

Application News

No. SCA_100_023

UV-Vis Spectroscopy

Glass Plate Analysis in Accordance with DIN EN 410 Part 1 – single glazing from soda-lime glass with different thickness

Introduction

Glass has become an important material in building. Of course, windows and glass doors are commonplace, but also conservatory, train station roofs or even bigger constructions made predominately from glass with only little supporting structure are possible. The solar characteristics of glazing are an important factor of the energy efficiency of buildings.

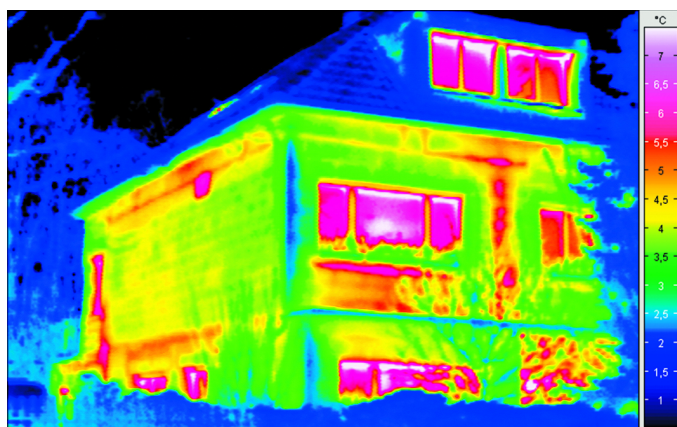


Figure 1: Thermographic image of a residential building.[1]

Several norms and regulations are in place for the measurement and characterization of glass properties to ensure that constructors can judge the suitability of any material for their project.

- DIN EN 410[2] describes the luminous and solar characteristics of glass after measurement of the ultraviolet to near-infrared transmission and reflection spectra. For single glazing from soda-lime glass or similar material, standard values are included, while for multiple glazing and other materials, further measurements are required.
- DIN EN 673[3] describes the thermal transmittance (U_g -value) of glazing, which is the most important factor for the thermal insulation. It is important for multiple glazing.

- DIN EN 12898[4] describes the corrected emissivity (ϵ) of glazing. It is important when the thermal properties of a glazing divert from these of soda-lime glass by special coating or use of polymer material.

This application note will concentrate on the DIN EN 410 and describes how measurements and calculations are carried out for single glazing.

Characteristics defined in DIN EN 410

The most basic characteristics defined in the EN 410 are the transmission through and the reflection on the glazing, as shown in Figure 2.

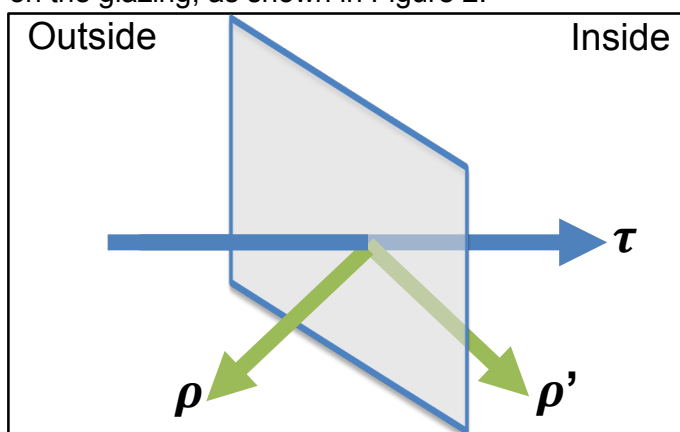


Figure 2: Properties of a single glazing:
 τ = Transmittance, ρ = Reflectance to the outside,
 ρ' = Reflectance to the inside.

There are three items calculated from each spectra:

- The light transmittance τ_v and light reflectance ρ_v , calculated with equation 1 and 2 from the transmission and reflection in the visible range.
- The solar direct transmittance τ_e and reflectance ρ_e , calculated with equation 3 and 4 from the UV – NIR spectra. This item is important for other calculations later on.
- The ultraviolet transmittance τ_{UV} and reflectance ρ_{UV} , calculated with equation 5 and 6 from the UV-part of these spectra.

$$\tau_v = \frac{\sum_{380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda \cdot \tau(\lambda)}{\sum_{380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda} \quad (1) \quad \rho_v = \frac{\sum_{380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda \cdot \rho(\lambda)}{\sum_{380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda} \quad (2)$$

$$\tau_e = \frac{\sum_{300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda \cdot \tau(\lambda)}{\sum_{300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda} \quad (3) \quad \rho_e = \frac{\sum_{300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda \cdot \rho(\lambda)}{\sum_{300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda} \quad (4)$$

$$\tau_{UV} = \frac{\sum_{280\text{ nm}}^{380\text{ nm}} U_\lambda \Delta\lambda \cdot \tau(\lambda)}{\sum_{280\text{ nm}}^{380\text{ nm}} U_\lambda \Delta\lambda} \quad (5) \quad \rho_{UV} = \frac{\sum_{280\text{ nm}}^{380\text{ nm}} U_\lambda \Delta\lambda \cdot \rho(\lambda)}{\sum_{280\text{ nm}}^{380\text{ nm}} U_\lambda \Delta\lambda} \quad (6)$$

Each equation is a fraction of sums. The terms from each denominator ($D_\lambda V(\lambda) \Delta\lambda$, $S_\lambda \Delta\lambda$ and $U_\lambda \Delta\lambda$) are given in tables in DIN EN 410 annex E. Therefore only $\tau(\lambda)$ and $\rho(\lambda)$ remain as unknown values, which are determined by transmission and reflection spectra.

The solar direct transmittance and reflectance from equations 3 and 4 are required for the calculation of solar direct absorptance, secondary internal heat and total solar energy transmittance as shown in Figure 3 and equations 7 to 10.

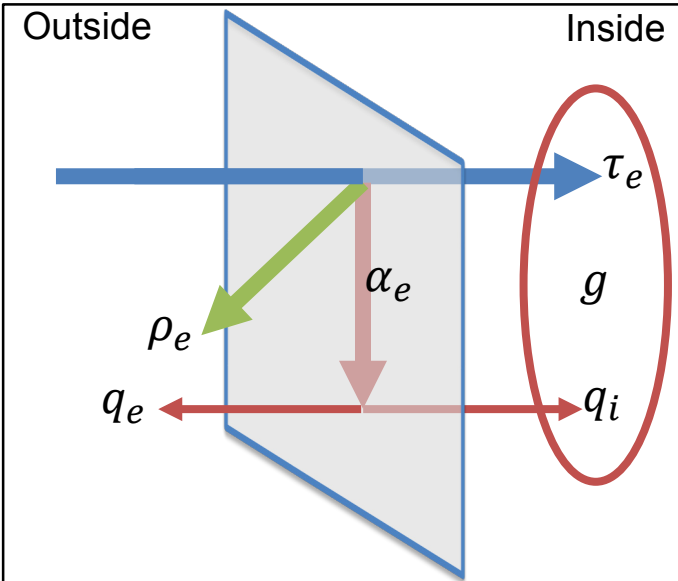


Figure 3: Solar energy is transmitted (τ_e), reflected (ρ_e) or absorbed (α_e). Absorbed energy generates secondary heat (q_e and q_i). The total solar energy transmittance g is the sum of solar direct transmittance τ_e and secondary heat q_i .

The solar direct absorptance α_e is the fraction of light that is absorbed by the glazing:

$$\alpha_e = 100\% - \tau_e - \rho_e \quad (7)$$

This absorption generates heat which is either radiated to the outside (q_e) or to the inside (q_i). Only the secondary internal heat to the inside is of interest here:

$$q_i = \alpha_e \frac{h_i}{h_e + h_i} \quad (8)$$

The heat transfer coefficients h_e and h_i are described in DIN EN 673. For uncoated soda-lime glass and similar materials, standard values are given in both norms:

$$h_i = 7.7 \frac{\text{W}}{\text{m}^2\text{K}}, h_e = 25 \frac{\text{W}}{\text{m}^2\text{K}}$$

With the values from equations 3 and 8, the total solar energy transmittance (g value) is calculated:

$$g = \tau_e + q_i \quad (10)$$

The unit of the g value and all intermediate results depend on the unit of the spectral data. Usually it is given in %, because the spectra are measured as %T and %R. All other units are cancelled out by the rules of fractional arithmetic.

From the g value, the shading coefficient SC is calculated:

$$SC = \frac{g}{0.87} \quad (11)$$

Locally defined shading coefficients exist which differ in the denominator, but are not specified by the DIN norm. A common denominator is 0.8.

The important U_g value is defined in DIN EN 673:

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{h_i} + \frac{1}{h_t} \quad (12)$$

The total heat transmission coefficient h_t combines several properties of the glazing panes and gas interlayers. For single glazing and with the standard values given for soda-lime glass, the calculation of U_g in $\frac{\text{W}}{\text{m}^2\text{K}}$ is simply a function of the thickness x in m:

$$\frac{1}{U_g} = \frac{\text{m}^2\text{K}}{25\text{ W}} + \frac{\text{m}^2\text{K}}{7.7\text{ W}} + x \cdot 1 \frac{\text{m}\cdot\text{K}}{\text{W}} \quad (13)$$

Another important characteristic for the people who will dwell in the finished buildings is the general color rendering index R_a , which describes how colors of items behind the glazing are distorted. It is calculated from the transmission spectrum of the glazing, the spectral distribution of the standard illuminant D65 and reflection spectra of color standards. A value of 100 indicates perfect color trueness.

▪ Samples and Measurement Method

Six soda-lime float glass samples with different thickness were measured. They are shown in Figure 4.

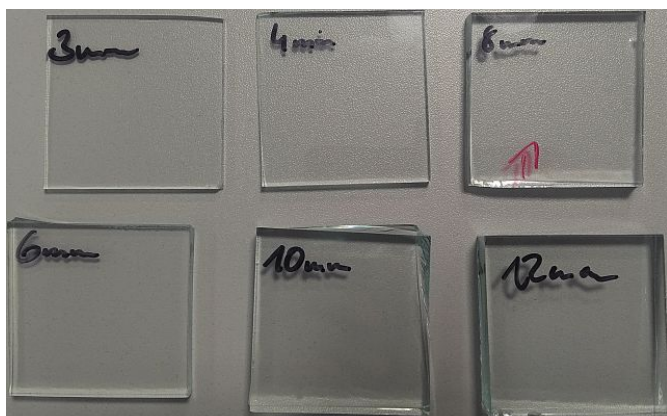


Figure 4: Investigated glass samples

From equations 1 to 6 and the wavelength values given in the tables from DIN EN 410 annex E it is clear that the measurement range must be 2500 – 280 nm at 5 nm data interval. The UV-3600plus with the ISR-1503F integrating sphere fulfills all further technical requirements. To measure with a good signal / noise ratio, the scan speed was set to “slow” and the slit width to 20 nm.

The total transmittance and total reflectance at 8° incident angle were measured with the measurement configuration shown in Figure 5.

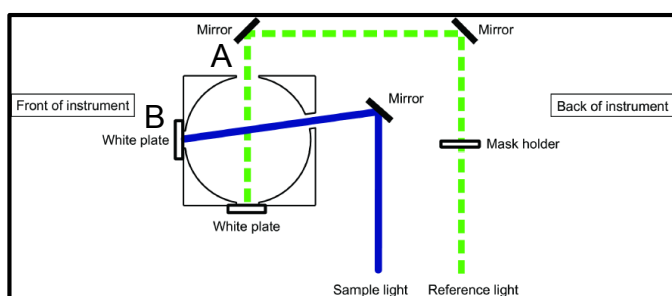


Figure 5: Measurement configuration of the ISR-1503.

For the transmittance measurements, the sample was placed at port A and signal and reference beam were switched. For the 8° reflectance measurements, the white plate at port B was switched with the sample after baseline measurement. The 10 and 12 mm plates were supported by the sample base assy. The transmission spectra are shown in Figure 6, the reflection spectra are shown in Figure 7.

▪ Spectra

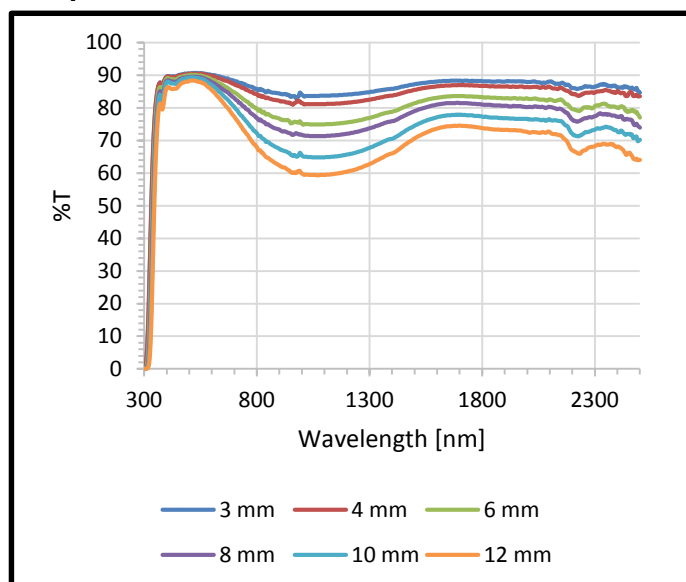


Figure 6: Transmission spectra of all samples.

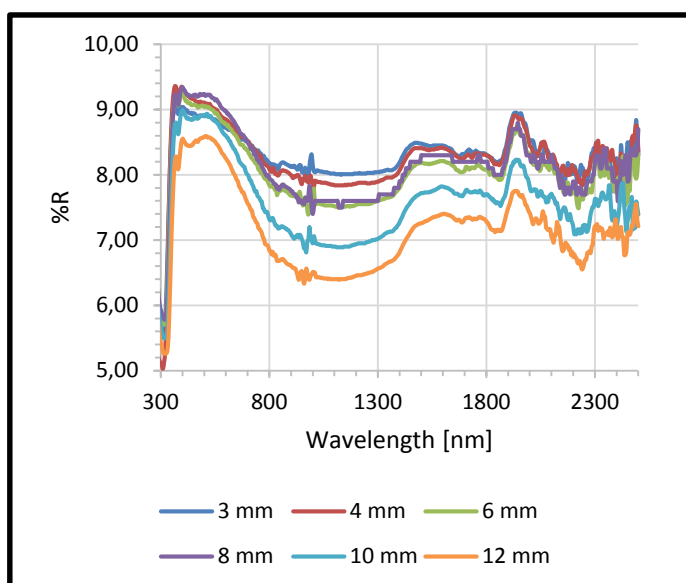


Figure 7: Reflection spectra of all samples.

As seen from the spectra, a portion of the near infrared light is absorbed by the glass, which leads to the lower transmittance and reflectance values in the region of 800 – 1300 nm. Because these samples were not coated on any side, the spectra of both sides are the same.

For the evaluation, an excel-document was created with the relevant tables and formula inside. The document was prepared such, that the excel export-function of LabSolutions UV-Vis copies the spectrum into the correct columns for all calculations.

▪ Evaluation Results

The results for all samples are given in Table 1.

x mm	3	4	6	8	10	12
$U_g \frac{W}{m^2K}$	5.78	5.75	5.69	5.62	5.56	5.50
g %	88.03	87.17	84.94	83.42	81.21	78.93
τ_v %	90.36	90.11	89.43	88.76	88.18	86.91
ρ_v %	8.83	8.97	8.91	9.10	8.76	8.42
τ_e %	86.92	85.79	82.79	80.80	77.74	74.59
ρ_e %	8.51	8.51	8.34	8.44	7.96	7.54
α_e %	4.57	5.70	8.87	10.75	14.30	17.88
q_i %	1.11	1.38	2.15	2.61	3.47	4.34
τ_{UV} %	70.64	69.93	64.78	61.07	57.40	53.47
ρ_{UV} %	8.15	8.19	8.07	7.99	7.50	6.99
SC %	101.19	100.20	97.64	95.88	93.35	90.72
R_a	98.71	98.52	97.99	97.66	97.03	96.45

Table 1: EN-410 evaluation results for all samples.

From these results it is visible, that only absorbance and secondary heat transmission are growing with larger thicknesses. All other values are declining. Because of the higher absorption and therefore the higher secondary heat transmission, the U_g value is only decreasing by a small degree even at a sample thickness four times the value of the thinnest sample. Therefore, using thermal protection coating or double glazing with the appropriate gas filling is much more efficient for heat insulation purposes. All results match the specification of the sample producer.

• Recalculation for other Thickness

Annex A of DIN EN 410 describes the procedure to calculate values for glazing made from the same base material but with different thickness or coloration as the measured sample.

Basically, the transmission and reflection spectra are converted with the knowledge of the refractive index n . The important formulae in the procedure are given in equations 14 and 15:

$$\rho_s(\lambda) = \left[\frac{n(\lambda)-1}{n(\lambda)+1} \right]^2 \quad (14) \quad \tau_{i,y}(\lambda) = [\tau_{i,x}]^{\frac{y}{x}} \quad (15)$$

Equation 14 describes the reflectance at the air-glass interface, equation 15 describes the internal transmittance, where $\tau_{i,x}$ is calculated from the measured transmission spectrum.

The equations for calculating converted spectra from these values are not cited here because of their complexity. The important point for the further discussion is, that the internal transmittance is calculated with an exponent $\frac{y}{x}$, where x is the true thickness of the measured sample and y is the thickness to which the results are converted. It is not a linear correlation between thickness and transmittance or reflectance values.

Converted spectra and the resulting calculation items were calculated by a visual basic program and imported into excel. The results in Table 2 are calculated from the measured spectra of the 3 mm sample, while the results in Table 3 are calculated from the measured spectra of the 12 mm sample. U_g is omitted from the table, since the spectral data has no influence on this value.

y mm	4	6	8	10	12
g %	87.14	85.13	83.24	81.45	79.74
τ_v %	89.91	89.03	88.15	87.28	86.43
ρ_v %	8.13	8.06	7.99	7.92	7.85
τ_e %	85.48	82.77	80.21	77.79	75.48
ρ_e %	7.69	7.49	7.31	7.14	6.99
α_e %	6.83	9.74	12.48	15.07	17.53
q_i %	1.66	2.37	3.03	3.66	4.26
τ_{UV} %	66.72	60.60	55.88	52.03	48.77
ρ_{UV} %	7.14	6.81	6.57	6.37	6.21
SC %	100.16	97.85	95.68	93.62	91.66
R_a	95.51	93.67	91.86	90.09	88.35

Table 2: Values calculated from the 3 mm sample.

y mm	3	4	6	8	10
g %	88.04	86.91	84.76	82.76	80.87
τ_v %	90.48	90.08	89.27	88.48	87.69
ρ_v %	8.18	8.15	8.08	8.01	7.95
τ_e %	86.70	85.16	82.27	79.56	77.00
ρ_e %	7.78	7.66	7.46	7.27	7.10
α_e %	5.52	7.17	10.28	13.18	15.90
q_i %	1.34	1.74	2.50	3.20	3.86
τ_{UV} %	74.01	70.36	64.61	60.16	56.54
ρ_{UV} %	7.54	7.33	7.03	6.80	6.61
SC %	101.20	99.89	97.43	95.12	92.95
R_a	98.58	98.35	97.87	97.40	96.92

Table 3: Values calculated from the 12 mm sample.

It is visible that the values calculated from the converted spectra divert from the values calculated from measured spectra. In most cases the error is lower when x is larger than y (Table 3).

In this experiment there is no clear correlation between error and difference between x and y , but it is visible, that τ_{UV} and ρ_{UV} show a bigger deviation than the values calculated with a broader spectral range. For example, g and R_a calculated from the spectra of 12 mm sample show nearly the same values as calculated from each true thickness, even though these values are considerably off for the conversion from 3 mm to 12 mm with around 10 % relative error.

Figure 11 shows the measured transmission spectra of the 3 mm and 12 mm sample and the converted spectra from 12 mm to 3 mm and 3 mm to 12 mm.

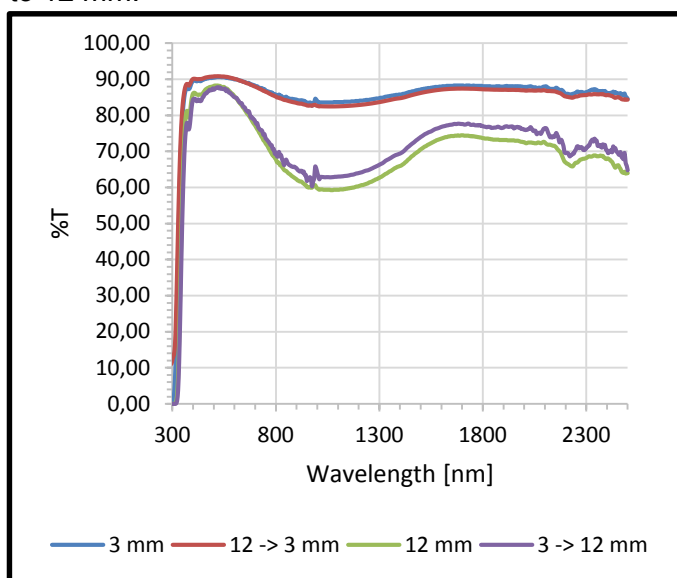


Figure 11: Measured and converted transmission spectra.

There is a visible difference between measured and converted spectrum, especially for 12 mm sample thickness. The discrepancy is largest in the UV spectral range, as expected from Tables 2 and 3. At some wavelengths there is a discrepancy of around 10 %T. But also in the near-infrared range the calculated transmittance is below the measured transmittance. The same is observed for the reflection spectra. Therefore, the error is accumulated in the absorbance, which is calculated from transmittance and reflectance by equation 7.

Figure 12 shows the same spectra in the visible spectral range.

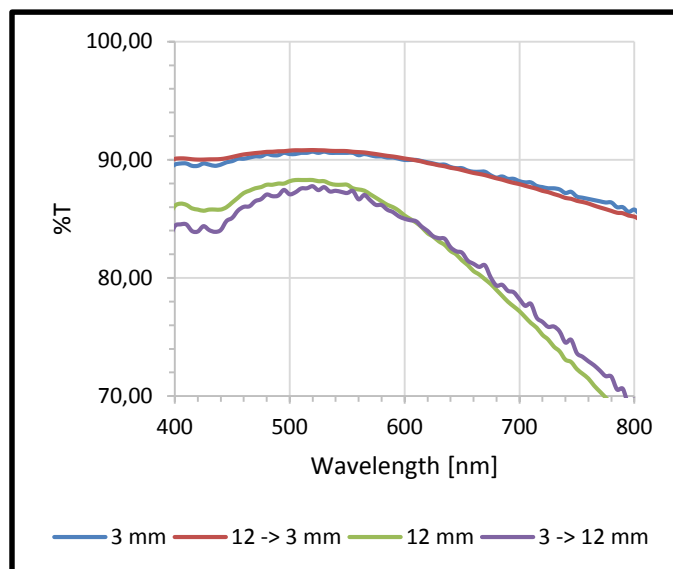


Figure 12: Zoom into the visible spectra range of Figure 11.

In the visible spectral range, both the measured and converted spectrum of the 3 mm sample are nearly the same. There is a small deviation between the spectra of the 12 mm sample, especially at the blue edge of the visible range. But even this deviation is below 2 %T.

These results may vary for samples with a different refractive index or coating. But for the uncoated soda-lime float glass samples investigated in this application there are several rules of thumb that can be derived:

- Converting the spectra to that of a sample with different thickness yields spectra that divert at some points from the measured spectra of these samples.
- It's better to recalculate values for a thin sample from the measurement of a thick sample.
- The conversion is less reliable in the UV range and most reliable in the visible range.
- There is no apparent connection between thickness difference and error, e.g. a conversion from 12mm to 3 mm yields nearly the same deviation as a conversion from 12 mm to 10 mm.

Comparison to JIS R3106

A similar norm for glass in building is the Japanese JIS R3106[5], which defines most of the properties in the same way as Din EN 410. However, the definition of solar (in some publications also translated as “daylight”) transmittance uses a different weighting factor instead of $S_{\lambda}\Delta\lambda$:

$$\tau_e = \frac{\sum_{\lambda} E_{\lambda} \cdot \Delta\lambda \cdot \tau(\lambda)}{\sum_{\lambda} E_{\lambda} \cdot \Delta\lambda} \quad (16) \quad \rho_e = \frac{\sum_{\lambda} E_{\lambda} \cdot \Delta\lambda \cdot \rho(\lambda)}{\sum_{\lambda} E_{\lambda} \cdot \Delta\lambda} \quad (17)$$

The obligatory limits of the sum for JIS compliant analysis are 300 – 2100 nm, but calculating it with a range of 300 -2500 nm is recommended if this measurement range is technically possible. $E_{\lambda} \cdot \Delta\lambda$ is given in a table in JIS R3106 for the range of 300 -2500 nm in 5 nm steps and though both S_{λ} and E_{λ} describe the distribution of solar energy, the values are not exact same because of different rounding and wavelength interval.

Table 4 shows values for τ_e and ρ_e calculated with the definition from JIS R3106 for a measurement range of 300 -2500 nm and the relative deviation to the same values calculated from the same spectra with the definition from DIN EN 410.

Thickness mm	3	4	6	8	10	12
τ_e (JIS) %	87.09	85.79	82.49	80.35	76.91	73.50
ρ_e (JIS) %	8.45	8.43	8.24	8.34	7.84	7.41
τ_e (DIN) %	86.92	85.79	82.79	80.80	77.74	74.59
ρ_e (DIN) %	8.51	8.51	8.34	8.44	7.96	7.54
$\delta\tau_e$ %	0.20	0.00	0.36	0.56	1.06	1.46
$\delta\rho_e$ %	0.65	0.96	1.20	1.23	1.54	1.71

Table 4: Comparison of solar transmittance and reflectance calculated with the definition from JIS R3106 and DIN EN 410.

The relative deviation between JIS and DIN values were calculated with equation 18:

$$\delta = \frac{|\text{DIN} - \text{JIS}|}{\text{DIN}} \cdot 100\% \quad (18)$$

Only a small deviation is observed. As seen in Table 4, it becomes larger with a higher thickness. The relative deviation is larger for the reflectance values, since the absolute values of ρ_e are only around a tenth of the τ_e value of the same sample.

Daylight Transmittance Software

The calculation of solar transmittance, reflectance and other properties defined in JIS R3106 are implemented in the Shimadzu Daylight Transmittance software. Spectra are either measured by controlling the UV-3600plus with the software or imported from UVProbe.

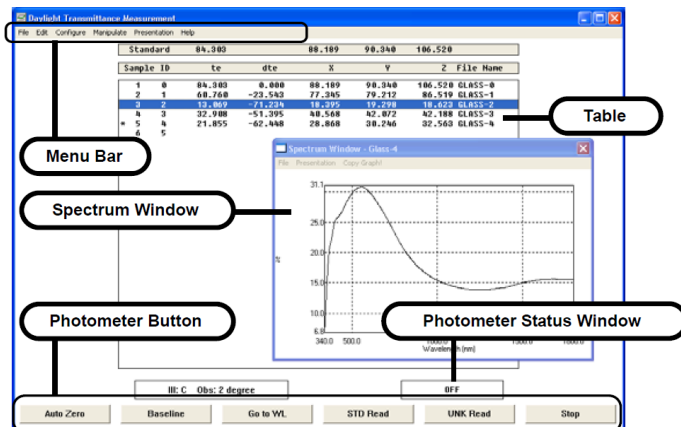


Figure 13: Layout of the Daylight Transmittance Measurement Software main window.

By loading the table for $S_{\lambda}\Delta\lambda$ as user-defined weighting factor and adjusting the measurement range to 300 – 2500 nm and sampling pitch to 10 nm, the calculations of the daylight transmission software can be adapted to the DIN EN 410.

Solar, visible and UV transmittance, reflectance and absorbance and the glass color of can be calculated this way and printed in a report. Thickness- and Hitch standard correction are also implemented. The calculation of U_g and g value are not possible with this software.

▪ Conclusion

The formulae from the main part of DIN EN 410 were converted into an excel sheet and six samples of soda-lime float glass of different thickness were evaluated. The results calculated from transmission and reflection spectra measured with the UV-3600 plus + ISR-1503F matched the specifications of the sample producer. It is the ideal system for this kind of analysis.

The impact of the sample thickness on the thermal transmission is only small. Therefore, multiple glazing and heat protection coatings are important for the best thermal efficiency. The calculation of the U_g value for multiple glazing is described in DIN EN 673, which will be the focus of another application note. Standard values for the emissivity ε and secondary heat transfer coefficients h_i and h_e of soda-lime glass were used here.

The conversion of transmittance and reflectance for a different sample thickness as described in annex A yielded slightly different values compared to the measurement of a sample with that thickness. The error made by this conversion was only small for conversion from high to small thickness, but large in the opposite direction.

A comparison to the similar Japanese norm JIS R3016 shows, that a small difference for τ_e , ρ_e and values derived from these results from a slightly different weighting factor for the solar energy distribution. Since most properties are defined in the same way in both norms, the calculations are easily adjusted by changing this scaling factor.

While common spreadsheet software is sufficient for the calculations described in this application note, the calculations required to describe multiple glazing or advanced characteristics from the annexes of DIN EN 410 are more complex and require the use of macro programming.

▪ Analytical Conditions

Instrument: UV-3600plus + ISR-1503F

Range: 2500 – 280 nm

Data point interval: 5 nm

Speed: Slow

Slit width: 20 nm

Light source switch wavelength: 290 nm

Detector switch wavelength : 1650, 1000

Grating switch wavelength : 850 nm

▪ Literature

- [1] Thermographic image: Sakret GmbH
- [2] DIN EN 410:2011, Glass in building – Determination of luminous and solar characteristics of glazing (EN 410:2011)
- [3] DIN EN 673:2011, Glass in building – Determination of thermal transmittance (U value) – Calculation method (EN 673:2011)
- [4] DIN EN 12898, Glass in building – Determination of the emissivity (prEN 12898:2017)
- [5] JIS R 3016:1998, Testing method on transmittance, reflectance and emittance of flat glasses and evaluation of solar heat gain coefficient. (R 3106:1998)



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