Fraunhofer ISE

Report TLSF-2407-004
Determination of technical data for glazing with applied solar-control films for Alpen-Handel e.U.

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Inhalt

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The results in this report refer to the tested sample. Fraunhofer ISE did not have any influence on the selection of samples.

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1 Overview

This report gives technical values for single, double and triple glazing units with solar-control films applied to the indoor surface. The values were calculated at Fraunhofer ISE, based on results of spectral measurements made at Fraunhofer ISE of solar-control film samples supplied by Alpen-Handel in Vienna and microscope slides, and spectral data sets for clear 4 mm glass panes as documented in EN 14501:2021.

The solar-control films are functional adhesive films that are applied to the indoor surface of a glazing unit. For the reported glazing units, the solar-control films significantly reduce the total solar energy transmittance (g value).

The single, double and triple glazing units that were chosen as the basis for comparison consist of clear glass panes without coatings and air-filled gaps, being examples of older glazing units with high g values, for which renovation with the solar-control films would reduce the risk of overheating.

2 Summaries of technical data according to ISO 9050:2003

The technical performance values of the window film were determined according to ISO 9050:2003 (international standard). The technical performance values of the window film products 2099 and 4099 on 4 mm clear glass, as measured according to the criteria in the specification, and the technical performance values of 4 mm clear glass without film applied are as presented in Table 1:

Table 1 Summary of the g values (SHGC) and normal-hemispherical UV transmittance (TUV or τ_{UV}) according to ISO 9050:2003 for single glazing with and without solar-control films.
The uncertainty for transmittance is ±0.01, the uncertainty for g value is ±0.02.

Category	g value (SHGC) [-]	TUV (τ_{UV}) [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.26	0.00
Solar-control film type 4099 applied to 4 mm clear glass	0.41	0.00
4 mm clear glass without solar-control film	0.89	0.75

The samples of this window film on glass show significant performance in blocking the solar energy that enters indoors compared to glass without film as documented by their g values (SHGC), which is the practical technical performance value to characterise the control of solar radiation.

The window glass with products 2099 and 4099 applied can reduce indoor temperature increase by blocking the total solar energy radiation entering indoors, thereby saving cooling energy.

In addition, the products transmit 0 % of the ultraviolet rays entering through the glass, thus providing a 100% blocking of harmful ultraviolet rays from entering indoors.

The performance values of this window film are data that have been measured and in the TestLab Solar Facades laboratory of Fraunhofer ISE, that is certified according to ISO 17025:2015, an international standard specification.

The results in Table 2 and Table 3 refer to single glazing, double glazing units and triple glazing units consisting of 4 mm clear glass panes as specified in Table 8, with and without solar-control films applied to the indoor surface, and air-filled gaps. The glazing configurations are specified in detail in Sections 5.6, 5.8 and 5.10. The technical values are calculated according to ISO 9050:2003, ISO 10292:1994, EN 410:2011 and EN 673:2011.
For each type of glazing and solar-control film, ratios are also given for each technical characteristic value for a glazing configuration with a solar-control film on the indoor surface to the same glazing configuration without a solar-control film.
It is noted that, for a given type of solar-control film, the absolute g value decreases from triple glazing through double glazing to single glazing. This is because less of the solar energy absorbed by the solar-control film is transferred indoors for the poorly insulating single glazing.

Table 2 (this and next page)
Summary of normal-hemispherical UV transmittance, light transmittance, solar transmittance and the g values according to ISO 9050:2003 for single, double and triple glazing as specified in Sections 5.6, 5.8 and 5.10. The uncertainty for transmittance is ±0.01, the uncertainty for g value is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, UV = ultra-violet, L = light, e = (solar) energy, nh = normal-hemispherical, g = g value (total solar energy transmittance).
The values are given to three decimal places to identify small differences or trends.

Type of glazing	Technical characteristics				Ratios of technical characteristic values of a glazing unit with indoor solar-control film to the same glazing unit without			
Single glazing	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.205	0.109	0.262	0.001	0.227	0.125	0.296
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.463	0.219	0.407	0.001	0.512	0.251	0.460
4 mm clear glass	0.754	0.905	0.872	0.885	-	-	-	-

Type of glazing	Technical characteristics				Ratios of technical characteristic values of a glazing unit with indoor solar-control film to the same glazing unit without			
Double glazing with specified indoor pane	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.190	0.100	0.451	0.002	0.230	0.130	0.564
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.422	0.197	0.607	0.002	0.512	0.257	0.759
4 mm clear glass	0.608	0.825	0.767	0.800	-	-	-	-
Triple glazing with specified indoor pane	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	g [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.000	0.177	0.091	0.478	0.000	0.234	0.134	0.656
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.386	0.179	0.616	0.002	0.510	0.263	0.845
4 mm clear glass	0.508	0.757	0.680	0.729	-	-	-	-

Table 3 Summary of g values (total solar energy transmittance) according to EN 410:2011 and ISO 9050:2003 for single, double and triple glazing as specified in Sections 5.6, 5.8 and 5.10 and corresponding g-value ratios (expressed as a percentage) for each glazing unit with an indoor solar-control film compared to the same glazing unit without a solar-control film.
The uncertainty for g value is ±0.02. g = g value (total solar energy transmittance).
Some values are given to three decimal places to identify small differences or trends.

	Single glazing (pp. 15 and 16)		**Double glazing** (pp. 17 and 18)		**Triple glazing** (pp. 19 and 20)	
	EN 410:2011	ISO 9050:2003	EN 410:2011	ISO 9050:2003	EN 410:2011	ISO 9050:2003
Indoor pane	g [-]	g [-]	g [-]	g [-]	g [-]	g [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.251	0.262	0.445	0.451	0.474	0.478
Solar-control film type 4099 applied to 4 mm clear glass	0.392	0.407	0.600	0.607	0.609	0.616
4 mm clear glass	0.882	0.885	0.798	0.800	0.727	0.729
Indoor pane	g-value ratio [%]	g-value ratio [%]	g-value ratio [%]	g-value ratio [%]	g-value ratio [%]	g-value ratio [%]
Solar-control film type 2099 applied to 4 mm clear glass	28	30	56	56	65	66
Solar-control film type 4099 applied to 4 mm clear glass	44	46	75	76	84	84

3 Sample description

The test samples used for this report are shown in the following list.
Solar-control films of type 2099 and type 4099, manufactured by M-Glass Corp., were supplied by Alpen-Handel e.U. to Fraunhofer ISE.
The samples TLSF-6008 and TLSF-6009 were prepared at Fraunhofer ISE by applying the solar-control films to low-iron glass substrates of the same type as sample TLSF-6010.
The solar-control films were delivered to Fraunhofer ISE on 28th May 2024.

The low-iron glass substrates (microscope slide) from Paul Marienfeld GmbH & Co. KG were provided by Fraunhofer ISE.

Table 4 Sample descriptions.

Fraunhofer ISE ID	Descriptions as confirmed by Alpen-Handel e.U.	Thickness (mm)	Dimensions (mm)
TLSF-6008	Solar-control film type 2099 from M-Glass Corp. applied to low-iron microscope slide	1.056	75 mm x 25 mm
TLSF-6009	Solar-control film type 4099 from M-Glass Corp. applied to low-iron microscope slide	1.054	75 mm x 25 mm
TLSF-6010	Low-iron microscope slide	0.095	75 mm x 25 mm

4 Description of methods

TestLab Solar Façades is accredited for thermal-optical testing of windows, façades and other products according to DIN EN ISO/IEC 17025:2018. The initial accreditation was in 2006. The accreditation encompasses the determination by measurement and calculation of the g value, transmittance, reflectance and U value. The flexible accreditation also includes procedures developed at Fraunhofer ISE which go beyond the state of the art as documented in standards.

The DAkkS registration number for the accreditation is **D-PL-11140-03-00**.

The spectral measurements in the medium infrared range for wavelengths longer than 3.2 µm are not included among the accredited services offered by the TestLab Solar Façades. However, the measurement instruments are included in the quality management system of Fraunhofer ISE, which is certified according to ISO 9001:2015. The instruments are calibrated regularly against traceable standards.

4.1 Description of spectral transmittance and reflectance measurements in the solar spectral range

The spectral normal-hemispherical transmittance and the spectral near-normal-hemispherical reflectance of the samples were measured in the range from 280 nm to 2500 nm using a Perkin-Elmer Lambda-900 spectrometer and a 220 mm integrating sphere coated with sintered PTFE.
The reference used for the reflectance measurements with the Lambda-900 spectrometer is a mirror reflectance standard that is traceable to reflectance standards calibrated externally by RI.SE, the Swedish national metrological institute (calibration certificate number: 105105-2P02127-K03rev1 of 2020-04-06).

The angle of incidence was 0° for the transmittance measurements and 8° for the reflectance measurements.

4.2 Description of reflectance measurements in the infrared spectral range

The spectral hemispherical reflectance for near-normal incidence (8° angle of incidence) of the film-coated surfaces of samples TLSF-6008 and TLSF-6009 and of one glass surface of sample TLSF-6010 was measured over the IR spectral range from 1.5 µm to 25 µm. A highly sensitive Fourier spectrometer, model Vertex 80 from the Bruker company, was used. The spectrometer is equipped with two diffusely reflecting, gold-coated integrating spheres for measurements in the medium infrared. Diffusely reflecting standards from NIST and

NPL, the national metrological institutes of the UK and the USA, are used as references.

The measurement instruments are included in our quality management system, which is certified according to ISO 9001:2015, and are calibrated regularly against traceable standards. However, as mentioned in the introduction to Section 3, these measurements are not accredited according to ISO 17025:2018.

4.3 Calculation of the light and solar energy characteristics

The light and solar energy properties of the samples in Table 4 were calculated from the spectra measured in the solar spectral range according to EN 410:2011 and ISO 9050:2003. A program which was written and validated at Fraunhofer ISE was used for these calculations.

The Optics program, Version 6.0, from LBNL, Berkeley, USA was used to calculate the optical properties of the solar-control films applied to 4 mm clear glass. The Optics program implements the algorithms that are included in Annex A to both EN 410:2011 and ISO 9050:2003 to calculate "the spectral transmittance and reflectance of a coated glass plate with thickness *y* from the spectral transmittance and reflectance of a plate of a different glass with thickness *x* on which the same coating has been deposited".

EN 14501:2021, Table A.15 was used as the source of the spectral transmittance and reflectance data and the emissivity values of the 4 mm clear glass. The Optics program was also used to calculate the optical properties of single, double and triple glazing consisting of the 4 mm clear glass panes and air-filled cavities, with a solar-control film applied to the indoor surface of the glazing unit. The further technical properties were calculated using the g-value algorithms documented in EN 410:2011 and ISO 9050:2003, and the WIS program, version 3.01 SP 2, developed by TNO, Delft, the Netherlands and validated within the EU-funded WinDat research project.

4.4 Calculation of the normal-hemispherical thermal emissivity at 283 K (10 °C)

The normal-hemispherical thermal emissivity of these samples was determined from the near-normal-hemispherical reflectance $\rho_{nh}(\lambda)$ measurements in the infrared spectral range. To calculate the normal-hemispherical emissivity ε_{nh}, the function $(1 - \rho_{nh}(\lambda))$ was weighted with the Planck blackbody radiation spectrum for a temperature of 283 K (10 °C) over the spectral range from 1.5 µm to 25 µm. The corrected emissivity ε was calculated from the normal-hemispherical emissivity according to the equation specified in EN 12898:2019.

5 Results

The measurements were carried out between 04.06.2024 and 09.07.2024.

5.1 Calculated technical values for measured samples according to EN 410:2011 and analogously to EN 12898:2019

The technical values calculated according to EN 410:2011 and analogously to EN 12898:2019 from the normal-hemispherical spectra for the samples are presented in Table 5.

Table 5 Summary of normal-hemispherical transmittance and near-normal-hemispherical reflectance values according to EN 410:2011 and emissivity according to EN 12898:2019 for the samples described in Table 4.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), ρ' = reflectance with light incident on the back surface (film), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, ε_{nh}= normal-hemispherical emissivity of the front surface (glass), ε_{nh}'= normal-hemispherical emissivity of the back surface (film for samples TLSF-6008 and TLSF-6009, glass for sample TLSF-6010), ε= corrected emissivity of the front surface (glass), ε'= corrected emissivity of the back surface (film for samples TLSF-6008 and TLSF-6009, glass for sample TLSF-6010).
The values are given to three decimal places to identify small differences or trends.

Fraunhofer ISE ID	Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{L,nh}$ [-]	$\rho_{e,nh}$ [-]	$\rho'_{L,nh}$ [-]	$\rho'_{e,nh}$ [-]	ε_{nh} [-]	ε_{nh}' [-]	ε [-]	ε' [-]
TLSF-6008	Solar-control film type 2099 applied to low-iron microscope slide	0.001	0.207	0.112	0.293	0.294	0.121	0.085	0.888	0.812	0.836	0.769
TLSF-6009	Solar-control film type 4099 applied to low-iron microscope slide	0.001	0.467	0.225	0.071	0.063	0.073	0.058	0.888	0.926	0.836	0.870
TLSF-6010	Low-iron microscope slide	0.874	0.913	0.913	0.082	0.081	0.082	0.081	0.888	0.888	0.836	0.836

5.2 Calculated technical values for measured samples according to ISO 9050:2003 and analogously to EN 12898:2019

The technical values calculated according to ISO 9050:2003 and analogously to EN 12898:2019 from the normal-hemispherical spectra for the samples are presented in Table 6.

Table 6 Summary of normal-hemispherical transmittance and near-normal-hemispherical reflectance values according to ISO 9050:2003 and emissivity analogously to EN 12898:2019 for the samples described in Table 4.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), ρ' = reflectance with light incident on the back surface (film), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, ε_{nh}= normal-hemispherical emissivity of the front surface (glass), ε_{nh}'= normal-hemispherical emissivity of the back surface (film for samples TLSF-6008 and TLSF-6009, glass for sample TLSF-6010), ε= corrected emissivity of the front surface (glass), ε'= corrected emissivity of the back surface (film for samples TLSF-6008 and TLSF-6009, glass for sample TLSF-6010).
The values are given to three decimal places to identify small differences or trends.

Fraunhofer ISE ID	Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{L,nh}$ [-]	$\rho_{e,nh}$ [-]	$\rho'_{L,nh}$ [-]	$\rho'_{e,nh}$ [-]	ε_{nh} [-]	ε_{nh}' [-]	ε [-]	ε' [-]
TLSF-6008	Solar-control film type 2099 applied to low-iron microscope slide	0.001	0.207	0.112	0.293	0.300	0.121	0.084	0.888	0.812	0.836	0.769
TLSF-6009	Solar-control film type 4099 applied to low-iron microscope slide	0.001	0.467	0.223	0.071	0.063	0.073	0.058	0.888	0.926	0.836	0.870
TLSF-6010	Low-iron microscope slide	0.882	0.913	0.914	0.082	0.081	0.082	0.081	0.888	0.888	0.836	0.836

5.3 Calculated technical values for 4 mm clear glass panes with and without solar-control films according to EN 410:2011 and analogously to EN 12898:2019

The technical values calculated according to EN 410:2011 and analogously to EN 12898:2019 from the normal-hemispherical spectra for the samples of 4 mm clear glass, with and without the applied solar-control films, are presented in Table 7.

Table 7 Summary of normal-hemispherical transmittance and near-normal-hemispherical reflectance values according to EN 410:2011 and emissivity analogously to EN 12898:2019 calculated for samples on 4 mm clear glass ("Pane 1" in EN 14501:2021).
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), ρ' = reflectance with light incident on the back surface (film), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, ε_{nh}= normal-hemispherical emissivity of the front surface (glass), ε_{nh}'= normal-hemispherical emissivity of the back surface (film for the applied-film samples, glass for the clear glass sample), ε= corrected emissivity of the front surface (glass), ε'= corrected emissivity of the back surface (film for the applied-film samples, glass for the clear glass sample).
The values are given to three decimal places to identify small differences or trends.

Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{L,nh}$ [-]	$\rho_{e,nh}$ [-]	$\rho'_{L,nh}$ [-]	$\rho'_{e,nh}$ [-]	ε_{nh} [-]	ε_{nh}' [-]	ε [-]	ε' [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.205	0.110	0.288	0.272	0.121	0.085	0.890	0.812	0.837	0.769
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.463	0.221	0.071	0.062	0.073	0.058	0.890	0.926	0.837	0.870
4 mm clear glass	0.725	0.905	0.870	0.082	0.078	0.082	0.078	0.890	0.890	0.837	0.837

5.4 Calculated technical values for 4 mm clear glass panes with and without solar-control films according to ISO 9050:2003 and analogously to EN 12898:2019

The technical values calculated according to ISO 9050:2003 and analogously to EN 12898:2019 from the normal-hemispherical spectra for the samples of 4 mm clear glass, with and without the applied solar-control films, are presented in Table 8.

Table 8 Summary of normal-hemispherical transmittance and near-normal-hemispherical reflectance values according to ISO 9050:2003 and emissivity analogously to EN 12898:2019 for samples on 4 mm clear glass ("Pane 1" in EN 14501:2021).
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), ρ' = reflectance with light incident on the back surface (film), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, ε_{nh}= normal-hemispherical emissivity of the front surface (glass), ε_{nh}'= normal-hemispherical emissivity of the back surface (film for the applied-film samples, glass for the clear glass sample), ε= corrected emissivity of the front surface (glass), ε'= corrected emissivity of the back surface (film for the applied-film samples, glass for the clear glass sample).
The values are given to three decimal places to identify small differences or trends.

Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{L,nh}$ [-]	$\rho_{e,nh}$ [-]	$\rho'_{L,nh}$ [-]	$\rho'_{e,nh}$ [-]	ε_{nh} [-]	ε_{nh}' [-]	ε [-]	ε' [-]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.205	0.109	0.288	0.277	0.121	0.084	0.890	0.812	0.837	0.769
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.463	0.219	0.071	0.062	0.073	0.058	0.890	0.926	0.837	0.870
4 mm clear glass	0.754	0.905	0.872	0.082	0.078	0.082	0.078	0.890	0.890	0.837	0.837

5.5 Calculated technical values for single glazing with and without the solar-control films applied to the indoor surface according to EN 410:2011 and EN 673:2011

The results in Table 9 refer to 4 mm single glazing with the same optical properties as in Table 7, with the applied solar-control film on the indoor surface.
The technical values are calculated according to EN 410:2011 and EN 673:2011.

Table 9 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to EN 410:2011 for single glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,\,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.205	0.110	0.272	0.618	0.141	0.251	5.7
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.463	0.221	0.062	0.717	0.171	0.392	6.0
4 mm clear glass	0.725	0.905	0.870	0.078	0.052	0.012	0.882	5.9

5.6 Calculated technical values for single glazing with and without the solar-control films applied to the indoor surface according to ISO 9050:2003 and ISO 10292:1994

The results in Table 10 refer to 4 mm single glazing with the same optical properties as in Table 8, with the applied solar-control film on the indoor surface.
The technical values are calculated according to ISO 9050:2003 and ISO 10292:1994.

Table 10 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to ISO 9050:2003 for single glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Sample	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.205	0.109	0.277	0.614	0.153	0.262	5.6
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.463	0.219	0.062	0.719	0.188	0.407	5.9
4 mm clear glass	0.754	0.905	0.872	0.078	0.05	0.013	0.885	5.8

5.7 Calculated technical values for double glazing with and without the solar-control films applied to the indoor surface according to EN 410:2011 and EN 673:2011

The results in Table 11 refer to double glazing consisting of an outdoor pane of 4 mm clear glass pane, 12 mm air-filled gap and an indoor pane with the same optical properties as in Table 7, with the applied solar-control film on the indoor surface.
The technical values are calculated according to EN 410:2011 and EN 673:2011.

Table 11 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to EN 410:2011 for double glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Indoor pane of specified double glazing	$\tau_{UV,nh}$ [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.000	0.190	0.100	0.291	0.609	0.345	0.445	2.8
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.422	0.199	0.126	0.675	0.401	0.600	2.9
4 mm clear glass	0.576	0.825	0.766	0.138	0.096	0.032	0.798	2.8

5.8 Calculated technical values for double glazing with and without the solar-control films applied to the indoor surface according to ISO 9050:2003 and ISO 10292:1994

The results in Table 12 refer to double glazing consisting of an outdoor pane of 4 mm clear glass pane, 12 mm air-filled gap and an indoor pane with the same optical properties as in Table 8, with the applied solar-control film on the indoor surface.
The technical values are calculated according to ISO 9050:2003 and ISO 10292:1994.

Table 12 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to ISO 9050:2003 for double glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Indoor pane of specified double glazing	$\tau_{UV,nh}$ [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,\,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.001	0.190	0.100	0.294	0.606	0.351	0.451	2.8
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.422	0.197	0.126	0.677	0.410	0.607	2.9
4 mm clear glass	0.608	0.825	0.767	0.138	0.095	0.033	0.800	2.9

5.9 Calculated technical values for triple glazing with and without the solar-control films applied to the indoor surface according to EN 410:2011 and EN 673:2011

The results in Table 13 refer to triple glazing consisting of an outdoor pane of 4 mm clear glass pane, 10 mm air-filled gap, a middle pane of 4 mm clear glass, 10 mm air-filled gap and an indoor pane with the same optical properties as in Table 7, with the applied solar-control film on the indoor surface.
The technical values are calculated according to EN 410:2011 and EN 673:2011.

Table 13 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to EN 410:2011 for triple glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Indoor pane of specified triple glazing	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.000	0.177	0.092	0.307	0.601	0.382	0.474	2.0
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.386	0.181	0.176	0.643	0.428	0.609	2.0
4 mm clear glass	0.477	0.757	0.679	0.185	0.136	0.048	0.727	2.0

5.10 Calculated technical values for triple glazing with and without the solar-control films applied to the indoor surface according to ISO 9050:2003 and ISO 10292:1994

The results in Table 14 refer to triple glazing consisting of an outdoor pane of 4 mm clear glass pane, 10 mm air-filled gap, a middle pane of 4 mm clear glass, 10 mm air-filled gap and an indoor pane with the same optical properties as in Table 8, with the applied solar-control film on the indoor surface.
The technical values are calculated according to ISO 9050:2003 and ISO 10292:1994.

Table 14 Summary of normal-hemispherical solar values, the secondary internal heat transfer factors and the g values according to ISO 9050:2003 for triple glazing as specified.
The uncertainty for transmittance is ±0.01, the uncertainty for reflectance and absorptance is ±0.02. These uncertainty values do not take the uncertainty of the wavelength calibration into account. With these spectral distributions, we do not expect that the measurement uncertainty would be significantly larger if the wavelength calibration were taken into account.
τ = transmittance with light incident on the front surface, ρ= reflectance with light incident on the front surface (glass), α = absorptance with light incident on the front surface (glass), UV = ultraviolet, L = light, e = (solar) energy, nh = normal-hemispherical, q_i = secondary internal heat transfer factor, g = g value (total solar energy transmittance), U = U value (thermal transmittance).
The values are given to three decimal places to identify small differences or trends.

Indoor pane of specified triple glazing	τ_{UV} [-]	$\tau_{L,nh}$ [-]	$\tau_{e,nh}$ [-]	$\rho_{e,nh}$ [-]	$\alpha_{e,\,nh}$ [-]	q_i [-]	g [-]	U [$Wm^{-2}K^{-1}$]
Solar-control film type 2099 applied to 4 mm clear glass	0.000	0.177	0.091	0.309	0.600	0.387	0.478	2.0
Solar-control film type 4099 applied to 4 mm clear glass	0.001	0.386	0.179	0.17	0.646	0.436	0.616	2.0
4 mm clear glass	0.508	0.757	0.680	0.185	0.135	0.049	0.729	2.0

6 References

EN 410:2011 (E) Glass in building – Determination of luminous and solar characteristics of glazing, 2011.

EN 673:2011 (E) Glass in building – Determination of thermal transmittance (U value) – Calculation method, 2011.

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EN 14501:2021 Blinds and shutters – Thermal and visual comfort – Performance characteristics and classification, 2021.

ISO 9050:2003 Glass in building – Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors, 2003.

ISO 10292:1994 Glass in building – Calculation of steady-state *U* values (thermal transmittance) of multiple glazing, 1994.