Evaluation of Optical and Thermal Properties of Window Glazing

JITKA MOHELNÍKOVÁ [1] AND HAŞIM ALTAN [2]
[1] Institute of Building Structures, Faculty of Civil Engineering, Brno University of Technology, Veveri 95, 662 37 Brno, Czech Republic, E-mail: mohelnikova.j@fce.vutbr.cz
[2] Building Energy Analysis Units, School of Architecture, University of Sheffield, Arts Tower, Western Bank, Sheffield S10 2TN, United Kingdom, E-mail: h.altan@sheffield.ac.uk

Abstract
Optical properties of glazings for window applications serve as input data for the assessment of visual and thermal comfort in buildings. Large amount of advanced glazings are used in many building today. Some special glasses have ability to filter ultraviolet or infrared part of solar radiation, others reduce transmittance of visible light or on the other hand antireflective glazings can increase transmittance for visible radiation. There are also glasses highly reflective for long-wave IR radiation – so called "infrared or heat mirrors". These glasses belong into the main group of glasses recommended for architectural purposes generally called as low-emissivity glazings. This paper topic is aimed at the classification of low-emissivity glasses and the comparison of their properties with ordinary glass transmittance and reflectance.

Keywords
Glazings for window applications, light transmittance and reflectance, solar transmittance and reflectance, visible radiation, daylighting, wavelength, glass coatings, low-emissivity glazings, solar radiation, thermal comfort in buildings.

1. Introduction

Increasing demands for energy savings in buildings have led to the glass unit production. Glass units contain minimal two layers of glass panes with distant cavity sealed together as one glass product. The air within the cavity of glass units is very often replaced by insulating gas as argon, krypton or xenon for reduction of heat losses through glazings. Insulation gas SF_6 is used for acoustics purposes [9]. In addition to the possibility of insulating gases the cavity of glass units can be filled with special gels for different applications and purposes, for example for increasing of thermal insulation and/or fire resistant properties or in the protection against glare effect in the case of large glazed cladding areas [13].

The insulating filling itself within the glass unit cavity can not be sufficient for strict demands on the thermal insulation of glazed parts of claddings and windows. For this reason special glazings were developed to reduce heat losses and enhance indoor thermal comfort in buildings. Glasses highly reflective in long-wave infrared radiation range are called in the optical terminology as "infrared or heat mirrors", but technical publications have often used the term of "low-emissivity glazings".

Low-emissivity glasses have one surface coated by special thin film for the purpose to improve their optical properties in a comparison with parameters of the ordinary glass. Low-emissivity (Low-e) glazings are made by applying of thin metal coatings (for example clear silver or tin oxide) on the glass [1], [4], [9], [12], [13]. Transparent metallic coating allows transmission of visible light through the glass pane but on the other hand it reduces significantly radiation losses of the glazing. Low-e thin film coatings deposited on the glass could reflect about ninety percent of the long wave infrared radiation back to the building interior. Low-emissivity coatings were developed in the early 1970s [1], [9].

The low-e glazing production has two main types of coatings - soft and hard coatings. The soft coating is deposited on the finished glass substrate (sputtered coating in a vacuum chamber) and the hard coating is incorporated into the surface during the glass manufacturing process (pyrolitic coating). The hard coating is more durable than the soft coating. The glass surface with soft coating must be closed into the sealed double or triple glass unit [1], [4], [9]. Single glazing systems have hard coating films.

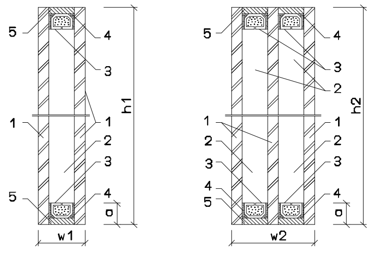

Fig 1 Scheme of a double and triple glazed unit
1-glass pane, 2-cavity, 3-distant edge profile, 4,5-sealants
a-glass unit edge, w1,w2-widths, h1, h2-heights of units

New types of glazings have a polyester foil with low-e coatings suspended within the cavity of the double glazed unit [4], [11]. This glazing operates as a triple pane unit but is not so heavy and it has higher solar transmittance compare to ordinary three-glass-pane unit.

2. Optical and thermal properties of glass

Optical properties of glazings determined according to standards EN 410 [15] as glass characteristics (see figure 4) are represented by the following parameters:

- Transmittance of UV part of solar radiation τ_{UV}
- Visible radiation transmittance τ_V
- Reflectance of visible radiation ρ_V (reflectance on the coated surface)
- Reflectance of visible radiation ρ'_V (reflectance on the surface without the coating)
- Solar spectral transmittance $\tau(\lambda)$ and reflectance $\rho(\lambda)$ for wavelength range from 280 to 2500 nm
- Direct solar radiation transmittance τ_e
- Direct solar radiation reflectance ρ_e (reflectance on the coated surface), ρ'_e (reflectance on the surface without the coating)
- Solar factor (total solar energy transmittance) **g**
- Normal emissivity ε_n
- General colour rendering index R_a

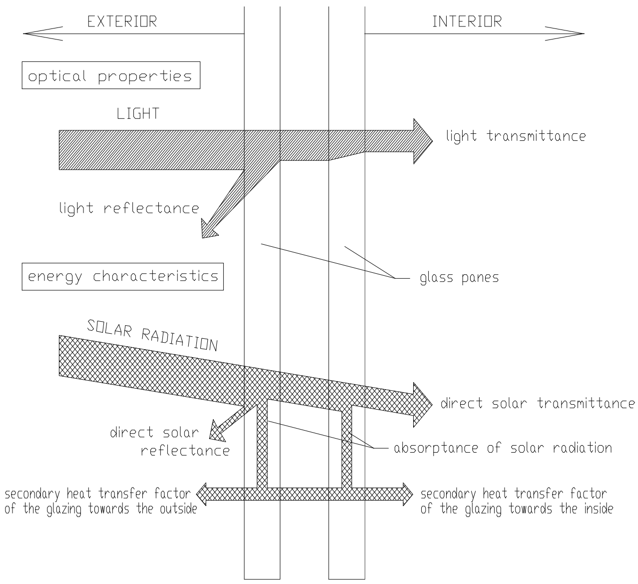

Fig 2 Glass optical properties and energy characteristics

2.1 Direct solar radiation transmittance

The total transmittance of direct solar radiation through the glass is recommended to consider in the wavelengths range from 300 to 2800 nm [13], [14] (the transmission of ordinary glasses at wavelengths lower than 300 nm has neglected values).

$$\tau_e = \frac{\int_{\lambda=300}^{2500} S_\lambda \tau(\lambda) d\lambda}{\int_{\lambda=300}^{2500} S_\lambda d\lambda} \tag{2}$$

where
S_λ …spectral distribution of energy from solar radiation
$\tau(\lambda)$…spectral transmission

For double and triple glazed units the spectral transmission $\tau(\lambda)$ could be calculated in the following way [14]

- spectral transmission of double glazed units

$$\tau(\lambda) = \frac{\tau_1(\lambda)\tau_2(\lambda)}{1-\rho'_1(\lambda)\rho_2(\lambda)} \tag{3}$$

- spectral transmission of triple glazed units

$$\tau(\lambda) = \frac{\tau_1(\lambda)\tau_2(\lambda)\tau_3(\lambda)}{[1-\rho'_1(\lambda)\rho_2(\lambda)][1-\rho'_2(\lambda)\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\rho_3(\lambda)} \tag{4}$$

where

$\tau_1(\lambda)$ spectral transmission of the outer glass
$\tau_2(\lambda)$ spectral transmission of the second glass
$\rho_1(\lambda)$ spectral reflection of the outer glass, measured in the direction of propagated radiation
$\rho'_1(\lambda)$ spectral reflection of the outer glass, measured against the direction of propagated radiation
$\rho_2(\lambda)$ spectral reflection of the inner glass, measured in the direction of propagated radiation
$\tau_3(\lambda)$ spectral transmission of the third glass
$\rho'_2(\lambda)$ spectral reflection of the second glass, measured against the direction of propagated radiation
$\rho_3(\lambda)$ spectral reflection of the third glass, measured in the direction of propagated radiation

2.2 Reflectance of solar radiation

Glass reflectance of direct solar radiation [14] is calculated according to the following formula:

$$\rho_e = \frac{\int_{\lambda=300}^{2500} S_\lambda \rho(\lambda) d\lambda}{\int_{\lambda=300}^{2500} S_\lambda d\lambda} \tag{5}$$

where $\rho(\lambda)$ spectral reflection of glazing
S_λ spectral distribution of energy from solar radiation

Spectral reflection of glass units [14] is determined according to the following equations (6) and (7):

- spectral reflectance of double glazed units:

$$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\rho_2(\lambda)}{1-\rho'_1(\lambda)\rho_2(\lambda)} \tag{6}$$

- spectral reflectance of triple glazed units:

$$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\rho_2(\lambda)[1-\rho'_2(\lambda)\rho_3(\lambda)] + \tau_1^2(\lambda)\tau_2^2(\lambda)\rho_3(\lambda)}{[1-\rho'_1(\lambda)\rho_2(\lambda)][1-\rho'_2(\lambda)\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\rho_3(\lambda)} \tag{7}$$

2.3 Light transmittance and reflectance

Visible part of solar radiation in the range of wavelengths from 380 to 780 nm is important for daylighting simulations. Light transmittance τ_v [14] of a single glazing

$$\tau_v = \frac{\int_{\lambda=380}^{780} D_\lambda \tau(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380}^{780} D_\lambda V(\lambda) d\lambda} \quad (8)$$

where

$\tau(\lambda)$ spectral light transmission

D_λ relative spectral power distribution of illuminant D_{65}

V_λ photopic luminous efficiency function

Light reflectance ρ_v [14] is determined from the equation

$$\rho_v = \frac{\int_{\lambda=380}^{780} D_\lambda \rho(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380}^{780} D_\lambda V(\lambda) d\lambda} \quad (9)$$

where

$\rho(\lambda)$ spectral light reflection

D_λ relative spectral power distribution of illuminant D_{65}

V_λ photopic luminous efficiency function

For the determination of light transmission $\tau(\lambda)$ and reflection $\rho(\lambda)$ of double and triple glazed units the equations (3), (4), (6), (7) can be used.

2.4 Absorptance of solar radiation

Absorptance of solar radiation within the glass α_e is determined from the equation (1) and relations for solar transmittance and reflectance (2) and (5) as

$$\alpha_e = 1 - \tau_e - \rho_e \quad (10)$$

Absorbed part from solar radiation is divided into two components q_i and q_o, where q_i is secondary heat transfer factor of the glazing toward the interior in buildings and q_o is secondary heat transfer of the glazing toward outdoors [14], [15].

Heat transfer coefficients on the inner and outer side of the glazing h_i, h_e [$Wm^{-2}K^{-1}$] are important for the determination of the value of q_i. These coefficients depend mainly on the kind of the glass pane and its surface, on the position and installation of the glass in building envelopes, on wind speed and air convection along a glass surface, on indoor and outdoor temperatures and also on temperatures on inner and outer surface of a glass pane.

Radiant flux from the glass to the inside is determined for single glazings and for double and triple glass units as:

- single glazing:

$$q_i = \alpha_e \frac{h_i}{h_e + h_i} \quad (11)$$

- double glazed unit:

$$q_i = \frac{\left(\frac{\alpha_{e1} + \alpha_{e2}}{h_e} + \frac{\alpha_{e2}}{\Lambda}\right)}{\frac{1}{h_i} + \frac{1}{h_i e} + \frac{1}{\Lambda}} \quad (12)$$

- triple glazed unit:

$$q_i = \frac{\left(\frac{\alpha_{e1}}{\Lambda_{23}} \frac{\alpha_{e3} + \alpha_{e2}}{\Lambda_{12}} + \frac{\alpha_{e3} + \alpha_{e2} + \alpha_{e1}}{h_e}\right)}{\frac{1}{h_i} + \frac{1}{h_e} + \frac{1}{\Lambda_{12}} + \frac{1}{\Lambda_{23}}} \quad (13)$$

where

Λ thermal conductivity between the outer and inner glass pane

Λ_{12} thermal conductivity between the outer and second glass pane

Λ_{23} thermal conductivity between the second and third glass pane

h_i heat transfer coefficient on the inner glass surface

h_e heat transfer coefficient on the glass outer surface

α_{e1}, α_{e2}, α_{e3} absorptance of the outer, second, third glass

2.5 Emissivity of glass

Transmittance of solar radiation inside of the building could significantly increase indoor temperature in the consequence of the so call greenhouse effect.

Solar radiation transmitted through the glass acting on interior surfaces where it is partially reflected and absorbed (within non-transparent constructions). After the absorption the energy of solar radiation transforms into qualitatively different kind of energy. The transformation into thermal energy is characteristic for building constructions. These constructions are heated and their surfaces radiate long-wave infrared radiation of the spectral range from 5 to 50 μm.

The ordinary glass is opaque for long wave infrared radiation that it is emitted from interior surfaces of common constructions with surface temperatures lower than 100°C. There is also very low glass reflectance in the IR range - $\rho(\lambda)\rightarrow 0$ and $\tau(\lambda)=0$, for the wavelengths range in the interval of $\lambda \in \langle 5\ \mu m, 50 \mu m \rangle$. From equation (1) derived on the principle of energy balance is obvious high glass absorptance in long-wave IR range, shortly described $\alpha(\lambda)\rightarrow 1$, for spectral range $\lambda \in \langle 5\ \mu m, 50 \mu m \rangle$.

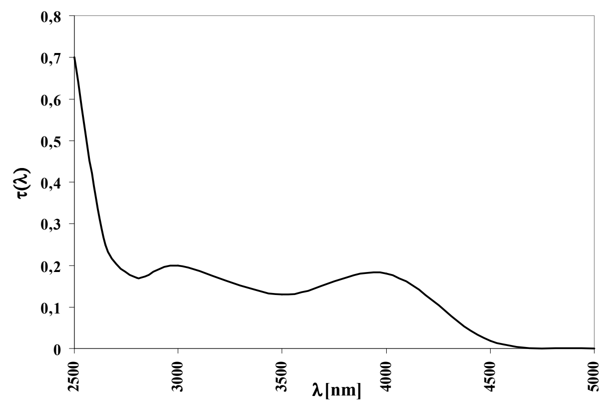

Fig 3 Spectral transmission of glass Float in near-infrared range of wavelengths between λ=2500 and λ=5000 nm

Energy $M(\lambda,T)$ [Wm^{-2}] emitted from the real (grey) body surfaces at the temperature T [K] is according to Kirchhoff law [8] derived as

$$M(\lambda,T) = \alpha(\lambda)\sigma T^4 = \varepsilon(\lambda)\sigma T^4 \quad (14)$$

where

$\alpha(\lambda)$ absorptance of the real (grey) body in the infrared part of electromagnetic radiation

$\varepsilon(\lambda)$ emissivity of the surface

$\sigma = (5.67051 \pm 0.00019).10^{-8} [\mathrm{Wm}^{-2}\mathrm{K}^{-4}]$ Stephan - Boltzmann constant [8]

From equation (14) is obvious, that surface absorptance is directly proportional to its emissivity. That practically means high thermal losses through window glazings during could days with low outdoor temperature. Heat accumulated inside of glass panes is lost by radiation and also convection (outdoor could air flows round the glass surface).

Heat losses could be limited in the way mentioned in chapter 1. The thin film coating is deposited on the glass surface. This film must have very high visible transmittance and very high infrared reflectance $\rho(\lambda)\to 1$ for the interval of $\lambda \in \langle 5\mu m, 50\ \mu m\rangle$.

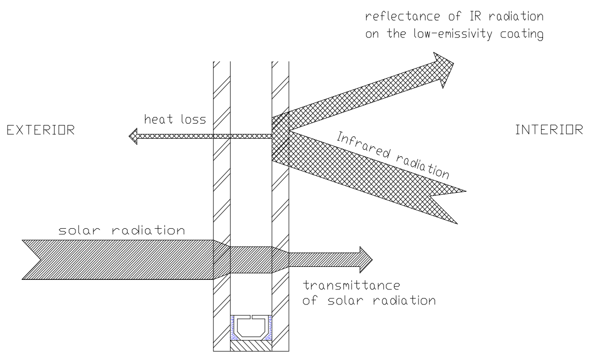

Fig 4 Function of low-emissivity glazings

Thin metal coatings have very high reflectance and low emissivity in the above mentioned range of IR radiation (the lower emissivity of the coating represents the higher surface reflectance). This assumption could be explained on the basis of the validity of equation (1) and (14) and the fact that the glass is non-transparent material for long wave infrared radiation. On the basis of these assumptions the relation between reflectance and emissivity in the infra-red range could be expressed as

$$\rho(\lambda) = 1 - \varepsilon(\lambda) \quad (15)$$

Emissivity depends on the temperature of the body and then on the wavelength of radiation emitted from it. The mean value of emissivity for given range of wavelengths $\lambda \in \langle \lambda_1, \lambda_2 \rangle$ is derived in the following equation

$$\bar{\varepsilon} = \frac{\int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda) \frac{dM(\lambda)}{d(\lambda)}}{\int_{\lambda_1}^{\lambda_2} \frac{dM(\lambda)}{d(\lambda)}} \quad (16)$$

The mean emissivity of the ordinary glass is about $\bar{\varepsilon}$ = 0.83 to 0.84 [9] and the average reflectance reaches value from 16 to 17 % ($\bar{\rho}$ = 0.16 – 0.17). Low-emissivity glazings have $\bar{\varepsilon}$ = 0.2 – 0.1 (or even lower) that indicates for high reflectance $\bar{\rho}$ = 0.90 and more.

2.6 Total energy transmitted through the glazing

The total energy transmitted through the glass pane or glass unit is expressed by coefficient of total transmittance of solar radiation energy g, which is called as solar factor

$$\phi_i = \phi.g \quad (17)$$

where ϕ_i total radiant flux going into the room

ϕ total radiant flux acting on the glass surface

Solar factor g consists of direct solar transmittance τ_e from equation (2) and part q_i from (11), (12), (13), which represents radiant flux from the glass inside of the room. This flux is considered as a side effect caused by absorption of solar radiation in the glass pane

$$g = \tau_e + q_i \quad (18)$$

As it has been noted in chapter 2.4, the determination of the component q_i depends on heat transfer coefficients h_i a h_e. These coefficients have values in accordance with standard recommendations [14], [16]

$h_e = 23\ \mathrm{Wm^{-2}K^{-1}}$ $\quad h_i = 3.6 + \frac{4{,}4\varepsilon_i}{0.83}\ \mathrm{Wm^{-2}K^{-1}}$

These values are valid for the following conditions:

- Outer surface: wind speed 4 $\mathrm{ms^{-1}}$, emissivity $\varepsilon = 0.83$
- Inner surface: natural convection, emissivity ε_t depends on the coating - for example:

if ε_t=0.83 $\Rightarrow$ h_i= 8 $\mathrm{Wm^{-2}K^{-1}}$, if ε_t=0.1 $\Rightarrow$ h_i = 4.1 $\mathrm{Wm^{-2}K^{-1}}$

The following figure shows the distribution of energy from solar radiation going through glazing.

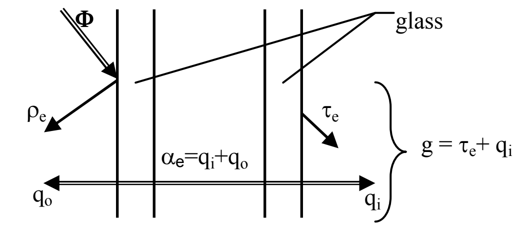

Fig 5 Distribution of solar radiation within the glass unit

3. Optical properties of selected glasses

Two selected glass samples (as glass Float and low-emissivity glazing) had been spectrally measured and their glazing characteristics were determined according to above mentioned equations (chapter 2) to compare their optical properties. The thicknesses of both glass samples were 4 mm.

Spectral transmission $\tau(\lambda)$ and reflection $\rho(\lambda)$ of the investigated glass samples were measured in the range of wavelengths from 280 to 2500 nm by the spectrometer. Properties of these glasses were also determined in the interval of IR radiation $\lambda \in \langle 5\mu m, 11\mu m\rangle$. This range was investigated for specification of the spectral reflectance coefficient at the wavelength of 10 μm. This wavelength corresponds in accordance with Wien law [8] to infrared radiation at temperature of 20°C (common room indoor temperature)

$$T\lambda_{max} = A \qquad (19)$$

where A= (2.897 ± 0.00013).10^{-3} [mK] constant for black body derived from Planck law [8].The above mentioned temperature and wavelength are crucial in the design of low-emissivity coatings for window glasses.

Spectral measurements ware carried out by two spectrometers: VARIAN CARY 5E (wavelength measuring range from 185 to 3300 nm) and ZEISS SPECORD M80 (wavelength measuring range from 2.5 to 50 μm). The spectral data were plotted into the graphs that are shown in Figures 6, 7 and 8. The glass Float (see Fig 6) has similar transmittance for UV radiation and visible light in comparison with sample B. Both glasses limit UV radiation up to wavelength of 300 nm.

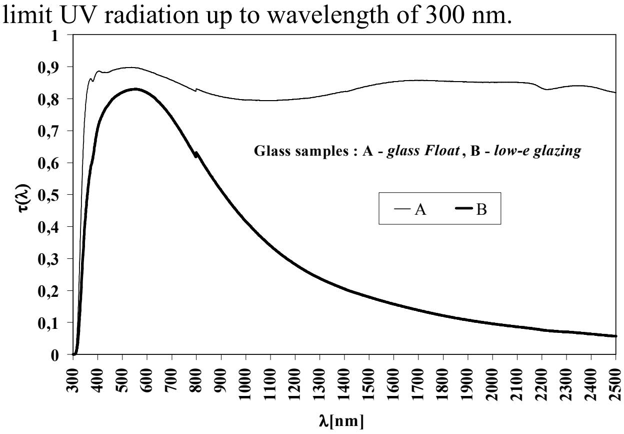

Fig. 6 Spectral transmission of selected glazings

The low-emissivity glazing-sample B has sufficient transmittance τ = 0.83 in the visible range. At the beginning of the IR range the transmission curve declines and from wavelength λ=2.5 μm this glass is non-transparent τ(λ)→0. Low-emissivity glazing reflectance is increased on account of a low transmittance (Fig.7).

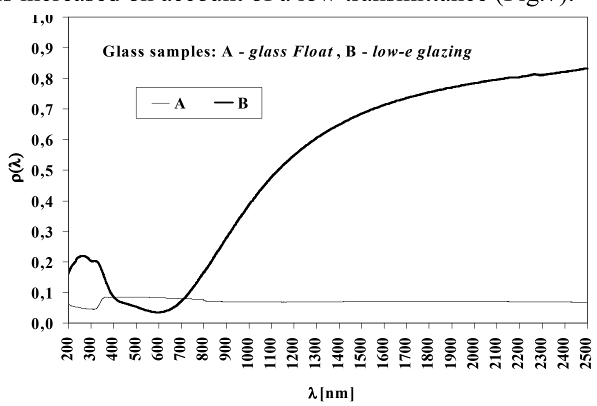

Fig. 7 Spectral reflection of selected glazings

The low-emissivity glazing absorbs more visible light than the ordinary Float glass. This effect is caused by a thin metal film coated on the glass surface. The existence of this coating is obvious from the comparison of visible reflectance ρ(λ=555nm) and absorptance values α(λ=555nm) in Table 1.

Glass	τ(λ=555nm)	ρ(λ=555nm)	α(λ=555nm)
Sample A	0.897	0.085	0.02
Sample B	0.83	0.04	0.14

Table 1) Visible range optical properties of glass samples

The following table presents glazing characteristics of investigated glass samples calculated according to equations (2), (5), (11), (18). These characteristics can be divided into two thematic groups as characteristics of solar loss of the glazing and characteristics of solar gain through the glazing.

characteristics	Glass sample A	Glass sample B
Solar loss of the glazing		
ρ_e	0.08	0.26
q_o	0.06	0.153
Solar gain through the glazing		
τ_e	0.84	0.56
q_i	0.02	0.027
g	0.86	0.587

Table 2) Properties of the investigated glass samples

Measurements in the long-wave IR range have proven (Fig 8) that glass sample B has very high reflectance (min ρ=0.87) and in the vicinity of the wavelength of 10 μm the reflectance reaches value of ρ = 0.915. This glass really operates as an infrared (heat) mirror.

Precious metals as silver, gold or copper are used for low-emissivity thin film coatings. The design of a composition (materials and thickness) of these special coatings and their deposition on glass substrates are based on the theoretical basis of Optics of thin films [2].

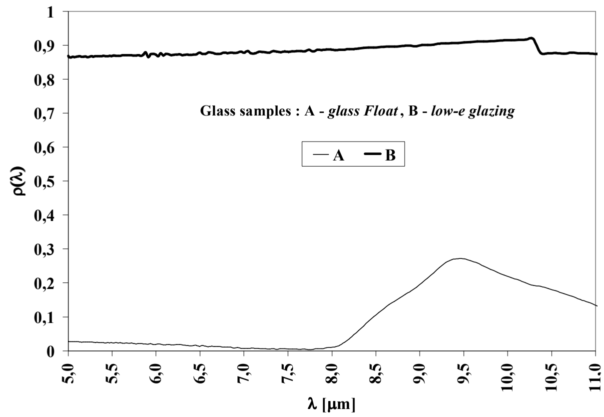

Fig. 8 Spectral reflection of selected glasses in infrared radiation range (wavelength interval between 5 and 11 μm)

4. Window glasses and thermal balance in rooms

Window glazings could significantly influence the energy balance in buildings. Low-e double glazed unit with overall heat coefficient U=1.8 $Wm^{-2}K^{-1}$ was compared to ordinary float glass unit - U=2.9 $Wm^{-2}K^{-1}$. The comparison of energy balances of the selected glazings were carried out for the reference room of dimensions 3.3m x 5m with a window 1.2 m x 1.5 m - South orientation. Thermal resistances of individual building constructions were determined as: peripheral wall 2.5 m^2WK^{-1}, internal wall 1.2 m^2WK^{-1}, partition 0.26 m^2WK^{-1}, roof 3.3 m^2WK^{-1}, floor 1.5 m^2WK^{-1}.

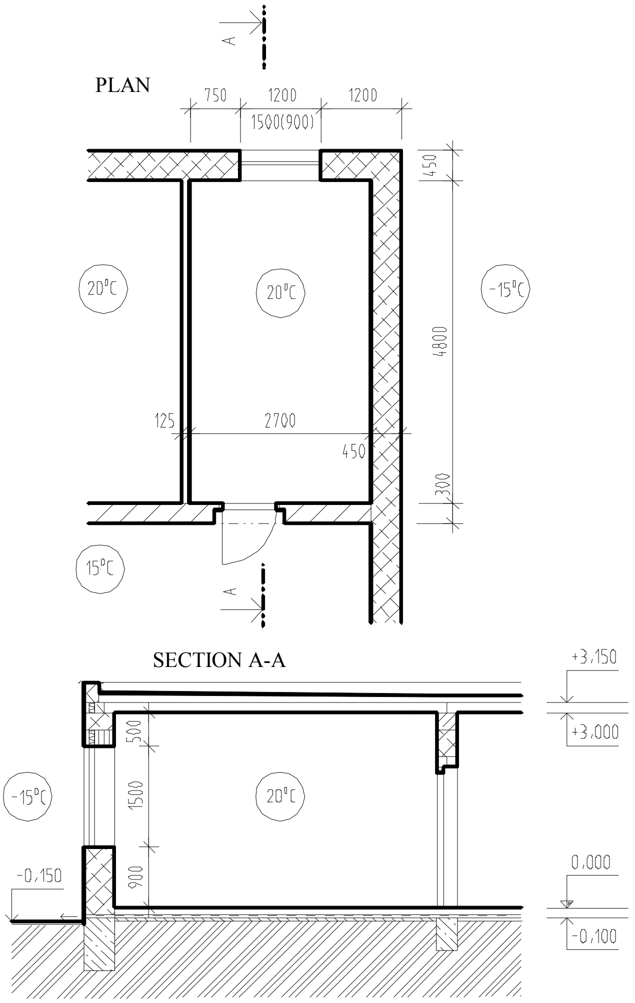

Fig. 9 Plan and section of the reference room

Energy balance of the reference room per month						
Month	**window** (1200mm x 1500mm)					
	Double glazed unit *(4mm glass -12mm air-4mm glass)*			**Low-e double glazed unit** *(4mm glass-12mm air- 4mm low-e glazing)*		
	HL	SG	EB	HL	SG	EB
October	186.73	48.43	138.30	162.00	38.75	123.25
November	249.00	33.60	215.40	219.23	26.88	192.35
December	299.60	29.70	269.90	265.28	23.76	241.52
January	313.70	40.24	273.46	278.18	32.19	245.99
February	269.55	51.15	218.40	238.62	40.92	197.70
March	273.75	73.41	200.34	241.60	58.73	182.87
April	189.88	59.83	130.05	165.10	47.87	117.23
Total energy balance of the room for the heating season						
October to April	HL	SG	EB	HL	SG	EB
	1782.21	336.4	**1445.9**	1570.01	269.1	**1300.91**
Energy savings 145 kWh						

HL - Heat loss [kWh/month], SG - Solar gain [kWh/month]
EB – Energy balance = Heat loss – Solar gain [kWh/month]

Table 3) Influence of glazings on energy balance of the reference room

A glazed area of twenty similar windows could represent significant energy savings in the case of low-e glazing (about 10.5 GJ) to compare the clear glass.
On the other hand special glazings with very low U-value [$Wm^{-2}K^{-1}$] mounted in ordinary frames in highly insulated façade could be a risk for condensation problems.

Window frames and metal edge frames of double glazed units could act as thermal bridges – as it is obvious from figure 10. This figure present a thermo-camera photograph of a part of a façade with low-e double glazed units in wooden frames (U=1.80 $Wm^{-2}K^{-1}$). Temperature profiles have shown high temperature at the position of wooden frames. Highest temperature was monitored at the boundary between the glass pane and frame. This effect is caused by a metal distant frame of the double glazed unit.

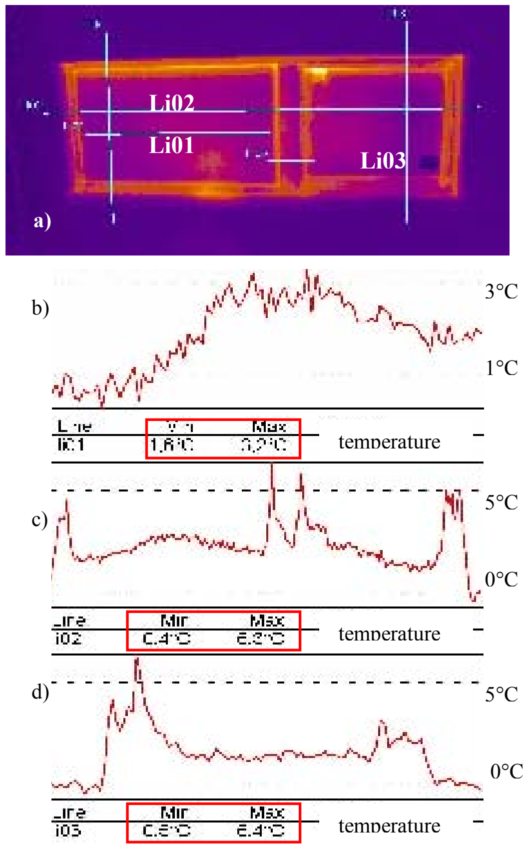

Fig. 10 Thermo-camera photograph of a facade with low-e glazing in wooden frame
a) Thermo-photograph of the window
b) temperature profile of the glass pane unit
c) temperature profile of the window in a horizontal section
d) temperature profile of the window in a vertical section

5. Double glazed units with insulation gas infill

The above mentioned considerations were carried out for window glazings that have improved their optical properties via IR reflective thin films. These films could only limit radiation heat losses. Convection heat losses of window glass units can be reduced by insulating gases filled into the cavity between two glass panes.

The following table presents U-values [$Wm^{-2}K^{-1}$] of a double glazed unit with two glass panes (one as a low-e glazing, th. 4 mm and the second one as float clear glass, th. 4mm) and insulating gases. U values were calculated in accordance with [16] for different slope of glass units from vertical position 90° to horizontal glazing 0°.
In calculations were considered that emissivity of the clear glass is ε_1=0.837, emissivity of the low-e glass is ε_2 =0.100. U-value determination of a double glass unit depends also on Grashoff, Prandtl and Nusselt number – see table 4.

gas	Slope of glass	Gr	Pr	Nu	U [$Wm^{-2}K^{-1}$]
Air	90°	4397.646	0.71117	0.745	**1.8**
	45°	4397.646	0.71117	1.523	2.0
	0°	4397.646	0.71117	1.212	2.25
Argon	90°	5509.132	0.66693	0.792	**1.45**
	45°	5509.132	0.66693	1.274	1.65
	0°	5509.132	0.66693	1.594	1.85
Krypton	90°	15973.315	0.72680	1.227	**1.3**
	45°	15973.315	0.72680	1.820	1.4
	0°	15973.315	0.72680	2.199	1.55

Table 4) U-value of double glazed unit with low-e glazing in differnt slopes
0° … horizontal position, 90° … vertical position
Gr … Grashoff number, Pr … Prandtl number,
Nu … Nusselt number

Table 4 has shown that horizontal glazings represent higher heat losses compare to vertical windows. For example roof windows with total area 10 m^2 have about 120 W greater heat losses than the same glazed area in a facade (it was calculated for indoor temperature +20°C and outdoor temperature –10°C).

6. Influence of glass parameters on daylight and energy simulations

Optical and thermal properties of glasses serve as input data for evaluation of indoor climate comfort in buildings. Daylight simulations require values of visible light transmittance of window glazings. Solar gain consideration needs total solar transmittance data. Overall heat loss coefficients U [$Wm^{-2}K^{-1}$] of glass units are necessary for the determination of glazing heat losses.

Table 5 presents deviations in daylight factor assessment. These deviations are caused by different values of visible transmittance τ_v. Values of light transmittance of clear glass were considered in the interval between 0.89 and 0.92.

Daylight factor DF [%] is a ratio between indoor illuminance in a certain position inside of a building to outdoor illuminance (determined on un-shaded plane and for conditions of uniformly overcast sky). In practical calculations values of daylight factor should by corrected for the influence of daylight losses (light transmittance of window glasses, pollution of glass panes and window shading elements).

In the following table values of DF [%] are considered as a value of daylight factor without light losses corrections. There are two values of the daylight factor (DF_o=2%, DF_o=5%) that are in the table corrected with light transmittance τ_v for the value of DF [%]. The differences between daylight factors DF are negligible for a single glass pane, but in the case of a double and triple glazing the differences could have considerable values.

Glass Transmittance	Corrected DF [%]	
	DF_o= 2 %	DF_o= 5 %
Single glazing		
τ_v = 0.89	1.78	4.45
τ_v = 0.92	1.84	4.6
Diference	**0.06**	**0.15**
Double glazing		
τ_v = 0.792	1.58	3.96
τ_v = 0.846	1.69	4.23
Diference	**0.11**	**0.27**
Triple glazing		
τ_v = 0.705	1.4	3.525
τ_v = 0.779	1.56	3.895
Diference	**0.16**	**0.37**

Table 5) Differences in the daylight factor determination caused by different values of light transmittance τ_v

Determination of solar gains in buildings is important for energy saving purposes. These gains depends on intensity of solar radiation, area of glazed parts in building envelopes and also on data of solar transmittance of glazing τ_e. Assessments of solar gains could give different results if input parameters for calculations vary in values.

Figure 11 shows values of calculation differences in solar gains that are determined for the total solar transmittance of glass τ_e in the interval between 0.86 and 0.83. The calculations were carried out for the mean solar radiation intensity 500 Wm^{-2} affecting the glass pane of area 5, 10, 20 and 50 m^2. The calculation difference is increased significantly with larger glazed area.

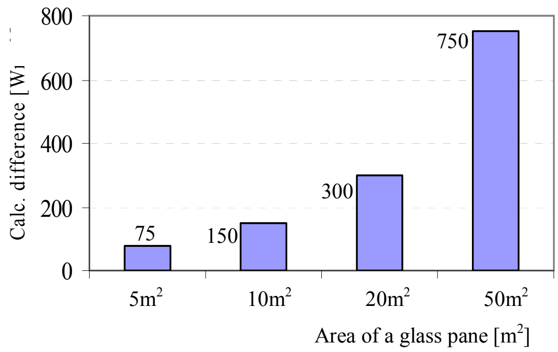

Fig. 11 Differences in the determination of solar gains through glazings with total solar transmittance τ_e=0.83 and τ_e=0.86
Calc. difference [W] = solar gain (τ_e=0.86) – solar gain (τ_e=0.83)

Similar problems could be in the case of glazing heat losses determination. The overall heat loss coefficients of glass U-value values [$Wm^{-2}K^{-1}$] could give great differences in the total results of heat losses. These calculation differences are increased with the glass area. Figure 12 presents results from heat losses calculations for glazed area of 5, 10, 20 and 50 m^2. Two values of the overall heat loss coefficient were considered: U=1.3 $Wm^{-2}K^{-1}$ and U=1.1 $Wm^{-2}K^{-1}$ (it means the calculation difference ΔU=0.2 $Wm^{-2}K^{-1}$). Heat losses were calculated for the temperature difference between indoor temperature +20°C and outdoor temperature –10°C.

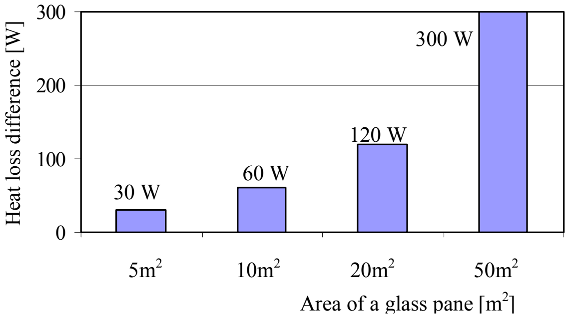

Fig. 12 Differences in the determination of heat losses through glazings with U=1.1 $Wm^{-2}K^{-1}$ and U=1.3 $Wm^{-2}K^{-1}$
Heat loss difference [W] = Heat loss (U=1.1 $Wm^{-2}K^{-1}$) - Heat loss (U=1.3 $Wm^{-2}K^{-1}$)

7. Conclusion

Special advanced glazings that belong into the group of low-emissivity glasses have found wide applications in solar architecture. The design of energy-efficient buildings requires minimal demands for HVAC systems in real climatic conditions. Glass plays important role in low-energy buildings because these buildings are based on utilisation of thermal gains from solar radiation. Natural ventilation together with maximal possible access of daylight represents main requirements for the design of passive solar buildings [1], [3], [4], [10], [11], [12], [13].

The design, construction and utilisation of low-energy solar buildings have brought experiences that an excessive tendency toward energy savings could lead into inconvenient indoor climate – as glare effect, overheating or on the other hand insufficient room daylighting, problems with room ventilation and other practical problems.

Proper and effective operation and comfort utilisation of low-energy buildings require consideration of demands for indoor climate even during the design process. Optical and thermal properties of window glasses are one of the main input data for the building design that could significantly influence results of modelling of visual and thermal comfort in buildings.

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