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TRANSIENT THERMAL LOADS AT DOUBLE GLAZED INSULATING UNITS[1]

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Abstract: *Temperature fields at insulating glass units (IGU) with different thermal performances are obtained by mathematical modeling and numerical simulation of the heat transfer, taking into account the daily variation of the external temperature and solar radiation. Positive and negative gauge pressure in the hermetized gas space in the IGU is established in the winter and summer period correspondently. The climatic loads, caused by the gas temperature change are estimated. Higher internal loads at the IGU with the lower thermal performance due to coating influence on heat transfer are expected.*

Keywords: *heat transfer, modeling, CFD, insulating glass units, climatic loads.*

INTRODUCTION

The insulating glass units are widely used in the transparent building envelopes due to their relatively low thermal transmittance. Variety of geometries, component materials, number of glass layers, coatings and hermetically sealed gases are produced and available on the market today. The thermo-mechanical processes, caused by thermal loads at that multiplicity of constructions and configurations of IGU are not fully investigated: they continue to be open actual tasks (Neugebauer, 2009; Feldman et al., 2014).

The thermal loads on the units load to thermal stresses and deformations of the elements of the construction in the conditions of non-stationary heat transfer.

At the cyclic climate changes positive or negative gauge pressure in the hermetized gas space of the IGU and subsequent internal loads occur. They result in mechanical stresses and strains in the elements of IGU. Input value for estimation of these processes is so called isochoric pressure:

$$\Delta p_{is} = C_1 \Delta T + C_2 \Delta H + \Delta p_{met}, \text{ kPa} \tag{1}$$

where C_1=0,34 kPa/K; C_2=0,012 kPa/m. ΔH [m], Δp_{met} [kPa] and ΔT [K] are correspondently the changes of the altitude, meteorological pressure and gas temperature according the same at the manufacturing of the units.

The gauge pressure in the gas cavity affects most of the glass panes: they can be deformed in different directions within the day and year. The prediction of these processes is important for the choice of proper IGU type in order to prevent failures of the construction (Velchev at al, 2006).

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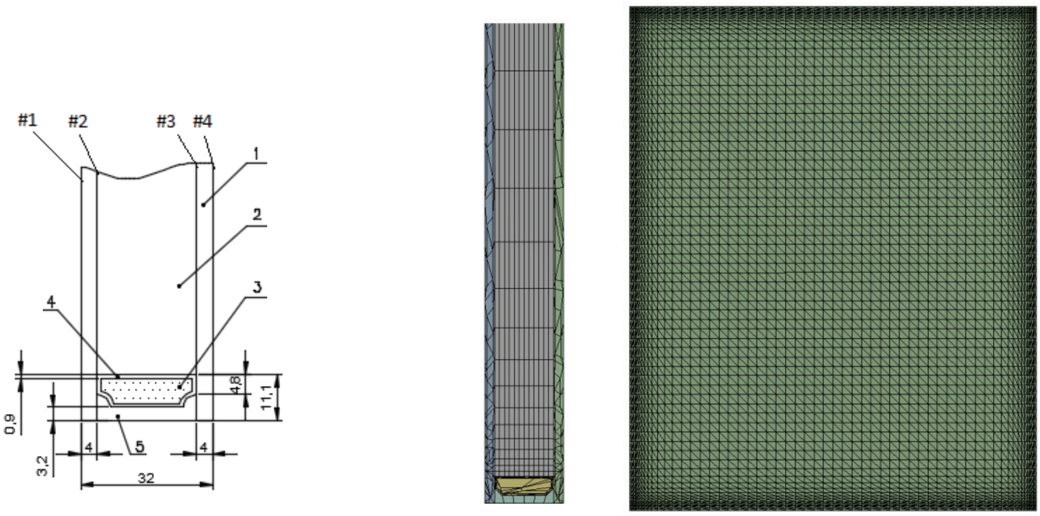
The terms in equation (1), appearing at changes of the altitude and meteorological pressure can be predicted according to the location where the IGU is used. The pressure difference due to the gas temperature change depends on the conditions of the heat transfer and can be computed by mathematical modeling and numerical simulation of temperature and fluid flow fields in the IGU. They vary with the cyclic changes of the external temperature and solar radiation. The coatings on the glasses in the IGU influence on the heat transfer: they increase the thermal resistance of the unit and the absorptances, and temperatures of the glasses (Table 1).

An algorithm for investigations of the transient heat transfer and mechanical behavior of the IGU elements by subsequent numerical analyses by software "ANSYS" and „ABAQUS" is developed (Penkova et al, 2017; Ivanov et al., 2017). It is applied for estimations of temperature fields, thermal stresses and glass deflection at IGU with low emissivity coating on the internal glass pane at the dally variations of external temperature and solar radiation in Sofia for January and July (the mounts with expected higher and lower temperatures in the IGU). An investigation of the heat transfer and internal loads at the same construction but without coating is presented in that paper in order to do comparative analysis of the processes in both variants of IGU.

EXPOSITION

Object of investigation

The investigated IGU (fig. 1) with gross sizes 1038 mm x 1288 mm is a part of vertical east oriented curtain wall façade in Sofia. The hermetizated gas is argon. The emmisivities of the coated (#3), uncoated glass surfaces and aluminum are correspondently 0.03, 0.84 and 0.06.



a) б)

Fig.2. Double glazed insulating glass unit: a) Cross section б) Finite volumes mesh
1 - glass, 2 - argon; 3- silicagel; 4- aluminium; 5- silicon

Parameters of the investigated variants are given in table 1.

Table 1. Energy parameters of insulating glass units

Parameter	4 mm uncoated glass/ 24 mm argon/ 4 mm glass uncoated glass	4 mm uncoated glass / 24 mm argon / 4 mm glass with low-e coating
Thermal transmittance	$U=2.7\ Wm^{-2}K^{-1}$	$U=1.2\ Wm^{-2}K^{-1}$
Solar heat gain coefficient	g=0.79	g=0.63
Visible transmittance	$T_{vis}=82\%$	$T_{vis}=82\%$
Total absobtances of the glasses	External glass: $\hat{A}_1=0,13$ Internal glass: $\hat{A}_2=0,18$	External glass: $\hat{A}_1=0,13$ Internal glass: $\hat{A}_2=0,1$

Numerical simulation of the heat transfer and fluid flow in insulating glass units

The transient heat transfer can be accepted as consecutive steady states, determined at the room and external climate conditions (Penkova et al, 2013; Penkova et al, 2017). Detail information about 3D temperature, velocity and pressure fields in insulating glass units can be obtained by numerical solution of the system of partial differential equations bellow.

Fluid domain (hermetized glass cavity):

- continuity equation;
- momentum equations;
- energy equation;
- turbulence model;
- boundary layer model.

The hermetized gas can be accepted as ideal and uncompressible.

Solid domains (glass panes, spacer and seals):

- energy equation for non-moving media (Fourier-Kirchhoff equation).

The thermal properties of the solid parts of the IGU are discussed in (Penkova et al, 2017). The abortion of the solar energy by the solid elements can be modeled by heat source (heat generation rate) in the energy equation. The radiation heat exchange in the infrared spectrum between the surfaces of the gas cavity is computed by Radiosity solver method in ANSYS/CFX. The view factors of the seeing each other finite volume surfaces is computed and additional matrix equation is formed and solved.

The boundary conditions includes the heat transfer by radiation and convection between the external surfaces and the ambient environment, and the internal surfaces and the room. These heat transfers are reflected by heat fluxes as function of surfaces temperatures. The heat transfer coefficients for the external and internal surfaces, participating in the heat fluxes are accepted: $h_{c,se} = 20\ Wm^{-2}K^{-1}$ (convection); $h_{csi} = 7.7\ Wm^{-2}K^{-1}$ (convection and radiation). The external heat flux contain term for the radiation heat transfer. The room temperature is accepted as 20 °C for January and 24 °C for July.

The climatic data, participating in the boundary conditions are given in tables 2 and 3: Is – solar irradiation ad T_{out} – external (outer) temperature. They are determined by free internet software PVGIS. The moments of the day are fixed to contain the maximal value of the solar radiation. The results about the average argon temperature $T_{g,av}$, the gas temperature difference according the same at the process of the hermetization (293 K) and the correspondent gauge pressure in the cavity of IGU are given in the same tables for the both investigated variants.

Higher vacuum pressures in the IGU and maximal glass deflections (sinking) are expected at the nigh time in January for the both investigated variants. In the same time the relatively low temperature of the external glass leads to additional tensile stresses. The negative gauge pressures are higher for the construction without coating in January. The differences between Δp vary in the day (table 3). It is about 10% at the periods with the higher internal loads. That difference is influencing insignificantly on the mechanical behavior of the IGU elements in comparison with the loads of wind, meteorological pressure and altitude changes.

The maximal positive gauge pressure is obtained for the moments of the days with higher solar irradiation in July for the both variants. At that period the coated glass is with higher temperature (figure 2 and 3) which is a precondition for higher thermal stresses. The expected deflections of the glass panes are in different direction in the summer and winter seasons.

Stresses in the glass panes, several order lower than the maximum permissible value for the IGU with low-e coating are established in the previous thermal load analyses on the base of the obtained temperature fields and isochoric pressures in tables 1 and 2. The stress analyses prove the safety of the construction (Ivanov et al., 2017). The computed gas and glass temperatures changes according the reference temperature of 293 K for the IGU without coatings are lower in July and approximately equal in January in comparison with the unit with a coating. That is precondition for an expectation for relatively low stresses and strains at the UGU without coating.

Table 2. Climatic conditions and loads in July

Time	I_s	T_{out}	UGU with low-e coating			UGU without coatings			Differences between Δp
			$T_{g,av}$	ΔT	$\Delta p=C_1.\Delta T$	$T_{g,av}$	ΔT	$\Delta p=C_1.\Delta T$	
h:min	Wm^{-2}	K	K	K	kPa	K	K	kPa	%
4:07	0	292	293	0	0.06	293	0	-0.04	167
5:07	105	293	295	2	0.72	294	1	0.40	44
6:07	461	294	300	7	2.45	297	4	1.52	38
7:07	671	295	303	10	3.54	300	7	2.27	36
8:07	741	296	304	11	3.74	300	7	2.31	38
9:07	697	297	305	12	4.04	301	8	2.71	33
10:07	567	298	304	11	3.67	300	7	2.55	30
11:07	378	299	302	9	2.96	300	7	2.27	23
12:07	157	299	299	6	1.96	298	5	1.74	11
13:07	73	299	298	5	1.64	298	5	1.56	5
14:07	72	299	298	5	1.69	298	5	1.55	8
15:07	69	298	297	4	1.42	297	4	1.34	6
16:07	63	297	297	4	1.20	296	3	1.09	9
17:07	52	296	296	3	1.00	295	2	0.84	15
18:07	36	294	295	2	0.63	294	1	0.48	24
19:07	16	293	294	1	0.37	294	1	0.22	39
20:07	0	293	294	1	0.27	293	0	0.15	44

Table 3. Climatic conditions and loads in January

Time	I_s	T_{out}	UGU with low-e coating			UGU without coatings			Differences between Δp
			$T_{g,av}$	ΔT	$\Delta p=C_1.\Delta T$	$T_{g,av}$	ΔT	$\Delta p=C_1.\Delta T$	
h:min	Wm^{-2}	K	K	K	kPa	K	K	kPa	%
6:52	0	271	280	-13	-4.56	278	-14.74	-5.01	10
7:52	413	273	286	-7	-2.40	283	-10	-3.52	47
8:52	642	274	289	-4	-1.22	285	-8	-2.68	120
9:52	575	276	290	-3	-1.14	286	-7	-2.47	117
10:52	392	276	287	-6	-1.89	284	-9	-2.91	54
11:52	150	277	285	-8	-2.76	283	-10	-3.35	21
12:52	23	276	283	-10	-3.47	282	-11	-3.87	12
13:52	21	276	283	-10	-3.49	282	-11	-3.90	12
14:52	18	275	282	-11	-3.71	281	-12	-4.17	12
15:52	13	274	281	-12	-3.92	280	-13	-4.35	11
16:52	4	273	281	-12	-4.14	280	-13	-4.58	11
17:52	0	272	280	-13	-4.36	279	-14	-4.80	10
18:52	0	271	280	-13	-4.54	278	-15	-4.99	10
19:52	0	271	280	-13	-4.55	278	-15	-5.00	10

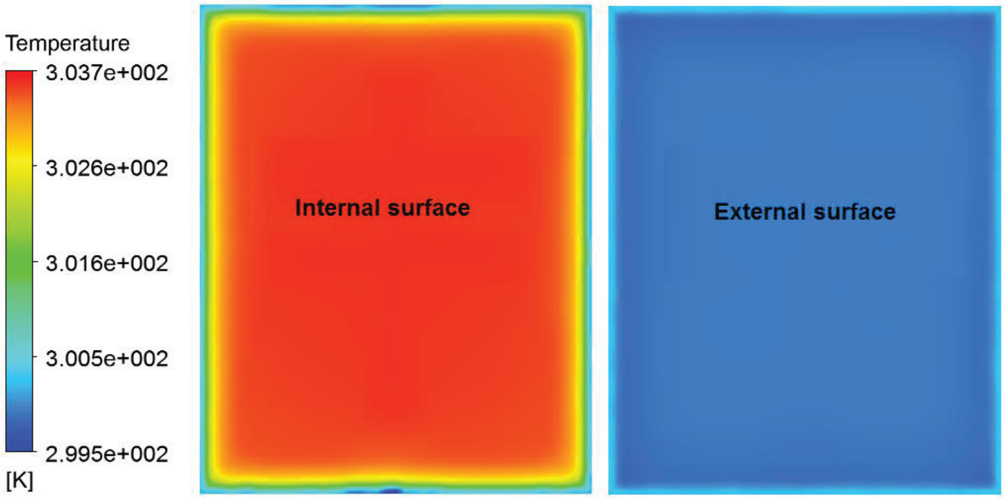


Fig. 2. Temperature fields in IGU with uncoated glasses, July 9:07 h.

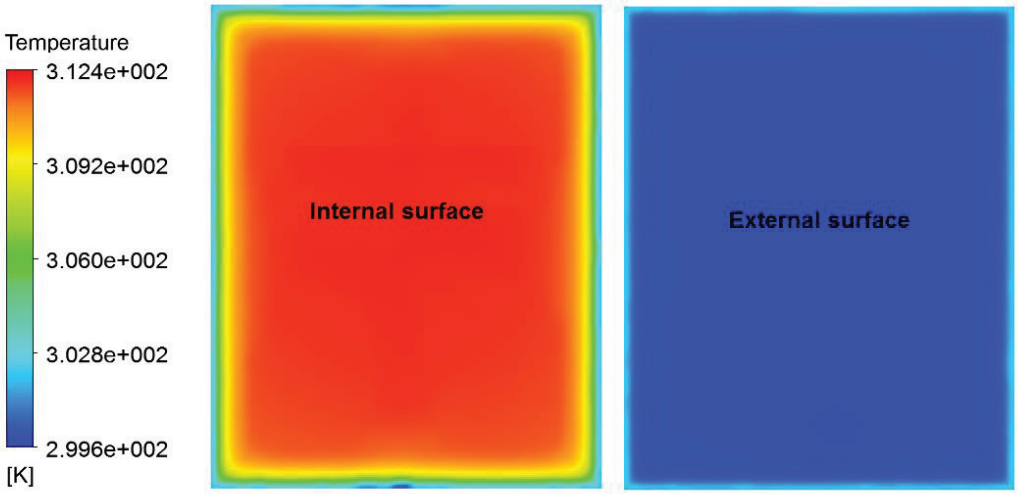


Fig. 3. Temperature fields in IGU with coating on the internal glass, July 9:07 h.

CONCLUSION

The obtained by modeling and numerical simulations thermal loads at double glazed insulating glass unit with coating are higher in comparison with the same construction without coating. That is resulting in higher thermal stresses and internal loads in the summer periods and lowers in the winter at the more energy efficient construction. These differences are insignificant in the periods with the maximal thermal loads and cannot be a factor at the choice of constructions.

The failures of the units due to thermal loads are not expected for the both investigated variants.

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