

IMPROVEMENT OF THE INSULATING POWER OF GLASS WINDOW PANES

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Abstract

The paper presents a concept of two-cell window panes partitioned by polyethylene foil. A simplified method of calculating heat losses from the panes is discussed and the calculations verified by means of FLUENT software. The addition of polyethylene foil a pane may raise some doubts concerning light transmittance by the window panes. Thus, a method of checking the transmittance of visible radiation from the two-cell panes is described.

Streszczenie

W artykule zaprezentowano koncepcję wkładu dwukomorowego ze środkową przegrodą wykonaną z folii. Przedstawiono również uproszczoną metodę obliczania strat ciepła przez wkład okienny oraz jej weryfikację przy wykorzystaniu programu FLUENT. Wprowadzenie folii polietylenowej do wkładu okiennego może budzić obawy odnośnie transmitancji światła przez taki wkład. Opisano więc sposób sprawdzenia transmitancji promieniowania widzialnego przez dwukomorowy wkład okienny.

Keywords: Window glass pane; Calculation of heat losses; Window pane with polyethylene foil; CFD simulation; Calculation of light transmittance.

1. INTRODUCTION

With the dramatic increase of energy costs, the reduction of energy losses from buildings focuses attention of administration, building industry and common citizens. Reduction of heat losses through walls is enforced by more stringent building codes, requiring more insulation. The insulation of walls can be dealt with by applying relatively simple measures. i.e., increasing thickness of the masonry, adding additional layer of insulating material (mineral wool, polystyren). It is widely known that windows, constitute weak point of the building thermal envelope. Typically, about 30% of heat is lost through windows. To reduce these losses several techniques have been introduced [1-11].

- double and triple glass panes
- selective emissive coatings

- low conductivity gas (argon, krypton) between the glass panes.

The scope of the paper includes a concept of two-cell window panes partitioned by polyethylene foil. A simplified method of calculating heat losses from the panes is discussed and the calculations verified by means of FLUENT software. Addition of polyethylene foil to the panes may evoke some doubts concerning light transmittance by the window panes. Thus, a method of checking transmittance of visible radiation from the two-cell panes is described.

2. THE CONCEPT OF TWO-CELL PANES

A traditional window consists of two panes with air between them. Such panes are single-cell. To improve insulating power of air between panes, the air layer may be extended, for example, by spacing the panes.

If the air between the panes was still, an increase of the insulating power would depend, almost linearly, on the distance between the panes. However, at a certain thickness of the panes, air movements connected with free convection appear and air circulation in the panes intensifies the process of heat exchange.

One of the solutions is to introduce two-cell panes [12] divided with foil. According to the results of convective heat exchange analyses, the foil improves insulating power of window panes, mainly due to additional resistance occurring at two sides of foil and associated with adhesion forces. Accordingly, the intensity of gas convective movement in panes is significantly decreased, hindering transport of heat across the gap. In other words, the use of the foil reduces free convection, and the predominating mechanism of the heat transfer process is conduction. This helps to increase the thickness of the layer of almost still air, and, at the same time, improves the insulating power of panes. It should be mentioned that the panes may be spaced about 30 mm apart without essential constructional changes, rendering 14 mm wide cells.

However, there are certain concerns as to the behaviour of foil after several years. Yet, basing on the results of tests conducted by manufacturers of polyethylene foil, it may be assumed that the foil does not change its physical and optical properties with the passage of time.

2.1. Heat flow through two-cell panes

The main focus was a complete analysis of heat flow through two-cell panes.

Therefore, a physical model of the heat flow through the two-cell panes was created (Fig.1) and some simplifications introduced into the model. It was assumed that the fall of temperature along the height of the pane is insignificant, so, accordingly, the task may be regarded as one-dimensional. This enables the use of the equation of the criteria to determine the intensity of heat exchange by means of free convection in the gap between the panes. Accordingly, a simple model of the heat exchange in the window panes was constructed, without the need of solving the momentum and mass conservation equations.

Thus, the whole issue was reduced to solving a system of three non-linear algebraic equations which designate unknown temperatures at the internal surfaces of the panes and the foil temperature. For further simplification, it was also assumed that the fall of

temperature along the foil thickness is negligible. Such an assumption is justified by very small (millimetre fractions) thickness of the foil.

A more detailed model was also constructed and solved by means of FLUENT software. This model was used to verify the validity of the simplified one.

In the discussed case, the window panes were divided into four zones: pane/air, cell/air, cell/pane, assuming that the thickness of the foil separating cells is zero (Fig.1).

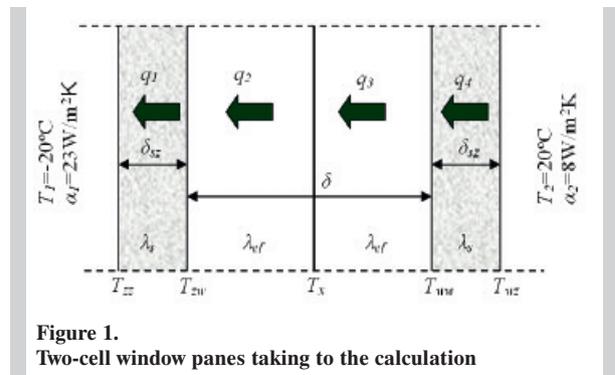


Figure 1.
Two-cell window panes taking to the calculation

For each of the four cells air density flux q was designated by means of the following equation:

$$q = -\lambda \Delta T / \delta \tag{1}$$

where:

ΔT – difference of temperatures

λ – heat conduction coefficient

δ – width of a gap.

This leads to a system of three equations, where the unknowns are the temperatures at the internal surfaces of the panes and on the foil surface.

$$\begin{aligned} q_1 &= q_2 \\ q_2 &= q_3 \\ q_3 &= q_4 \end{aligned} \tag{2}$$

where:

$$\begin{aligned} q_1 &= \lambda_{sz} (T_{zw} - T_{zz}) / \delta_{sz} \\ q_2 &= q_x (0.5\delta, H, T_{zw}, T_x) \\ q_3 &= q_x (0.5\delta, H, T_x, T_{wv}) \\ q_4 &= \lambda_{sz} (T_{wz} - T_{wv}) / \delta_{sz} \end{aligned} \tag{3}$$

and:

$$\begin{aligned} q_1 &= \alpha_1 (T_{zz} - T_1) \\ q_4 &= \alpha_2 (T_{wz} - T_2) \end{aligned} \quad (4)$$

where:

H – height of the window pane

α_1, α_2 – outdoor and indoor film coefficients

The value of the heat transfer coefficient for the pane was derived from standard [13]. Function q_s makes it possible to designate the heat flux within the air in consideration of the convection movements inside the cell by employing the effective heat conduction coefficient λ_{ef} calculated in accordance with Ozisik criterion equation [14]. The selection of the criterion equation was preceded by wider deliberations [15]. Appropriate heat and temperature transfer coefficients were derived in accordance with standard [16, 17, 18].

The manner of calculating Nusselt number results not only in non-linearity of the equations, but, first and foremost, in the absence of continuous differential coefficients. For this reason, the above system of equations is solved with the use of Hooke-Jeevs non-gradient method.

2.2. Verification of the model of heat flow

The constructed model of the heat flow in the window panes takes into account the convective movements of the gas between the panes. The model was solved by means of FLUENT software [19]. Three panes with different spacing were tested: 16 mm (typical), 22 and 28 mm (widened). In Fig. 2 and Table 1 the results of simulations are compliant with the calculated results; whereas, Fig. 3 and Fig. 4 show exemplary results of modelling the temperature distribution and air current lines in the panes.

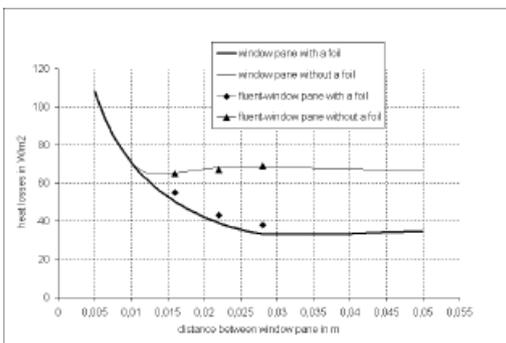


Figure 2.
The heat flux comparison for the pane with foil and without foil

As indicated in Fig. 2, a significant reduction of the heat fluxes flowing through the panes containing foil is an important outcome.

The analyses carried out with the use of FLUENT software confirm the calculation results and the derived characteristics. The tendency observed on the grounds of the two methods is identical.

The results reveal adequate consistency, especially in consideration of the simplification of the heat flow in the physical model. For panes without foil bigger consistency of the two methods may be observed, probably due to the fact that pane without foil is a considerably simpler physical example, and simplifications made in the model only insignificantly distort the picture of real heat flow-related phenomena. Verification of the simplified model enables its acceptance as a tool for the analysis of the heat flow through the panes. At the same time, it substantiates the reliability of the results.

FLUENT software offers possibilities of more profound analyses of the modelled phenomena by observing distribution of temperature and air velocity inside a pane. The temperature distribution and air current lines in panes with and without foil are shown below.

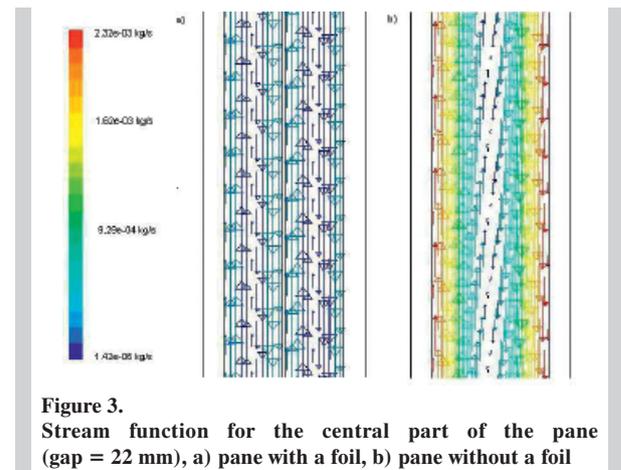


Figure 3.
Stream function for the central part of the pane (gap = 22 mm), a) pane with a foil, b) pane without a foil

In Fig. 3 the air current lines refer to 22 mm panes. As far as the panes without foil are concerned, the width of the gap evokes obvious convection intensifying the heat flow. Whereas, as far as the pane with foil is concerned, specific gaps are 11 mm wide and it is explicitly observed that the phenomenon of convection is not significant.

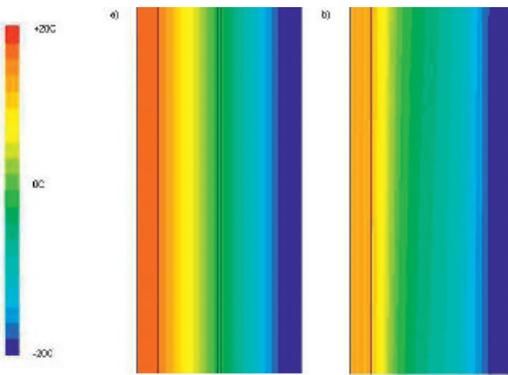


Figure 4.
Contours of temperature for the central part of the pane (gap=22mm), a) pane with a foil, b) pane without a foil

Analogically, the same system may be observed in Fig. 4, presenting temperature distributions for the panes with and without foil. Undoubtedly, the temperature of the internal pane with foil is higher, providing better protection against heat losses and preventing humidity dropouts in the lower parts of the internal pane.

3. ADVANTAGES OF TWO-CELL PANES

The results of the analyses of the heat flow through the panes with the foil and without it for different panes spacing are compiled in Fig. 2. The maximal reduction of heat losses is achieved for 29 mm spacing. Such spacing, however, would require some small constructional changes of the frame. But, for a 26 mm spacing, the heat losses are reduced by almost 50%, which is a very good result. The advantages of using two-cell panes for different spacing are shown in Fig. 5.

According to the above analysis, two-cell panes with

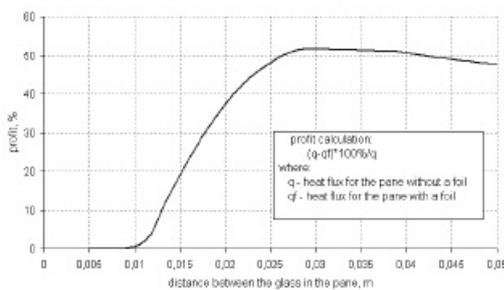


Figure 5.
Relative profit for the pane with a foil for different distance between the glass in the pane

a partition made of foil considerably improve thermal insulation of transparent partitions. They offer an opportunity of reducing heat losses by almost 50% in case of widened spacing of panes.

Thanks to the use of foil, convection is negligible. Calculations carried out in FLUENT software enabled determination of the convection movements. For example, for panes with a 16 mm spacing without foil, the maximal velocity was 0.18 m/s; whereas for pane with foil only 0.02 m/s.

4. LIGHT TRANSMISSION BY TWO-CELL PANES

The use of two-cell panes with foil partition may evoke certain questions concerning transmission of light by such panes. Hence, an analysis was carried out to check if, and to what extent, the insertion of foil in panes will worsen transmission of light [12].

There are two methods of designating transmittance, absorption and reflection for a set of flat-parallel plates (to which window panes may be classified) [20]: ray-tracing and net radiation.

The net radiation method assumes that an unknown ray of light falling on each of the surfaces of each plate has the intensity representing total contribution of direct and indirect reflections. Also, an unknown ray of light is discharged from each of the surfaces. This gives eight unknown intensity values for each plate. As the plates are arranged in a series, the intensity values are independent from one another. This enables the construction of the equations system for calculating the transmission resultant.

Fig. 6 shows the rays related to a single flat-parallel plate .

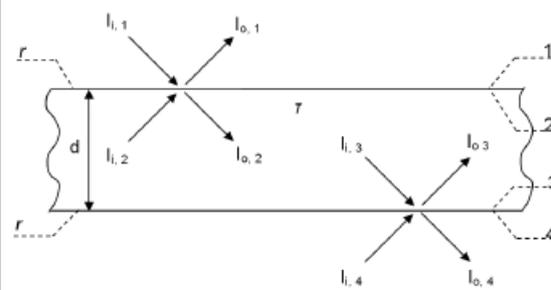


Figure 6.
Rays for a singular plat in the net radiation method.
 I_i – intensity of incident ray
 I_o – intensity of leaving ray

The following relations occur among the intensities of the rays, constituting a system of eight equations for each of the polarisation components:

$$I_{o,1} = rI_{i,1} + (1-r)I_{i,2} \quad (5)$$

where:

r – reflection coefficient

$$I_{o,2} = (1-r)I_{i,1} + rI_{i,2} \quad (6)$$

$$I_{o,3} = rI_{i,3} + (1-r)I_{i,4} \quad (7)$$

$$I_{o,4} = (1-r)I_{i,3} + rI_{i,4} \quad (8)$$

$$I_{i,3} = I_{o,2}\tau \quad (9)$$

$$I_{i,3} = I_{o,2}\tau \quad (9)$$

where:

τ – absorbing coefficient

The path of the ray in the plate is assumed as:

$$L = d/\cos\varphi_2 \quad (10)$$

$$I_{i,2} = I_{o,3}\tau \quad (11)$$

As the analysis is not focused on designating the absolute value of the transmitted radiation energy, but only on the transmittance of the system, further assumptions may be made:

$$I_{i,1} = 1 \quad \text{– for the first plate} \quad (12)$$

$$I_{i,1} = I_{o,4_{poprz}} \quad \text{– for other}$$

Because the analysis concerns short-term (visible) radiation from the surroundings inside the plates, the intensity of the radiation in the opposite direction is zero:

$$I_{i,4} = 0 \quad \text{– for the last plate} \quad (13)$$

$$I_{i,4} = I_{o,1_{nast}} \quad \text{– for other}$$

For a system consisting of n plates, a matrix of $8n$ equations is constructed.

On the grounds of the calculation method described above, the transmittance for solar radiation for pane with foil and without foil was calculated. The analyses were carried out by averaging both polarization components for each incidence angle within the range: $0-90^\circ$.

The calculations indicated that the insertion of foil into the panes has a very small impact on the transmission of light (Fig. 7). The foil reduces the quantity of solar energy reaching the inside of the two-cell panes only by several percent. Accordingly, the foil partition in panes may be regarded as an energy-efficient solution, improving the insulating power of the external shell of the building.

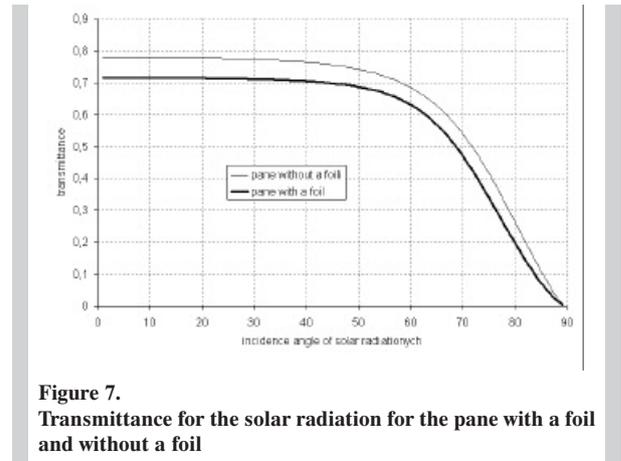


Figure 7.
Transmittance for the solar radiation for the pane with a foil and without a foil

5. CONCLUSIONS

Presented analyses and their results indicate that two-cell panes with the partition made of foil considerably improve thermal insulation of transparent partitions. Accordingly, the heat losses may be reduced by almost 50% in case of widened spacing of the panes.

Thanks to the insertion of foil, the phenomenon of convection is practically negligible, hindering, at the same time, transport of heat across the gap. In other words, the use of foil limits free convection, and the predominating mechanism of the heat flow process is conduction.

Behaviour of foil after several years may evoke certain reservations. However, according to tests run by foil manufacturers, polyethylene foil should not change its physical and optical properties with the passage of time.

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