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

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

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

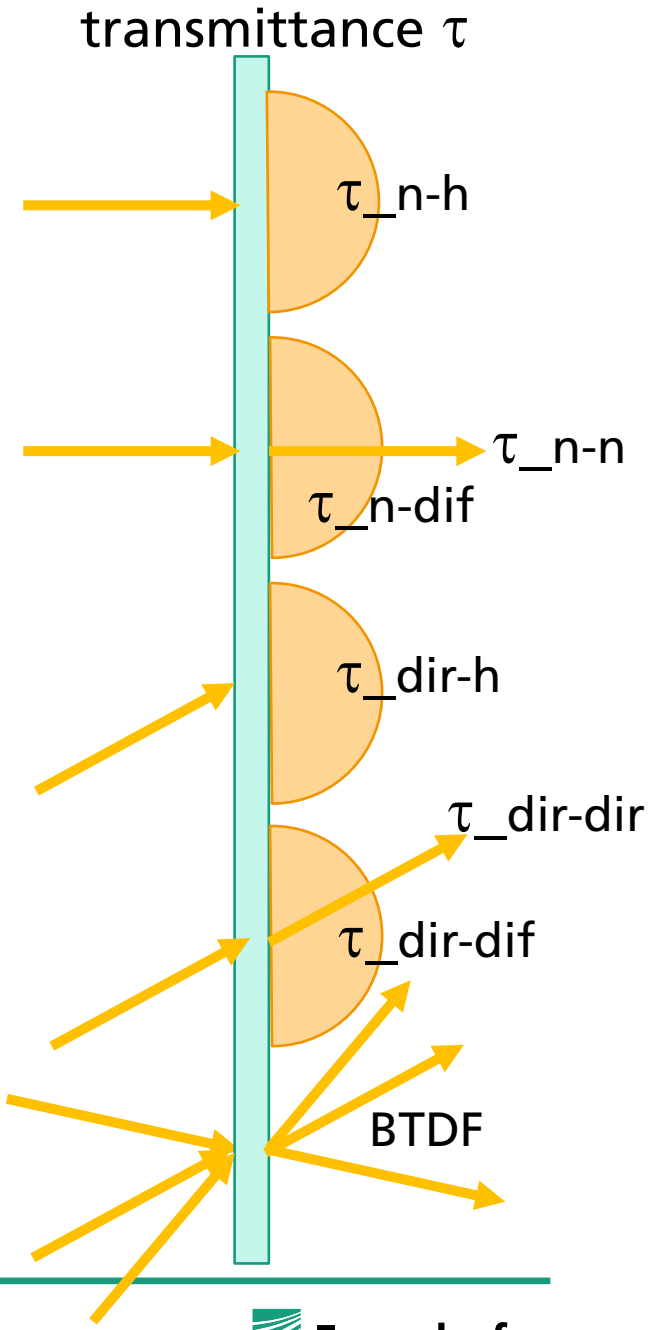
  (τ_n-h, τ_n-n, ρ_n-h) is challenging.
- Angle-selective shading and fenestration systems require optical properties measured at least at oblique incidence

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

Venetian blind system mounted in the Köln Triangle building in Cologne

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*



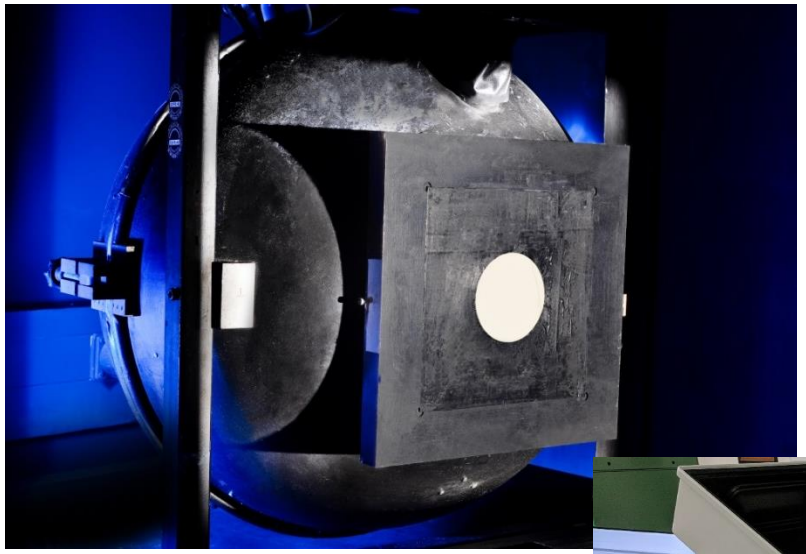
*Bidirectional scattering distribution function BSDF

Bidirectional transmittance distribution function BTDF

Bidirectional reflectance distribution function BRDF

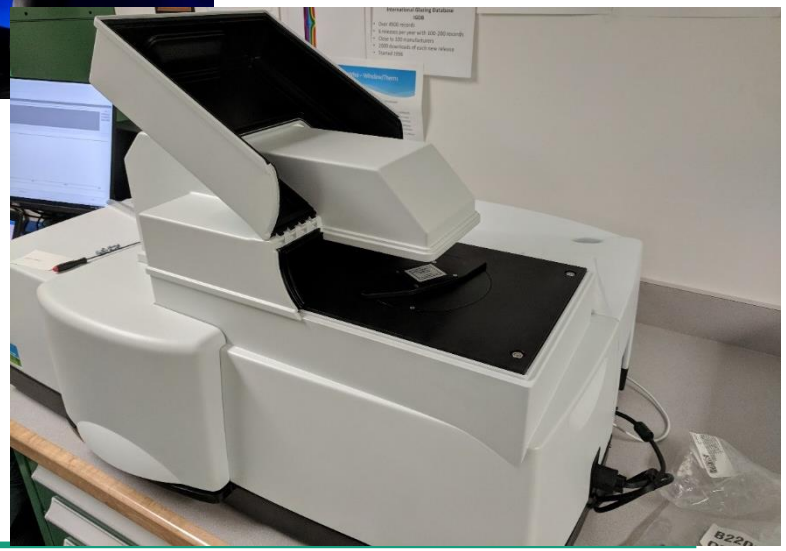
Integrating-sphere measurements of normal-hemispherical transmittance and reflectance of light-scattering glass panes according to modified NFRC standards

- 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

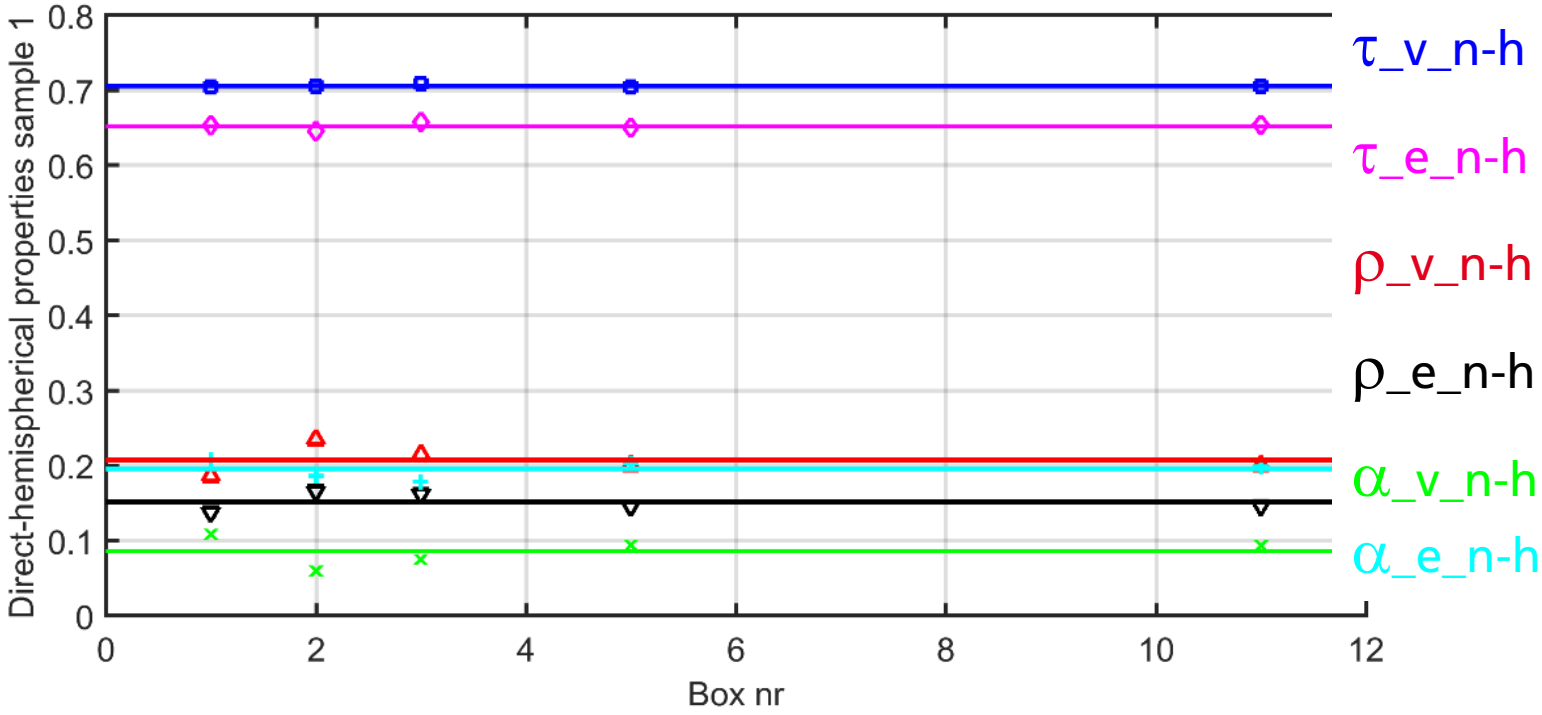
Measured light-scattering laminated glass sample



Commercial spectrophoto-meter with new integrating sphere at LBNL

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

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



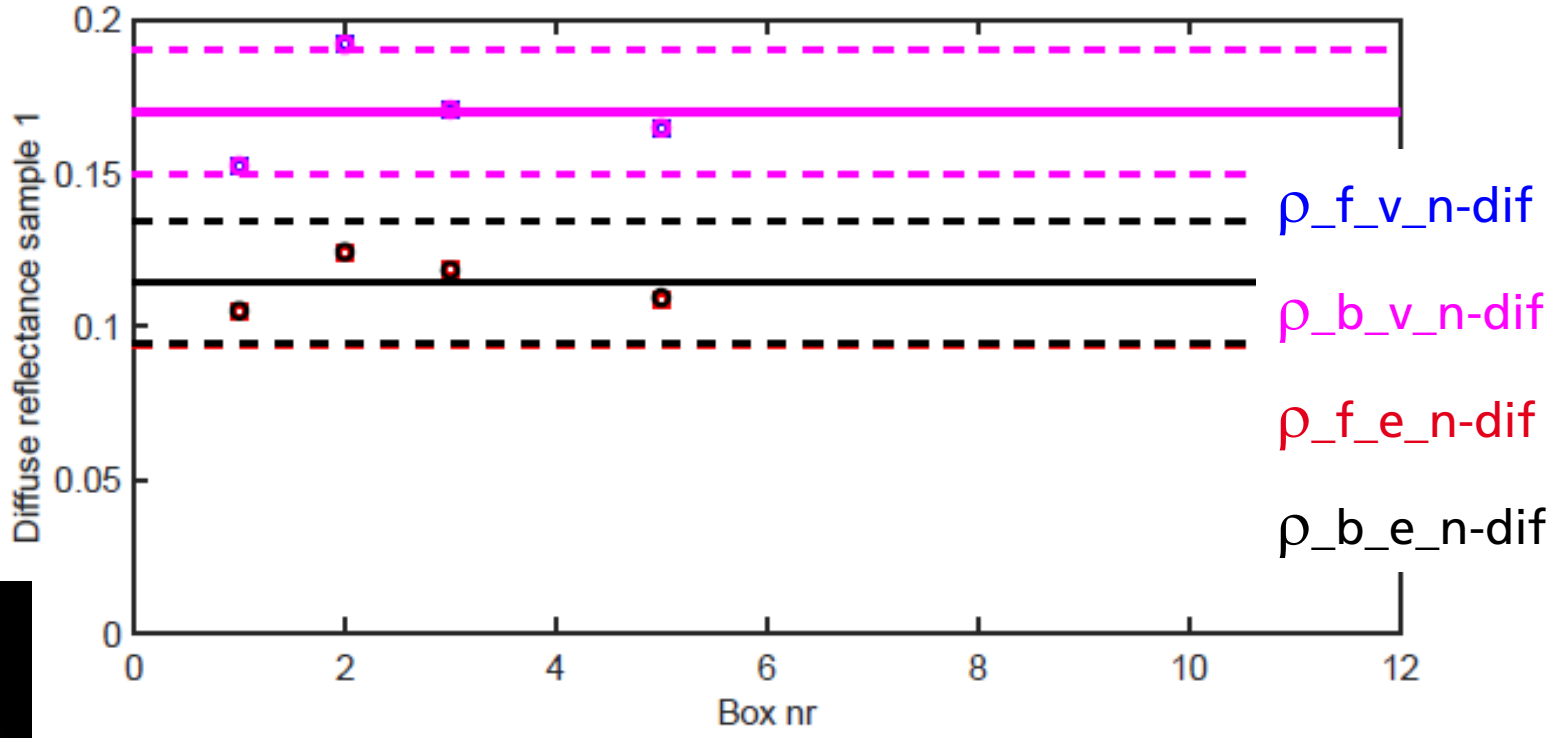
Measured light-scattering glass laminate

With room lighting

Without room lighting

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

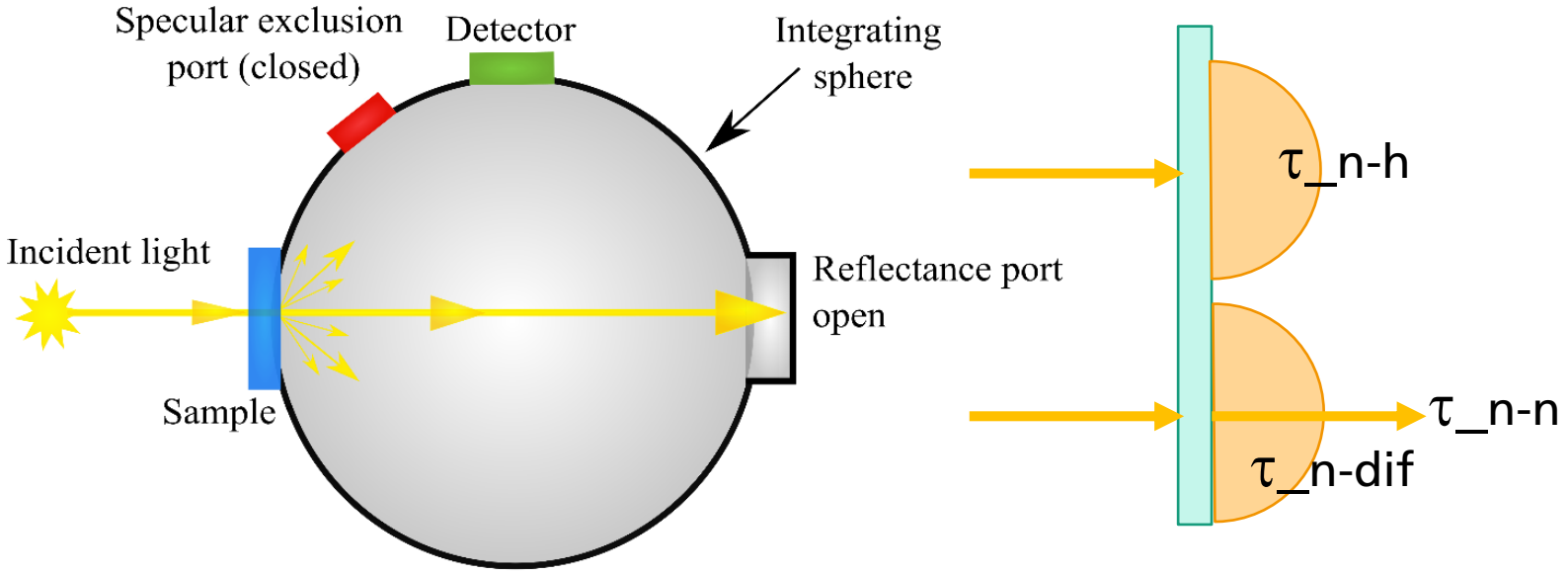


Measured light-scattering glass laminate

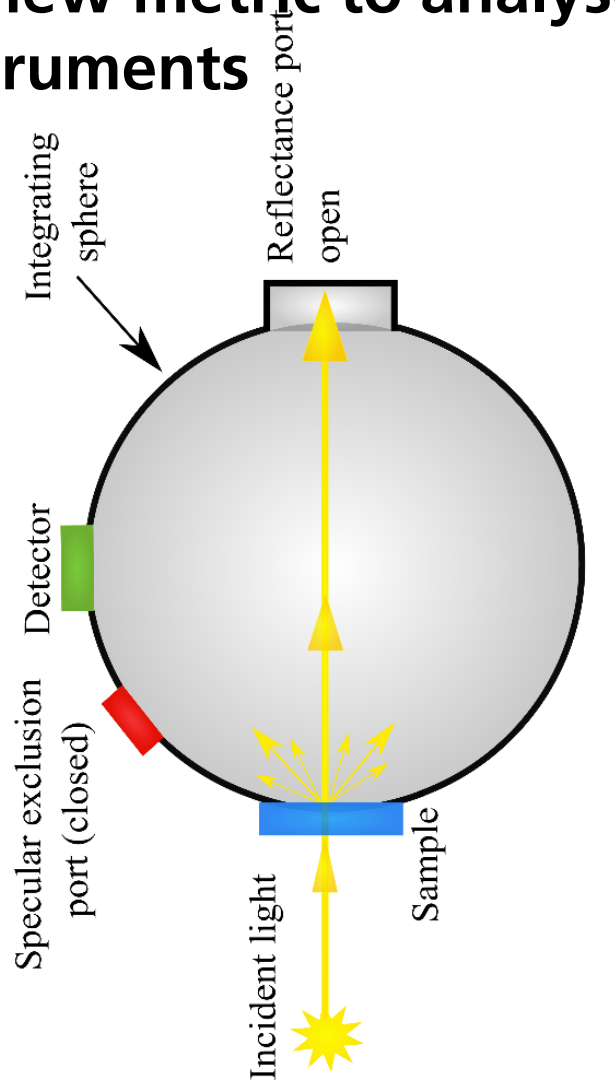
With room lighting

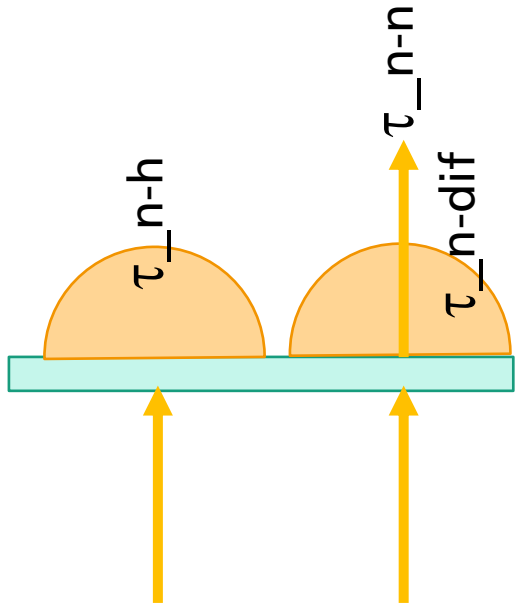
Without room lighting

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



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



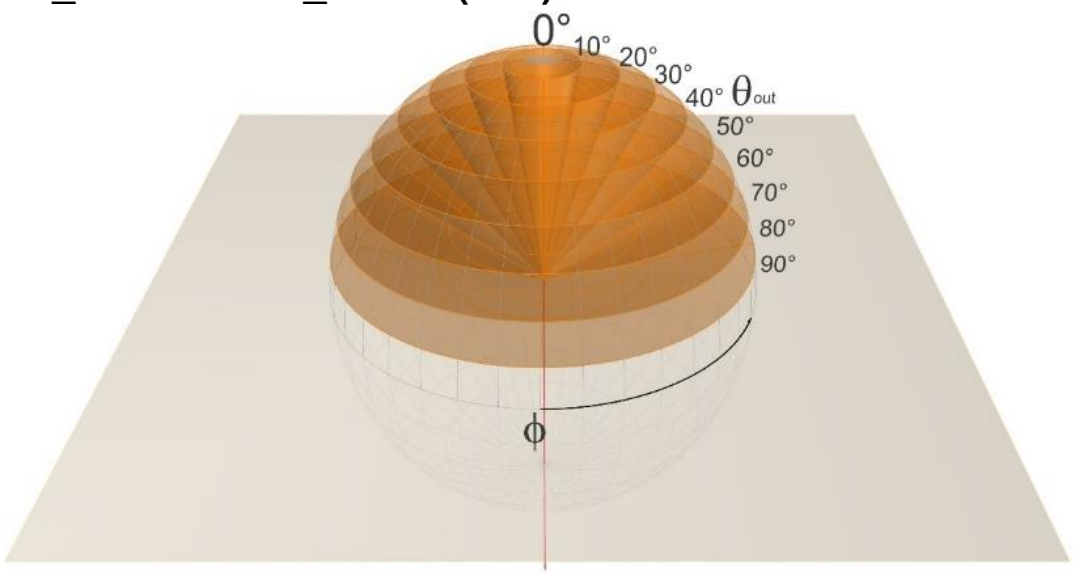


τ_n-n = τ_n-con(0°) (ideal)

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

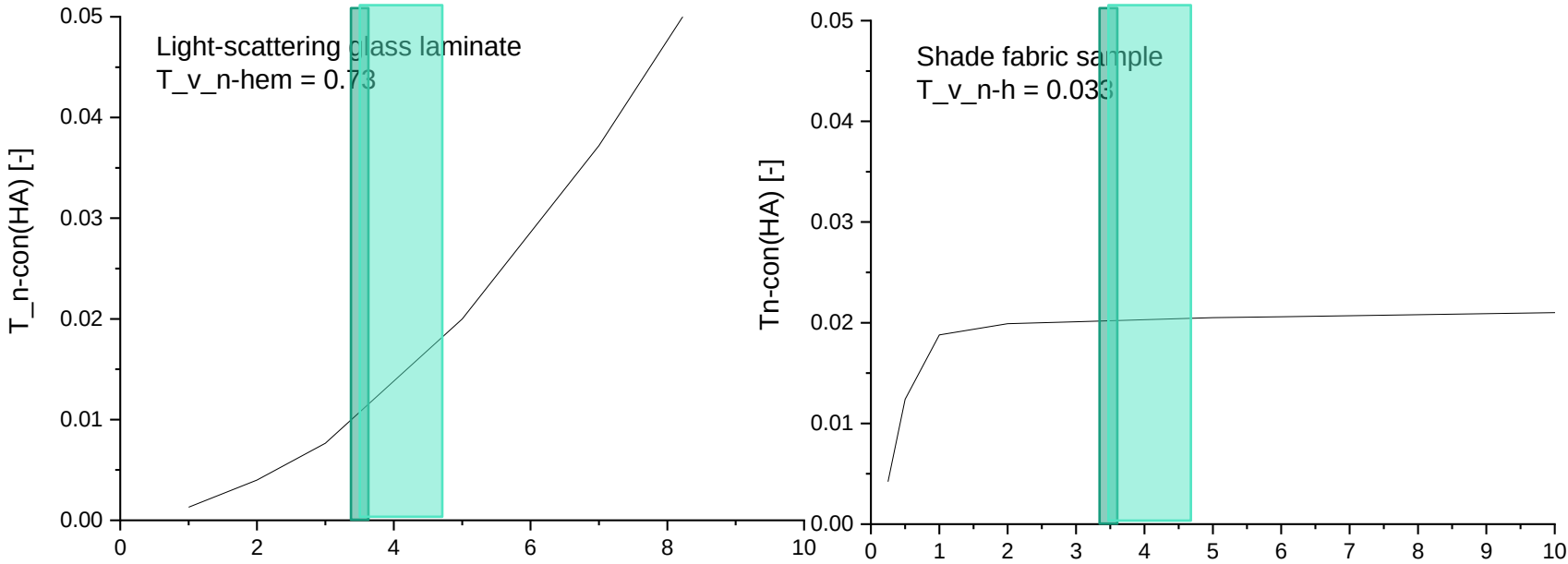
τ_n-con = τ_n-con(θ_{out})

τ_n-hem= τ_n-con(90°)



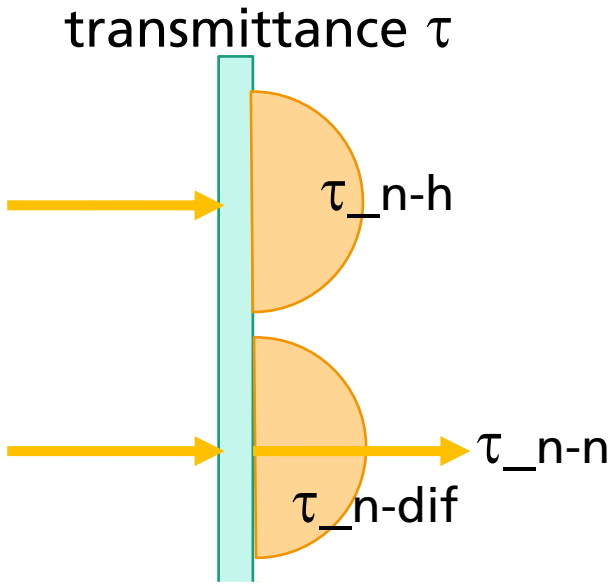
Normal-conical transmittance τ_n-con for a light-scattering glass sample and a shade fabric as examples

- 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



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



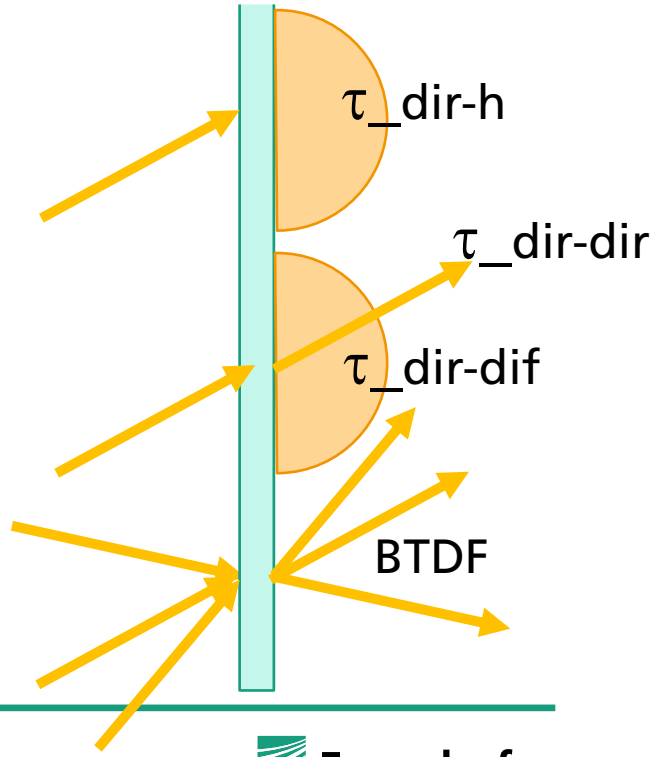
A hierarchy of spatial resolution for optical properties - transmittance τ and reflectance ρ

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



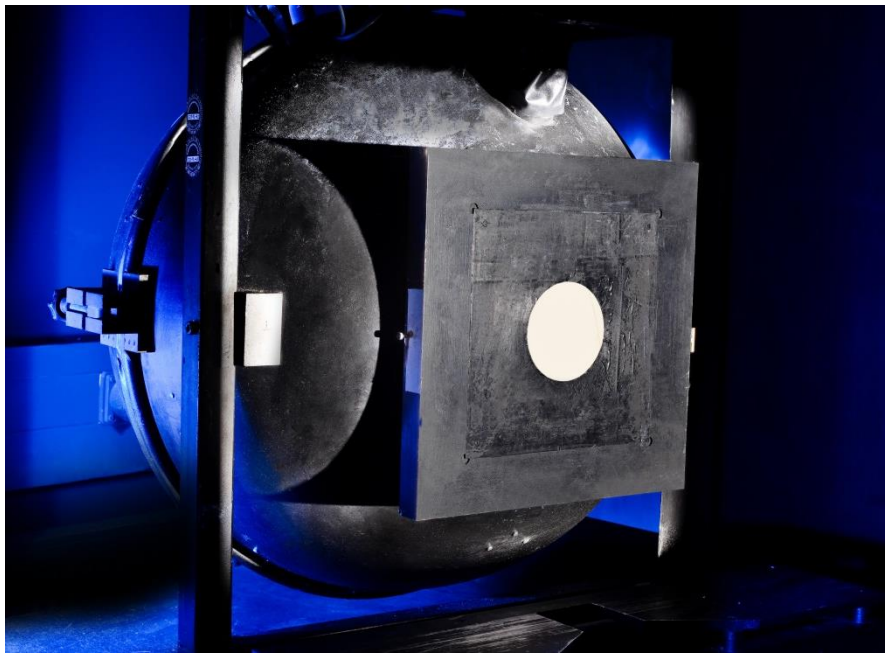
Characterization of solar shading

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

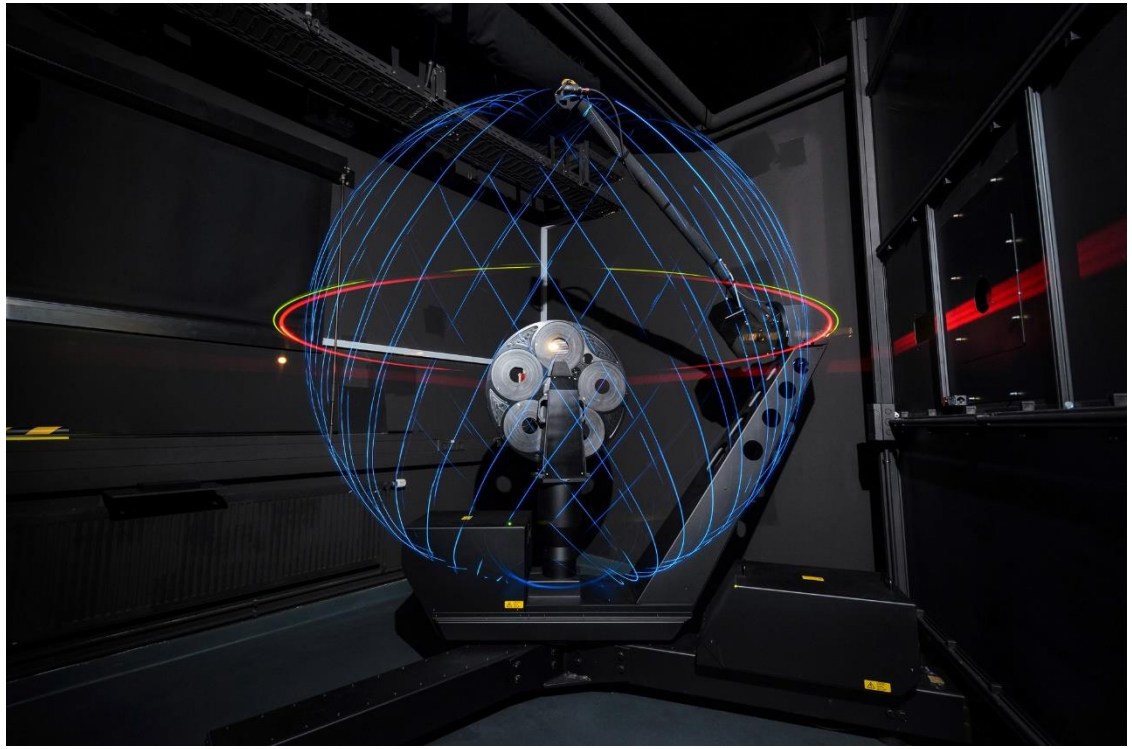
Characterization of solar shading

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

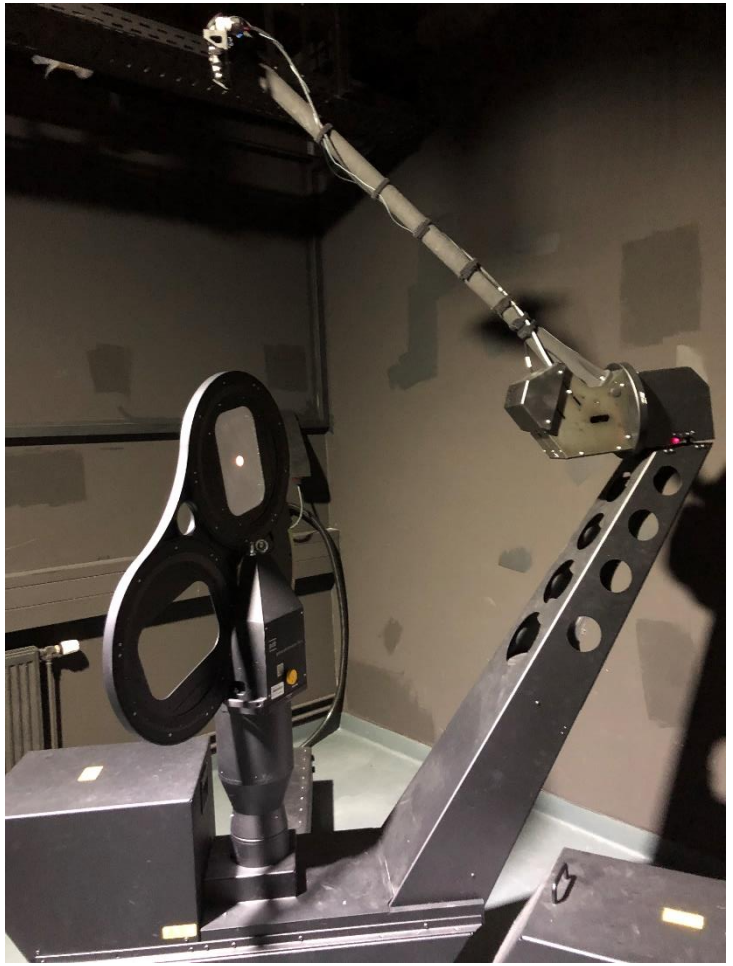
Characterization of solar shading

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

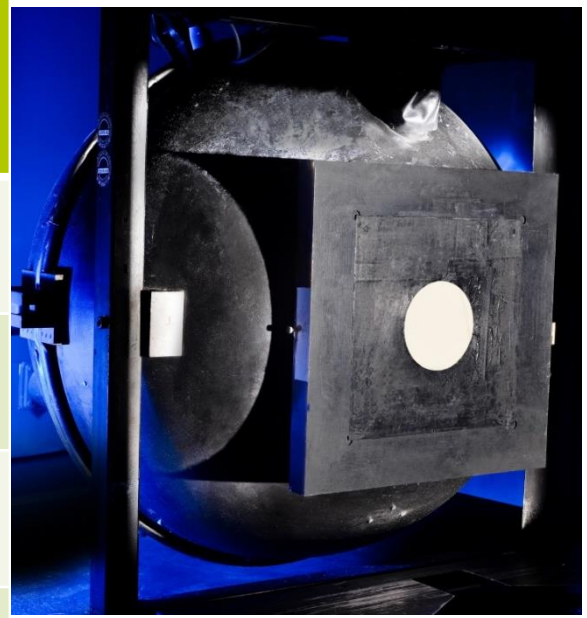
Measured shading fabric sample in photogoniometer sample holder



pgII photogoniometer with measured shading fabric

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

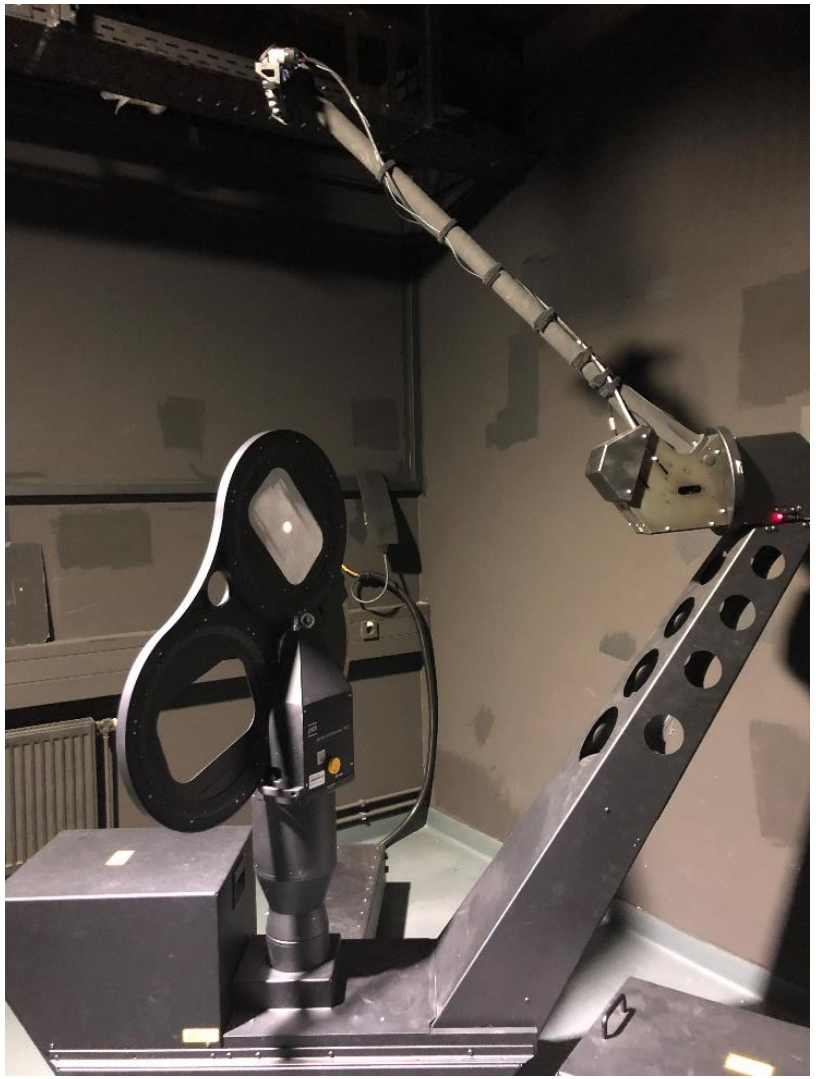
Incidence angles		τ_v_dir-h (Integ-rating sphere)	τ_v_dir-h (Photo-gonio-meter)	Differ-ence in τ_v_dir-h
θ_{in}	ϕ_{in}			
0	0	0.0194	0.0196	0.0002
20	0	0.0192	0.0188	0.0004
40	0	0.0185	0.0177	0.0008
60	0	0.0155	0.0149	0.0006
80	0	0.0086	0.0059	0.0026



Agreement generally within 0.01 also for other incidence angles.

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



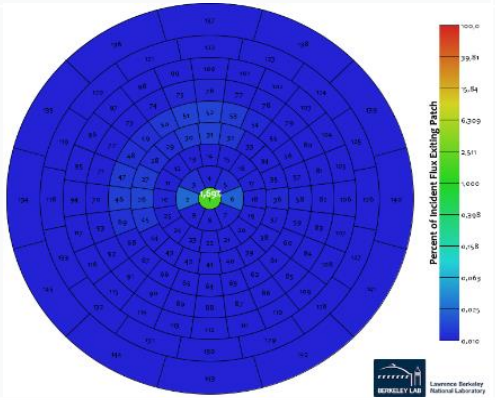
Validation of direct-hemispherical and direct-direct transmittance by comparing photogoniometric results

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

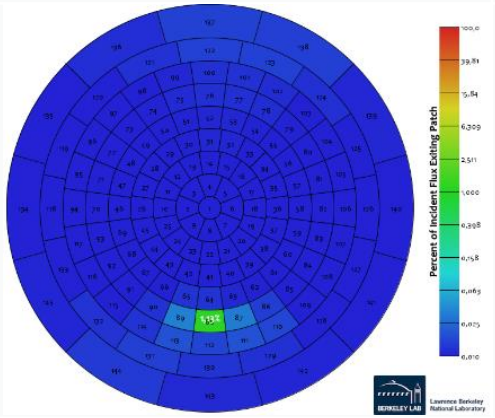
Measured shading fabric sample


In the photogonio-meter sample holder

LBNL

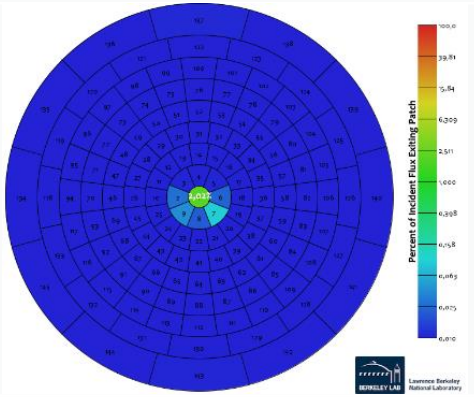


$\tau_{dir\text{-}h}$ = 2.8%, $\tau_{dir\text{-}dir}$ = 1.69%

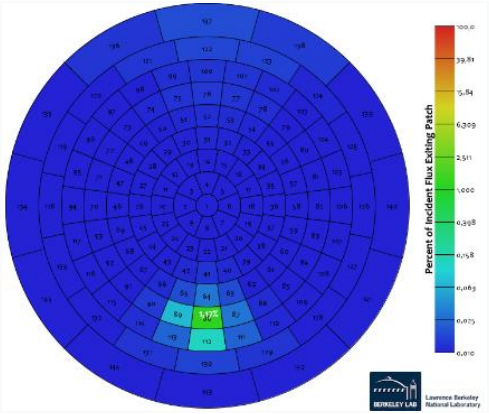


$\tau_{dir\text{-}h}$ = 2.5%, $\tau_{dir\text{-}dir}$ = 1.13%

Fraunhofer ISE



$\tau_{dir\text{-}h}$ = 3.3%, $\tau_{dir\text{-}dir}$ = 2.02%

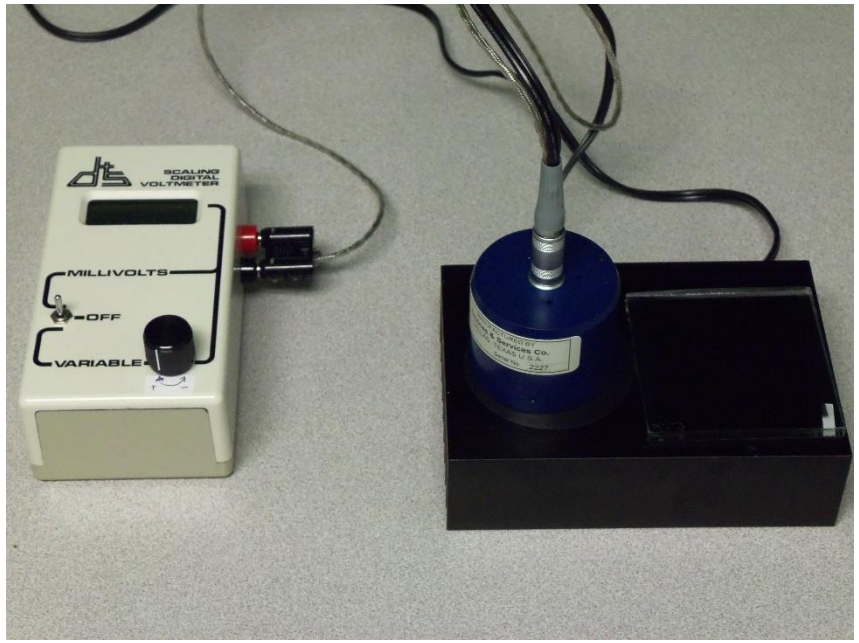


$\tau_{dir\text{-}h}$ = 2.7%, $\tau_{dir\text{-}dir}$ = 1.17%

Figures by D. Moroder-Geisler, Bartenbach

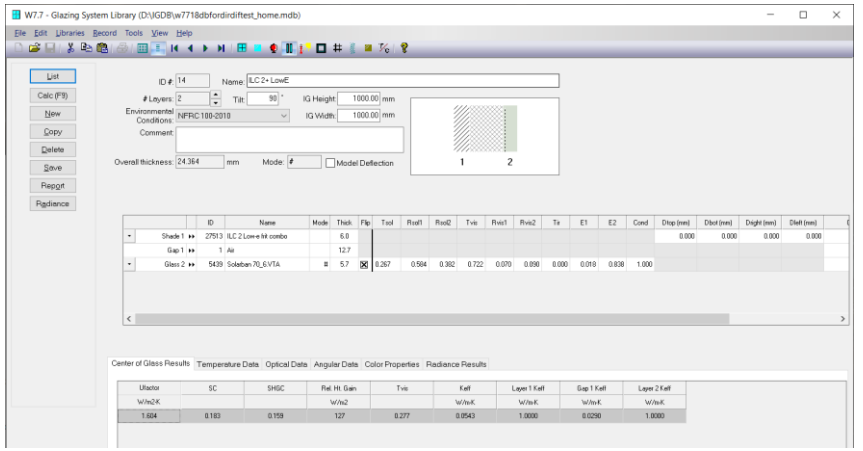
NFRC 301 covers thermal emissivity of rough glazing surfaces – also applicable to solar-shading materials with low transmittance

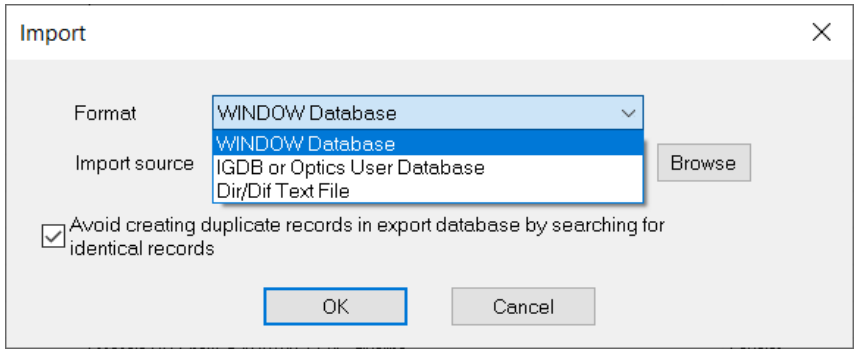
- FTIR instruments with an integrating sphere are not common among glazing manufacturers since coated glass is smooth and can be measured with a near-normal reflectance accessory
- A broadband emissometer was compared to FTIR instruments equipped with integrating spheres to find a low-cost and easy-to-use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



Modelling glazing AND SHADING MATERIALS in WINDOW 7.8

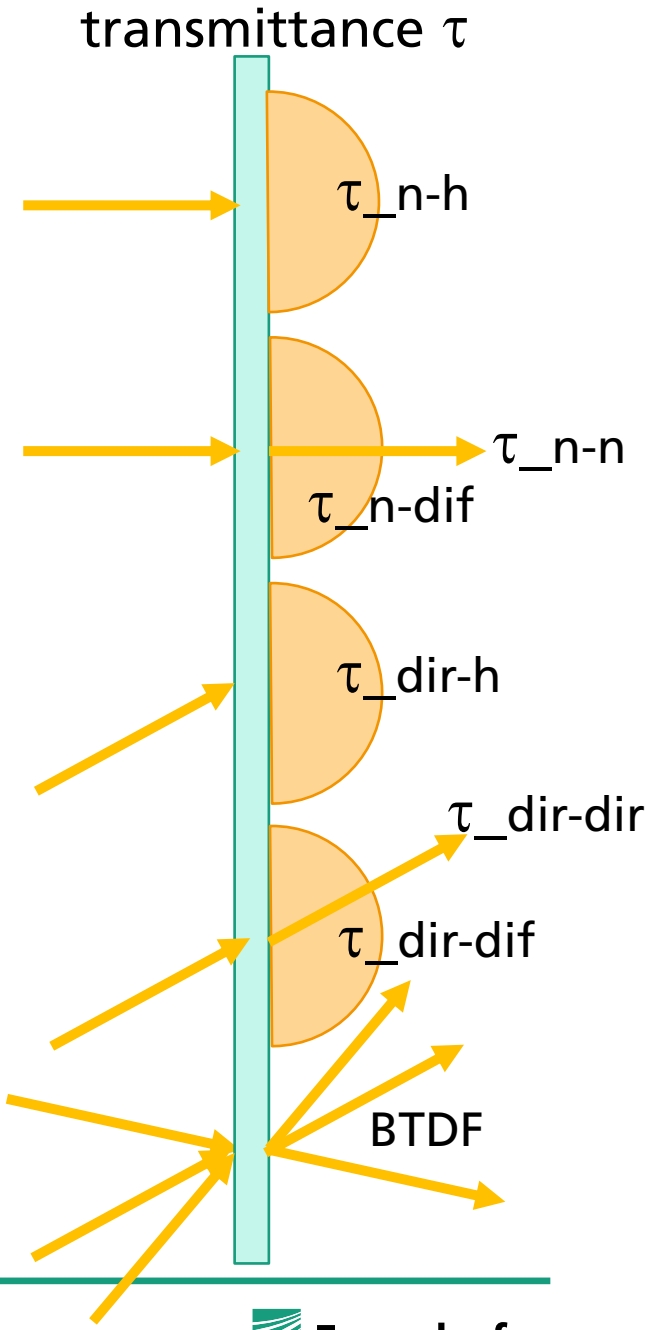
- Text files with data for normal-normal and normal-diffuse reflectance and transmittance can be imported
- Allows for U and SHGC (g-value) calculation of window configurations where one or more of the panes is a diffuse glazing
- Public version soon to be released which will allow for NFRC to update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





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!



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