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Road vehicles — Safety glazing materials — Method for the determination of solar transmittance

Véhicules routiers — Vitrages de sécurité — Méthode de détermination du facteur de transmission du rayonnement solaire

Reference number
ISO 13837:2008(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13837 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 11, *Safety glazing materials*.

Introduction

A review of existing standards and industry specifications and procedures reveals a lack of agreement with respect to the basis for defining and measuring the ultraviolet (UV), visible (VIS) and infrared (IR) transmittance properties of glazing materials. To avoid the continued preparation and promulgation of conflicting standards by individual entities, there is an interest in the automotive and glazing industries to harmonize on a worldwide basis the test procedures and protocol used to assess the solar transmittance properties of glazing materials.

INTERNATIONAL STANDARD **ISO 13837:2008(E)**

Road vehicles — Safety glazing materials — Method for the determination of solar transmittance

1 Scope

This International Standard specifies test methods to determine the direct and total solar transmittance of safety glazing materials for road vehicles. Two computational conventions (denoted convention “A” and convention “B”) are included, both of which are consistent with current international needs and practices.

This International Standard applies to monolithic or laminated, clear or tinted samples of safety glazing materials. Essentially flat sections of glazing parts can be used in this test, as well as flat samples of the same materials.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9845-1:1992, *Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5*

CIE 85:1989, *Solar spectral irradiance*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
standardize
adjust an instrument output to correspond to a previously established calibration, using one or more homogeneous specimens or reference materials

3.1.2
transmittance
ratio of transmitted flux to incident flux, under specified geometric and spectral conditions

3.1.3
air mass (ratio)
ratio of the mass of atmosphere in the actual observer-sun path to the mass that would exist if the observer were at sea level, at standard barometric pressure, and the sun were directly overhead

3.1.4
solar indirect transmittance
fraction of the solar radiation absorbed by the safety glazing materials and reradiated to the interior

NOTE The fraction is the secondary heat transfer factor as defined in ISO 9050.

3.2 Symbols

Symbol	Definition
T_{UV}	ultraviolet (UV) direct solar energy transmitted through a glazing
T_{DS}	direct solar (DS) energy transmitted through a glazing
q_{i}	secondary heat transfer to the inside of a glazing
T_{TS}	total solar energy ($T_{\mathrm{DS}} + q_{\mathrm{i}}$) transmitted to the inside of a glazing
λ	wavelength, in nm
$\Delta\lambda$	uniform λ interval
E_λ	solar energy within a $\Delta\lambda$
E'_λ	E_λ in trapezoidal form $\left(E_1/2, E_2 \cdots E_{n-1}, E_n/2\right)$
$E'_\lambda(\mathrm{n})$	normalized $\left[E'_\lambda \big/ \sum\left(E'_{300} \cdots E'_{2\,500}\right)\right]$
NOTE Additional definitions are specific to the computational convention chosen and are defined with the appropriate convention.	

4 Computational conventions

4.1 Convention “A”

Convention “A” defines the UV range from 300 nm to 400 nm for air mass 1,5 global. This definition is consistent with ISO 3917 and CIE 20:1972, and the best average solar flux specified in ISO 9845-1:1992, Table 1, Column 5.

4.2 Convention “B”

Convention “B” defines the UV range from 300 nm to 380 nm for air mass 1,0 global. This definition is consistent with ISO 9050 and EN 410, and the maximum possible solar flux found in CIE 85:1989, Table 4.

NOTE This International Standard defines each convention and computations are based on established methods (see Annex A). The tables incorporated in each computational convention simplify the calculations, leading to high accuracy with minimum effort. Since the results will differ depending on which convention is chosen, it is essential that the convention chosen be clearly identified when results are reported.

5 Apparatus

This method requires spectral transmittance data to be obtained from samples of glazing materials using a scanning spectrophotometer. This instrument, preferably equipped with an integrating sphere, shall be capable of measuring transmittance over that part of the electromagnetic spectrum in which the sun's energy is transmitted to the earth's surface.

6 Procedure

6.1 Sample preparation

Cut out (if necessary) and clean the flattest area of curved test specimens with distilled water and reagent grade methanol, or use an alternate procedure appropriate to the material, if necessary. Cut and clean flat samples similarly.

6.2 Measurement

Standardize the spectrophotometer in accordance with the manufacturer's instructions. Place a clean sample normal to the measuring beam in the transmittance sample position. Note its film side and curvature orientation, if applicable. Record the sample spectral data in accordance with the instrument manufacturer's recommendation.

6.3 Calculation by computational convention “A”

6.3.1 Definitions specific to computational convention “A”

6.3.1.1 Solar UV transmittance [$T_{\mathrm{UV}}(400)$]

See Table 1. The transmittance is weighted interval by interval and derived from ISO 9845-1:1992, Table 1, Column 5 (with air mass 1,5 global) from 300 nm to 400 nm, at intervals of 5 nm.

6.3.1.2 Solar direct transmittance [$T_{\mathrm{DS}}(1,5)$]

See Table 2. The transmittance is weighted interval by interval and derived from ISO 9845-1:1992, Table 1, Column 5 (with air mass 1,5 global) from 300 nm to 2 500 nm, at intervals of 5 nm, 10 nm and 50 nm.

6.3.1.3 Solar total transmittance [$T_{\mathrm{TS}}(1,5)$]

The transmittance is the sum of the direct transmittance as defined in 6.3.1.2 and the indirect transmittance as defined in 3.1.4.

6.3.2 Computation method

6.3.2.1 Compute direct solar transmittance by integration using the solar weight data in Tables 1 and 2. Transmission (T) for each solar range (λ_1 to λ_n) is determined by the following functions:

$$\%T_{\mathrm{UV}}(400) = \sum_{300}^{400} \%T_\lambda \times E'_\lambda(\mathrm{n}) \left\{\text{Table 1}\right\} \tag{1}$$

$$\%T_{\mathrm{DS}}(1{,}5) = \sum_{300}^{2\,500} \%T_\lambda \times E'_\lambda(\mathrm{n}) \left\{\text{Table 2}\right\} \tag{2}$$

where $E'_\lambda(\mathrm{n})$ is the normalized solar energy computed trapezoidally in wavelength interval ($\Delta\lambda$).

6.3.2.2 Transmittance shall be measured to at least 2 300 nm. If it is not possible to measure transmittance to the recommended 2 500 nm, the last value shall be multiplied by the remaining $E'_\lambda(\mathrm{n})$ weight values in Table 2.

6.4 Calculation by computational convention “B”

6.4.1 Definitions specific to computational convention “B”

6.4.1.1 Solar UV transmittance [$T_{\mathrm{UV}}(380)$]

See Table 3. The transmittance is weighted interval by interval and derived from CIE 85:1989, Table 4 (with air mass 1,0 global) from 300 nm to 380 nm, at intervals of 5 nm.

6.4.1.2 Solar direct transmittance [$T_{\mathrm{DS}}(1,0)$]

See Table 4. The transmittance is weighted interval by interval and derived from CIE 85:1989, Table 4 (with air mass 1,0 global) from 300 nm to 2 500 nm, at intervals of 5 nm, 10 nm and 50 nm.

6.4.1.3 Solar total transmittance [$T_{\mathrm{TS}}(1,0)$]

The transmittance is the sum of the direct transmittance as defined in 6.4.1.2 and the indirect transmittance as defined in 3.1.4.

6.4.2 Computation method

6.4.2.1 Compute direct solar transmittance by integration using the solar weight data in Tables 3 and 4. Transmission (T) for each solar range (λ_1 to λ_n) is determined by the following functions:

$$\%T_{\mathrm{UV}}(380) = \sum_{300}^{380} \%T_{\lambda} \times E'_{\lambda}(\mathrm{n}) \left\{\text{Table 3}\right\} \tag{3}$$

$$\%T_{\mathrm{DS}}(1{,}0) = \sum_{300}^{2\,500} \%T_{\lambda} \times E'_{\lambda}(\mathrm{n}) \left\{\text{Table 4}\right\} \tag{4}$$

where $E'_{\lambda}(\mathrm{n})$ is the normalized solar energy computed trapezoidally in wavelength interval ($\Delta\lambda$).

6.4.2.2 Transmittance shall be measured to at least 2 300 nm. If it is not possible to measure transmittance to the recommended 2 500 nm, the last value shall be multiplied by the remaining $E'_{\lambda}(\mathrm{n})$ weight values in Table 4.

6.5 Total solar transmittance

This International Standard defines the determination of the direct solar transmittance of safety glazing materials computed by either of two computational conventions (“A” or “B”). If it is necessary to compute total solar transmittance, use the equations in Annex B and the direct solar transmittance results from 6.3 or 6.4, whichever is appropriate.

7 Expression of results

Record thickness, type, construction, and curvature orientation if applicable, of the specimen; the instrument and computational convention used (“A” or “B”); and the specimen's total UV and direct solar transmittance, and, if necessary, the specimen's total solar properties rounded to 0,1 %, in accordance with the rounding convention in Reference [6].

Table 1 — Solar global radiation through air mass 1,5 and partitioned into uniform spectral trapezoidal intervals

λ nm	E'_{λ}(n)
300	0,000 000
305	0,001 045
310	0,004 634
315	0,011 800
320	0,019 807
325	0,027 019
330	0,043 271
335	0,042 703
340	0,047 644
345	0,048 041
350	0,052 948
355	0,054 947
360	0,056 946
365	0,064 930
370	0,072 925
375	0,075 901
380	0,077 991
385	0,075 890
390	0,073 777
395	0,092 335
400	0,055 446
$\%T_{\mathrm{UV}}(400) = \sum_{300}^{400} \%T_{\lambda} \times E'_{\lambda}(\mathrm{n})$	
NOTE Modified wavelength intervals in ISO 9845-1:1992, Table 1, Column 5.	

Table 2 — Solar global radiation through air mass 1,5 and partitioned into uniform spectral trapezoidal intervals

λ, nm	E'_{λ}(n)	λ, nm	E'_{λ}(n)	λ, nm	E'_{λ}(n)
300	0,000 000	410	0,011 712	850	0,049 016
305	0,000 048	420	0,011 973	900	0,039 872
310	0,000 214	430	0,010 839	950	0,016 652
315	0,000 545	440	0,013 166	1 000	0,037 501
320	0,000 915	450	0,015 431	1 050	0,034 127
325	0,001 248	460	0,016 175	1 100	0,020 859
330	0,001 999	470	0,015 988	1 150	0,012 512
335	0,001 973	480	0,016 466	1 200	0,021 415
340	0,002 201	490	0,015 565	1 250	0,023 934
345	0,002 219	500	0,015 661	1 300	0,018 651
350	0,002 446	510	0,016 043	1 350	0,001 642
355	0,002 538	520	0,015 016	1 400	0,000 136
360	0,002 630	530	0,015 900	1 450	0,003 746
365	0,002 999	540	0,015 681	1 500	0,009 548
370	0,003 369	550	0,015 790	1 550	0,013 934
375	0,003 506	560	0,015 539	1 600	0,012 093
380	0,003 603	570	0,015 184	1 650	0,011 636
385	0,003 506	580	0,014 646	1 700	0,010 440
390	0,003 408	590	0,014 112	1 750	0,008 111
395	0,004 265	600	0,014 568	1 800	0,001 553
400	0,007 684	610	0,015 020	1 850	0,000 231
		620	0,014 760	1 900	0,000 000
		630	0,014 502	1 950	0,000 682
		640	0,014 525	2 000	0,001 878
		650	0,014 547	2 050	0,004 040
		660	0,014 333	2 100	0,004 507
		670	0,014 079	2 150	0,004 134
		680	0,012 749	2 200	0,003 604
		690	0,011 426	2 250	0,003 583
		700	0,012 375	2 300	0,003 468
		710	0,013 315	2 350	0,003 242
		720	0,010 313	2 400	0,002 251
		730	0,011 094	2 450	0,001 070
		740	0,012 248	2 500	0,000 433
		750	0,012 119		
		760	0,009 197		
		770	0,010 675		
		780	0,011 438		
		790	0,011 201		
		800	0,032 812		

$$\%T_{\mathrm{DS}}(1,5) = \sum_{300}^{2\,500} \%T_{\lambda} \times E'_{\lambda}(\mathrm{n})$$

NOTE Modified wavelength intervals in ISO 9845-1:1992, Table 1, Column 5.

Table 3 — Solar global radiation through air mass 1,0 and partitioned into uniform spectral trapezoidal intervals

λ nm	E'_λ(n)
300	0,000 000
305	0,005 026
310	0,014 169
315	0,027 622
320	0,040 070
325	0,049 865
330	0,070 579
335	0,067 061
340	0,072 643
345	0,071 541
350	0,077 316
355	0,078 834
360	0,080 353
365	0,090 180
370	0,100 040
375	0,102 521
380	0,052 180

$$\%T_{\mathrm{UV}}(380) = \sum_{300}^{380} \%T_\lambda \times E'_\lambda(\mathrm{n})$$

NOTE Modified wavelength intervals in CIE 85:1989, Table 4.

Table 4 — Solar global radiation through air mass 1,0 and partitioned into uniform spectral trapezoidal intervals

λ, nm	E'_λ(n)	λ, nm	E'_λ(n)	λ, nm	E'_λ(n)
300	0,000 000	410	0,013 072	850	0,045 890
305	0.000 215	420	0,013 715	900	0,042 634
310	0,000 606	430	0,012 238	950	0,018 065
315	0,001 181	440	0,014 670	1 000	0,033 953
320	0,001 714	450	0,016 974	1 050	0,030 606
325	0,002 133	460	0,017 279	1 100	0,020 713
330	0,003 018	470	0,016 900	1 150	0,011 434
335	0,002 868	480	0,017 266	1 200	0,020 192
340	0,003 107	490	0,016 186	1 250	0,021 564
345	0,003 060	500	0,016 186	1 300	0,017 439
350	0,003 307	510	0,016 483	1 350	0,002 378
355	0,003 372	520	0,015 351	1 400	0,000 279
360	0,003 437	530	0,016 203	1 450	0,004 445
365	0,003 857	540	0,015 918	1 500	0,009 458
370	0,004 278	550	0,015 982	1 550	0,012 435
375	0,004 385	560	0,015 581	1 600	0,010 940
380	0,004 463	570	0,015 133	1 650	0,010 588
385	0,004 438	580	0,014 649	1 700	0,009 403
390	0,004 412	590	0,014 168	1 750	0,007 222
395	0,005 246	600	0,014 414	1 800	0,001 912
400	0,009 117	610	0,014 659	1 850	0,000 348
		620	0,014 379	1 900	0,000 000
		630	0,014 099	1 950	0,000 892
		640	0,013 966	2 000	0,002 044
		650	0,013 833	2 050	0,003 782
		660	0,013 624	2 100	0,004 029
		670	0,013 363	2 150	0,003 659
		680	0,012 234	2 200	0,003 224
		690	0,011 111	2 250	0,003 151
		700	0,011 826	2 300	0,003 028
		710	0,012 536	2 350	0,002 858
		720	0,010 445	2 400	0,002 131
		730	0,010 972	2 450	0,001 116
		740	0,011 707	2 500	0,000 000
		750	0,011 484		
		760	0,009 045		
		770	0,010 192		
		780	0,010 732		
		790	0,010 526		
		800	0,030 876		

$$\%T_{\mathrm{DS}}(1,0) = \sum_{300}^{2\,500} \%T_\lambda \times E'_\lambda(\mathrm{n})$$

NOTE Modified wavelength intervals in CIE 85:1989, Table 4.

Annex A
(informative)

Derivation of solar weight tables in this International Standard

A.1 The solar weight tables in this International Standard were derived as follows:

a) Tables 1 and 2 were derived from ISO 9845-1:1992 (air mass 1,5 global);

b) Tables 3 and 4 were derived from CIE 85:1989 (air mass 1,0 global).

A.2 The list below explains each column of the two spreadsheets in Tables A.1 and A.2, which show derivations of Tables 1 to 4.

- **Column (1)**: Ultraviolet and visible wavelengths, in micrometers, from 295 nm to 790 nm.
- **Column (2)**: Ultraviolet and visible energy levels at corresponding wavelengths from ISO 9845-1:1992 or from CIE 85:1989. $E_{\lambda 1}$ values at missing wavelengths from either publication were determined by picking point values from a wavelength versus energy spline fit curve.
- **Column (3)**: Column (2) calculated in trapezoidal form (E'_{λ}), in accordance with the following technique:

$$E'_{\lambda} = 0{,}5 \times \left\{ E_{300/2}, E_{305}, E_{310}, \cdots E_{395}, E_{400/2} \right\}; \qquad \Delta\lambda = 5 \text{ nm};$$

$$E'_{\lambda} = 1{,}0 \times \left\{ E_{400/2}, E_{410}, E_{420}, \cdots E_{790}, \qquad \right\}; \qquad \Delta\lambda = 10 \text{ nm}.$$

- **Column (4)**: Column (3) normalized (portion of 300 nm to 2 500 nm normalization):

$$E'_{\lambda}(\text{n}) = E'_{\lambda} / \sum \left(E'_{300} \cdots E'_{2\,500} \right).$$

- **Column (5)**: Infrared and ultraviolet wavelengths, in micrometers:
  - for infrared, from 800 nm to 2 500 nm, and
  - for ultraviolet, from 295 nm to 400 nm (Table A.1) or from 295 nm to 380 nm (Table A.2).
- **Column (6)**: Infrared and ultraviolet energy levels at corresponding wavelengths from ISO 9845-1:1992 or from CIE 85:1989. $E_{\lambda 1}$ values at missing wavelengths from either publication were determined by picking point values from a wavelength versus energy spline fit curve.
- **Column (7)**: Column (6) calculated in trapezoidal form (E'_{λ}), in accordance with the following technique:

$$E'_{\lambda} = 1{,}0 \times \left\{ E_{800/2} \right\} + 5{,}0 \times \left\{ E_{800/2}, E_{850}, E_{900}, \cdots E_{2\,450}, E_{2\,500/2} \right\}; \qquad \Delta\lambda = 50 \text{ nm};$$

$$E'_{\lambda} = 0{,}5 \times \left\{ E_{300/2}, E_{305}, E_{310}, \cdots E_{395}, E_{400/2} \right\}; \qquad \Delta\lambda = 5 \text{ nm} \qquad \text{(see Table A.1)};$$

$$E'_{\lambda} = 0{,}5 \times \left\{ E_{300/2}, E_{305}, E_{310}, \cdots E_{375}, E_{380/2} \right\}; \qquad \Delta\lambda = 5 \text{ nm} \qquad \text{(see Table A.2)}.$$

- **Column (8)**: Column (7) normalized [portion of 300 nm to 2 500 nm normalization (DS), or UV regions normalized from 300 nm to 400 nm or normalized from 300 nm to 380 nm]:

$$E'_{\lambda}(\text{n}) = E'_{\lambda} \Big/ \sum \left(E'_{300} \cdots E'_{2\,500} \right).$$

A.3 Solar integration process The equations below are overview examples for Table A.1 [300 nm to 400 nm (UV) and 300 nm to 2 500 nm (DS)]:

$$\%T\left(\lambda_{300} \text{ to } \lambda_{400}\right) = \frac{\sum\limits_{\lambda=300}^{395} (\%T_{\lambda} \times E_{\lambda}) + \frac{\%T_{400} \times E_{400}}{2}}{\sum\limits_{\lambda=300}^{395} (E_{\lambda}) + \frac{E_{400}}{2}}$$

$$\%T\left(\lambda_{300} \text{ to } \lambda_{2\,500}\right) = \left(\frac{0{,}5 \sum\limits_{\lambda=300}^{400} (\%T_{\lambda} \times E_{\lambda}) + \sum\limits_{\lambda=410}^{800} (\%T_{\lambda} \times E_{\lambda}) + 5 \sum\limits_{\lambda=850}^{2\,500} (\%T_{\lambda} \times E_{\lambda})}{0{,}5 \sum\limits_{\lambda=300}^{400} E_{\lambda} + \sum\limits_{\lambda=410}^{800} E_{\lambda} + 5 \sum\limits_{\lambda=850}^{2\,500} E_{\lambda}} \right)$$

A.4 The graph in Figure A.1 illustrates normalized energy within specified wavelength intervals versus wavelength. The graph in Figure A.2 illustrates hemispherical solar spectral irradiance.

Table A.1 — Derivation table of $\Delta\lambda$ versus $E'_\lambda(\text{n})$ for global air mass 1,5

Light	(1)	(2)	(3)	(4)
	λ, nm [a]	E_λ [b]	E'_λ [c]	$E'_\lambda(\text{n})$ [d]
Ultraviolet	295	0,0	0,00	0,000 000
	300	0,0	0,00	0,000 000
	305	9,2	4,60	0,000 048
	310	40,8	20,40	0,000 214
	315	103,9	51,95	0,000 545
	320	174,4	87,20	0,000 915
	325	237,9	118,95	0,001 248
	330	381,0	190,50	0,001 999
	335	376,0	188,00	0,001 973
	340	419,5	209,75	0,002 201
	345	423,0	211,50	0,002 219
	350	466,2	233,10	0,002 446
	355	483,8	241,90	0,002 538
	360	501,4	250,70	0,002 630
	365	571,7	285,85	0,002 999
	370	642,1	321,05	0,003 369
	375	668,3	334,15	0,003 506
	380	686,7	343,35	0,003 603
	385	668,2	334,10	0,003 506
	390	649,6	324,80	0,003 408
	395	813,0	406,50	0,004 265
	400	976,4	732,30	0,007 684
Visible	410	1 116,2	1 116,20	0,011 712
	420	1 141,1	1 141,10	0,011 973
	430	1 033,0	1 033,00	0,010 839
	440	1 254,8	1 254,80	0,013 166
	450	1 470,7	1 470,70	0,015 431
	460	1 541,6	1 541,60	0,016 175
	470	1 523,7	1 523,70	0,015 988
	480	1 569,3	1 569,30	0,016 466
	490	1 483,4	1 483,40	0,015 565
	500	1 492,6	1 492,60	0,015 661
	510	1 529,0	1 529,00	0,016 043
	520	1 431,1	1 431,10	0,015 016
	530	1 515,4	1 515,40	0,015 900
	540	1 494,5	1 494,50	0,015 681
	550	1 504,9	1 504,90	0,015 790
	560	1 480,9	1 480,90	0,015 539
	570	1 447,1	1 447,10	0,015 184
	580	1 395,8	1 395,80	0,014 646
	590	1 344,9	1 344,90	0,014 112
	600	1 388,4	1 388,40	0,014 568
	610	1 431,5	1 431,50	0,015 020
	620	1 406,7	1 406,70	0,014 760
	630	1 382,1	1 382,10	0,014 502
	640	1 384,3	1 384,30	0,014 525
	650	1 386,4	1 386,40	0,014 547
	660	1 366,0	1 366,00	0,014 333
	670	1 341,8	1 341,80	0,014 079
	680	1 215,0	1 215,00	0,012 749
	690	1 089,0	1 089,00	0,011 426
	700	1 179,4	1 179,40	0,012 375
	710	1 269,0	1 269,00	0,013 315
	720	982,9	982,90	0,010 313
	730	1 057,3	1 057,30	0,011 094
	740	1 167,3	1 167,30	0,012 248
	750	1 155,0	1 155,00	0,012 119
	760	876,5	876,50	0,009 197
	770	1 017,4	1 017,40	0,010 675
	780	1 090,1	1 090,10	0,011 438
	790	1 067,5	1 067,50	0,011 201
	-	-	-	-
	-	-	-	-
	-	-	-	-
	-	-	-	-

Light	(5)	(6)	(7)	(8)
	λ, nm [a]	E_λ [b]	E'_λ [e]	$E'_\lambda(\text{n})$ [d]
Infrared	800	1 042,4	3 127,20	0,032 812
	850	934,3	4 671,50	0,049 016
	900	760,0	3 800,00	0,039 872
	950	317,4	1 587,00	0,016 652
	1 000	714,8	3 574,00	0,037 501
	1 050	650,5	3 252,50	0,034 127
	1 100	397,6	1 988,00	0,020 859
	1 150	238,5	1 192,50	0,012 512
	1 200	408,2	2 041,00	0,021 415
	1 250	456,2	2 281,00	0,023 934
	1 300	355,5	1 777,50	0,018 651
	1 350	31,3	156,50	0,001 642
	1 400	2,6	13,00	0,000 136
	1 450	71,4	357,00	0,003 746
	1 500	182,0	910,00	0,009 548
	1 550	265,6	1 328,00	0,013 934
	1 600	230,5	1 152,50	0,012 093
	1 650	221,8	1 109,00	0,011 636
	1 700	199,0	995,00	0,010 440
	1 750	154,6	773,00	0,008 111
	1 800	29,6	148,00	0,001 553
	1 850	4,4	22,00	0,000 231
	1 900	0,0	0,00	0,000 000
	1 950	13,0	65,00	0,000 682
	2 000	35,8	179,00	0,001 878
	2 050	77,0	385,00	0,004 040
	2 100	85,9	429,50	0,004 507
	2 150	78,8	394,00	0,004 134
	2 200	68,7	343,50	0,003 604
	2 250	68,3	341,50	0,003 583
	2 300	66,1	330,50	0,003 468
	2 350	61,8	309,00	0,003 242
	2 400	42,9	214,50	0,002 251
	2 450	20,4	102,00	0,001 070
	2 500	16,5	41,25	0,000 433
		Sums:	**95 305,20**	**1,000 000**

Trapezoidal: $E'_\lambda(\text{n})$ *at 2 500 nm = 0,5 × (16,5 × 5,0)*

Light	λ, nm [a]	E_λ [b]	E'_λ [f]	$E'_\lambda(\text{n})$ [d]
Ultraviolet	295	0,0	0,00	0,000 000
	300	0,0	0,00	0,000 000
	305	9,2	4,60	0,001 045
	310	40,8	20,40	0,004 634
	315	103,9	51,95	0,011 800
	320	174,4	87,20	0,019 807
	325	237,9	118,95	0,027 019
	330	381,0	190,50	0,043 271
	335	376,0	188,00	0,042 703
	340	419,5	209,75	0,047 644
	345	423,0	211,50	0,048 041
	350	466,2	233,10	0,052 948
	355	483,8	241,90	0,054 947
	360	501,4	250,70	0,056 946
	365	571,7	285,85	0,064 930
	370	642,1	321,05	0,072 925
	375	668,3	334,15	0,075 901
	380	686,7	343,35	0,077 991
	385	668,2	334,10	0,075 890
	390	649,6	324,80	0,073 777
	395	813,0	406,50	0,092 335
	400	976,4	244,10	0,055 446
		Sums:	**4 402,45**	**1,000 000**

Trapezoidal: $E'_\lambda(\text{n})$ *at 400 nm = 0,5 × (976,4 × 0,5)*

[a] See ISO 9845-1:1992, Table 1, Column 5.

[b] Air mass 1,5 g.

[c] $E'_\lambda = E_\lambda \times D$, where $D = 0{,}5$ for UV ; $D = 1{,}0$ for VIS.

[d] $E'_\lambda(\text{n}) = E'_\lambda \Big/ \sum E'_\lambda$.

[e] $E'_\lambda = E_\lambda \times D$, where $D = 5{,}0$ for IR.

[f] $E'_\lambda = E_\lambda \times D$, where $D = 0{,}5$ for UV.

Table A.2 — Derivation table of $\Delta\lambda$ versus $E'_\lambda(\mathrm{n})$ for global air mass 1,0

Light	(1)	(2)	(3)	(4)	Light	(5)	(6)	(7)	(8)
	λ, nm [a]	E_λ [b]	E'_λ [c]	$E'_\lambda(\mathrm{n})$ [d]		λ, nm [a]	E_λ [b]	E'_λ [e]	$E'_\lambda(\mathrm{n})$ [d]
Ultraviolet	295	0,0	0,00	0,000 000	Infrared	800	1 125,2	3 375,60	0,030 876
	300	0,0	0,00	0,000 000		850	1 003,4	5 017,00	0,045 890
	305	47,0	23,50	0,000 215		900	932,2	4 661,00	0,042 634
	310	132,5	66,25	0,000 606		950	395,0	1 975,00	0,018 065
	315	258,3	129,15	0,001 181		1 000	742,4	3 712,00	0,033 953
	320	374,7	187,35	0,001 714		1 050	669,2	3 346,00	0,030 606
	325	466,3	233,15	0,002 133		1 100	452,9	2 264,50	0,020 713
	330	660,0	330,00	0,003 018		1 150	250,0	1 250,00	0,011 434
	335	627,1	313,55	0,002 868		1 200	441,5	2 207,50	0,020 192
	340	679,3	339,65	0,003 107		1 250	471,5	2 357,50	0,021 564
	345	669,0	334,50	0,003 060		1 300	381,3	1 906,50	0,017 439
	350	723,0	361,50	0,003 307		1 350	52,0	260,00	0,002 378
	355	737,2	368,60	0,003 372		1 400	6,1	30,50	0,000 279
	360	751,4	375,70	0,003 437		1 450	97,2	486,00	0,004 445
	365	843,3	421,65	0,003 857		1 500	206,8	1 034,00	0,009 458
	370	935,5	467,75	0,004 278		1 550	271,9	1 359,50	0,012 435
	375	958,7	479,35	0,004 385		1 600	239,2	1 196,00	0,010 940
	380	975,9	487,95	0,004 463		1 650	231,5	1 157,50	0,010 588
Visible	385	970,3	485,15	0,004 438		1 700	205,6	1 028,00	0,009 403
	390	964,8	482,40	0,004 412		1 750	157,9	789,50	0,007 222
	395	1 147,0	573,50	0,005 246		1 800	41,8	209,00	0,001 912
	400	1 329,0	996,75	0,009 117		1 850	7,6	38,00	0,000 348
	410	1 429,1	1 429,10	0,013 072		1 900	0,0	0,00	0,000 000
	420	1 499,4	1 499,40	0,013 715		1 950	19,5	97,50	0,000 892
	430	1 337,9	1 337,90	0,012 238		2 000	44,7	223,50	0,002 044
	440	1 603,8	1 603,80	0,014 670		2 050	82,7	413,50	0,003 782
	450	1 855,7	1 855,70	0,016 974		2 100	88,1	440,50	0,004 029
	460	1 889,0	1 889,00	0,017 279		2 150	80,0	400,00	0,003 659
	470	1 847,6	1 847,60	0,016 900		2 200	70,5	352,50	0,003 224
	480	1 887,6	1 887,60	0,017 266		2 250	68,9	344,50	0,003 151
	490	1 769,5	1 769,50	0,016 186		2 300	66,2	331,00	0,003 028
	500	1 769,6	1 769,60	0,016 186		2 350	62,5	312,50	0,002 858
	510	1 802,0	1 802,00	0,016 483		2 400	46,6	233,00	0,002 131
	520	1 678,3	1 678,30	0,015 351		2 450	24,4	122,00	0,001 116
	530	1 771,4	1 771,40	0,016 203		2 500	0,0	0,00	0,000 000
	540	1 740,3	1 740,30	0,015 918	**Sums:**			**109 326,1**	**1,000 000**
	550	1 747,2	1 747,20	0,015 982	*Trapezoidal:* $E'_\lambda(\mathrm{n})$ *at 2 500 nm = 0,5 × (0 × 5,0)*				
	560	1 703,4	1 703,40	0,015 581					
	570	1 654,4	1 654,40	0,015 133	**Light**	λ, nm [a]	E_λ [b]	E'_λ [f]	$E'_\lambda(\mathrm{n})$ [d]
	580	1 601,5	1 601,50	0,014 649					
	590	1 548,9	1 548,90	0,014 168	Ultraviolet	295	0,0	0,00	0,000 000
	600	1 575,8	1 575,80	0,014 414		300	0,0	0,00	0,000 000
	610	1 602,6	1 602,60	0,014 659		305	47,0	23,50	0,005 026
	620	1 572,0	1 572,00	0,014 379		310	132,5	66,25	0,014 169
	630	1 541,4	1 541,40	0,014 099		315	258,3	129,15	0,027 622
	640	1 526,9	1 526,90	0,013 966		320	374,7	187,35	0,040 070
	650	1 512,3	1 512,30	0,013 833		325	466,3	233,15	0,049 865
	660	1 489,5	1 489,50	0,013 624		330	660,0	330,00	0,070 579
	670	1 460,9	1 460,90	0,013 363		335	627,1	313,55	0,067 061
	680	1 337,5	1 337,50	0,012 234		340	679,3	339,65	0,072 643
	690	1 214,7	1 214,70	0,011 111		345	669,0	334,50	0,071 541
	700	1 292,9	1 292,90	0,011 826		350	723,0	361,50	0,077 316
	710	1 370,5	1 370,50	0,012 536		355	737,2	368,60	0,078 834
	720	1 141,9	1 141,90	0,010 445		360	751,4	375,70	0,080 353
	730	1 199,5	1 199,50	0,010 972		365	843,3	421,65	0,090 180
	740	1 279,9	1 279,90	0,011 707		370	935,5	467,75	0,100 040
	750	1 255,5	1 255,50	0,011 484		375	958,7	479,35	0,102 521
	760	988,8	988,80	0,009 045		380	975,9	243,98	0,052 180
	770	1 114,3	1 114,30	0,010 192	**Sums:**			**4 675,63**	**1,000 000**
	780	1 173,3	1 173,30	0,010 732	*Trapezoidal:* $E'_\lambda(\mathrm{n})$ *at 380 nm = 0,5 × (975,9 × 0,5)*				
	790	1 150,8	1 150,80	0,010 526					

[a] See CIE 85:1989, Table 4, Column 2.

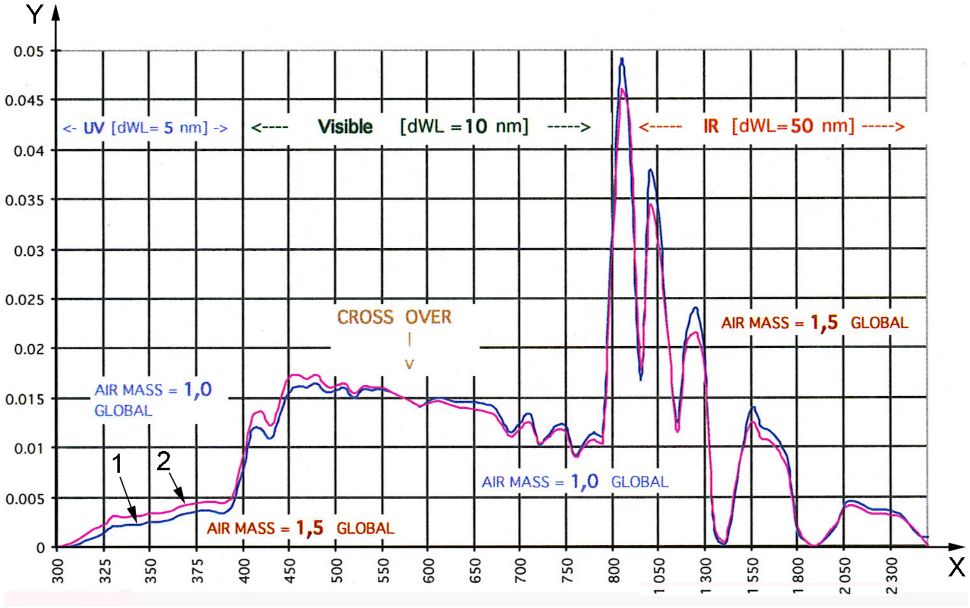
[b] Air mass 1,0 g.

[c] $E'_\lambda = E_\lambda \times D$, where $D = 0{,}5$ for UV; $D = 1{,}0$ for VIS.

[d] $/\, E'_\lambda(\mathrm{n}) = E'_\lambda \big/ \sum E'_\lambda$.

[e] $E'_\lambda = E_\lambda \times D$, where $D = 5{,}0$ for IR.

[f] $E'_\lambda = E_\lambda \times D$, where $D = 0{,}5$ for UV.



Key

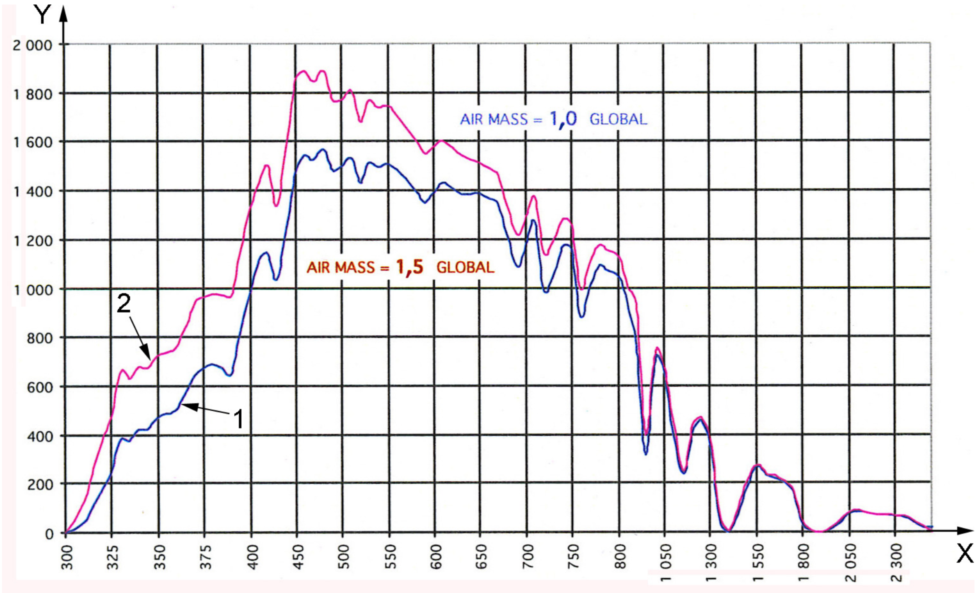
X wavelength, λ, in nm

Y normalized energy, E'_{λ}(n)

1 air mass 1,5 global

2 air mass 1,0 global

Figure A.1 — Normalized energy



Key

X wavelength, λ, in nm

Y solar energy within a uniform λ interval, E_{λ}

1 air mass 1,5 global

2 air mass 1,0 global

Figure A.2 — Hemispherical solar spectral irradiance (watts per square meter per micrometer)

Annex B
(informative)

Determination of total solar transmittance

B.1 Definitions

The total solar transmittance, T_{TS}, of a safety glazing material is the sum of the solar direct transmittance, T_{DS} (300 nm to 2 500 nm), and of the secondary heat transfer factor, q_{i}, of the glazing towards the inside; the latter resulting from heat transfer by convection and longwave IR radiation of that part of the incident solar radiation which has been absorbed by the safety glazing material, as expressed in the Equation (B.1):

$$T_{\mathrm{TS}} = T_{\mathrm{DS}} + q_{\mathrm{i}} \tag{B.1}$$

B.2 Secondary heat transfer factor to the inside

For the calculation of the secondary heat transfer factor to the inside, q_{i}, the heat transfer coefficients of the safety glazing material towards the outside, h_{e}, and towards the inside, h_{i}, are needed. These values mainly depend on the position of the safety glazing material, wind velocity, inside and outside temperatures, as well as on the temperature of the two external glazing material surfaces.

As the purpose of this International Standard is to provide basic information of the performance of safety glazing materials, conventional conditions have been stated for simplicity, as specified below.

a) The position of the safety glazing material is vertical.

b) Outside surface:

   1) wind velocities:

      - v_1 = approximately 4 m/s for vehicles at rest;
      - v_2 = 14 m/s for vehicles at 50 km/h;
      - v_3 = 28 m/s for vehicles at 100 km/h;
      - v_4 = 42 m/s for vehicles at 150 km/h;

   2) hemispherical emissivity = 0,837.

c) Inside surface:

   1) natural convection;

   2) emissivity is an optional consideration;

   3) air spaces in the case of double glazed units are unventilated.

Under these conventional, average conditions, standard values for h_{e1} to h_{e4} are obtained as follows:

- $h_{e1} = 21$ W/(m^2·K) at v_1;
- $h_{e2} = 61$ W/(m^2·K) at v_2;
- $h_{e3} = 106$ W/(m^2·K) at v_3;
- $h_{e4} = 146$ W/(m^2·K) at v_4;

and for h_i as shown in Equation (B.2) below:

$$h_i = 3{,}6 + \frac{4{,}4\varepsilon_i}{0{,}837}\ \mathrm{W/(m^2{\cdot}K)} \tag{B.2}$$

where

$$\text{for } v < 5\ \mathrm{m/s},\ h_e = 5{,}57 + 3{,}94v, \tag{B.3}$$

$$\text{for } v \leqslant 5\ \mathrm{m/s},\ h_e = 7{,}1v^{0{,}78} \tag{B.4}$$

and ε_i is the corrected emissivity.

NOTE 1 For Equations (B.3) and (B.4), see Reference [7].

NOTE 2 For ordinary glass, $\varepsilon_i = 0{,}837$ and $h_i = 8$ W/(m^2·K).

The corrected emissivity is defined and measured in accordance with EN 673. If other heat transfer coefficients are used to calculate the secondary heat transfer factor in order to meet special boundary conditions, this shall be indicated.

NOTE 3 Lower values than 0,837 for ε_i (due to surface coatings with higher reflection in the far infrared) are only to be taken into account if water condensation on the coated surface can be excluded.

The secondary internal heat transfer factor, q_i, of a single glazing is calculated using Equation (B.5):

$$q_i = \frac{h_i}{h_e + h_i}\alpha_e\ \mathrm{W/(m^2{\cdot}K)} \tag{B.5}$$

where the solar direct absorptance in accordance with the definitions given in ISO 9050 and EN 410, α_e, is calculated as follows:

$$\alpha_e = 100 - \%T_{DS} - \%R_{DS} \tag{B.6}$$

where R_{DS} is the solar direct reflectance (300 nm to 2 500 nm), determined in a manner similar to T_{DS}.

The definitions and equations used in ISO 9050 and EN 410 can be applied, if necessary, to calculate the total solar transmittance for multiple safety glazing materials, e.g. double glazing, and for vehicles at rest and in motion.

Bibliography

[1] ISO 3917, *Road vehicles — Safety glazing materials — Test methods for resistance to radiation, high temperature, humidity, fire and simulated weathering*

[2] ISO 9050, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

[3] EN 410, *Glass in building — Determination of luminous and solar characteristics of glazing*

[4] EN 673, *Glass in building — Determination of thermal transmittance (U value) — Calculation method*

[5] CIE 20:1972, *Recommendation for the integrated irradiance and the spectral distribution of simulated solar radiation for testing purposes*

[6] IEEE/ASTM SI 10(1), *Standard for Use of the International System of Units (SI): The Modern Metric System*

[7] MCADAMS, *Heat Transmission*, New York, McGraw Hill, 3rd ed., 1954

[8] *ASHRAE Handbook of Fundamentals* (1977), 2.15, Table 6

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1) Revision of ASTM E 380-93, *Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)*, Philadelphia 1993.

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