Evaluation of Optical and Thermal Properties of Window Glazing

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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 SF₆ 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 (pyrolytic 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 compared 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 $\tau_\text{UV}$
- Visible radiation transmittance $\tau_v$
- Reflectance of visible radiation $\rho_v$ (reflectance on the coated surface)
- Reflectance of visible radiation $\rho'_v$ (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 $\tau_e$
- Direct solar radiation reflectance $\rho_e$ (reflectance on the coated surface), $\rho'_e$ (reflectance on the surface without the coating)
- Solar factor (total solar energy transmittance) $g$
- Normal emissivity $e_n$
- 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).

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

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

For double and triple glazed units the spectral transmittance $\tau(\lambda)$ could be calculated in the following way [14]
- spectral transmittance of double glazed units
  $$\tau(\lambda) = \frac{\tau_1(\lambda)\tau_2(\lambda)}{1 - \rho_1(\lambda)\rho_2(\lambda)}$$ (3)
- spectral transmittance of triple glazed units
  $$\tau(\lambda) = \frac{\tau_1(\lambda)\tau_2(\lambda)\tau_3(\lambda)}{[1 - \rho_1(\lambda)\rho_2(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)]}$$ (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
$\rho_2(\lambda)$ spectral reflection of the inner glass, measured against the direction of propagated radiation
$\rho_3(\lambda)$ spectral transmission of the third glass
$\rho'_3(\lambda)$ 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:

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

where $\rho(\lambda)$ spectral reflection of glazing $S_\lambda$ 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:
  $$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\rho_2(\lambda)}{1 - \rho_1(\lambda)\rho_2(\lambda)}$$ (6)
- spectral reflectance of triple glazed units:
  $$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\rho_2(\lambda)\rho_3(\lambda)\tau_3^2(\lambda)\rho_1(\lambda)\rho_2(\lambda)}{[1 - \rho_1(\lambda)\rho_2(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)]} + \frac{\tau_1(\lambda)\rho_2(\lambda)\rho_3(\lambda)}{[1 - \rho_1(\lambda)\rho_2(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)][1 - \rho_1(\lambda)\rho_3(\lambda)]}$$ (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 $\tau_v$ [14] of a single glazing

$$\tau_v = \frac{\int_{\lambda=380}^{\lambda=780} D_1 \rho(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380}^{\lambda=780} D_1 V(\lambda) d\lambda}$$

(8)

where

$\rho(\lambda)$ spectral light transmission

$D_1$ relative spectral power distribution of illuminant $D_{65}$

$V_\lambda$ photopic luminous efficiency function

Light reflectance $\rho_r$ [14] is determined from the equation

$$\rho_r = \frac{\int_{\lambda=380}^{\lambda=780} D_1 \rho(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380}^{\lambda=780} D_1 V(\lambda) d\lambda}$$

(9)

where

$\rho(\lambda)$ spectral light reflection

$D_1$ relative spectral power distribution of illuminant $D_{65}$

$V_\lambda$ 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 $\alpha_c$ is determined from the equation (1) and relations for solar transmittance and reflectance (2) and (5) as

$$\alpha_c = 1 - \tau_v - \rho_r$$

(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 $h_i$, $h_o$ [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 gluazings and for double and triple glass units as:

- single glazing:

$$q_i = \frac{\alpha_c}{h_o + h_i}$$

(11)

- double glazing unit:

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

(12)

- triple glazed unit:

$$q_i = \frac{\alpha_c + \alpha_o + \alpha_i + \alpha_o + \alpha_i}{h_i}$$

(13)

where

$\Lambda$ thermal conductivity between the outer and inner glass pane

$\Lambda_{12}$ thermal conductivity between the outer and second glass pane

$\Lambda_{23}$ 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

$\alpha_{i1}, \alpha_{i2}, \alpha_{i3}$ absorptance of the outer, second, third glass pane.

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 $\rho(\lambda)$→0 and $\tau(\lambda)$→0, for the wavelengths range in the interval of $\lambda$∈(5 μm,50μm). From equation (1) derived on the principle of energy balance is obvious high glass absorptance in long-wave IR range, shortly described $\alpha(\lambda)$→1, for spectral range $\lambda$∈(5 μm,50μm).

![Fig 3 Spectral transmission of glass Float in near-infrared range of wavelengths between $\lambda$=2500 and $\lambda$=5000 nm](image)

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
\[ M(\lambda, T) = \alpha(\lambda) \sigma T^4 = \varepsilon(\lambda) \sigma T^4 \]  
(14)

where

\( \alpha(\lambda) \): absorbance of the real (grey) body in the infrared part of electromagnetic radiation

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

\[ \sigma = (5.67051 \pm 0.00019 \times 10^{-8}) \text{ Wm}^{-2}\text{K}^{-4} \]

Stephan - Boltzmann constant [8]

From equation (14) is obvious, that surface absorbance is directly proportional to its emissivity. That practically means high thermal losses through window glazings during cold 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 \( \rho(\lambda) \rightarrow 1 \) for the interval of \( \lambda \in (5 \mu m, 50 \mu m) \).

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

\[ \rho(\lambda) = 1 - \varepsilon(\lambda) \]  
(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 \( \lambda \in (\lambda_1, \lambda_2) \) is derived in the following equation

\[ \bar{\varepsilon} = \frac{1}{\lambda_2 - \lambda_1} \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda) dM(\lambda) \]  
(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

\[ \phi_i = \phi \cdot g \]  
(17)

where \( \phi_i \): total radiant flux going into the room

\( \phi \): total radiant flux acting on the glass surface

Solar factor \( g \) consists of direct solar transmittance \( \tau_d \) 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

\[ g = \tau_d + q_i \]  
(18)

As it has been noted in chapter 2.4, the determination of the component \( q_i \) depends on heat transfer coefficients \( h_r \) and \( h_c \). These coefficients have values in accordance with standard recommendations [14], [16]

\[ h_r = 23 \text{ Wm}^{-2}\text{K}^{-1} \quad h_c = 3.6 + \frac{4.4e_1}{0.83} \text{ Wm}^{-2}\text{K}^{-1} \]

These values are valid for the following conditions:
- Outer surface: wind speed 4 ms\(^{-1}\), emissivity \( e_1 = 0.83 \)
- Inner surface: natural convection, emissivity \( e_1 \) depends on the coating - for example:
- \( e_1 = 0.83 \Rightarrow h_r = 8 \text{ Wm}^{-2}\text{K}^{-1} \), if \( e_1 = 0.1 \Rightarrow h_r = 4.1 \text{ Wm}^{-2}\text{K}^{-1} \)

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

### 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 \( \lambda \in (5 \mu m, 11 \mu m) \). 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)

\[ T_{x_{\text{max}}} = A \]  
(19)

where \( A = (2.897 \pm 0.00013) \times 10^{-5} \) [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 were 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](image)

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

![Fig. 7 Spectral reflection of selected glazings](image)

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 \( \rho(\lambda=555nm) \) and absorptance values \( \alpha(\lambda=555nm) \) in Table 1.

<table>
<thead>
<tr>
<th>Glass</th>
<th>( \tau(\lambda=555nm) )</th>
<th>( \rho(\lambda=555nm) )</th>
<th>( \alpha(\lambda=555nm) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>0.897</td>
<td>0.085</td>
<td>0.02</td>
</tr>
<tr>
<td>Sample B</td>
<td>0.83</td>
<td>0.04</td>
<td>0.14</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>characteristics</th>
<th>Glass sample A</th>
<th>Glass sample B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar loss of the glazing</td>
<td>( \rho )</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>Sample A</td>
<td>0.08</td>
<td>0.26</td>
</tr>
<tr>
<td>Sample B</td>
<td>0.06</td>
<td>0.153</td>
</tr>
<tr>
<td>Solar gain through the glazing</td>
<td>( q_e )</td>
<td>( q_i )</td>
</tr>
<tr>
<td>Sample A</td>
<td>0.84</td>
<td>0.56</td>
</tr>
<tr>
<td>Sample B</td>
<td>0.02</td>
<td>0.027</td>
</tr>
<tr>
<td>g</td>
<td>0.86</td>
<td>0.587</td>
</tr>
</tbody>
</table>

**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 \( \rho = 0.87 \)) and in the vicinity of the wavelength of 10 μm the reflectance reaches value of \( \rho = 0.915 \). 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)](image)

**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 m²WK⁻¹, internal wall 1.2 m²WK⁻¹, partition 0.26 m²WK⁻¹, roof 3.3 m²WK⁻¹, floor 1.5 m²WK⁻¹.

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⁻²K⁻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⁻²K⁻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. 9 Plan and section of the reference room

![Thermo-camera photograph of a façade with low-e glazing in wooden frame](image)

**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⁻²K⁻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-value determination of a double glass unit depends also on Grashof, Prandtl and Nusselt number – see table 4.

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

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

The calculation difference is affected by different values of light transmittance τ. Assessments of solar gains could give different results if input parameters for calculations vary in values.

Determination of solar gains in buildings is important for energy saving purposes. These gains depend on intensity of solar radiation, area of glazed parts in building envelopes and also on data of solar transmittance of glazing τ. 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 for 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 m². 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=0.83 and τ=0.86
Calc. difference [W] = solar gain (τ=0.86) – solar gain (τ=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⁻²K⁻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 m². Two values of the

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⁻²K⁻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. 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 be 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 (DF₉=2%, DF₅=5%) that are in the table corrected with light transmittance τ, 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.

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overall heat loss coefficient were considered: \( U=1.3 \, \text{Wm}^{-2}\text{K}^{-1} \) and \( U=1.1 \, \text{Wm}^{-2}\text{K}^{-1} \) (it means the calculation difference \( \Delta U=0.2 \, \text{Wm}^{-2}\text{K}^{-1} \)). Heat losses were calculated for the temperature difference between indoor temperature +20°C and outdoor temperature –10°C.

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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