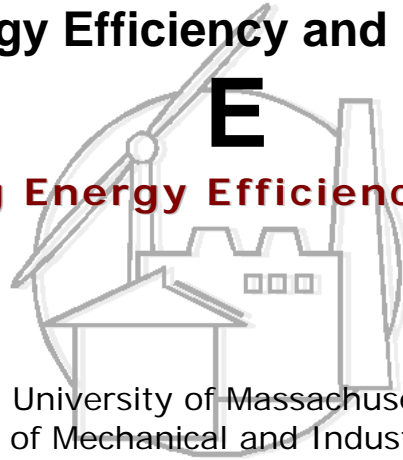


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**Comparison of the results of numerical modeling of convection heat transfer in glazing cavities with ISO 15099 and WINDOW 4.1 correlations.**

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# Introduction

The objective of the present study is to compare ISO 15099 [1] and WINDOW 4.1 [2] methods of calculation of convective heat transfer in vertical rectangular glazing cavities with results of 2-Dim modeling convection heat transfer in ones. It is important because ISO 15099 correlations are intended for using in the programs evaluating thermal properties of fenestrations. For modeling convection heat transfer in vertical rectangular glazing cavities we used the program FIDAP [3] for the solution of the dynamics and heat exchange of flows of a fluid by means of finite elements method.

## 1. Cavities in double-glazing systems.

Comment A.F.: *This part of the work is an extension of our paper about the correlation of 3-Dim convection heat transfer in vertical frame cavities. For suggested in the paper correlation we need to have more accurate values of Nusselt number for 2-Dim cavity than ISO 10599 correlation gives for frame cavities. I assumed that ISO 10599 correlation for glazing cavities is more accurate and consistent with numerical modeling and tried to check that.*

Geometry and the boundary conditions accepted for the numerical modeling are shown in figure 1.

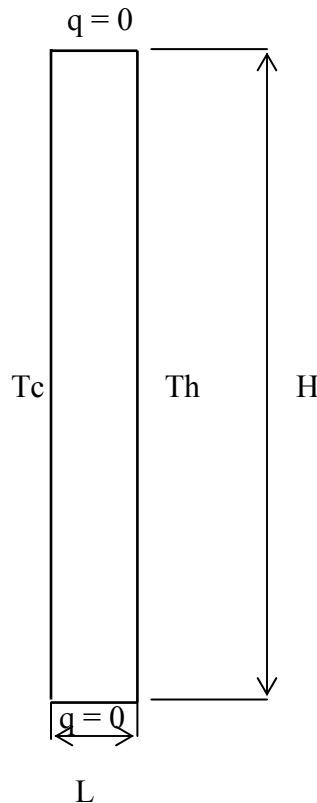


Figure 1. Geometry and the boundary conditions of modeled glazing system.

Results of present study, calculations according to ISO 15099 correlation and Window's method for aspect ratio ( $A = H/L$ )  $A = 20$  and  $A = 40$  are summarized in Table 1.

Table 1. The comparison of average Nusselt number for glazing cavity obtained in the present study and according to ISO 15099 and Window 4.1.

Raleigh number	A = 20				A = 40			
	Present study	ISO15099	W4.1	ISO15099 Equation (52)	Present study	ISO15099	W4.1	ISO15099 Equation (52)
5000	1.179	1.087	1.034	1.087	1.092	1.056	1.034	1.056
10000	1.372	1.312	1.240	1.312	1.200	1.275	1.240	1.087
20000	1.685	1.689	1.625	1.584	1.401	1.688	1.625	1.312
50000	2.209	2.466	2.348	2.033	1.853	2.466(33%)	2.348	1.683
70000	2.425	2.777	2.689	2.227	2.048	2.777	2.689	1.845
100000	2.672	3.127(17%)	3.104	2.450	2.283	3.127(37%)	3.104	2.033

## Results and discussion

ISO 15099 and Window 4.1 correlations have very close results.

The comparison of numerical modeling results with ISO 15099 and Window 4.1 correlations shows that these correlations do not take into account aspect ratio of glazing cavity and for cavities with aspect ratio more than 20 give discrepancy more than 20%.

If only equation (52) from ISO 10599 is used the results (see Table 1) are **more corresponding to numerical modeling** (difference not more than 10%) and change according to aspect ratio of glazing cavities.

It seems that ISO 10599 and Window 4.1 correlations are suitable only for cavities with aspect ratio  $A \leq 20$  and for Raleigh number not more than 50000.

*Comment A.F.: I think that it is very difficult problem to build good correlation for whole range of Ra numbers and aspect ratio of glazing cavities rather with good experimental data. From the other point we know that various experimental works give different results for the same cavities and boundary conditions (differences can be about 10% and more).*

*I think also that we can and must refine and improve equation (52) to make one more close to numerical results in those I trust more than in universal correlation kind of ISO 15099 or Window 4.1.*

## Conclusion

For calculation of convection heat transfer in glazing cavities with aspect ratio  $A \leq 20$  and Raleigh number  $\leq 50000$  it is better to use ISO 15099 or Window 4.1 correlations and for cavities with aspect ratio more than 20 it is better to use only equation (52) from ISO 15099.

In correlation for vertical frame cavities (see “The method of calculation of convection heat transfer in jamb frame cavities” A.F.&D.C.)

$$Nu = 1 + (Nu_{2D} - 1) (1 + A_h (0.8 - A/100)) (2/\pi) \arctg(A_h),$$

it can be recommended for calculation of  $Nu_{2D}$  (Nusselt number for two-dimensional cavity with vertical aspect ratio  $H/L$ ) to use equation (52) from ISO 15099.

## 2. Convection heat transfer through cavities in triple glazing systems.

This part of the work is devoted to comparison between measured convection heat transfer through triple glazing system with two cavities and calculated according to methods used a conductance for modeling one – dimensional heat transfer through the glazing gaps (in central part of glazing) in simulating programs [1,2].

*Comment A.F.: In this part of the work I am checking the next assumption: It is not correct to use results and correlations obtained for single cavity at modeling heat transfer in glazing systems with two and more parallel cavities because ones interact between himself. And cavities have not the same boundary conditions as single cavity has at experimental conditions.*

We modeled convection heat transfer in glazing systems with middle glass (thickness 3mm) and two equal cavities (thickness 20mm) with aspect ratio  $A = H/L$ :  $A = 20$  and  $A = 40$ .

Geometry and the boundary conditions for numerical modeling are shown in figure 2.

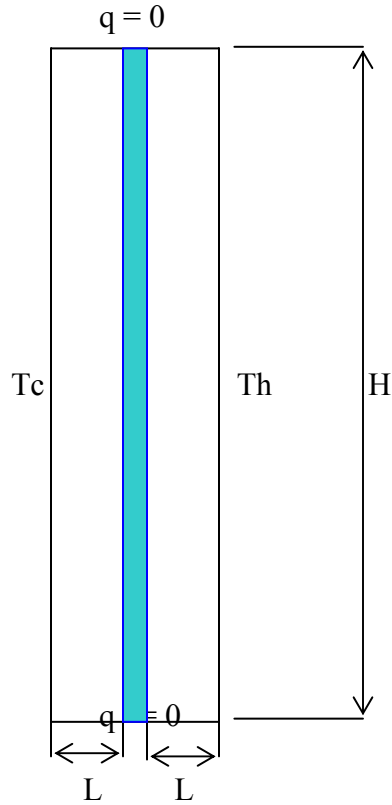


Figure 2. Geometry and the boundary conditions of the modeled glazing system.

It is assumed that average Nusselt numbers of both cavities of glazing system are the same. The average Nusselt number is equal to dimensionless heat flux and was defined through a ratio measured heat flux ( $q$ ) and reference heat flux

$$Nu = q / Q, \quad (1)$$

where

$Q = k\Delta T / (2L)$  - reference heat flux;  
 $k$  – gas conductivity for average temperature of cavity;  
 $\Delta T = T_h - T_c$ .

For comparison with numerical modeling heat transfer through glazing system (fig. 2) was calculated using concept of effective conductivity of glazing cavity

$$K_{eff} = Nu \cdot k.$$

Further we are using the next designations:  $Nu_1$  – Nusselt number of single cavity;  $Nu_2$  – Nusselt number of two cavities (in triple glazing system). Then 1-dimensional heat flux through glazing system with two cavities and glass between them can be expressed as

$$q = \Delta T / (2L / (Nu_1 \cdot k) + d / k_{glass}), \quad (2)$$

where  $\Delta T = T_h - T_c$ ;

$d$ ,  $k_{\text{glass}}$  – thickness and conductivity of glass between cavities.

The average Nusselt number for this glazing system can be determined as a ratio heat flux ( $q$ ) and reference heat flux ( $Q$ )

$$\text{Nu}_2 = q / Q = \Delta T / (2L / (\text{Nu}_1 \cdot k) + d / k_{\text{glass}}) / (k \cdot \Delta T / (2L)) = 1 / (1 / \text{Nu}_1 + \varepsilon), \quad (3)$$

where

$$\varepsilon = d \cdot k / (2L \cdot k_{\text{glass}}).$$

Expanding last expression in (3) into a series and retaining only first two terms of series we have

$$\text{Nu}_2 = \text{Nu}_1 \cdot (1 - \text{Nu}_1 \cdot \varepsilon). \quad (4)$$

Make estimation of term  $\text{Nu}_1 \cdot \varepsilon$  in (4):

$$\text{Nu}_1 \cdot \varepsilon \leq 2 \cdot d \cdot k / (2L \cdot k_{\text{glass}}) < 2 \cdot 0.003 \cdot 0.024 / (2 \cdot .02 \cdot 1) = 0.0036 \text{ (0.36\% of Nu}_1\text{)}.$$

We see that the effect of a glass between cavities on Nusselt number is very small.

Dropping term  $\text{Nu}_1 \cdot \varepsilon$  we finally obtain

$$\text{Nu}_2 = \text{Nu}_1. \quad (5)$$

Thus the dimensionless heat flux through system of two equal cavities and glass between them is equal to the dimensionless heat flux through single cavity under half of total temperature difference applied to system.

Results of numerical modeling of triple glazing system and calculated heat transfer through this system using thermal properties of single cavity as is accepted in modern computer programs for aspect ratio  $A = 20$  and  $A = 40$  are summarized in the Table 2 and show in Figure 3.

Table 2. The comparison of average Nusselt number for glazing system with two cavities obtained in the present numerical study and calculated through thermal properties of single cavity.

Raleigh Number	$T_h - T_c, ^\circ\text{C}$	A = 20		A = 40	
		Present study	Nu2	Present study	Nu2
6126	10	1.388	1.222	1.207	1.116
12250	20	1.726	1.452	1.414	1.245
24500	40	2.170	1.795	1.755	1.486
30630	50	2.316	1.918	1.887	1.591
36750	60	2.441	2.023(17%)	2.00	1.683(16%)

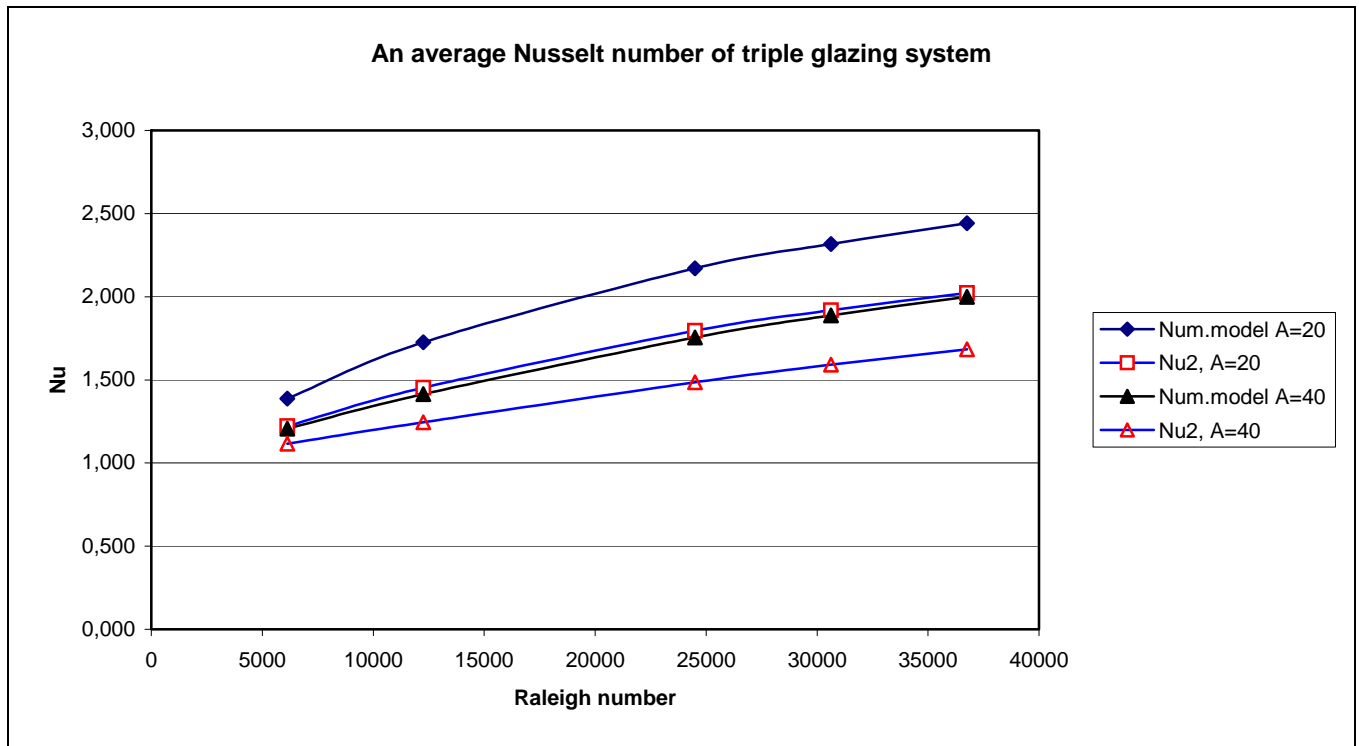


Figure 3. The comparison results of numerical modeling of convection heat transfer through triple glazing system with results of calculation this system using thermal properties single cavity as it is accepted nowadays in standards and computer programs.

## Conclusion

Results of numerical modeling of convection heat transfer through triple glazing system differ by more than 15% from ones obtained by calculation of heat transfer through this system using thermal properties of single cavity and intensity of heat transfer for triple glazing system is higher than obtained by modeling this system by methods used in modern computer programs [1, 2].

That is confirmation of the assumption about strong heat interaction between cavities in triple UG and another boundary conditions than were applied in experimental works used as source for correlations [1, 2].

The approach used in present study can be applied for estimation of convection heat transfer in glazing system with three and more cavities.

*Comment A.F.: Dragan, the glazing is the most important part of fenestration having more than 50% area of one but calculation of UG thermal properties is nowadays based on old approach (20 years old experimental data and correlations for them given for narrow range of aspect ratio) that is proved by results above.*

*It is time to think about renovation of calculation methods of thermal properties of glazing systems.*

*I see now only two ways:*

*The first and the simplest is to obtain and use in THERM tabulated values of Nusselt numbers for UG with two and more cavities and aspect ratio from 30 to 100;*

*The other way is to incorporate into THERM simple program of modeling natural convection in rectangle glazing cavities.*

## **References**

1. ISO/DIS 15099 “Thermal Performance of Windows, Doors and Shading Devices –Detailed Calculations”, 2000-01-12.
2. E.U. Finlayson, D.K. Arasteh, C. Huizenga, M.D. Rubin, and M.S. Reilly. WINDOW 4.0: Documentation of Calculation Procedures. July 1993.
- 3.FDI.2000. FIDAP 8.52 Users and Reference Manual. Fluid Dynamics International, Fluid Dynamics Analysis Package Revision 8.52, Evanston, IL.