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CFD MODELLING AND ANALYTICAL CALCULATIONS OF THERMAL TRANSMITTANCE OF MULTI-LAYER GLAZING WITH ULTRATHIN INTERNAL GLASS PARTITIONS

MODELOWANIE CFD ORAZ OKREŚLANIE METODAMI ANALITYCZNYMI WSPÓŁCZYNNIKA PRZENIKANIA CIEPŁA WIELOWARSTWOWEGO OSZKLENIA Z WEWNĘTRZNYMI ULTRACIENKIMI SZYBAMI

A b s t r a c t

In recent times, there has been a demand for developing new technologies for glazing with superior thermal performance, good optical quality and of the lowest possible weight. In the paper, CFD modeling and analytical calculation of the thermal performance of multi-layer glazing with ultrathin internal glass partitions is presented.

Keywords: *fenestrations*, *CFD modelling*

S t r e s z c z e n i e

Obecnie istnieje potrzeba rozwoju technologii okien z bardzo niskimi wartościami współczynników przenikania ciepła i jednocześnie posiadających dobre walory optyczne, a także niską wagę. W artykule zaprezentowano wyniki symulacji CFD wieloszybowego oszklenia z ultracienkimi wewnętrznymi szybami, które następnie porównano z wynikami obliczeń analitycznych wykonanymi zgodnie ze stosowną normą.

Słowa kluczowe: *oszklenia*, *modelowanie CDF*

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1. Introduction

The Ansys Fluent numerical CFD tool allows for the simulation of the behavior of systems, processes and equipment involving the flow of gases and liquids, heat and mass transfer, chemical reactions and related physical phenomena and can be used for simulating energy efficient building systems and components including the thermal performance of windows [1, 2, 4]. In the paper, the heat transfer through multi-layer glazing has been analyzed. The glazing consists of two standard glass panes (internal and external) and 11 ultra-thin organic glass panes separated by 12 argon gaps. The study of heat transfer through the glazing was conducted using Ansys Fluent CFD software [1, 2, 4].

The glazing geometry was represented by a two-dimensional CFD model. The numerical simulation results have been compared to analytical calculation results based on the PN-EN 673 procedure [6].

2. CFD model of glazing

2.1. Geometry and materials

The modeled glazing consists of two 4 mm glass layers (internal and external) with the emissivity of 0.837 on both outer surfaces and with low emissivity coatings of 0.037 on both surfaces of the internal gas gaps. The other 11 organic glass layers have a thickness of 0.4 mm and an emissivity of 0.837 on every surface. The spacer is made of steel with an emissivity of 0.2. The twelve 13 mm width gas gaps are filled with a mixture of argon (90%) and air (10%). The dimensions of the glazing are 623 mm (width), 622 mm (height) and 163 mm (thickness).

Table 1

Material properties applied in the calculations

Material	ρ [kg/m^3]	λ [W/(mK)]	c_p [J/(kgK)]	ε [–]
Glass	2500	1	840	0.837
Glass with low emissivity coating	2500	1	840	0.037
Organic glass	1180	0.19	1260	0.837
Steel	2719	16.3	871	0.2

The investigated glazing prototype made by the Vis Inventis company was placed in a Styrofoam frame. A view of the analyzed glazing is given in Fig. 1.

The CFD model geometry is presented in Fig. 2. Thermal properties of the glazing construction materials applied for calculation are listed in Table 1, while gas thermal properties are presented in Table 2.

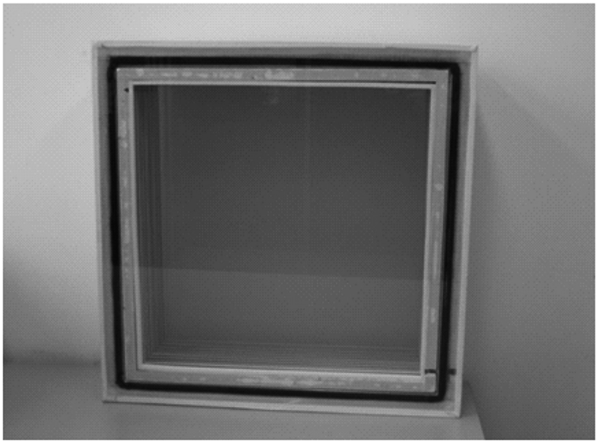

Fig. 1. The view of the glazing

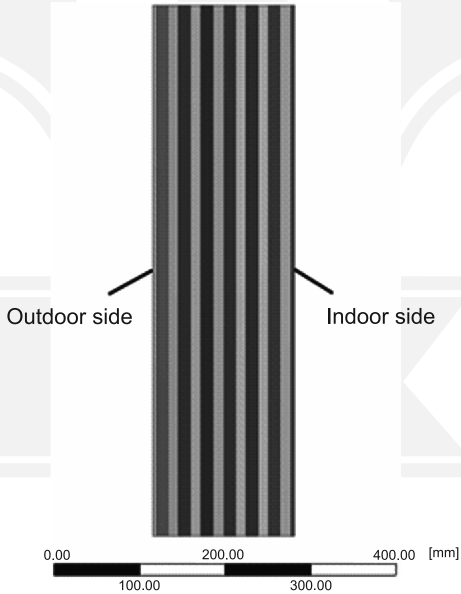

Fig. 2. The cross-section of the glazing

Table 2

90% Argon, 10% air mixture thermal properties applied in the calculations

θ [ºC]	ρ [kg/m³]	λ [W/(mK)]	c_p [J/(kgK)]	μ [kg/(ms)]
0	1.7135	0.01712	567.9	$2.062 \cdot 10^{-5}$
10	1.6523	0.01765	567.9	$2.124 \cdot 10^{-5}$
20	1.5949	0.01818	567.9	$2.186 \cdot 10^{-5}$

2.2. Boundary conditions

Boundary conditions have been set as prescribed for analytical calculations by the PN-EN 673 [6] standard. Free external air stream heat transfer coefficients of 7.6 W/(m^{2}K) and 21.4 W/(m^{2}K) were assumed for the internal and external glass surfaces respectively. The indoor and outdoor temperatures were set at 20ºC and 5ºC.

2.3. CFD settings and mesh

The settings for the finite element CFD model for the convective and radiative heat transfer are listed in Table 3 [4].

The calculations have been performed with a mesh of ~ 400 000 elements. The solution was grid independent. The cells' quality was checked by factors – aspect ratio (max. 2.1) and skewness (max. $1.3 \cdot 10^{-10}$). Part of the mesh in the lower left portion of the glazing is presented in Fig. 3.

Table 3

CFD model settings

Solver	Stationary	
Viscous model	Laminar	
Fluid thermal properties	Density, conductivity and dynamic viscosity	Piecewise-linear
	Specific heat	Constant
Discretization schemes	Gradient	Least squares cell based
	Pressure	Body force weighted
	Momentum	Second order upwind
	Energy	Second order upwind
Radiation model	Discrete Transfer Radiation Model (DTRM)	

2.4. Simulation results

With regard to the total thermal transmittance of glazing, the overall heat transfer coefficient calculated with the use of CFD model was equal to 0.297 W/(m^{2}K). The value of the transmittance is relatively low, at a level comparable with thermal transmittance of solid walls in EU buildings.

The calculated temperature and the 90% argon, 10% air mixture velocity distribution in all the modeled glazing and in the lower part of the glazing are presented in Figures 4 and 5 respectively.

The velocity vectors of the 90% argon, 10% air mixture in the lower left hand corner of the glazing are presented in Fig. 6.

As it can be seen in Figure 6, the intensity of convection gas movements depends on the gap location.

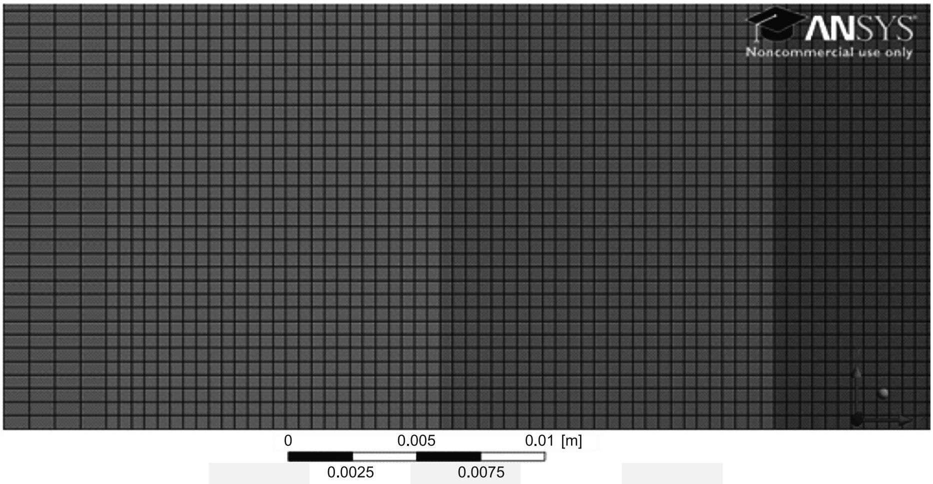

Fig. 3. The cross-section of the glazing with mesh - the lower left part of the glazing

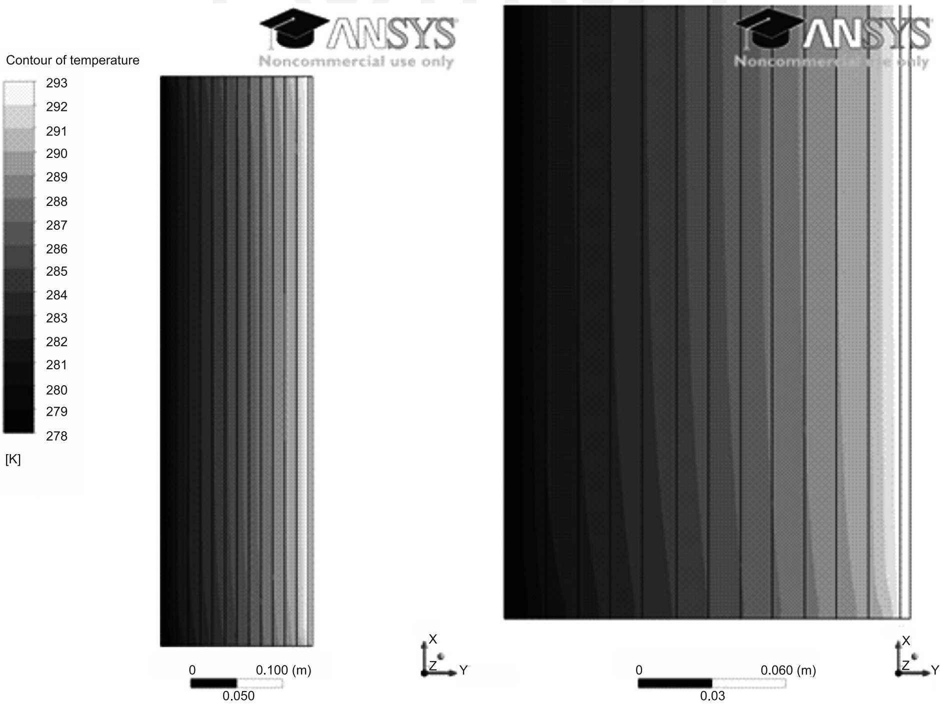

Fig. 4. Contours of temperature in the overall model and in the lower part of the glazing

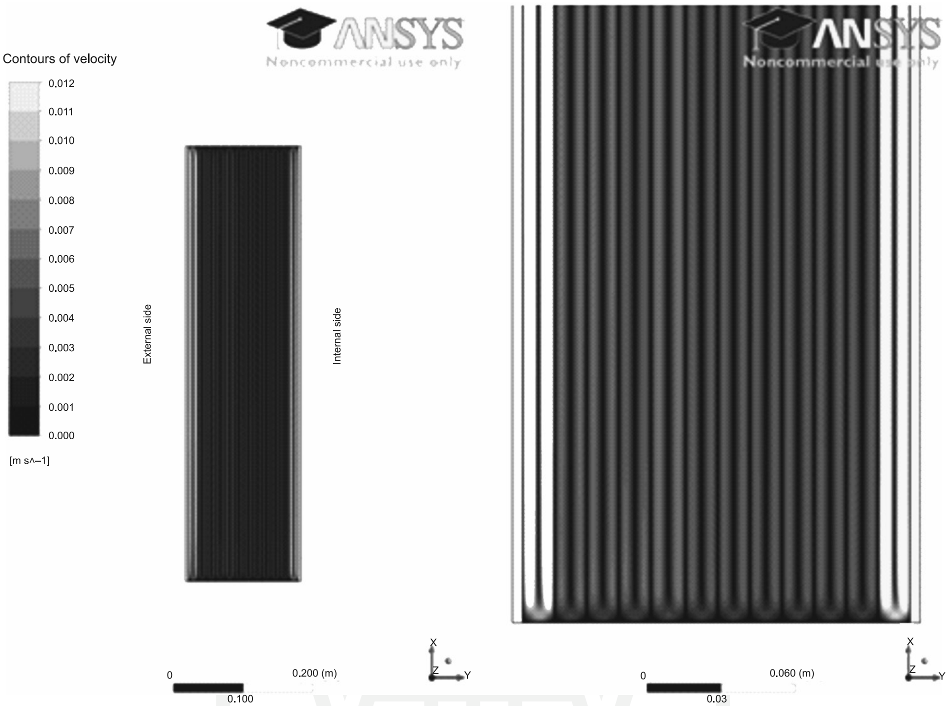

Fig. 5. Contours of gas velocity in the overall model and in the lower part of the glazing

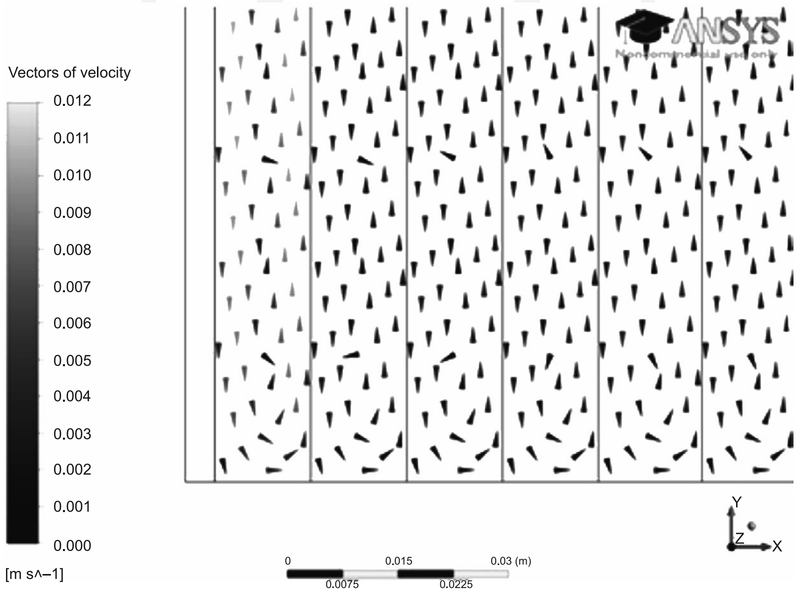

Fig. 6. Vectors of gas velocity in the lower left hand corner of the glazing

3. Analytical calculations

The overall heat transfer coefficient of glazing can be calculated analytically with the use of the PN-EN 673 [6] standard for flat and parallel surfaces in the central area of glazing. The standard does not take into account thermal bridges through the spacer or through the window frame.

The standardized boundary conditions assumed for the analytical calculations are listed in table 4.

Table 4

Boundary conditions assumed for analytical calculations

Thermal resistivity of soda lime glass	1 [mK/W]
Thermal resistivity of organic glass	5.26 [mK/W]
Temperature difference between bounding glass surfaces	15 [K]
External heat transfer coefficient for uncoated soda lime glass surfaces	23 [W/(m^{2}K)]
Internal radiative heat transfer coefficient for uncoated soda lime glass surfaces	4.4 [W/(m^{2}K)]
Internal convective heat transfer coefficient for uncoated soda lime glass surfaces	3.6 [W/(m^{2}K)]
Constant in Nusselt number for vertical glazing	0.035
Exponent in Nusselt number for vertical glazing	0.38

The calculation results of the glazing according to the PN-EN 673 standard [6] are as follows:

– total thermal conductance of the glazing $h_t = 0.187$ [W/(m^{2}K)],
– thermal transmittance of the glazing $U = 0.181$ [W/(m^{2}K)].

The thermal transmittance of the glazing calculated with the PN-EN 673 standard is 39% lower than the value calculated with the Ansys Fluent CFD program, which is a very significant difference.

There is a need to assess if CFD simulations or analytical calculations lead to proper results. That is why experimental validation has been performed using the calorimetric hot box test stand described in [3]. The measurement results as well as the analytical and CFD calculation results are presented in Table 5 [3].

Table 5

Measured and calculated results of thermal transmittance (*U*-value) of multi-layer glazing

Calculated *U*-value of glazing – CFD numerical simulation	0.3 (0.297) [W/(m^{2}K)]
Measured by a calorimetric hot box CHB system *U*-value of glazing – measurement results according to PN-EN ISO 12567-1 [6, 10]	0.3 (0.319) [W/(m^{2}K)]
Analytically calculated *U*-value of glazing – calculation according to PN-EN 673 [6, 11]	0.2 (0,181) [W/(m^{2}K)]

It is easily noticed, that a very good agreement between CFD simulations and experiment has been achieved. The discrepancy is about 7%. It should be also mentioned, that the value obtained by the use of the PN-EN 673 [6] standard leads to unsatisfactory results.

4. Conclusions

The *U*-value calculation results of multi-layer glazing with ultrathin internal glass partitions have been presented. The CFD simulations as well as the analytical calculations prescribed in the PN-EN 673 [6] standard have been applied. A significant difference between the results has been achieved. The measurement results gained with the use of the calorimetric hot box test stand have been applied in order to validate the results [3].

The CFD simulation and measurement results show that the method described in the PN-EN 673 [6] standard is not appropriate for such a kind of multi-layered glazing that was investigated.

The obtained data stipulates that the CFD approach can provide good agreement between the measured and the calculated thermal transmittance (*U*-value) of multi-layer glazing.

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