Solar Radiation Glazing Factors for Electrochromic Windows for Building Applications

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*Building Enclosure Science & Technology (BEST 2 - 2010),
Portland, Oregon, U.S.A., 12-14 April, 2010.*

Introduction

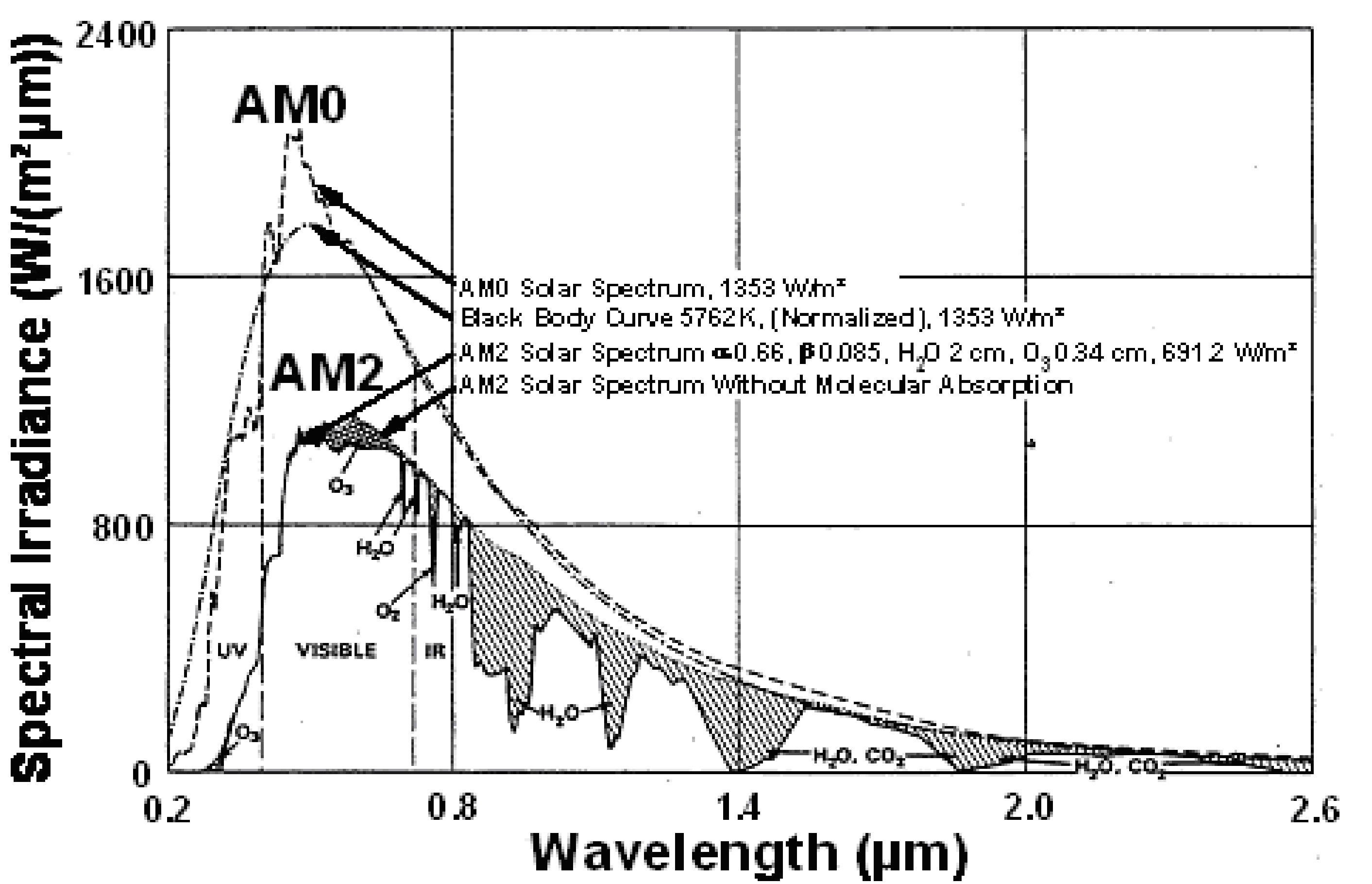
- **Electrochromic windows (ECWs)**
- **Regulates solar radiation by application of an external voltage**
- **May decrease heating, cooling and electricity loads in buildings**
- **Dynamic and flexible solar radiation control**
- **May be characterized by a number of solar radiation glazing factors**

Solar Radiation Glazing Factors

- Ultraviolet Solar Transmittance, T_{uv}
- Visible Solar Transmittance, T_{vis}
- Solar Transmittance, T_{sol}
- Solar Material Protection Factor, SMPF
- Solar Skin Protection Factor, SSPF
- External Visible Solar Reflectance, $R_{vis,ext}$
- Internal Visible Solar Reflectance, $R_{vis,int}$
- Solar Reflectance, R_{sol}
- Solar Absorbance, A_{sol}
- Emissivity, ε
- Solar Factor, SF (from Tsol, Rsol and ε)
- Colour Rendering Factor, CRF

A number between 0 and 1 (0 and 100 %).

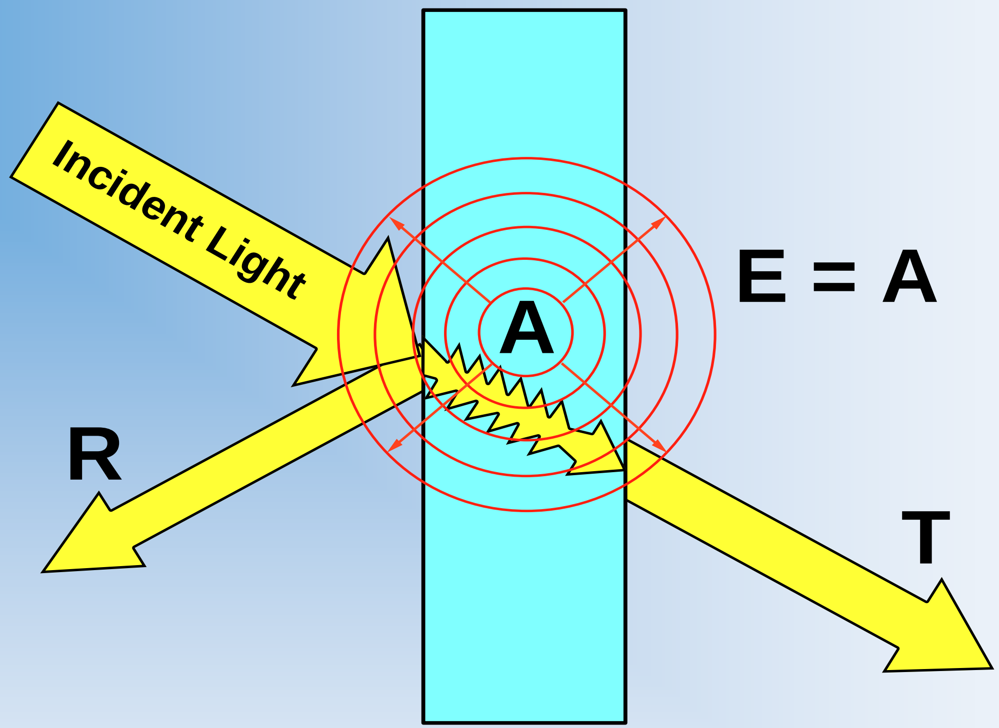
Solar Radiation



- Solar Spectrum
  280-3000 nm
- Solar Ultraviolet (UV)
  280-380 nm
- Visible Light (VIS)
  380-780 nm
- Near Infrared (NIR)
  780-3000 nm

- AM0 (outer space)
- AM2 (earth's surface, the sun 30º above the horizon)
- Molecular absorption (in O_2, O_3, H_2O and CO_2)
- Redrawn from: A.L. Fahrenbruch and R.H. Bube, "Fundamentals of solar cells. Photovoltaic solar energy conversion", pp. 26-31, Academic Press, 1983.

Transmittance, Absorbance and Reflectance

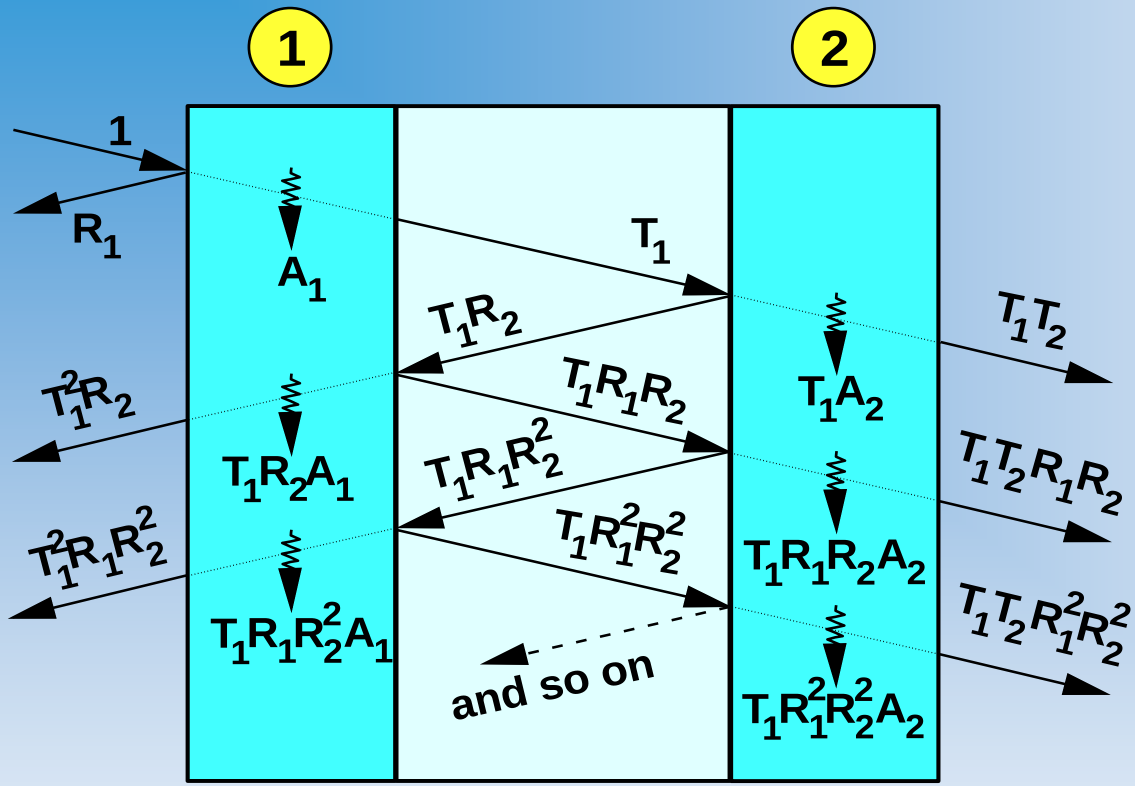


T + A + R = 1

$$T(\lambda) + A(\lambda) + R(\lambda) = 1 \quad (100\ \%)$$

$$E(\lambda) = A(\lambda)$$

Solar Radiation through Window Panes and other Glass Structures



Single Glass Pane

$$T(\lambda) = T_1$$

$$R(\lambda) = R_1$$

Two-Layer Window Pane

$$T(\lambda) = \frac{T_1 T_2}{1 - R_{1b} R_2}$$

$$R_{ext}(\lambda) = R_1 + \frac{T_1^2 R_2}{1 - R_{1b} R_2}$$

$$R_{int}(\lambda) = R_{2b} + \frac{T_2^2 R_{1b}}{1 - R_2 R_{1b}}$$

Three-Layer Window Pane

$$T(\lambda) = \frac{T_1 T_2 T_3}{[1 - R_{1b} R_2][1 - R_{2b} R_3] - T_2^2 R_{1b} R_3}$$

$$R_{ext}(\lambda) = R_1 + \frac{T_1^2 R_2 [1 - R_{2b} R_3] + T_1^2 T_2^2 R_3}{[1 - R_{1b} R_2][1 - R_{2b} R_3] - T_2^2 R_{1b} R_3}$$

$$R_{int}(\lambda) = R_{3b} + \frac{T_3^2 R_{2b} [1 - R_2 R_{1b}] + T_3^2 T_2^2 R_{1b}}{[1 - R_3 R_{2b}][1 - R_2 R_{1b}] - T_2^2 R_3 R_{1b}}$$

Solar Radiation Glazing Factor Definitions

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Ultraviolet Solar Transmittance (T_{uv})

$$T_{uv} = \frac{\sum_{\lambda=300\,nm}^{380\,nm} T(\lambda) S_{\lambda} \Delta\lambda}{\sum_{\lambda=300\,nm}^{380\,nm} S_{\lambda} \Delta\lambda}$$

Visible Solar Transmittance (T_{vis}) (Light Transmittance)

$$T_{vis} = \frac{\sum_{\lambda=380\,nm}^{780\,nm} T(\lambda) D_{\lambda} V(\lambda) \Delta\lambda}{\sum_{\lambda=380\,nm}^{780\,nm} D_{\lambda} V(\lambda) \Delta\lambda}$$

Solar Transmittance (T_{sol})

$$T_{sol} = \frac{\sum_{\lambda=300\,nm}^{2500\,nm} T(\lambda) S_{\lambda} \Delta\lambda}{\sum_{\lambda=300\,nm}^{2500\,nm} S_{\lambda} \Delta\lambda}$$

Solar Radiation Glazing Factor Definitions

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Solar Material Protection Factor (SMPF)

$$\mathrm{SMPF} = 1 - \tau_{df} = 1 - \frac{\sum_{\lambda=300\,\mathrm{nm}}^{600\,\mathrm{nm}} T(\lambda) C_\lambda S_\lambda \Delta\lambda}{\sum_{\lambda=300\,\mathrm{nm}}^{600\,\mathrm{nm}} C_\lambda S_\lambda \Delta\lambda}$$

Solar Skin Protection Factor (SSPF)

$$\mathrm{SSPF} = 1 - F_{sd} = 1 - \frac{\sum_{\lambda=300\,\mathrm{nm}}^{400\,\mathrm{nm}} T(\lambda) E_\lambda S_\lambda \Delta\lambda}{\sum_{\lambda=300\,\mathrm{nm}}^{400\,\mathrm{nm}} E_\lambda S_\lambda \Delta\lambda}$$

B. P. Jelle, A. Gustavsen, T.-N. Nilsen and T. Jacobsen, "Solar Material Protection Factor (SMPF) and Solar Skin Protection Factor (SSPF) for Window Panes and other Glass Structures in Buildings", *Solar Energy Materials & Solar Cells*, 91, 342-354, 2007.

Solar Radiation Glazing Factor Definitions

ROBUST

External Visible Solar Reflectance ($R_{vis,ext}$) (External Light Reflectance)

$$R_{vis,ext} = \frac{\sum_{\lambda=380\,nm}^{780\,nm} R_{ext}(\lambda) D_\lambda V(\lambda) \Delta\lambda}{\sum_{\lambda=380\,nm}^{780\,nm} D_\lambda V(\lambda) \Delta\lambda}$$

Internal Visible Solar Reflectance ($R_{vis,int}$) (Internal Light Reflectance)

$$R_{vis,int} = \frac{\sum_{\lambda=380\,nm}^{780\,nm} R_{int}(\lambda) D_\lambda V(\lambda) \Delta\lambda}{\sum_{\lambda=380\,nm}^{780\,nm} D_\lambda V(\lambda) \Delta\lambda}$$

Solar Reflectance (R_{sol})

$$R_{sol} = \frac{\sum_{\lambda=300\,nm}^{2500\,nm} R_{ext}(\lambda) S_\lambda \Delta\lambda}{\sum_{\lambda=300\,nm}^{2500\,nm} S_\lambda \Delta\lambda}$$

Solar Radiation Glazing Factor Definitions

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Solar Absorbance (A_{sol})

$$A_{sol} = 1 - T_{sol} - R_{sol} = 1 - \frac{\sum_{\lambda=300\,nm}^{2500\,nm} T(\lambda) S_{\lambda} \Delta\lambda}{\sum_{\lambda=300\,nm}^{2500\,nm} S_{\lambda} \Delta\lambda} - \frac{\sum_{\lambda=300\,nm}^{2500\,nm} R_{ext}(\lambda) S_{\lambda} \Delta\lambda}{\sum_{\lambda=300\,nm}^{2500\,nm} S_{\lambda} \Delta\lambda}$$

Solar Radiation Glazing Factor Definitions

Emissivity (ε)

■ **Specular IR reflectance measurements**

$$\varepsilon = c_{corr}\varepsilon_n = \frac{\varepsilon}{\varepsilon_n}\varepsilon_n = c_{corr}(1 - R_n) = c_{corr}\left[1 - \frac{1}{30}\sum_{i=1}^{30} R_n(\lambda_i)\right]$$

■ **Heat flow meter measurements**

$$\varepsilon = \frac{2\left(q_{tot} - \frac{\kappa}{d}\Delta T\right)}{4\sigma T_m^3 \Delta T + q_{tot} - \frac{\kappa}{d}\Delta T}$$

■ **Total hemispherical emissivity**

(Hemispherical reflectometer and integrating over the hemisphere)

$$\varepsilon = 2\int_0^{\pi/2} \varepsilon_t(\theta)\sin\theta\cos\theta\, d\theta$$

$$\varepsilon_t(\theta, \phi, \lambda) = 1 - \frac{\int_0^{\infty} R(\lambda)P(\lambda, T)d\lambda}{\int_0^{\infty} P(\lambda, T)d\lambda}$$

$$P(\lambda, T) = \frac{8\pi hc}{\lambda^5 (e^{hc/(\lambda kT)} - 1)}$$

Solar Radiation Glazing Factor Definitions

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Solar Factor (SF)
(Total Solar Energy Transmittance)

$$SF = T_{sol} + q_i$$

q_i = secondary heat transfer factor towards the inside

Further details in ISO/FDIS 9050:2003(E), ISO 10292:1994(E), EN-ISO 6946:1996 and EN 410:1998 E

Colour Rendering Factor (CRF)

$$CRF = \frac{R_a}{100} = \frac{1}{800}\sum_{i=1}^{8} R_i$$

$R_i = 100 - 4.6\Delta E_i$ = specific colour rendering index

$$\Delta E_i = \sqrt{(U^*_{t,i} - U^*_{r,i})^2 + (V^*_{t,i} - V^*_{r,i})^2 + (W^*_{t,i} - W^*_{r,i})^2}$$ = total distortion of colour i

Solar Radiation Glazing Factor Definitions

where

λ = wavelength (nm)

$\Delta\lambda$ = wavelength interval (nm)

$T(\lambda)$ = spectral transmittance of the glass

$R_{ext}(\lambda)$ = external spectral reflectance of the glass

$R_{int}(\lambda)$ = internal spectral reflectance of the glass

R_n = average spectral reflectance calculated by summation of spectral reflectance values at 30 distinct wavelengths and divided by 30 as shown in Eq.20 above

λ_i = wavelength and λ_i values for the 30 wavelengths are given in ISO 10292:1994(E) and EN 12898:2001 E

S_λ = relative spectral distribution of ultraviolet solar radiation or solar radiation (ISO/FDIS 9050:2003(E), ISO 9845-1:1992(E))

D_λ = relative spectral distribution of illuminant D65 (ISO/FDIS 9050:2003(E), ISO 10526:1999(E))

$V(\lambda)$ = spectral luminous efficiency for photopic vision defining the standard observer for photometry (ISO/FDIS 9050:2003(E), ISO/CIE 10527:1991(E))

$S_\lambda\Delta\lambda$ values at different wavelengths for ultraviolet solar radiation or solar radiation are given in ISO/FDIS 9050:2003(E)

$D_\lambda V(\lambda)\Delta\lambda$ values at different wavelengths are given in ISO/FDIS 9050:2003(E)

τ_{df} = CIE damage factor (ISO/FDIS 9050:2003(E), CIE No 89/3:1990)

$C_\lambda = e^{-0.012\lambda}$ (λ given in nm)

$C_\lambda S_\lambda\Delta\lambda$ values at different wavelengths are given in ISO/FDIS 9050:2003(E)

F_{sd} = skin damage factor (ISO/FDIS 9050:2003(E), McKinlay and Diffey 1987)

E_λ = CIE erythemal effectiveness spectrum

$E_\lambda S_\lambda\Delta\lambda$ values at different wavelengths are given in ISO/FDIS 9050:2003(E)

q_{tot} = total heat flow density between two parallel, flat infinite isothermal surfaces (W/m^2) (EN 1946-2:1999 E, EN 1946-3:1999 E)

κ = thermal conductivity of the medium separating the two surfaces (W/(mK))

$\kappa = \kappa_{air} = 0.0242396(1 + 0.0030520\theta - 1.282 \cdot 10^{-6}\theta^2)$ (W/(mK))

(values accurate to 0.6 % between θ = 10ºC and θ = 70ºC)
(θ given in ºC) (EN 1946-2:1999 E, EN 1946-3:1999 E)

$\theta = (T_m - 273.15\ K)ºC/K$ (ºC)

T_m = mean temperature of the two surfaces (K)

ΔT = temperature difference between the two surfaces (K)

d = distance between the two surfaces (m)

$\sigma = \pi^2 k^4/(60\hbar^3 c^2)$ = Stefan-Boltzmann's constant $\approx 5.67\cdot 10^{-8}\ W/(m^2K^4)$

$$\varepsilon_t(\theta,\phi,\lambda) = 1 - \frac{\int_0^\infty R(\lambda)P(\lambda,T)d\lambda}{\int_0^\infty P(\lambda,T)d\lambda}$$ (Surface Optics Corporation 2009)

$$P(\lambda,T) = \frac{8\pi hc}{\lambda^5(e^{hc/(\lambda kT)} - 1)}$$ = Planck's function (Surface Optics Corporation 2009)

R = hemispherical reflectance

T = temperature (K)

θ and ϕ are integrating angles over the hemisphere

h = Planck's constant $\approx 6.63\cdot 10^{-34}$ Js

k = Boltzmann's constant $\approx 1.38\cdot 10^{-23}$ J/K

c = velocity of light $\approx 3.00\cdot 10^{8}$ m/s

T_{sol} = solar transmittance (Eq.13)

$A_{sol} = q_i + q_e$ (A_{sol} from Eq.19)

q_i = secondary heat transfer factor towards the inside

q_e = secondary heat transfer factor towards the outside (complete details for calculation of SF given in ISO/FDIS 9050:2003(E), with additions in ISO 10292:1994(E) and EN-ISO 6946:1996, note that ε and R_{sol} enter into q_i in Eq.22, R_{sol} from A_{sol})

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i$$ = general colour rendering index (EN 410:1998 E)

$R_i = 100 - 4.6\Delta E_i$ = specific colour rendering index

$$\Delta E_i = \sqrt{(U^*_{t,i} - U^*_{r,i})^2 + (V^*_{t,i} - V^*_{r,i})^2 + (W^*_{t,i} - W^*_{r,i})^2}$$ = total distortion of colour i

(complete details for calculation of CRF given in EN 410:1998 E)

Solar Factor (SF) for Single Glazing

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$$SF = T_{sol} + q_i = T_{sol} + A_{sol} \frac{h_i}{h_e + h_i}$$

T_{sol} = solar transmittance (Eq. 13)

R_{sol} = solar reflectance (Eq. 18)

$A_{sol} = 1 - T_{sol} - R_{sol}$ = solar absorbance (Eq. 19 and Eq. 20)

$h_e = 23\ W/(m^2K)$ (Eq. 44, see applicable assumptions)

$$h_i = \left(3.6 + \frac{4.4\varepsilon}{0.837}\right) W/(m^2K)$$ (Eq. 45, see applicable assumptions)

ε = corrected emissivity of the inside surface

Solar Factor (SF) for Double Glazing

ROBUST

$$SF = T_{sol} + q_i = T_{sol} + \frac{\dfrac{A_{sol,1} + A_{sol,2}}{h_e} + \dfrac{A_{sol,2}}{\Lambda}}{\dfrac{1}{h_i} + \dfrac{1}{h_e} + \dfrac{1}{\Lambda}}$$

$$A_{sol,1} = \frac{\sum_{\lambda = 300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \left\{ A_1 + \dfrac{A_{1b} T_1 R_2}{1 - R_{1b} R_2} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda = 300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda}$$

$$A_{sol,2} = \frac{\sum_{\lambda = 300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \left\{ \dfrac{A_2 T_1}{1 - R_{1b} R_2} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda = 300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda}$$

Λ = thermal conductance between the outer surface of the outer (first) pane and the innermost surface of the inner (second) pane

$A_1 = 1 - T_1 - R_1$

$A_{1b} = 1 - T_1 - R_{1b}$

$A_2 = 1 - T_2 - R_2$

Solar Factor (SF) for Triple Glazing

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$$SF = T_{sol} + q_i = T_{sol} + \frac{\dfrac{A_{sol,1} + A_{sol,2} + A_{sol,3}}{h_e} + \dfrac{A_{sol,2} + A_{sol,3}}{\Lambda_{12}} + \dfrac{A_{sol,3}}{\Lambda_{23}}}{\dfrac{1}{h_i} + \dfrac{1}{h_e} + \dfrac{1}{\Lambda_{12}} + \dfrac{1}{\Lambda_{23}}}$$

$$A_{sol,1} = \frac{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} \left\{ A_1 + \dfrac{T_1 A_{1b} R_2 (1 - R_{2b} R_3) + T_1 T_2^2 A_{1b} R_3}{(1 - R_{1b} R_2)(1 - R_{2b} R_3) - T_2^2 R_{1b} R_3} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda}$$

$$A_{sol,2} = \frac{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} \left\{ \dfrac{T_1 A_2 (1 - R_{2b} R_3) + T_1 T_2 A_{2b} R_3}{(1 - R_{1b} R_2)(1 - R_{2b} R_3) - T_2^2 R_{1b} R_3} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda}$$

$$A_{sol,3} = \frac{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} \left\{ \dfrac{T_1 T_2 A_3}{(1 - R_{1b} R_2)(1 - R_{2b} R_3) - T_2^2 R_{1b} R_3} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{2500\text{ nm}} S_\lambda \Delta\lambda}$$

Λ_{12} = thermal conductance between the outer surface of the outer (first) pane and the centre of the middle (second) pane

Λ_{23} = thermal conductance between the centre of the middle (second) pane and the centre of the inner (third) pane

$A_1 = 1 - T_1 - R_1$ (Eq. 71)

$A_{1b} = 1 - T_1 - R_{1b}$ (Eq. 72)

$A_2 = 1 - T_2 - R_2$ (Eq. 73)

$A_{2b} = 1 - T_2 - R_{2b}$

$A_3 = 1 - T_3 - R_3$

Solar Factor (SF) for Multiple Glazing

ROBUST

$$SF = T_{sol} + q_i$$

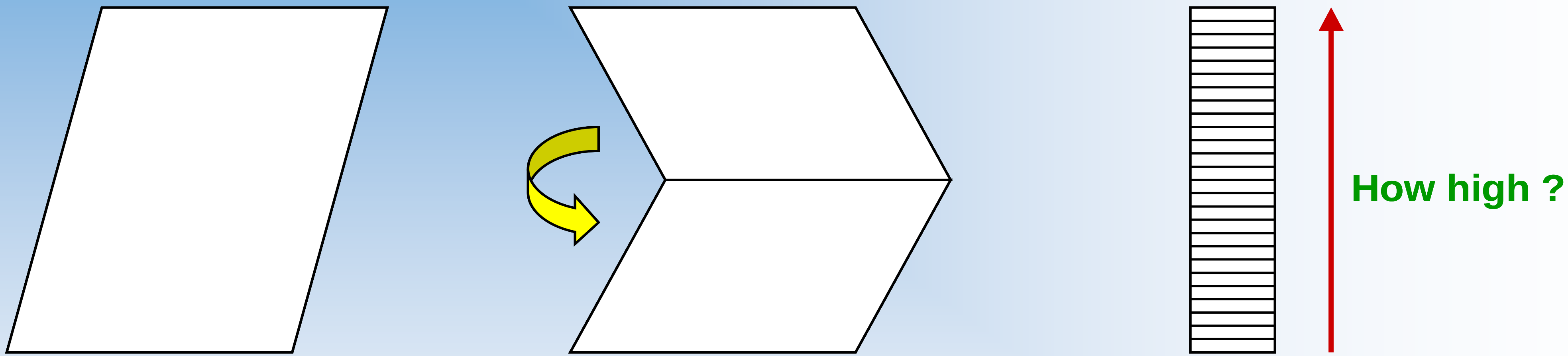
$$q_i = \frac{\dfrac{A_{sol,1} + A_{sol,2} + A_{sol,3} + \ldots + A_{sol,n}}{h_e} + \dfrac{A_{sol,2} + A_{sol,3} + \ldots + A_{sol,n}}{\Lambda_{12}} + \dfrac{A_{sol,3} + \ldots + A_{sol,n}}{\Lambda_{23}} + \dfrac{A_{sol,n}}{\Lambda_{(n-1)n}}}{\dfrac{1}{h_i} + \dfrac{1}{h_e} + \dfrac{1}{\Lambda_{12}} + \dfrac{1}{\Lambda_{23}} + \ldots + \dfrac{1}{\Lambda_{(n-1)n}}}$$

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{\Lambda} + \frac{1}{h_i}$$

$$\Lambda = \left(\sum^{N} \frac{1}{h_s} + \sum^{M} d_m r_m \right)^{-1}$$

How Good are You at Guessing?

The A4 Paper Folding



- **Fold an A4 paper 100 times.**
- **Press out all air between the paper sheets.**
- **Put the paper pile on the table in front of you.**
- **Guess how far above the table does the paper pile reach ?**

Puzzles for You to Solve…

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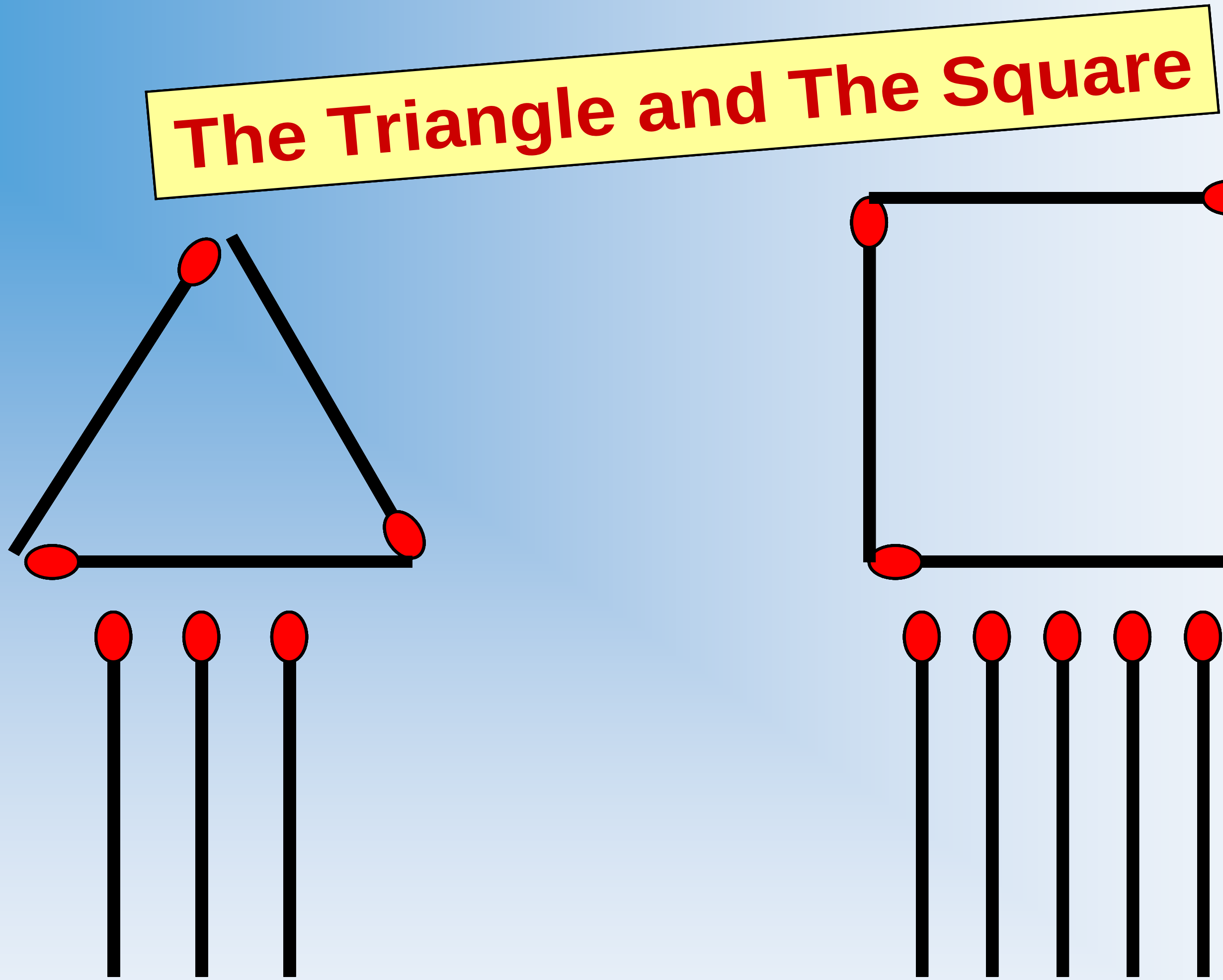


Triangle: **Make 4 identical equilateral triangles *as the one above* (same size also!) out of a total of 6 matches.**

Square: **Make 6 identical squares *as the one above* (same size also!) out of a total of 9 matches.**

Some More Puzzles for You to Solve…

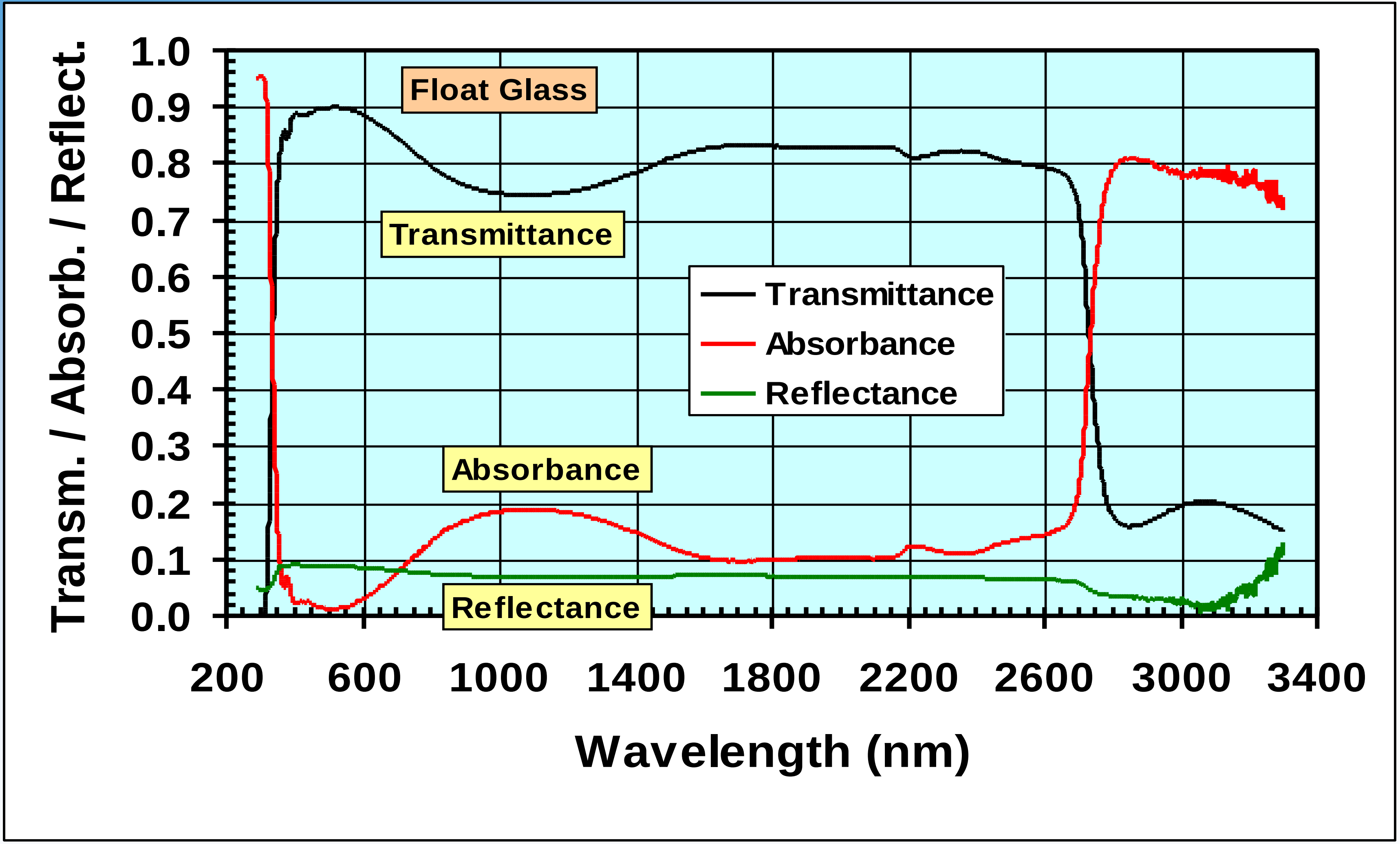
Digging a hole:

5 men digs 4 holes in 3 days.
How long time does one man use to dig half a hole ?

Solve the expression:

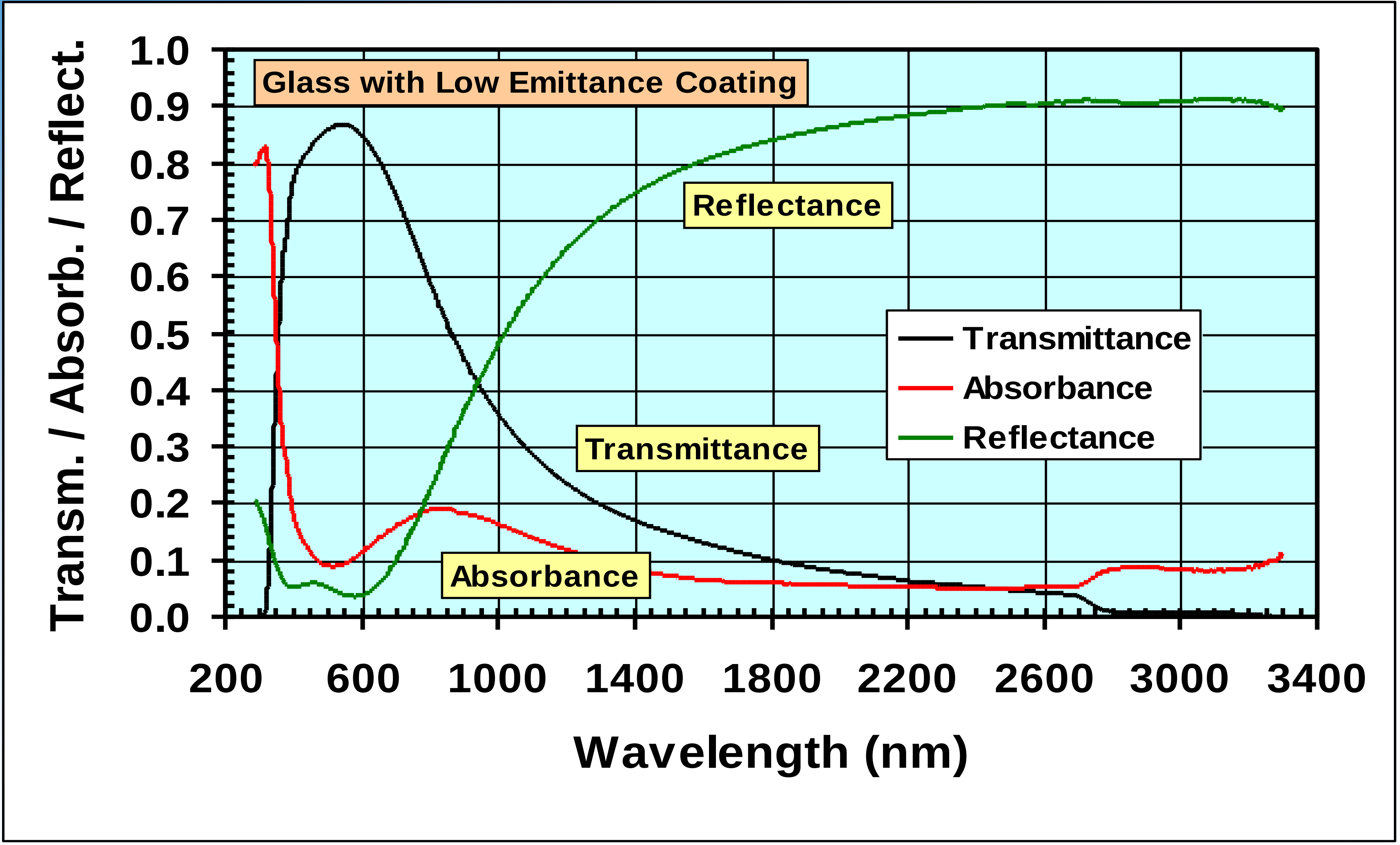
$$(x-a)(x-b)(x-c)\cdot\ldots\cdot(x-z) = ?$$

Spectroscopical Data for Float Glass



ROBUST

Spectroscopical Data for Low Emittance Glass



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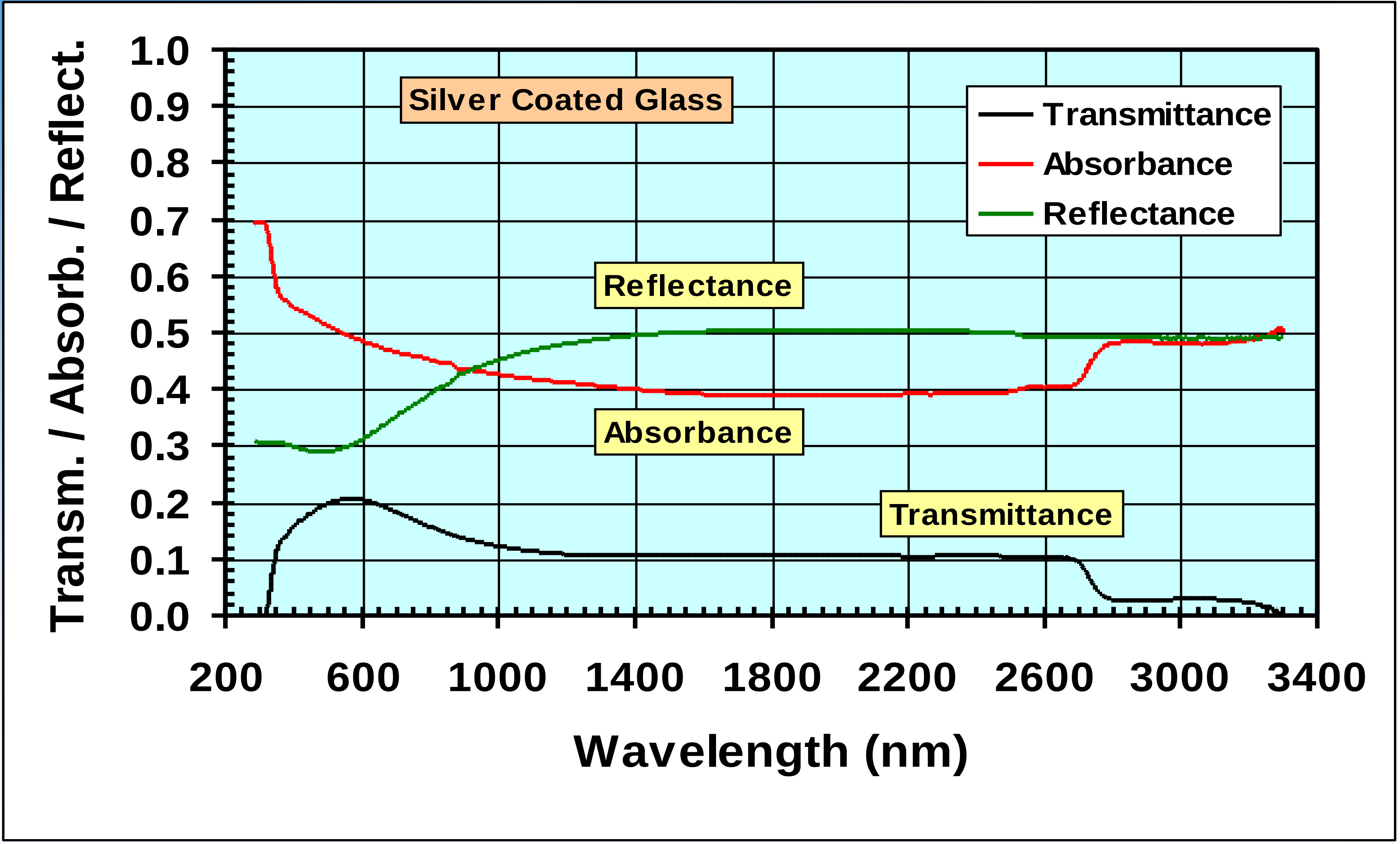
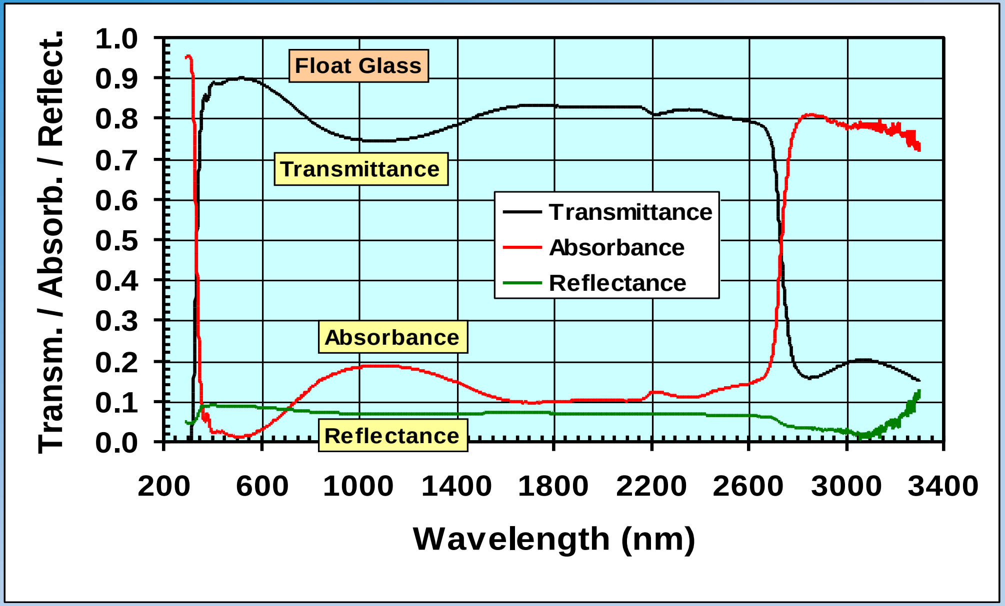
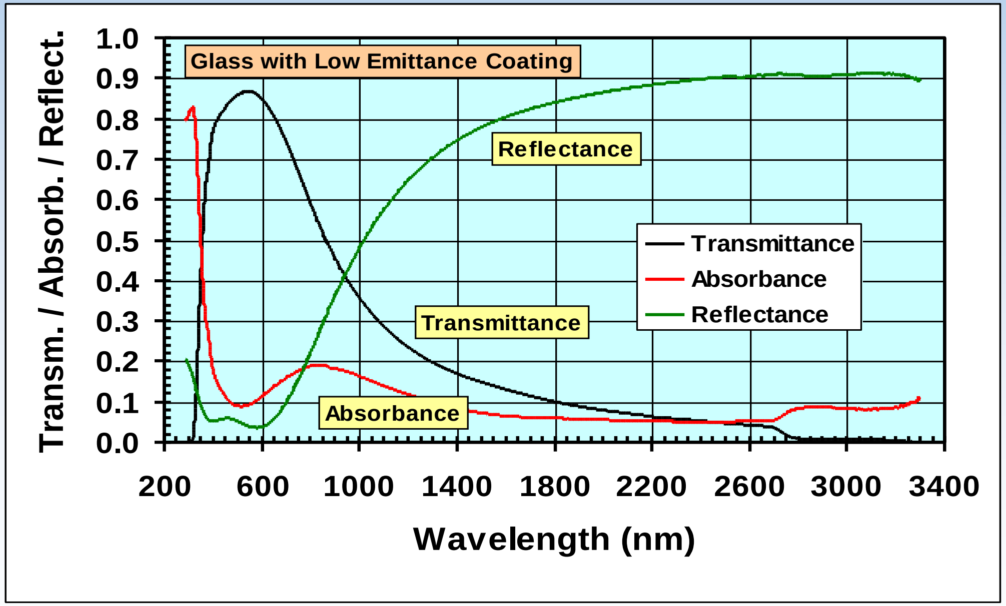
Spectroscopical Data for Dark Silver Coated Glass

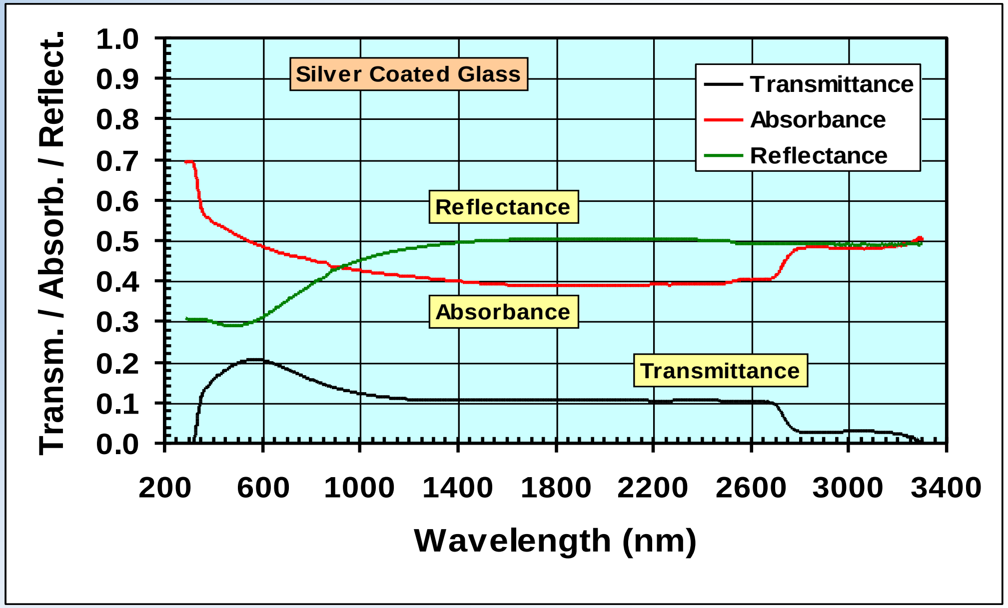


Spectroscopical Data for Miscellaneous Glass

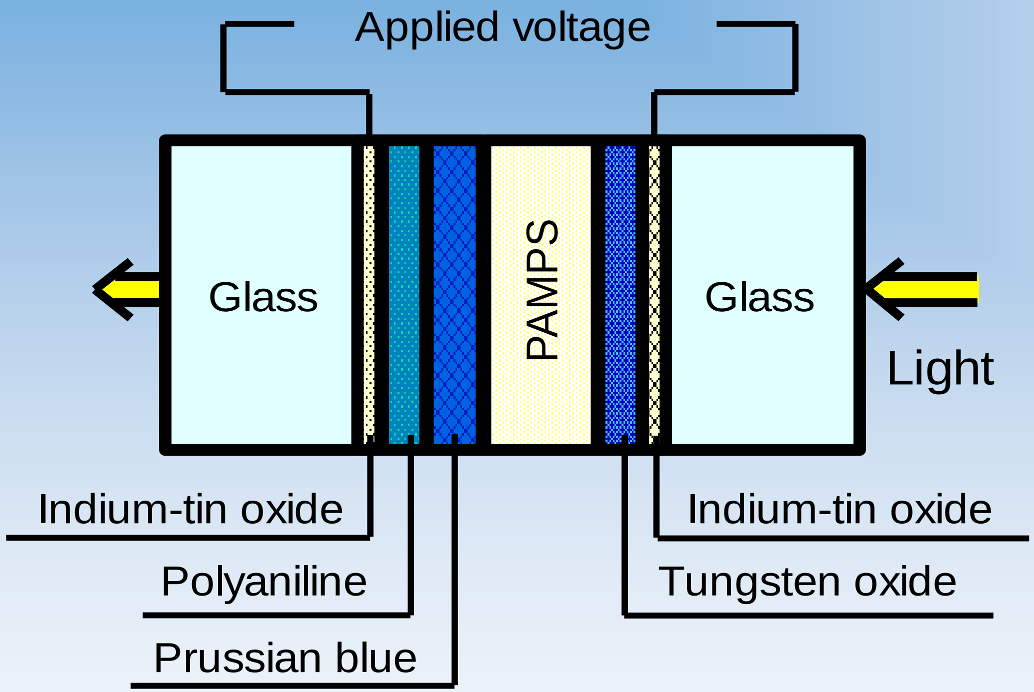
ROBUST



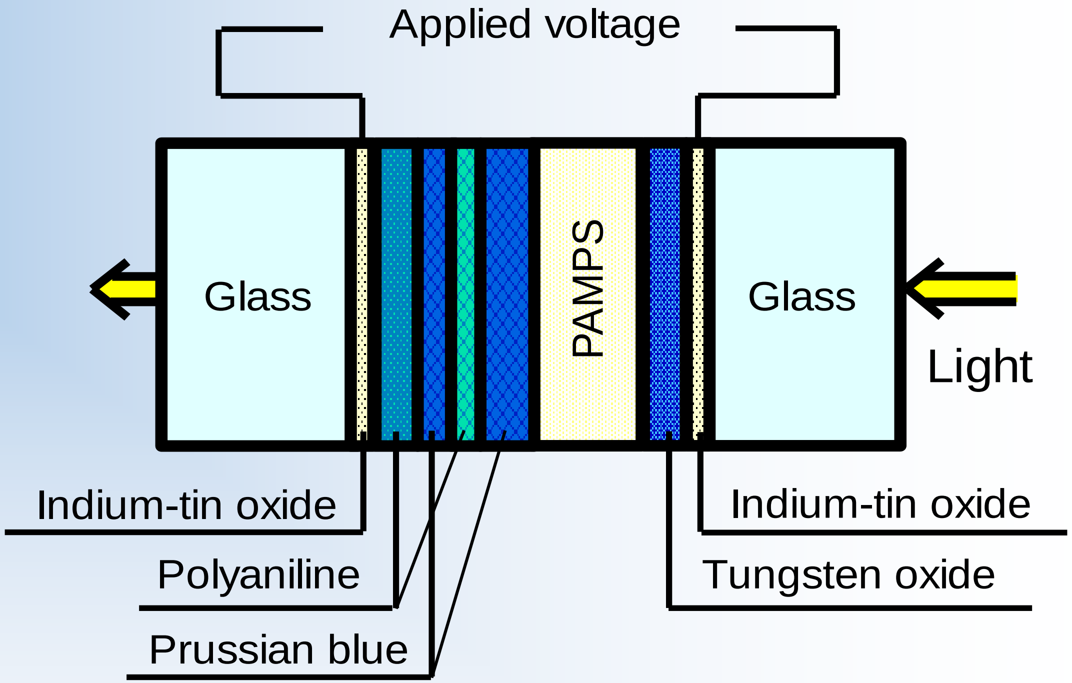




Electrochromic Window Configurations



Window configuration ECW1



Window configuration ECW2 (PANI-PB multilayer)

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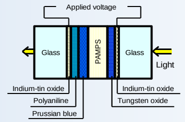
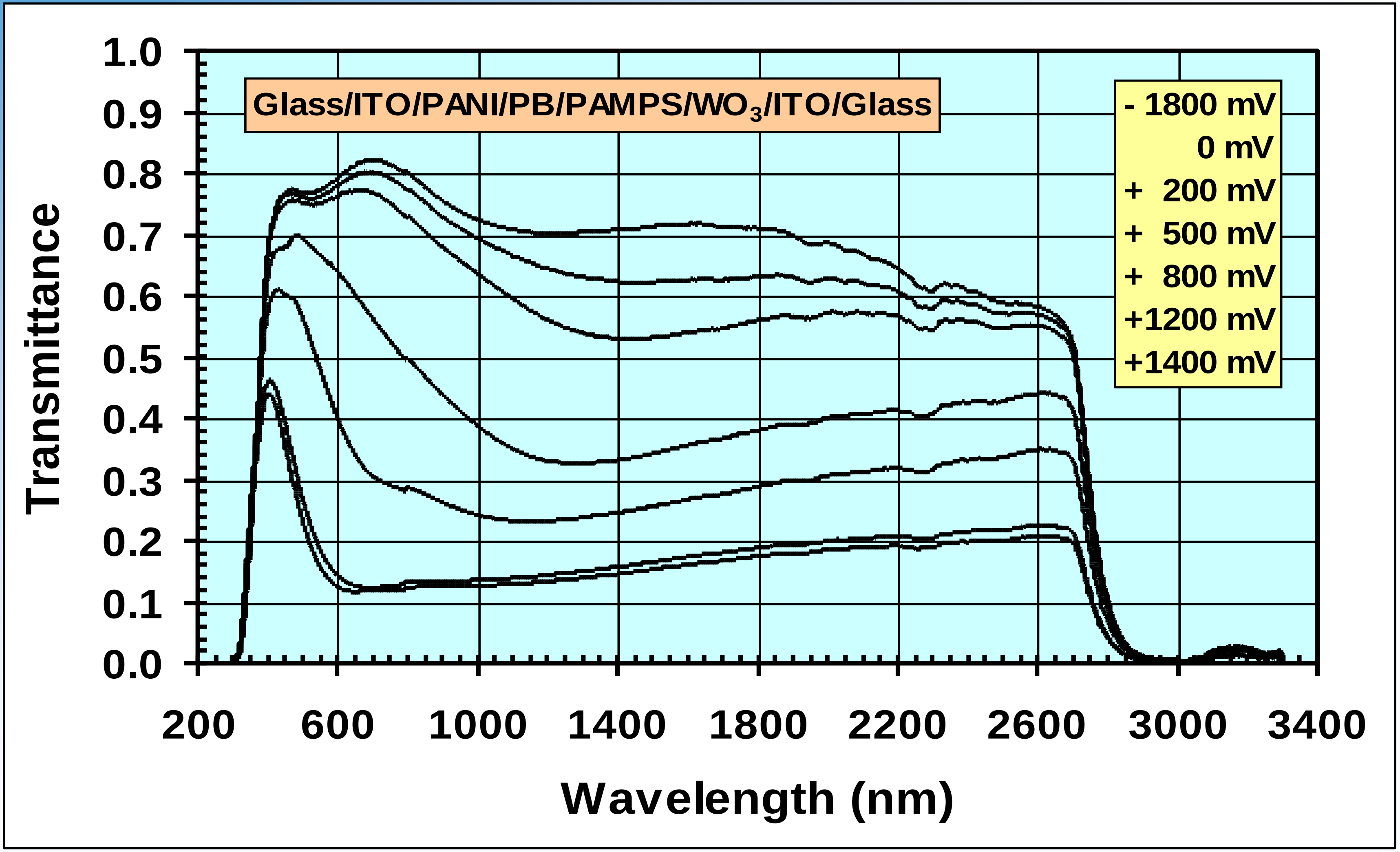
Spectroscopical Data for Electrochromic Windows

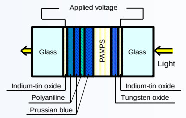
Window configuration ECW1

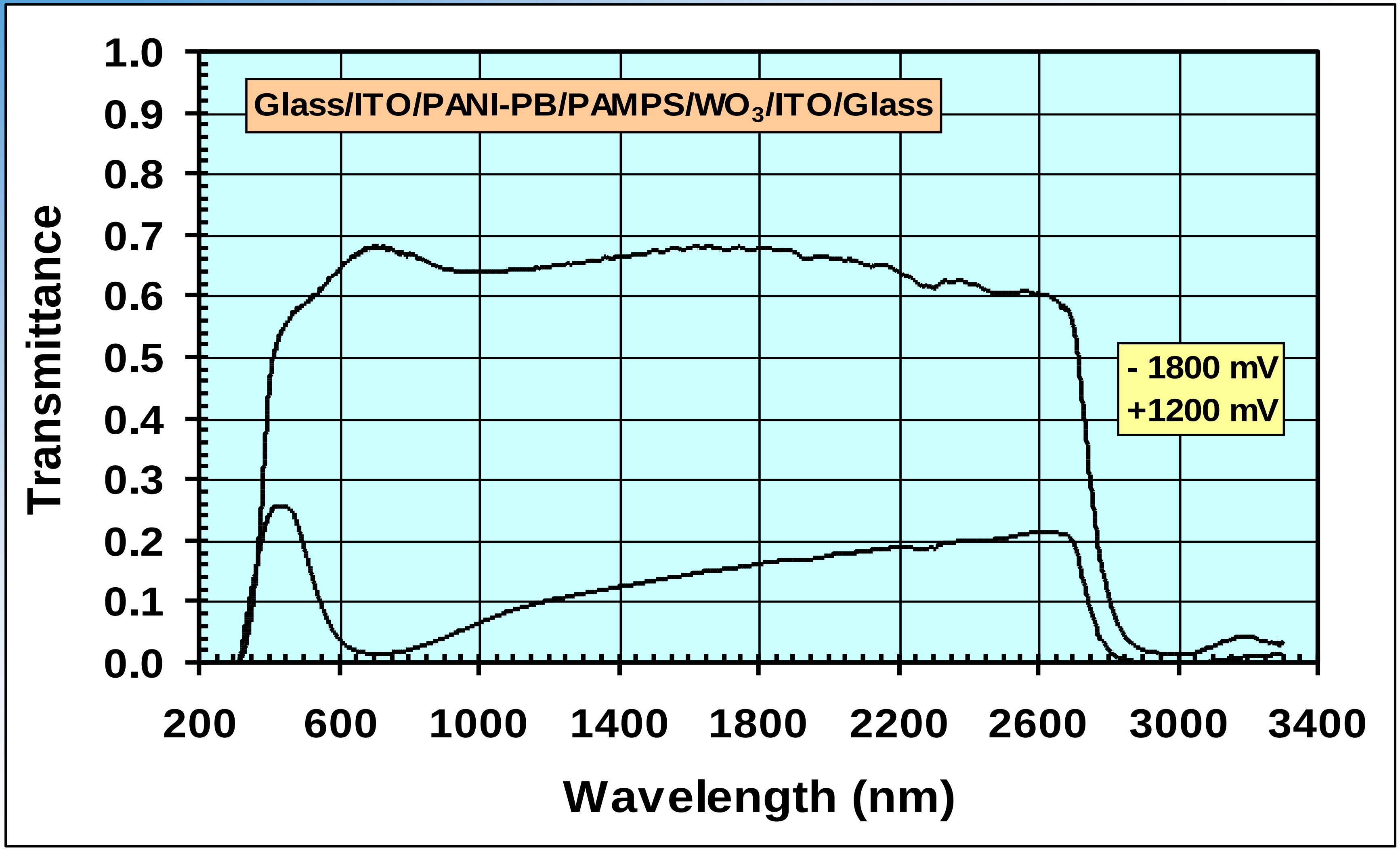




Spectroscopical Data for Electrochromic Windows

Window configuration ECW2 (PANI-PB multilayer)





Solar Radiation Glazing Factors for Miscellaneous Glass (Float – Low Emittance – Dark Silver)

Glass Type	T_{uv}	T_{vis}	T_{sol}	SMPF	SSPF	$R_{vis,ext}$	$R_{vis,int}$	R_{sol}	A_{sol}	ε	SF
Float Glass G	0.65	0.89	0.83	0.20	0.81	0.09	0.09	0.08	0.09	0.836	0.85
Low Emittance Glass LE/G	0.41	0.86	0.59	0.32	0.89	0.04	0.04	0.27	0.14	0.836	0.62
Dark Silver Glass S/G	0.10	0.20	0.16	0.85	0.97	0.30	0.30	0.38	0.47	0.836	0.28

Solar Radiation Glazing Factors for Electrochromic Windows

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Glass Configuration	T_{uv}	T_{vis}	T_{sol}	SMPF	SSPF	$R_{vis,ext}$	$R_{vis,int}$	R_{sol}	A_{sol}	ε	SF
ECW1 (-1800 mV)	0.23	0.78	0.74	0.43	0.93	0.09	0.09	0.08	0.18	0.837	0.79
ECW1 (0 mV)	0.23	0.77	0.72	0.43	0.93	0.09	0.09	0.08	0.21	0.837	0.77
ECW1 (+200 mV)	0.24	0.75	0.68	0.44	0.93	0.09	0.09	0.08	0.24	0.837	0.74
ECW1 (+500 mV)	0.25	0.66	0.52	0.48	0.93	0.09	0.09	0.08	0.40	0.837	0.62
ECW1 (+800 mV)	0.26	0.47	0.36	0.54	0.92	0.09	0.09	0.08	0.56	0.837	0.51
ECW1 (+1200 mV)	0.24	0.19	0.19	0.68	0.93	0.09	0.09	0.08	0.73	0.837	0.38
ECW1 (+1400 mV)	0.23	0.17	0.17	0.71	0.93	0.09	0.09	0.08	0.75	0.837	0.37
ECW2 (-1800 mV)	0.10	0.62	0.61	0.61	0.97	0.09	0.09	0.08	0.31	0.837	0.69
ECW2 (+1200 mV)	0.12	0.10	0.10	0.82	0.97	0.09	0.09	0.08	0.82	0.837	0.31
EC1/Float (-) EC1T/A/G	0.18	0.70	0.62	0.50	0.95	0.14	0.04	0.12	0.26	0.837	0.65
EC1/Float (+) EC1C/A/G	0.18	0.15	0.15	0.75	0.95	0.09	0.04	0.08	0.77	0.837	0.25
EC1/LowE (-) EC1T/A/LE/G	0.12	0.67	0.45	0.55	0.97	0.11	0.03	0.23	0.32	0.837	0.54
EC1/LowE (+) EC1C/A/LE/G	0.12	0.14	0.11	0.78	0.97	0.09	0.03	0.09	0.80	0.837	0.22
EC1/Float/Float (-) EC1T/A/G/A/G	0.15	0.63	0.53	0.55	0.96	0.18	0.17	0.15	0.32	0.837	0.60
EC1/Float/Float (+) EC1C/A/G/A/G	0.14	0.14	0.13	0.78	0.96	0.09	0.17	0.08	0.79	0.837	0.20
EC1/LowE/LowE (-) EC1T/A/LE/G/A/LE/G	0.07	0.58	0.33	0.64	0.98	0.13	0.09	0.25	0.41	0.837	0.45
EC1/LowE/LowE (+) EC1C/A/LE/G/A/LE/G	0.07	0.12	0.08	0.83	0.98	0.09	0.09	0.09	0.83	0.837	0.17
EC2/LowE/LowE (-) EC2T/A/LE/G/A/LE/G	0.03	0.46	0.26	0.74	0.99	0.11	0.09	0.22	0.52	0.837	0.38
EC2/LowE/LowE (+) EC2C/A/LE/G/A/LE/G	0.03	0.07	0.04	0.89	0.99	0.09	0.09	0.08	0.87	0.837	0.13

Solar Radiation Glazing Factor Modulation for Electrochromic Windows

ROBUST

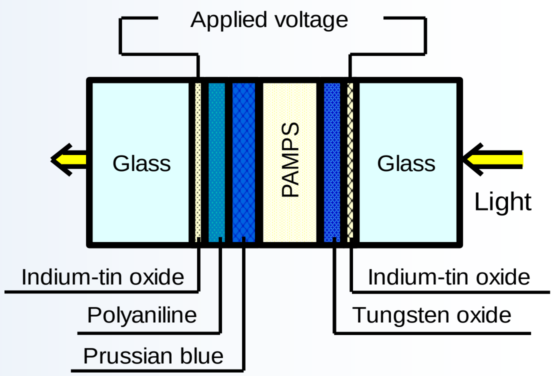
Glass Configuration	ΔT_{uv}	ΔT_{vis}	ΔT_{sol}	ΔSMPF	ΔSSPF	$\Delta R_{vis,ext}$	$\Delta R_{vis,int}$	ΔR_{sol}	ΔA_{sol}	ε	ΔSF
ECW1 (-1800 mV) ECW1 (+1400 mV)	0.00	0.61	0.57	-0.28	0.00	0.00	0.00	0.00	-0.57	-	0.42
ECW2 (-1800 mV) ECW2 (+1200 mV)	-0.02	0.52	0.51	-0.21	0.00	0.00	0.00	0.00	-0.51	-	0.38
EC1/Float (-) EC1T/A/G EC1/Float (+) EC1C/A/G	0.00	0.55	0.47	-0.25	0.00	0.05	0.00	0.04	-0.51	-	0.40
EC1/LowE (-) EC1T/A/LE/G EC1/LowE (+) EC1C/A/LE/G	0.00	0.53	0.34	-0.23	0.00	0.02	0.00	0.14	-0.48	-	0.32
EC1/Float/Float (-) EC1T/A/G/A/G EC1/Float/Float (+) EC1C/A/G/A/G	0.01	0.49	0.40	-0.23	0.00	0.09	0.00	0.07	-0.47	-	0.40
EC1/LowE/LowE (-) EC1T/A/LE/G/A/LE/G EC1/LowE/LowE (+) EC1C/A/LE/G/A/LE/G	0.00	0.46	0.25	-0.19	0.00	0.04	0.00	0.16	-0.42	-	0.28
EC2/LowE/LowE (-) EC2T/A/LE/G/A/LE/G EC2/LowE/LowE (+) EC2C/A/LE/G/A/LE/G	0.00	0.39	0.22	-0.15	0.00	0.02	0.00	0.14	-0.35	-	0.25

Solar Radiation Glazing Factor Modulation for Electrochromic Windows

ROBUST

Solar Radiation Glazing Factor	ECW at -1800 mV	ECW at +1400 mV	Change in Solar Radiation Glazing Factor	ECW from -1800 mV to +1400 mV
T_{uv}	0.23	0.23	ΔT_{uv}	0.00
T_{vis}	0.78	0.17	ΔT_{vis}	0.61
T_{sol}	0.74	0.17	ΔT_{sol}	0.57
SMPF	0.43	0.71	ΔSMPF	-0.28
SSPF	0.93	0.93	ΔSSPF	0.00
$R_{vis,ext}$	0.09	0.09	$\Delta R_{vis,ext}$	0.00
$R_{vis,int}$	0.09	0.09	$\Delta R_{vis,int}$	0.00
R_{sol}	0.08	0.08	ΔR_{sol}	0.00
A_{sol}	0.18	0.75	ΔA_{sol}	-0.57
ε	0.837	0.837	Δε	-
SF	0.79	0.37	ΔSF	0.42

Window configuration ECW1

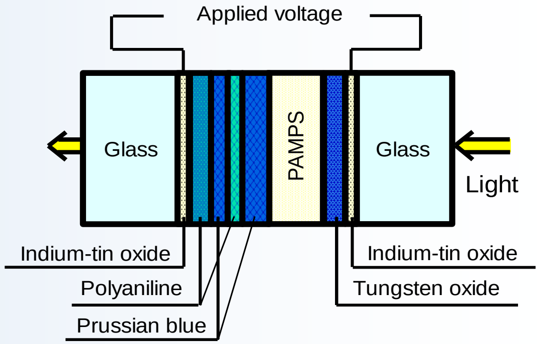


Solar Radiation Glazing Factor Modulation for Electrochromic Windows

ROBUST

Solar Radiation Glazing Factor	ECW at -1800 mV	ECW at +1200 mV	Change in Solar Radiation Glazing Factor	ECW from -1800 mV to +1200 mV
T_{uv}	0.10	0.12	ΔT_{uv}	-0.02
T_{vis}	0.62	0.10	ΔT_{vis}	0.52
T_{sol}	0.61	0.10	ΔT_{sol}	0.51
SMPF	0.61	0.82	ΔSMPF	-0.21
SSPF	0.97	0.97	ΔSSPF	0.00
$R_{vis,ext}$	0.09	0.09	$\Delta R_{vis,ext}$	0.00
$R_{vis,int}$	0.09	0.09	$\Delta R_{vis,int}$	0.00
R_{sol}	0.08	0.08	ΔR_{sol}	0.00
A_{sol}	0.31	0.82	ΔA_{sol}	-0.51
ε	0.837	0.837	Δε	-
SF	0.69	0.31	ΔSF	0.38

Window configuration ECW2



Conclusions

- **Electrochromic windows (ECWs)**
- **Enable a dynamic control of the solar radiation radiation throughput in windows**
- **May readily be characterized by solar radiation glazing factors**

ACKNOWLEDGEMENTS

This work has been supported by the Research Council of Norway through the SINTEF research project ”*Environmentally Favourable Energy Use in Buildings*” and the Research Council of Norway, AF Gruppen, Glava, Hunton Fiber as, Icopal, Isola, Jackon, maxit, Moelven ByggModul, Rambøll, Skanska, Statsbygg and Takprodusentenes forskningsgruppe through the SINTEF/NTNU research project ”*Robust Envelope Construction Details for Buildings of the 21st Century*” (ROBUST).

Solar radiation… dynamically controlled by electrochromic windows… and characterized by solar radiation glazing factors…