INSTITUT FÜR SOLARTECHNIK

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Certification of solar glass-ST
Solar Thermal collectors

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Contents

1 General information

1.1 Introduction

The performance of a solar thermal collector (ST) depends on the optical properties of the cover used. Assessing and quantifying the effect this glass has on the yield of the collector is a laborious task, and because cost-pressure on manufacturers has increased over the last years, this information has become ever more important in accurate estimations relating performance to price.

Currently there is no Norm for the testing of Solar Glass which is why SPF developed their own, whereby glass can be placed into varying performance-categories based on optical measurements. This classification allows an estimation of the effective collector yield in regards to different glass coverings. The SPF-glass-certificate provides thereby a foundation of technical specification for the acquisition and quality assessment of Solar Glass in the manufacturing of solar thermal collectors.

The SPF Solar Glass certificate encompasses solely optical properties. Aspects of safety, mechanical loading capacity and soiling are explicitly not part of the certificate. All relevant Norms and regulations are to be observed independent of this certificate. In particular, SPF recommends the use of hardened glass meeting the minimum requirements of EN12150.

Due to the differing properties Solar Thermal Collectors and Photovoltaic Modules require of Solar Glass, there are two respective assessments and certificates:

- Solar Glass PV, intended for Photovoltaic Modules
- Solar Glass ST, intended for Solar Thermal Collectors

1.2 Scope

The certification procedure presented here is intended for the evaluation of flat-plate single-glass thermal collectors of conventional construction (see Figure 1). In the case of other construction forms (e.g. double glazed collectors) the effect on estimated annual collector yield may vary, but in general one can assume these effects are small.

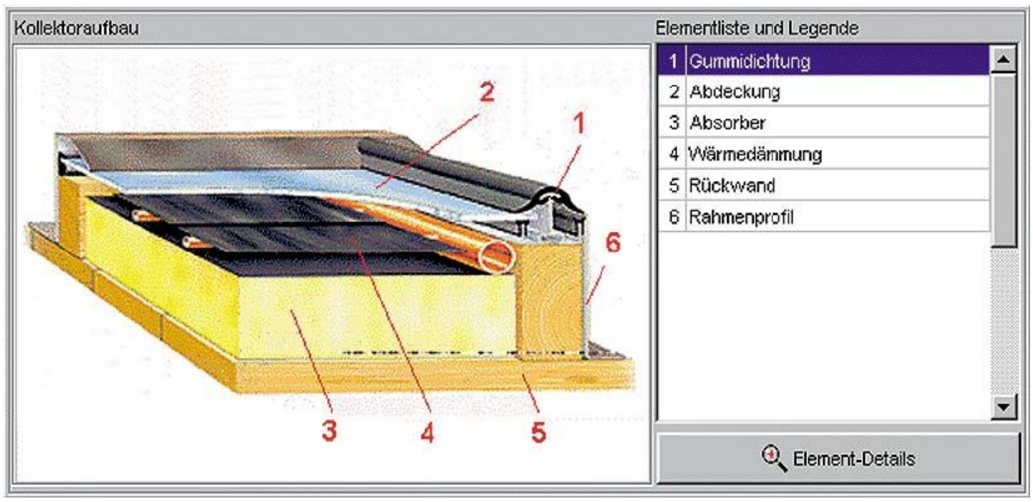

Figure 1: Typical construction of a solar thermal collector: Components: 1 rubber gasket, 2 glass cover, 3 thermal insulation, 4 absorber, 5 back plate, 6 frame

2 Technical fundamentals

2.1 Performance of solar glass

The optical performance of solar glass intended for use in solar thermal collectors can be characterised essentially with three main parameters:

Unilateral Transmission: The solar transmission factor defines the amount of incident radiation that is transferred through the glass and is available for the generation of heat at the absorber. This factor is made up mostly from the refractive index and chemical composition of the glass, as well as any relevant surface effects (structured surfaces or ant-reflex coatings). Impurities inherent in the manufacturing process can lead to significant reduction in transmission, for example high amounts of iron oxide. For normal glass as used in the fenestration industry for example, this effect is desirable, however in solar thermal collectors as much of the available solar spectrum should be utilised. Such impurities are hard to detect. The solar transmission factor is measured by “direct-hemispherical” orientated spectrometers over the complete wavelength range relevant for thermal collectors; 0.3 – 2.5 µm.

Incident angle factor: The influence of the incident angle of radiation is often underestimated. Generally speaking structured or only lightly structured glass has a good incident angle factor and is favoured by customers. A drawback of unstructured glass is that contamination from soiling is quickly visible. Another is that technical defects in the collector (e.g. insulation solvent evaporation, accrual of moisture and construction faults) are less concealable. A lightly structured glass reduces also the dazzle that reflection from the collector can have. If only the yield of the collector is observed then lightly structured or unstructured glass is more beneficial than prismatic glass.

Aging though photolysis: Photolysis or solarisation is a discolouration of the glass due to component oxidation resulting from long-term UV exposure and leads to a reduction in transmission. Not accounted for in this test are influences from soiling or degradation due to weather and climate.

2.2 The glass efficiency value

The efficiency value $\eta_{GL,ST}$ is introduced to simplify the evaluation of solar glass. It defines the influence a glass has on the annual collector yield of a reference system located in Rapperswil (typical central European climate: -8.82° Longitude, 47.23° Latitude) at an inclination angle of 40°.

The glass-efficiency-factor is a product of the above mentioned performance characteristics. Each factor is defined such that they and the overall glass-efficiency-factor $\eta_{GL,PV}$ are proportional to the simulated reference system:

$$\eta_{GL,ST} = F_{\tau,ST} \cdot F_{IAM,ST} \cdot F_{UV,ST} \qquad (2.1)$$

For a detailed explanation of each factor refer to Appendixes A-C. The effect these factors have on the reference system are calibrated accordingly; as such a ST glass-efficiency-factor of 1 corresponds to a simulation of a fictive glass cover without loss from internal absorption or reflection, having a response to the incident angle equivalent to unstructured low-iron glass and exhibiting no photo-degradation with time.

3 Certification

3.1 General

The rights and duties in the scope of the certification as well as its validity are contractually defined between the Institut für Solartechnik SPF and the manufacturer of the solar glass. The manufacturer can also be represented by distributors or OEM manufacturers. The duties in regard to the rules of the certification are non-negotiable. All certified Solar Glass types are published on the SPF website (www.solarenergy.ch) – a certification without publication is not possible. Along with the name of manufacturer and contractual representation the important characteristics and classification are displayed.

3.2 Classification and labelling

In the certification procedure a solar glass is categorised into one of three types:

U: Untreated solar glass
X: Double-side Anti-Reflex (AR) treated solar glass
Y: Single-side Anti-Reflex (AR) treated solar glass

Within these three categories a classification is then made based on the efficiency factor. These four classes are shown for each category in the following tables:

Table 1: Classification of untreated glass

U untreated glass					
Class U1			$\eta_{GL,ST}$	≥	0.900
Class U2	0.900	>	$\eta_{GL,ST}$	≥	0.885
Class U3	0.885	>	$\eta_{GL,ST}$	≥	0.870
Class U4	0.870	>	$\eta_{GL,ST}$	≥	0.850
Not solar glass	0.850	>	$\eta_{GL,ST}$		

Table 2: Classification of AR treated glass

Y Single-side AR treated glass					
Class Y1			$\eta_{GL,ST}$	≥	0.925
Class Y2	0.925	>	$\eta_{GL,ST}$	≥	0.910
Class Y3	0.910	>	$\eta_{GL,ST}$	≥	0.895
Class Y4	0.895	>	$\eta_{GL,ST}$	≥	0.870
Not solar glass	0.870	>	$\eta_{GL,ST}$		

X Double-side AR treated glass					
Class X1			$\eta_{GL,ST}$	≥	0.950
Class X2	0.950	>	$\eta_{GL,ST}$	≥	0.935
Class X3	0.935	>	$\eta_{GL,ST}$	≥	0.920
Class X4	0.920	>	$\eta_{GL,ST}$	≥	0.890
Not solar glass	0.890	>	$\eta_{GL,ST}$		

The glass certificate consists thus of the glass category and classification (e.g. **U3** refers to an untreated glass of the 3rd class). Below a certain threshold glass is no longer considered *solar glass*.

3.3 Certificate identification

For every glass certificate a unique identification is created containing all relevant information. These are listed below with an explanation for the short-forms:

Certifying body	:	SPF
Certificate number	:	Year (2 positions) ● sequential number (3 positions)
Type/Classification	:	see Table 1 and 2

An example of identification:
SPF02●17-X3: Glass with test number 17, tested in 2002, double-side anti-reflex treated glass with the classification 3.

3.4 Validity

The released certificates are valid for three (3) years. It is the duty of the bearer of the certificate to ensure that only the glass certified is distributed with the certificate. In the case where non-certified glass is distributed with an SPF certificate, especially with the knowledge of the certificate bearer, the certificate can be declared invalid and deleted from publication. The bearer of the ticket will be informed and has no claim to reimbursement.

Appendix A: Transmission factor $F_{\tau,ST}$

The transmission factor F_τ quantifies the effect of the solar transmittance on the collector yield of a thermal solar system. It is determined as follows:

$$F_{\tau,ST} = \tau_{sol} \tag{A.1}$$

Where τ_{sol} is defined as the "direct-hemispherical solar transmittance for near-normal incidence" of the collector cover. The reference solar spectrum is that for air mass 1.5, as specified for "hemispherical solar spectral irradiance" in ISO 9845-1.

The relationship presented in Eq. A.1 was validated with a parameter study in which the solar transmittance τ_{sol} of a solar system for domestic hot water was varied. The main specifications of the system studied are summarised in Table 3.

Table 3: Parameters of the reference system studied.

Collector data	***Area***	4 m²	***c_0***	0.80
	Angle of inclination	40°	***c_1***	4.0 W/m²K
	Orientation (azimuth)	0° (South)	***c_2***	0.01 W/m²K²
			K (IAM)	0.968
System data	***Storage volume***	400 l		
	Location	Rapperswil (CH)		
	Collector yield	2443 kWh		
	Solar Fraction SFi	ca. 52%		
	Daily energy demand	10 kWh		
c_0, c_1, c_2 : Coefficients of the collector efficiency curve K(IAM): Incidence angle modifier (IAM) of the collector at 50° angle of incidence				

The Polysun 3.3 simulation software was used to calculate the collector yield. Variation in the transmittance is accounted for indirectly via the coefficient c_0 of the collector efficiency curve. c_0 is a linear function of the transmittance.

The values specified in Table 3 are valid for a flat-plate collector equipped with a cover of 90% solar transmittance. The IAM weighting factor and the two degradation factors are equal to 1. A collector yield of 2443 kWh is achieved with this system. According to Eqns. A.1 and 2.1, the glass efficiency η_{Gl} is 0.9 and therefore this 2443 kWh corresponds to a relative collector yield of 0.900 (90%).

With these starting values, the solar transmittance of the cover was varied in the range from 0.80 to 1.00. This corresponds to a variation in c_0 between 0.711 and 0.889.

The results of the simulation are summarised in Figure 2. The calculated change in collector yield as a function of the solar transmittance is plotted with small circles. The assumed linear relationship described in Eq. A.1 is plotted as a blue line for comparison. The deviation resulting from this simplified description is plotted in red.

As the initial assumption was that the relative collector yield for τ_{sol} = 0.90 corresponds exactly to 0.900 (see above), i.e. that the transmission factor should be F_τ = 0.90 for τ_{sol} = 0.90, the deviation of the assumed linear dependence from the actual collector yield will be minimal for realistic transmittance values (around 90 %).

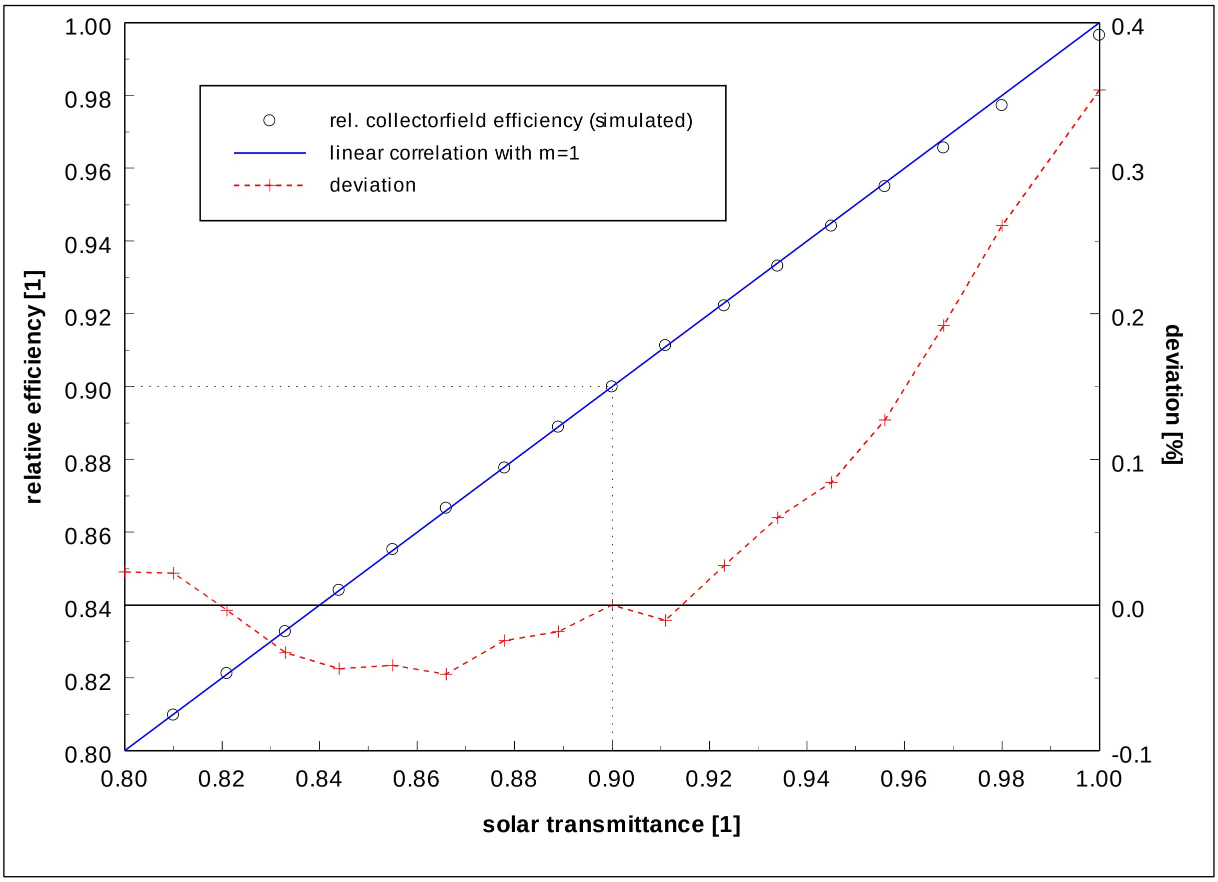

Figure 2: Relative collector yield in dependence of the solar transmission.

The deviation between the linear approximation and the simulation over the entire studied range is clearly between +0.4 % and -0.05%. For solar transmittance values of less than 92 %, i.e. the range for glass that has not been AR treated, the agreement is even better; ±0.05 %.

The constantly positive deviation above a solar transmittance of 92 % leads to a slight systematic overestimation of AR-treated glass as compared to untreated glass.

The discussion to here applies for a certain orientation of the collector field (see Table 3). An additional case was investigated to study other orientations. The collector yield of a collector with an AR-treated cover (τ_{Sol} = 0.956) was compared with the relative yield of the reference collector defined above as 0.900 (with τ_{Sol} = 0.9). The orientation of the collector field was varied between -60° (east) through 0° (south) to +60° (west), and the tilt angle ranged from 20° to 90°.

The simulation results in a relative collector yield of 0.955 for the case already considered (south orientation with a 40° tilt angle). At other orientations, the relative collector yield varies between 0.954 and 0.959 (see Figure 3). This means that the assumption made in Eq. A.1 is only very weakly affected by the orientation of the collector field.

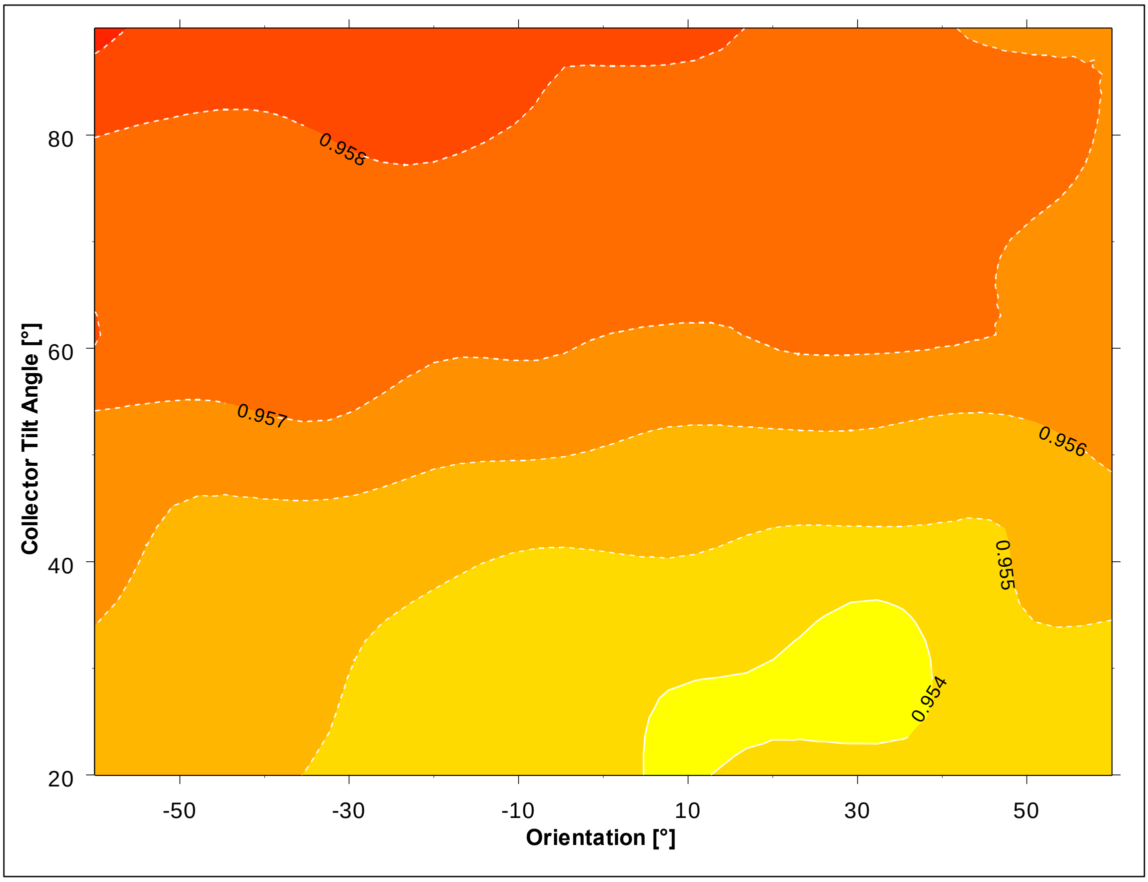

Figure 3: Relative collector yield for a collector with an AR-treated cover compared to the reference collector, as a function of the collector tilt angle and orientation.

Appendix B: The IAM weighting factor $F_{IAM,ST}$

The IAM weighting factor F_{IAM} quantifies the effect the incident angle-on the solar transmittance and collector yield of a thermal solar system. It is determined as follows:

$$F_{IAM,ST} = \min([F_{Vert}^{tr} \cdot F_{Hor}^{lo}]_{Str.in}, [F_{Vert}^{lo} \cdot F_{Hor}^{tr}]_{Str.in}, [F_{Vert}^{tr} \cdot F_{Hor}^{lo}]_{Str.out}, [F_{Vert}^{lo} \cdot F_{Hor}^{tr}]_{Str.out}) \quad \text{(B.1)}$$

Where:

$$F_{Geo}^{Axis} = \sum_n IAM_n^{Axis} \cdot S_n^{Geo} \quad \text{(B.2)}$$

IAM_n	measured incidence angle modifier at the incident angule position n
S_n	coefficient for the angular position n
n = 0,..,5	index of the incident angle position
$Axis \in (tr, lo)$	axis of the glass pane, to which the measured IAM refers (transversal, longitudinal)
$Geo \in (vert, hor)$	orientation of the corresponding glass pane axis (vertical, horizontal): the horizontal axis is parallel to the ground surface, the vertical axis and the ground surface determine the tilt angle
$(str.in, str.out)$	position of the structured surface of the glass pane with respect to the collector

F_{Geo}^{Axis} is thus the sum of the products of *n* measured values of the incidence angle modifier IAM_n with the corresponding coefficients S_n. The angles at which the IAM is measured and the corresponding coefficients are summarised in Table 7.1.

Table 4: Incident angles at which IAM is measured and respective coefficients

n	0	1	2	3	4	5
Angle [°]	0	30	40	50	60	70
S_n^V	0.6986	0.1715	0.0454	0.0389	0.0326	0.0231
S_n^H	0.5530	0.2113	0.0742	0.0756	0.0697	0.0334
IAM values of reference pane according to Fresnel	1	0.9965	0.9886	0.9678	0.9148	0.7846

This empirical relationship between the IAM and the collector yield was determined though sensitivity analysis. The IAM of a glass pane was varied in narrow angular intervals and the change in collector yield was observed. In this way, a weighting factor S was determined for each of these angular intervals. The total effect on the collector yield is obtained as the sum of the weighted effects from the individual angular intervals.

The system used for simulation again corresponds to reference solar system studied in Appendix A. The coefficients determined by the analysis are scaled such that F_{IAM} assumes the value of 1 for the reference glass pane. The reference glass pane was chosen to be a smooth, non-structured pane, 4 mm thick, with a refractive index n = 1.53 and an extinction coefficient k = 4 m^{-1}. The IAM can be calculated simply for this case with the help of the Fresnel equations. The calculated IAM values for the reference glass pane are also included in Table 4.

The practical significance of Eq. B.1 is principally the following: a glass pane can be orientated within a collector in four different ways (structure inside / outside, long axis of the glass pane parallel to the collector horizontal / vertical axis). Each of these orientations can have a different effect on the collector yield.

The effect on the collector yield can be calculated with the help of Eq. B.2, the coefficients from Table 4 and the measured IAM of a glass pane. The orientation which leads to the worst result is chosen as the *IAM weighting factor F_{IAM}*.

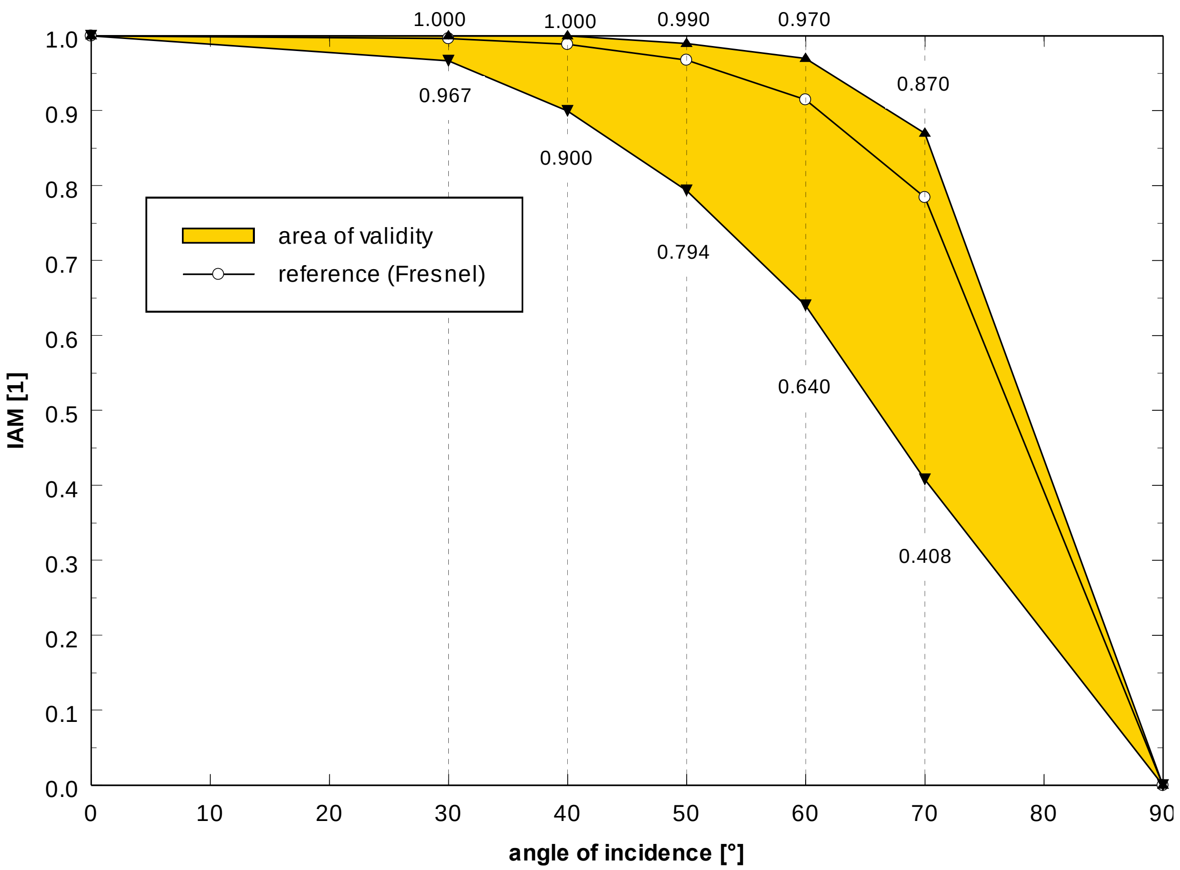

Figure 4: Valid range for calculating the factor F_{IAM}. The IAM values for the reference glass pane are noted within the shaded area.

The valid range for determining this factor from the IAM values is indicated in Figure 4.

It is evident that the dependence of the collector yield on the orientation of the collector plane is very closely connected with the IAM of the collector cover. This dependence is shown in Figure 4. The IAM of the glass pane chosen for this example has a very strong influence on the collector yield. The IAM weighting factor of this pane is F_{IAM} = 0.955. This means that a collector equipped with this glass cover would achieve only 95.5 % of the yield that could be obtained with the reference pane (with F_{IAM} = 1.0), for true south orientation and a tilt angle of 40°. As can be seen in Figure 5, the losses are even greater if other orientations are chosen.

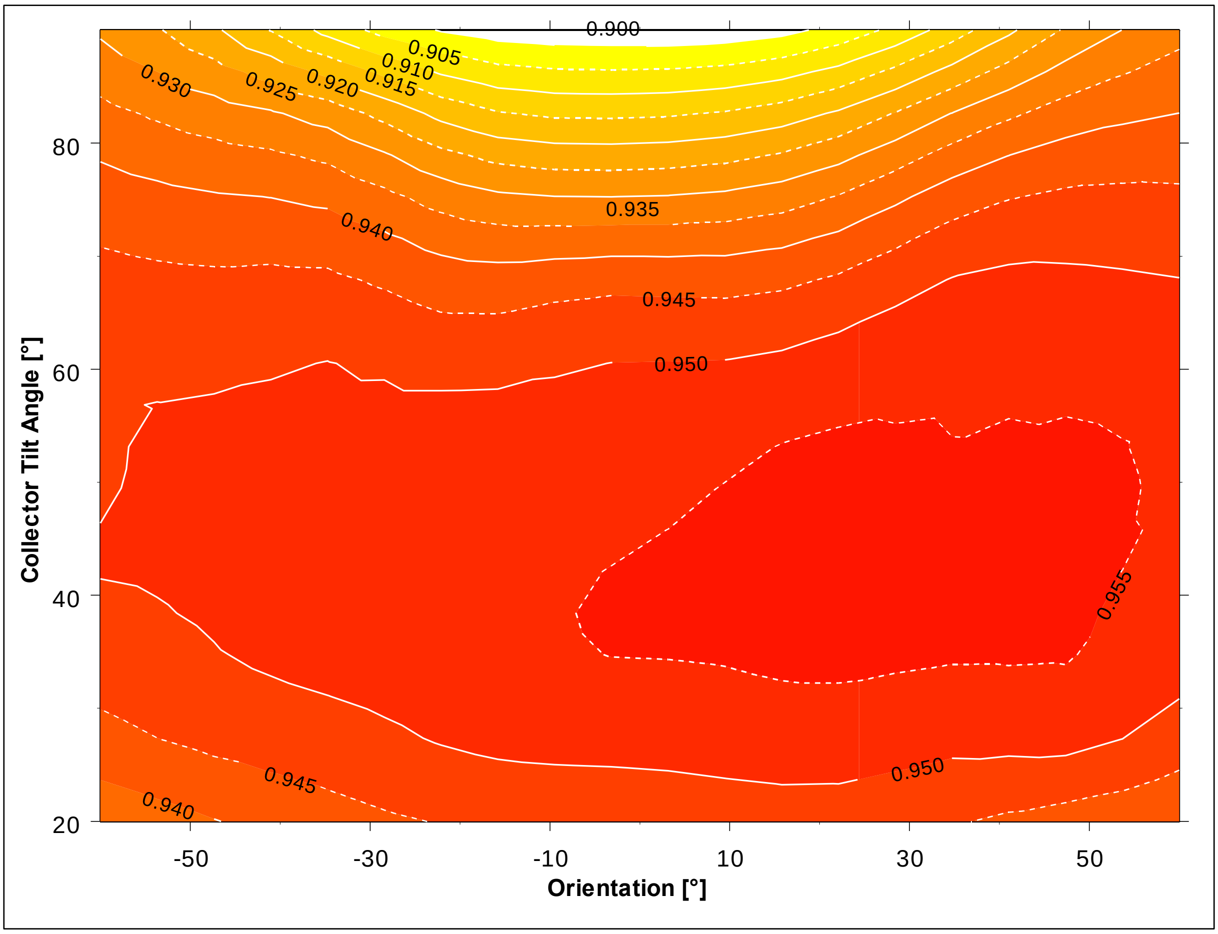

Figure 5: IAM weighting factor F_{IAM} for a glass pane with a poor IAM, as a function of the collector plane orientation.

Appendix C: Photolysis factor $F_{UV,ST}$

The photolysis or photo-degradation factor $F_{UV, ST}$ describes the change in solar transmittance due to photo-degradation caused by UV radiation (solarisation). It thus quantifies the effect of photo-degradation on the yield from a collector array in a thermal solar system. It is determined as follows:

$$F_{UV,ST} = \frac{\tau_{sol}^{UV}}{\tau_{sol}^{ref}} \tag{6.1}$$

Where τ_{sol}^{ref} is the solar transmittance of the glass pane before exposure, which has already been introduced in Appendix A. τ_{sol}^{UV} is the solar transmittance after the glass pane has been exposed to UV radiation. The radiation dose must be at least 80 kWh / m^2 for UVA and 3 kWh / m^2 for UVB. These quantities correspond approximately to the UV exposure over a period of 1 year in Central Europe.

Motivation

$F_{UV, ST}$ describes only a change in the solar transmittance τ_{sol}. Thus, the reason for introducing this quantity as a linear factor is analogous to Appendix A (Figure 2).

Appendix D: Glass-certificate as a basis for quality control

The SPF solar glass certificate is used by many manufacturers from PV modules as a basis for quality control. To ensure that this remains the case, SPF recommends the observation of the following points:

The technical specifications should be explicitly note the certificate classification as listed in Section 3.3. It is also worth noting that both glass material and surface coating are covered by the certificate. In the contractual arrangements (e.g. Delivery specifications, quality control agreements, orders etc.) it is worth anchoring the certification number in the duties regarding distribution of certified glass. Module manufacturers are advised to test random glass samples at SPF in the framework of *incoming goods inspection*. It is also recommended to refer only to reference measurements made by SPF. In this way a high quality control is ensured.

These recommendations relate only to the optical properties of the glass. All further aspects (e.g. tolerances, hardness, etc.) are to be considered separately.

Appendix E: Further documents and information

Glass in building; tempered safety glass, concepts, dimensions, processing, specifications, German Standard DIN 1249, Part 12

Glass in building, Basic soda lime silicate glass products - Part 5: Patterned glass, European Standard EN 572-5, November 1994

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