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BOX WINDOW DOUBLE SKIN FAÇADE. HEAT TRANSFER VALIDATION THROUGH INNER ENVELOPE

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Abstract: *This paper presents an iterative calculation method, for heat transfer through a double glass type window, used as inner envelope, for a box double skin façade. The calculations have been made for both cold and hot seasons, taking into account Brasov exterior weather conditions. These calculations are intended to be a starting point for modelling the same phenomenon with a CFD commercial software, in order to make a comparison. Finally the results and conclusions are given.*

Key words: *DSF, inner envelope, heat transfer, simulations.*

1. Introduction

It is considered a tall double-paned window with two glass sheets of 2 m. Heat transfer is considered nighttime, when solar radiation effect can be ignored, steady state in one direction and the effect of sashes is ignored. The sheets of window glass are 4 mm thick and is considered for them a thermal conductivity of 1.3 $W/m^{2o}C$. The calculation is done both for winter and summer seasons. The glasses are placed from one another at a spacing of 16 mm. The air temperature inside the building is considered 20°C, during the winter season and 24,3°C during the summer season and the outside air temperature is -21°C in the winter and 30°C for the summer season.

Based on the available results and according to [1] SR EN ISO 6946/2009 – "Building components and building elements - Thermal resistance and thermal transmittance - Calculation method", the convective heat transfer coefficients for interior and exterior can be considered with the values 7,7 and 25 $W/m^{2o}C$ and the emissivity of glass is considered 0.84.

It is desired to calculate the heat transfer for this double-paned window, in case of argon gas between glasses and display the results in the form of the global coefficient heat transfer *U*, thermal resistance *R*, heat flux density *Q/A* and bounding surface temperatures *T*.

In the end calculation results are compared with ANSYS® Steady State Thermal simulations, in same conditions and then the conclusions are presented.

2. Calculation Method

The situation considered in this paper is shown in Figure 1.

Since solar radiation effects are ignored and the glass is essentially opaque to infrared radiation in the case considered, the two sheets of glass is assumed that

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behave as two conventional opaque grey bodies.

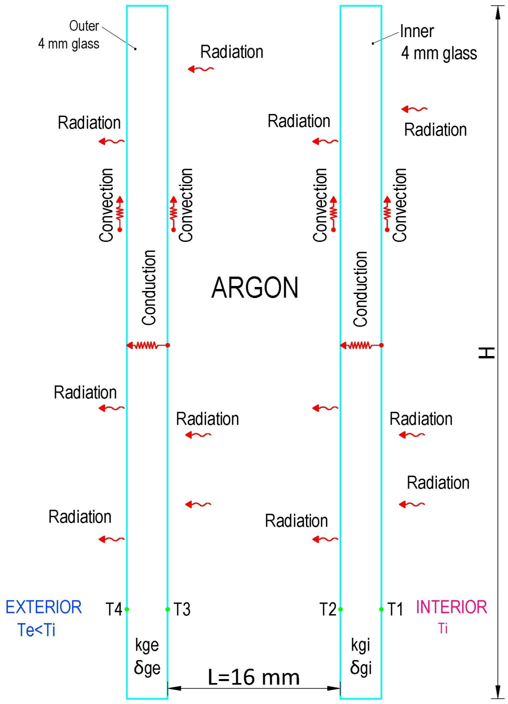

Fig. 1. *Considered heat transfer and temperature distribution, winter*

Also, considering steady state heat transfer means heat fluxes between all layers are equal, which can be expressed as:

$$\frac{Q_i}{A} = \frac{Q_{gi}}{A} = \frac{Q_b}{A} = \frac{Q_{ge}}{A} = \frac{Q_e}{A} \tag{1}$$

Radiant heat transfer will be treated by the introduction of radiative heat transfer coefficient h_r.

Radiative heat transfer coefficients to the inner surface of the inner glass and outer surface of the outer glass are:

$$h_{ri} = \sigma\varepsilon\left(T_i^2 + T_1^2\right)\left(T_i + T_1\right) \tag{2}$$

$$h_{re} = \sigma\varepsilon\left(T_4^2 + T_e^2\right)\left(T_4 + T_e\right) \tag{3}$$

Radiative heat transfer coefficient between the two panes of glass, considering same emissivity is:

$$h_{rb} = \frac{\sigma\left(T_2^2 + T_3^2\right)\left(T_2 + T_3\right)}{\frac{2}{\varepsilon} - 1} \tag{4}$$

The space between the two panes of glass forms a vertical high-aspect ratio rectangular enclosure. In order to find the convective heat-transfer coefficient between the two glass panes, the heat-transfer rate across this enclosure is assumed to be expressed in terms of the Rayleigh number Ra, and the aspect ratio AR, which are defined by the relations:

$$Ra = \frac{\beta g L^2\left(T_2 - T_3\right)}{\nu\alpha} \tag{5}$$

and

$$AR = \frac{H}{L} \tag{6}$$

The convective heat transfer coefficient between the two panes of glass is:

$$h_{cb} = \frac{Nu_b L}{k_b} \tag{7}$$

The thermal conductivity k_b, the kinematic viscosity ν and thermal diffusivity α, in the Rayleigh number are evaluated at the mean temperature in the gap, at

$$T_b = \frac{T_2 + T_3}{2} \tag{8}$$

In equation (7) *Nu* represents the Nusselt number and according to ElSherbiny et al. [2] can be expressed as the maximum of the following three Nusselt numbers:

$$Nu_a = 0{,}0605 \cdot Ra^{1/3} \quad (9)$$

$$Nu_b = \left[1 + \left\{\frac{0{,}104 \cdot Ra^{0{,}293}}{1 + (6310/Ra)^{1{,}36}}\right\}^3\right]^{1/3} \quad (10)$$

$$Nu_c = 0{,}242 \cdot \left(\frac{Ra}{AR}\right)^{0{,}273} \quad (11)$$

Thereby

$$Nu = \max(Nu_a, Nu_b, Nu_c) \quad (12)$$

Nu_a applies to turbulent boundary layer regime, Nu_b to conduction and the turbulent transition regime and Nu_c to the laminar boundary regime [4].

Overall heat transfer is typically expressed using thermal transmittance U [W/m^{2O}C], which is defined as follows:

$$\frac{Q}{A} = U(T_i - T_e) \quad (13)$$

Using all information above the total heat transmittance, U [W/m^{2O}C] can be expressed:

$$U = \frac{1}{R_i + \frac{\delta_{gi}}{k_{gi}} + R_b + \frac{\delta_{ge}}{k_{ge}} + R_e} \quad (14)$$

where

$$R_i = \frac{1}{(h_{ci} + h_{ri})} \quad (15)$$

$$R_b = \frac{1}{(h_{cb} + h_{rb})} \quad (16)$$

$$R_e = \frac{1}{(h_{ce} + h_{re})} \quad (17)$$

To complete the calculations it is required an iterative procedure, which involves the following steps:

1. Guess the initial values of temperatures T_1, T_2, T_3 and T_4;
2. Using initial values, calculate the heat transfer coefficients h_{ri}, h_{rb}, h_{re} and h_{cb};
3. Calculate Q/A, U and R;
4. With calculated values of Q/A, calculate T_1, T_2, T_3 and T_4 using

$$T_1 = T_i - \frac{Q}{A}\frac{1}{(h_{ci} + h_{ri})} \quad (18)$$

$$T_2 = T_1 - \frac{Q}{A}\frac{k_{gi}}{\delta_{gi}} \quad (19)$$

$$T_3 = T_2 - \frac{Q}{A}\frac{1}{(h_{cb} + h_{rb})} \quad (20)$$

$$T_4 = T_3 - \frac{Q}{A}\frac{k_{ge}}{\delta_{ge}} \quad (21)$$

All calculation have been executed in MS Excel and the results are presented in table 1 for the winter season and in table 2 for the summer season, in Brasov.

Table 1

Winter season			
Results	Iter. 1	Iter. 2	Iter. 3
T1 [^{o}C]	10,02	10,18	10,17
T2 [^{o}C]	9,64	9,81	9,8
T3 [^{o}C]	-16,18	-16,35	-16,35
T4 [^{o}C]	-16,56	-16,72	-16,72
R [m^{2o}C/W]	0,329	0,341	0,340
U [W/^{2o}C]	3,037	2,936	2,939
Q/A [W/m^2]	124,51	120,39	120,51

Table 2

Summer season			
Results	Iter. 1	Iter. 2	Iter. 3
T1 [^{o}C]	25,76	25,75	25,75
T2 [^{o}C]	25,81	25,81	25,81
T3 [^{o}C]	29,34	29,33	29,33
T4 [^{o}C]	29,39	29,39	29,39
R [m^{2o}C/W]	0,311	0,307	0,309
U [W/^{2o}C]	3,213	3,252	3,241
Q/A [W/m^2]	18,31	18,54	18,48

In order to obtain the results, the values of ν, k and α for argon have to be known over the temperature range covered in the situation considered. The values assumed in this paper are shown in Figures 2, 3 and 4.

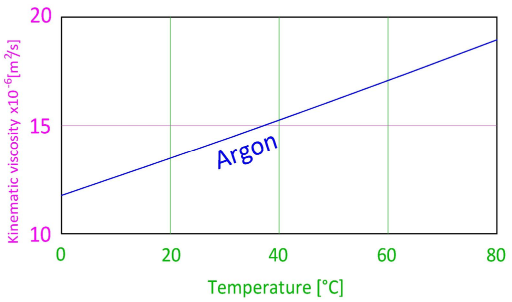

Fig. 2. *Variation of kinematic viscosity ν of air with temperature*

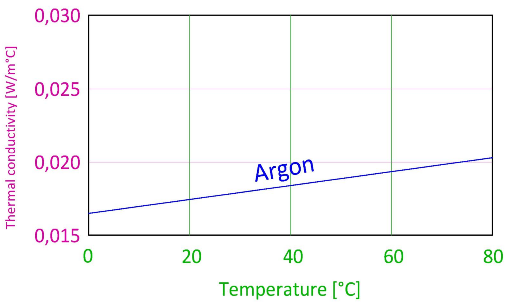

Fig. 3. *Variation of thermal conductivity k of air with temperature*

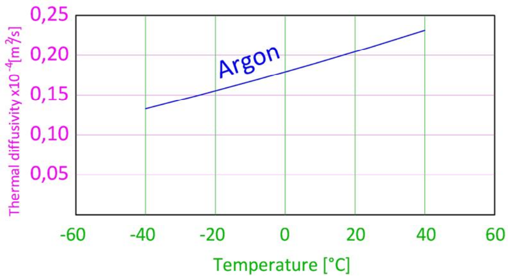

Fig. 4. *Variation of thermal diffusivity α of air with temperature*

3. Mathematical Model Conclusions

Analysing values of thermal resistance during all iterations, it can be seen that the largest contributor to the overall thermal resistance is the gas between the two glass sheets followed by the thermal resistance at the inner surface of the inner glass.

It has been found that the Nusselt number for the space between the two glass sheets was about 1,38 in case of winter and 0,87 in case of summer, indicating that the transfer of heat across the space between the two glass sheets is practical by conduction.

Another observation that can be made is related to the number of iterations, which was three, but it can also be easily seen that virtually is a small difference between the value of the iteration 2 iteration 3, which means that the calculation can be stop after two iterations, or it may be even a single time, since the error is less than 2-3%.

4. Steady State Simulation in ANSYS®

Digital analysis of the various phenomena in different fields, using computer simulation has become an essential part of science and engineering.

To verify the mathematical model that calculate the thermal resistance, thermal transmittance and heat flux density for insulating glass was considered necessary to compare the results with the values obtained using the same input data in a commercial simulation software.

The steady state simulation was performed in ANSYS® 14.5, entering same data to check two extreme climatic conditions, the winter season and the summer season, as in the mathematical model. Boundary conditions for the two cases are presented below, in Figures 5 and 6.

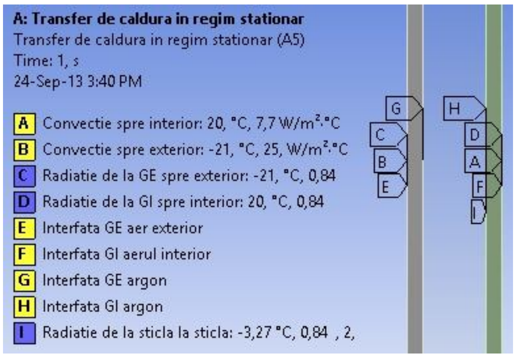

Fig. 5. *Boundary conditions for the winter season*

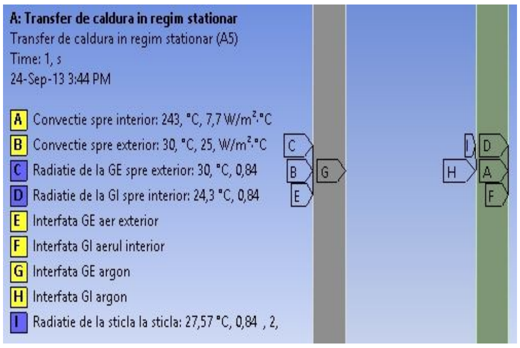

Fig. 6. *Boundary conditions for the summer season*

The results are presented as temperatures and total heat flux in figure 7 for the winter season and in figure 8 for the summer season.

As for the four temperatures T1, T2, T3 and T4 obtained from the simulations, the results for the two seasons are presented in table 3 in comparison with the mathematical model results, in order to easy make observations.

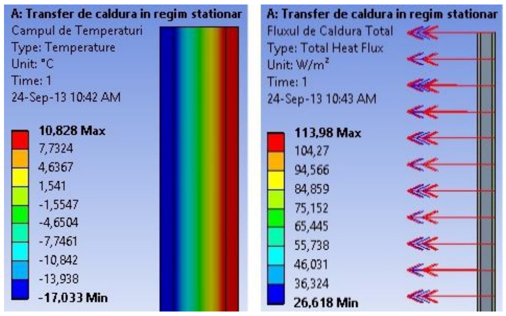

Fig. 7. *Considered heat transfer simulation results for temperatures (left) and total heat flux (right), winter season*

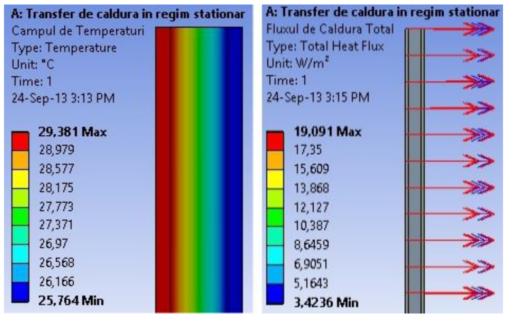

Fig. 8. *Considered heat transfer simulation results for temperatures (left) and total heat flux (right), summer season*

Table 3

Surface temperature values				
Mathematical model				
Season	T1	T2	T3	T4
Winter	10,17	9,80	-16,35	-16,72
Summer	25,75	25,81	29,33	29,39
ANSYS Simulation				
Season	T1	T2	T3	T4
Winter	10,83	10,48	-16,60	-16,95
Summer	25,79	25,84	29,32	29,38

As the user uses ANSYS® program, confidence in computer simulation will grow, and after familiarization with the work interface and performed a few simulations, there is an immediate efficiency and this will be apparent from the results.

This year in March has been adopted in our country to European standard EN ISO 12631:2012 "Thermal Performance of Curtain Walling - Calculation of thermal transmittance" [7]. This calculation is not double skin glass façades dedicated, but in Annex D "Ventilated and unventilated air spaces" is presented a model for calculating the overall thermal resistance R, using the relation:

$$R_{cw} = \frac{1}{U_{cw,1}} - R_{si} + R_s - R_{se} + \frac{1}{U_{cw,2}} \quad (22)$$

The method of calculation is not wrong, but has a limited application in case of double skin glass façades since it can be calculated only if the air layer in the cavity does not exceed a thickness of 300 mm, but it highlights the need to know the transmittance for inner and outer envelope that separates system, in above relation $U_{cw,1}$ and $U_{cw,2}$ being the thermal transmittances for the two curtain walls.

5. Conclusions

Due to the complexity of the double skin façade, in the sense that there are many elements which may vary from case to case depending on the location of the building, the local climate conditions, problem that arises in heat transfer is heat flux determination through entire system, according to its geometric configuration, the way the air flow through the cavity and thermophysical properties of the materials/elements bounding the cavity.

These calculations and simulations are intended to be a starting point for modelling the same phenomenon with entire double skin façade system, as all results are validated.

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