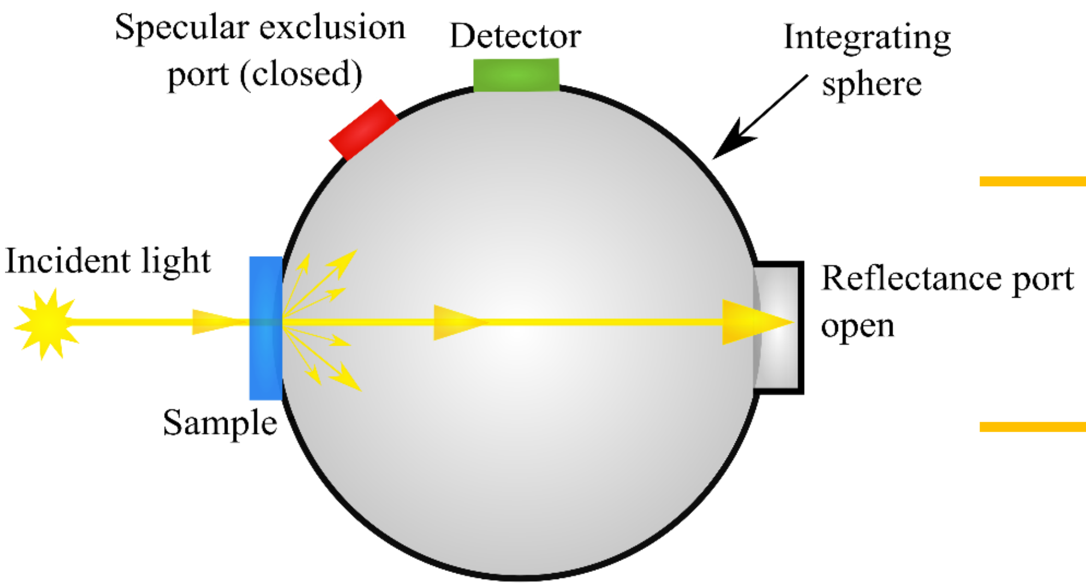
With room lighting

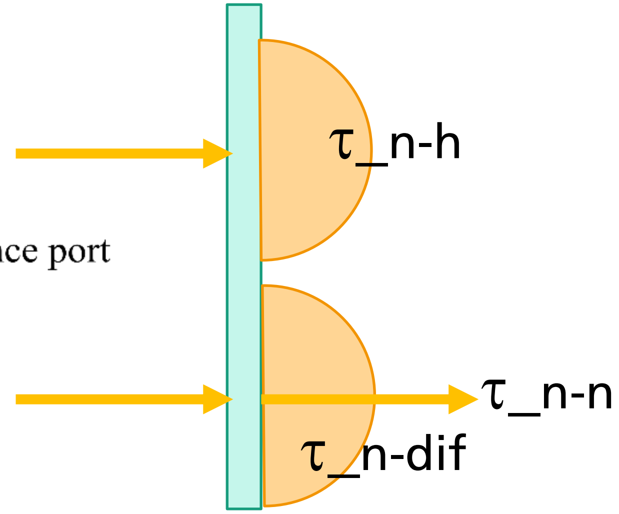
Without room lighting



© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

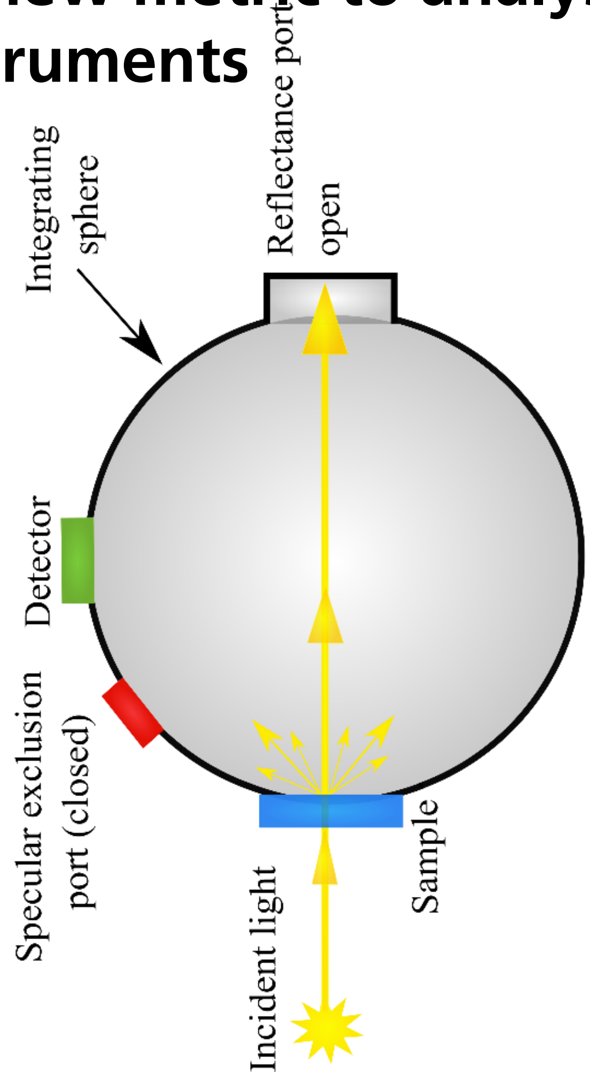
Normal-conical transmittance τ_n-con
- a new metric to analyse the interaction between samples and measuring instruments

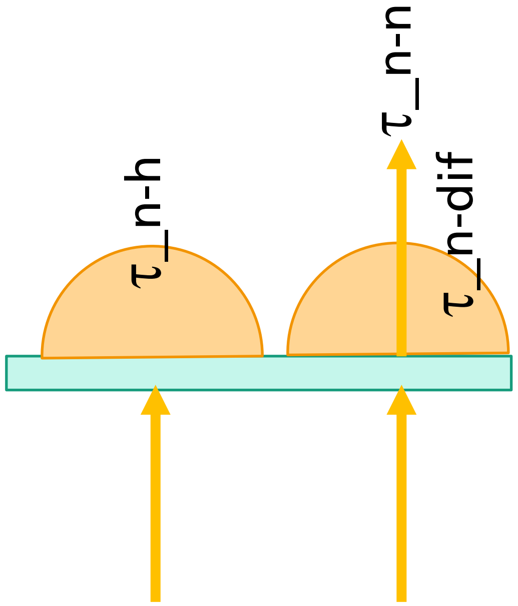




© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Normal-conical transmittance τ_n-con
- a new metric to analyse the interaction between samples and measuring instruments



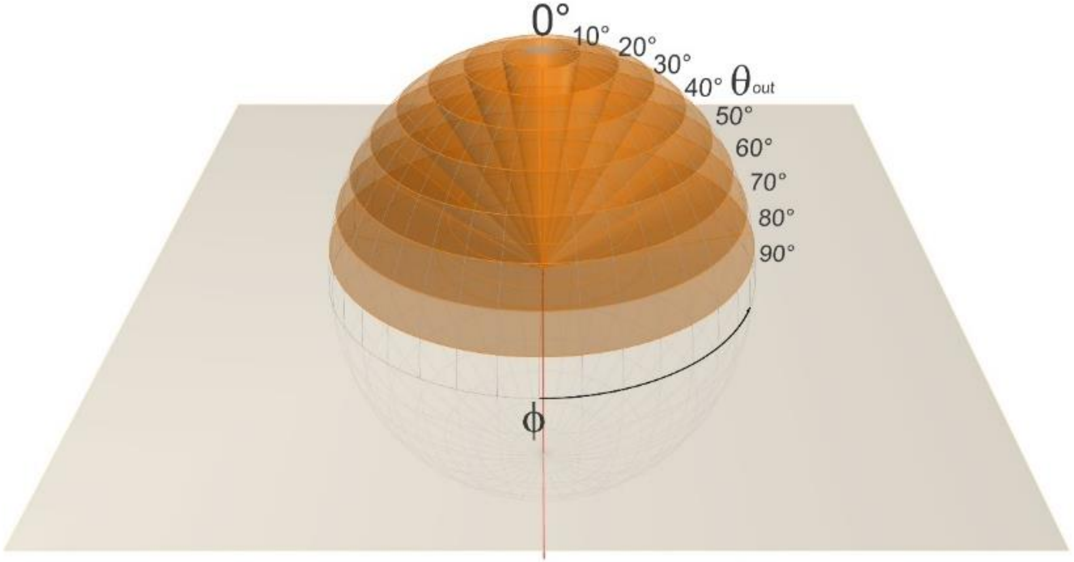


τ_n-n = τ_n-con(0°) (ideal)

τ_n-n = τ_n-con(θ_{out}): 3.3° < θ_{out} < 4.8° (real)

τ_n-con = τ_n-con(θ_{out})

τ_n-hem= τ_n-con(90°)

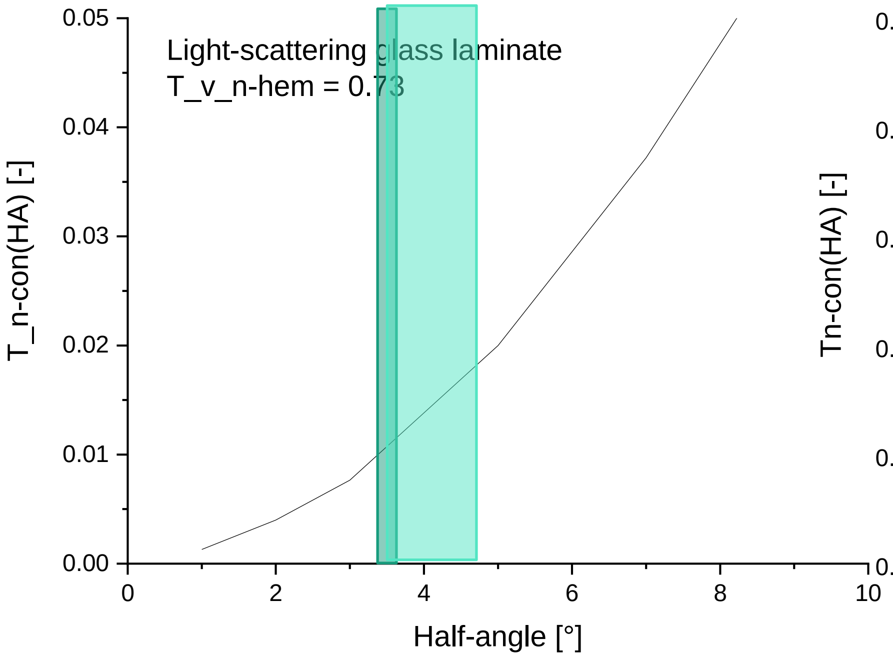


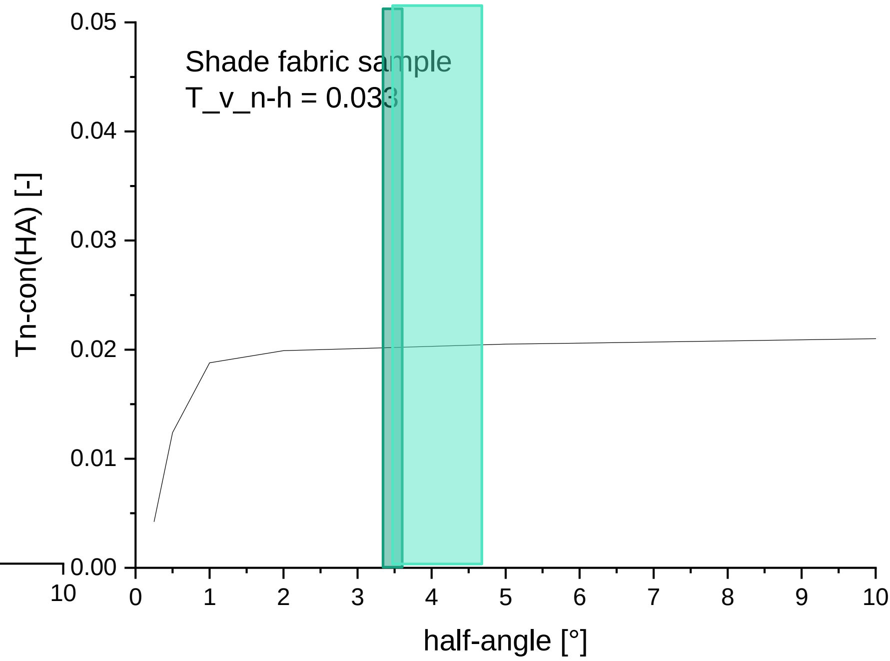
© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL
ICON
BERKELEY LAB ENERGY TECHNOLOGIES AREA
Fraunhofer ISE

Normal-conical transmittance τ_n-con for a light-scattering glass sample and a shade fabric as examples

- **Light-scattering glass laminate**
  - strong variation of τ_n-con with half-angle (HA)
  -> result very sensitive to instrument geometry

- **Shade fabric**
  - little variation of τ_n-con with half-angle (HA)
  -> result insensitive to instrument geometry

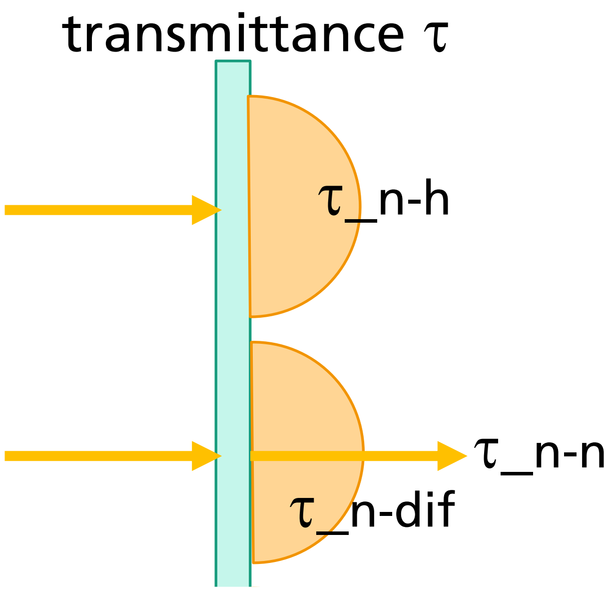




© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL
ICON
BERKELEY LAB ENERGY TECHNOLOGIES AREA
Fraunhofer ISE

A hierarchy of spatial resolution for optical properties - transmittance τ and reflectance ρ

Incidence direction	Exit directions	Qualifier	Symbol
Normal	Hemispherical	Normal-hemispherical	τ_n-h, ρ_n-h
Normal	Normal or diffuse	Normal-normal or normal-diffuse	τ_n-n, τ_n-dif ρ_n-n, ρ_n-dif



© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

transmittance τ

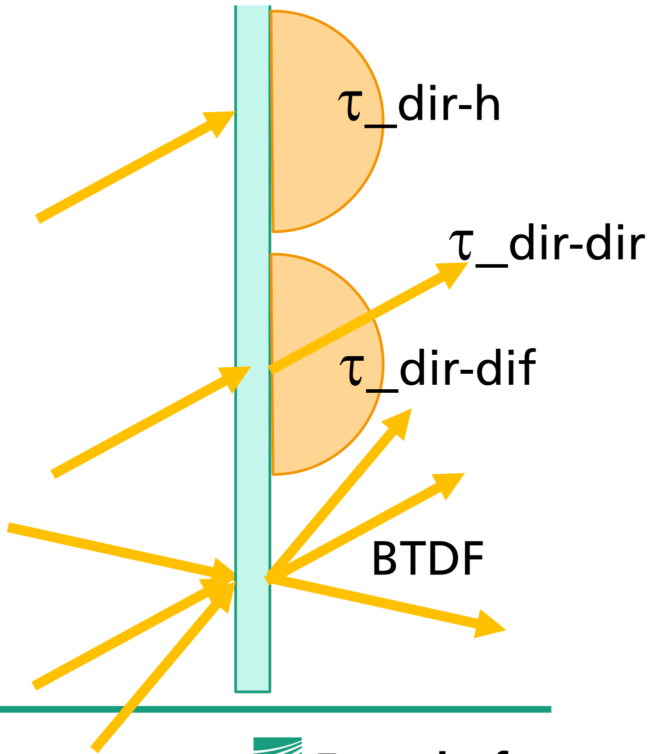
A hierarchy of spatial resolution for optical properties - transmittance τ and reflectance ρ

Incidence direction	Exit directions	Qualifier	Symbol
Direct (varying both θ and ϕ)	hemispherical	Direct-hemispherical	τ_dir-h, ρ_dir-h
Direct (varying both θ and ϕ)	Direct or diffuse	Direct-direct or direct-diffuse	τ_dir-dir, τ_dir-dif ρ_dir-dir, ρ_dir-dif
Direct (varying both θ and ϕ)	Direct (varying both θ and ϕ)	Bidirectional	BSDF, BTDF, BRDF*

*Bidirectional scattering distribution function BSDF

Bidirectional transmittance distribution function BTDF

Bidirectional reflectance distribution function BRDF



© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

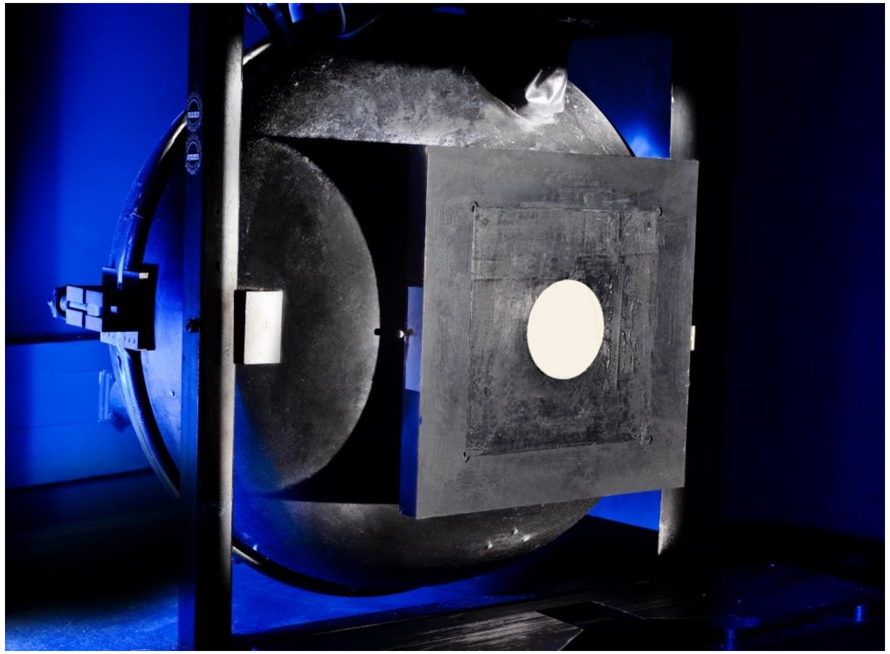
Characterization of solar shading

Measurement of directional-hemispherical transmittance τ_dir-h

- Rotatable integrating sphere
- **Spectral transmittance** measurements at different angles of incidence
- **Spectral weighting** with v(λ) curve to obtain direct-hemispherical visible transmittance

τ_v_dir-h

Measured shading fabric sample



"TAUWIN" rotatable integrating sphere at Fraunhofer ISE

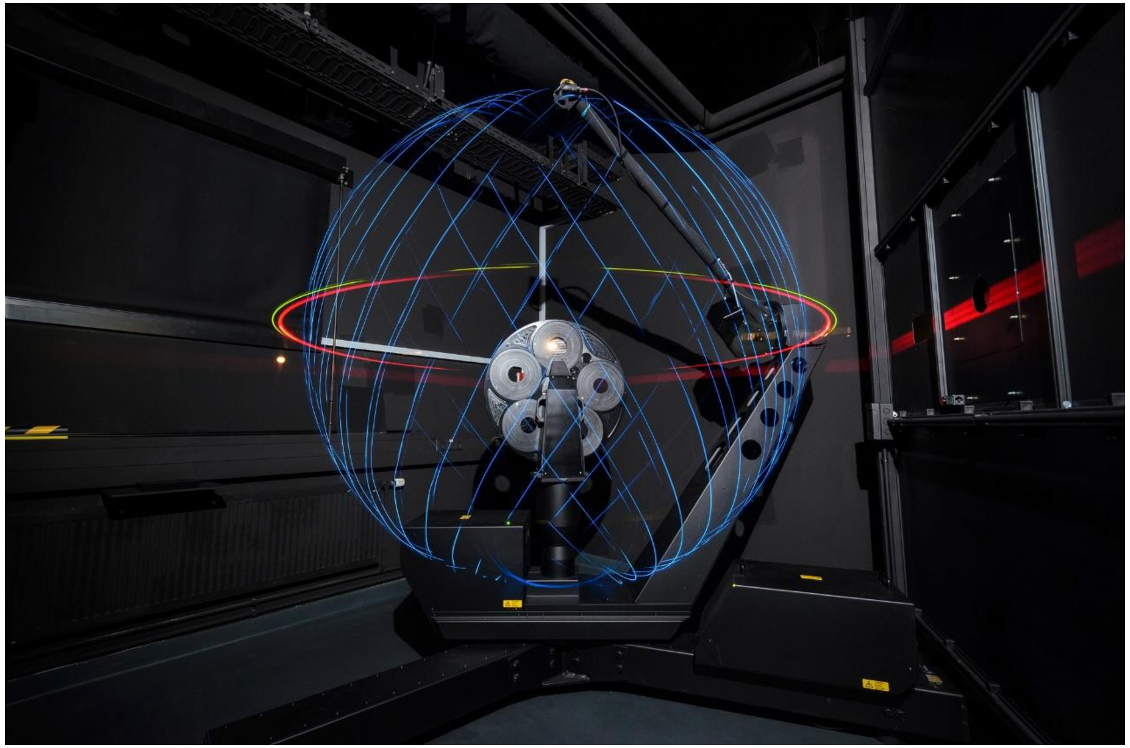
© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Characterization of solar shading
Measurement of bi-directional transmittance distribution function BTDF

- Photogoniometer
- **Visible (light) BTDF** measurements (corrected for dark signal) at different angles of incidence
- **Spatial integration** over hemisphere to obtain direct-hemispherical visible transmittance

τ_v_dir-h

Measured shading fabric sample in photogoniometer sample holder



pgII photogoniometer indicating paths traced by detector head

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

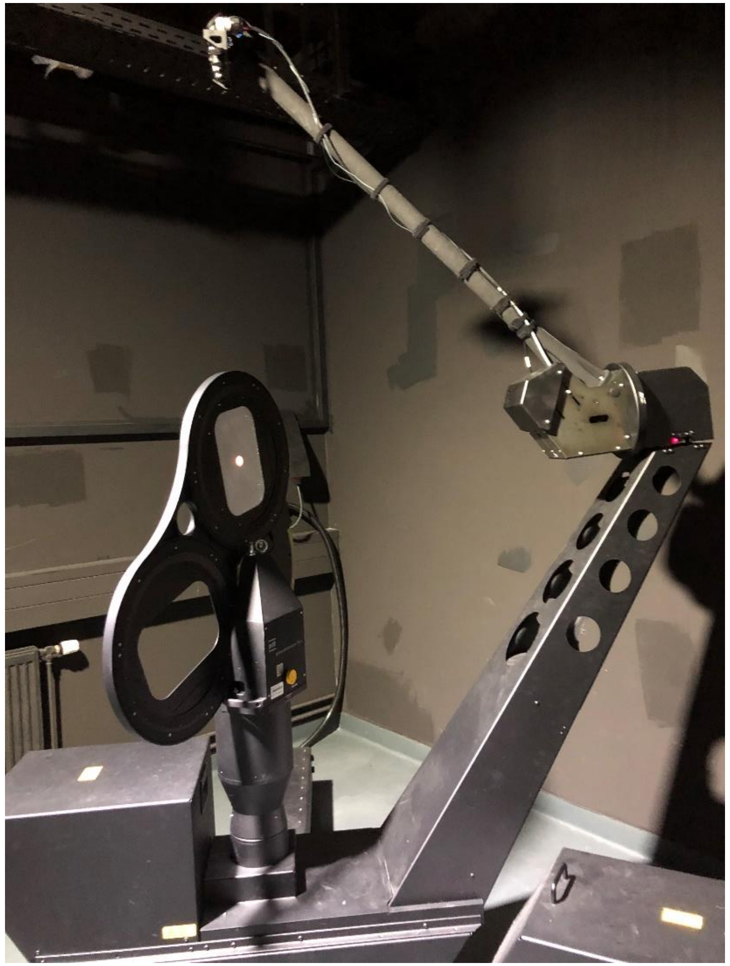
Characterization of solar shading

Measurement of bi-directional transmittance distribution function BTDF

- Photogoniometer
- **Visible (light) BTDF** measurements (corrected for dark signal) at different angles of incidence
- **Spatial integration** over hemisphere to obtain direct-hemispherical visible transmittance

τ_v_dir-h

Measured shading fabric sample in photogoniometer sample holder

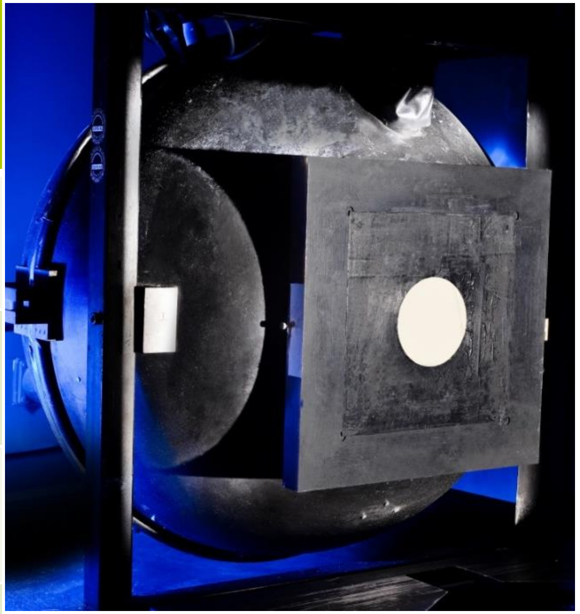


pgII photogoniometer with measured shading fabric

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Validation of direct-hemispherical transmittance results by comparing integrating-sphere and photogoniometric results for τ_v_dir-h

Incidence angles		τ_v_dir-h (Integ-rating sphere)	τ_v_dir-h (Photo-gonio-meter)	Differ-ence in τ_v_dir-h
θ_{in}	ϕ_{in}			
0	0	0.0194	0.0196	0.0002
20	0	0.0192	0.0188	0.0004
40	0	0.0185	0.0177	0.0008
60	0	0.0155	0.0149	0.0006
80	0	0.0086	0.0059	0.0026

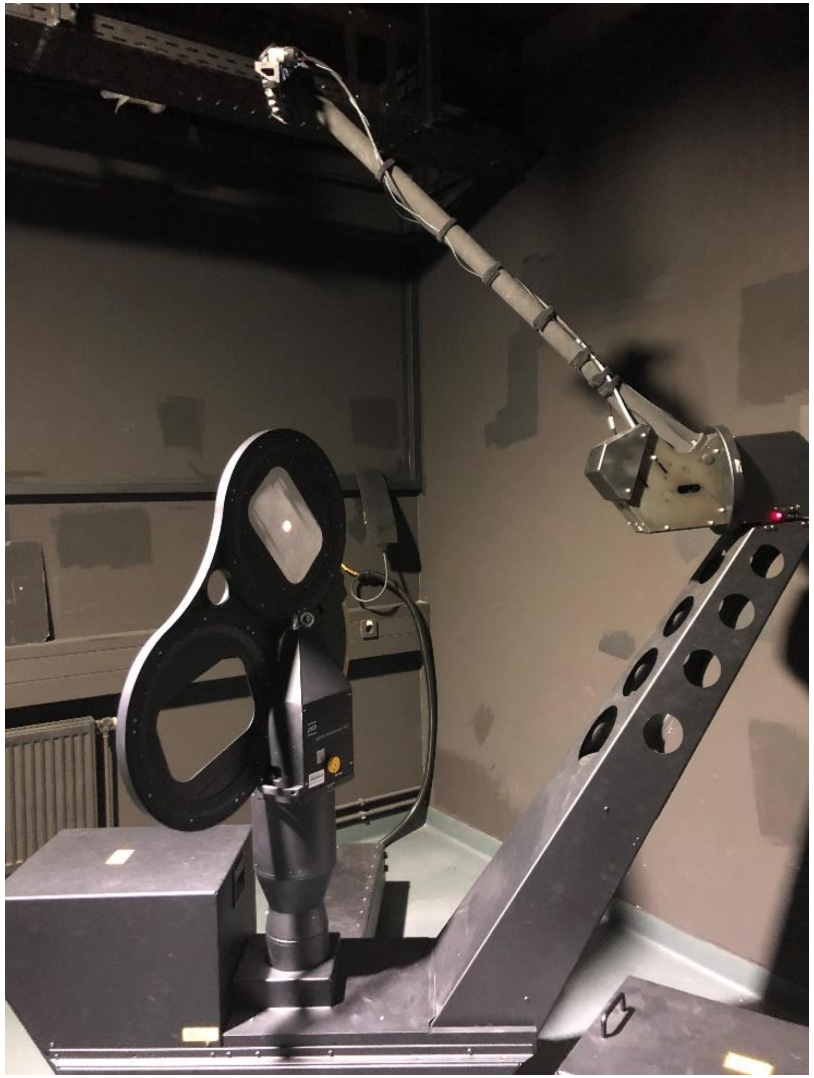


Agreement generally within 0.01 also for other incidence angles.

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Convergence on photogoniometric measurement procedures within IEA-SHC Task 61

- Fraunhofer ISE and LBNL collaborated with other members of task 61 to decrease the variance in our measurement results using photogoniometers
  - Dark signal correction for samples with dominating specular components
  - Beam size, shape and focus
  - Standardized conversion to Klems basis using Radiance



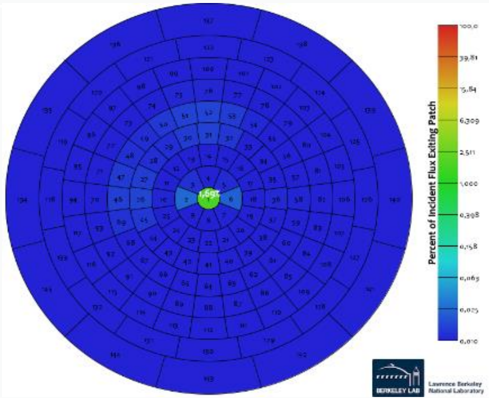
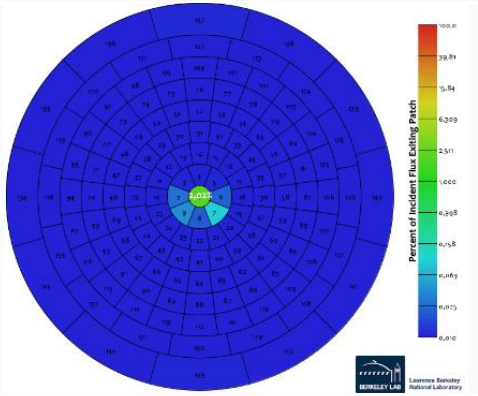
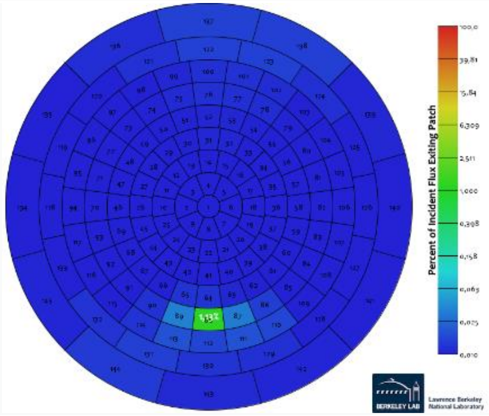
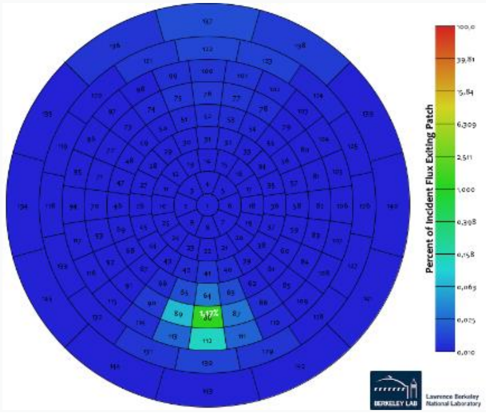
© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Validation of direct-hemispherical and direct-direct transmittance by comparing photogoniometric results

- Good agreement between direct-direct ar direct-hemispherical values
- Slightly different distribution around the specular direction

Measured shading fabric sample

In the photogonio-meter sample holder

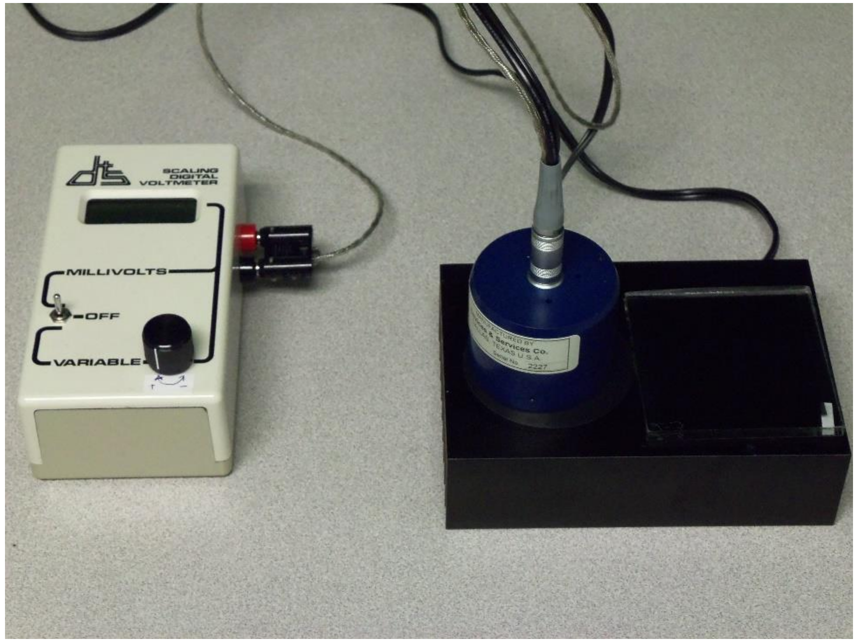
LBNL	Fraunhofer ISE
	
$\tau_{dir\text{-}h}$ = 2.8%, $\tau_{dir\text{-}dir}$ = 1.69%	$\tau_{dir\text{-}h}$ = 3.3%, $\tau_{dir\text{-}dir}$ = 2.02%
	
$\tau_{dir\text{-}h}$ = 2.5%, $\tau_{dir\text{-}dir}$ = 1.13%	$\tau_{dir\text{-}h}$ = 2.7%, $\tau_{dir\text{-}dir}$ = 1.17%

Figures by D. Moroder-Geisler, Bartenbach

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

NFRC 301 covers thermal emissivity of rough glazing surfaces – also applicable to solar-shading materials with low transmittance

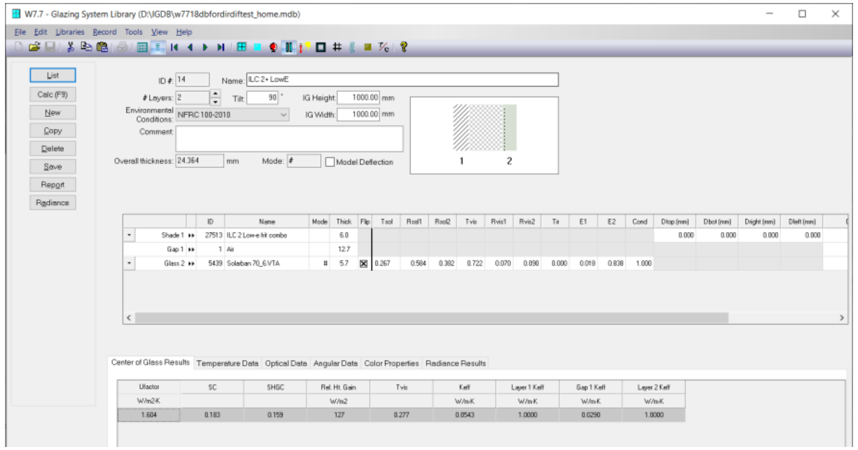
- FTIR instruments with an integrating sphere are not common among glazing manufacturers since coated glass is smooth and can be measured with a near-normal reflectance accessory
- A broadband emissometer was compared to FTIR instruments equipped with integrating spheres to find a low-cost and easy-to-use alternative to an IR integrating sphere
- Good agreement was achieved between 3 integrating spheres and 5 emissometers

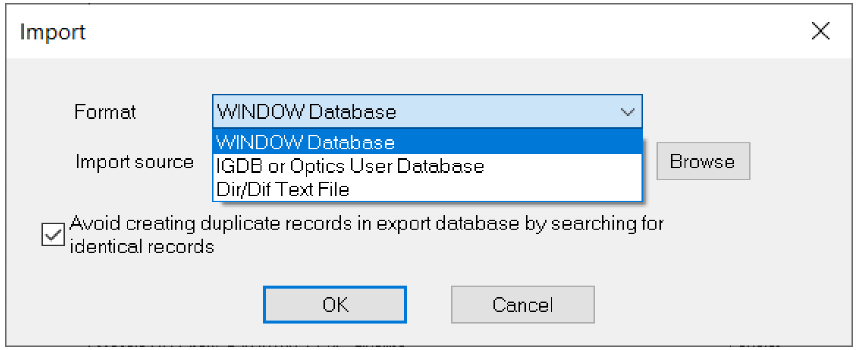


© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Modelling glazing AND SHADING MATERIALS in WINDOW 7.8

- Text files with data for normal-normal and normal-diffuse reflectance and transmittance can be imported
- Allows for U and SHGC (g-value) calculation of window configurations where one or more of the panes is a diffuse glazing
- Public version soon to be released which will allow for NFRC to update its simulation manual and allow for more accurate NFRC rating of windows with diffuse glazing

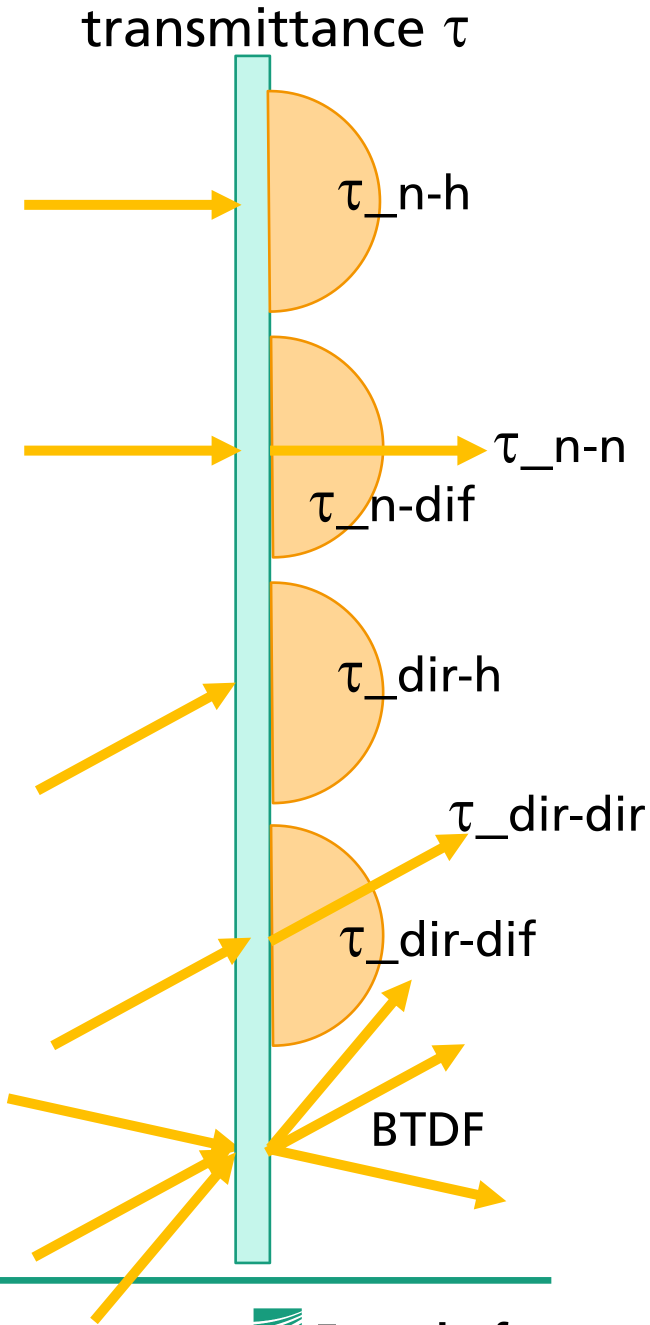




© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL
ICON
ENERGY TECHNOLOGIES AREA

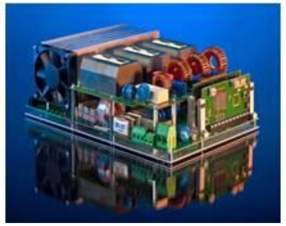
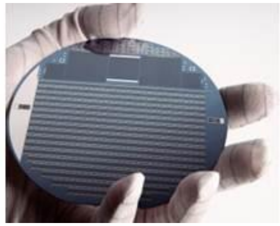
Achievements in measurement methodology

- Accurate optical measurement of “challenging” samples with suitable integrating spheres demonstrated for light-scattering glazing in inter-laboratory comparison
- Agreement demonstrated between integrating-sphere and goniophotometric results for direct-hemispherical properties
- Metric developed to aid analysis of “critical” combinations of samples and measurement instruments
- Emissivity measurements of rough, IR-opaque samples validated for different instruments
- WINDOW simulation program further developed to accept normal-normal and normal-diffuse spectra
- For connection between goniophotometric data and energy performance in buildings – see next presentation!



© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL

Thank you for your attention!

Fraunhofer Institute for Solar Energy Systems ISE

Lawrence Berkeley National Laboratory

Dr. Helen Rose Wilson

www.ise.fraunhofer.de

helen.rose.wilson@ise.fraunhofer.de

Dr. Jacob Jonsson

www.lbl.gov

jcjonsson@lbl.gov

© Fraunhofer ISE
FHG-SK: ISE-CONFIDENTIAL