Original scientific papers
UDK 66.017/.018+697
doi : 10.7251/COMEN1301062V

ACTIVE INSULATION – VARIATION OF TROMBE WALL

Siniša M. Vučenović[1]*, Kristina Fodor*[2]*, Imre Gut*[2] *and Jovan P. Šetrajčić*[2]

[1]University of Banja Luka, Faculty of Sciences – Physics,
Mladena Stojanovića 2, Banja Luka, RS-BiH,
[2] University of Novi Sad, Faculty of Sciences – Department of Physics,
Trg Dositeja Obradovića 4, Novi Sad, Vojvodina – Serbia,

Abstract: Trombe wall, which has been proposed in 1960s, became interesting nowadays as a method for additional heating of buildings. The main problem of the Trombe wall is the fact that this type of wall is a passive element. There have been attempts at solving this problem by introducing various active models of insulation. This paper presents a model of active insulation of buildings, whereby the control of insulation is achieved by a bridging method. The model is simulated in *MatLab* under conditions of non-stationary heat conduction, that exist in real conditions. We have calculated the effects of different combinations of layers of insulation and load-bearing walls and their thickness, on the temperature distribution, both inside the insulation system-load-bearing wall and the air temperature inside the building. We examined the time lag of air temperature inside the building in relation to the outside air temperature, i.e. thermal inertia of such systems.

Keywords: Trombe wall, active insulation, thermal inertia.

1. INTRODUCTION

One of the possible solutions in passive architecture is the use of the so-called Trombe wall. The name of the wall was given after a French engineer *Félix Trombe*, who suggested this type of wall as an additional source of heat in overall heat load of the buildings. This type of wall was introduced in the sixties of the past century. One research was carried out in the U.S. (in the winter 2001-2002), where Trombe wall was used in one object as additional method to the conventional heating system (standard HVAC system usually used in the U.S). It was concluded that Trombe wall could participate with up to 20% in the overall annual heat load [1]. Figure 1 shows distribution and contribution of the heat generated from the Trombe wall and one can see that by using Trombe wall significant energy savings can be achieved in heating of the buildings. It could be noticed that in some days the Trombe wall could warm up independently, when the HVAC system was turned off, especially at the beginning and at the end of the heating season (November and March). However, positive effect of additional heat production and energy savings during the winter turn into heat excess in the summer! During the warm days Trombe wall produces even more heat, causing more energy consumption for conventional HVAC system, which must take away that additional heat from the building. This negative aspect of Trombe wall has to be overcome and there were some ideas how to do that. In general all ideas included active or controlled insulation of the buildings [2,3], mostly through the removal and/or bridging of the additional heat. Methods of heat removal include various automated mechanisms of physical deflection of external insulation panels, which makes these methods relatively complex and expensive, with reduced lifetime. Methods which include bridging of additional heat are more reliable and less expensive, and they are the main motive for selecting this type of active insulation.

In this paper we have used the bridge-method which involves active (or supported) insulation, as shown schematically in Figure 2.

This type of active insulation implies the existence of air-layer between the external insulation layer and bearing wall (usually made of brick or concrete). On the top and bottom of the wall there are two holes, which can take in open or closed positions, regulated with automated mechanism. In case of a closed wall – insulation is of the passive type. With the simple system which includes the use of temperature sensors and computing device that regulate opening or closing of the doors on the holes, we get one variant of the Trombe wall with active insulation support system.

---

* Correspondig author: vucenovic.s@gmail.com

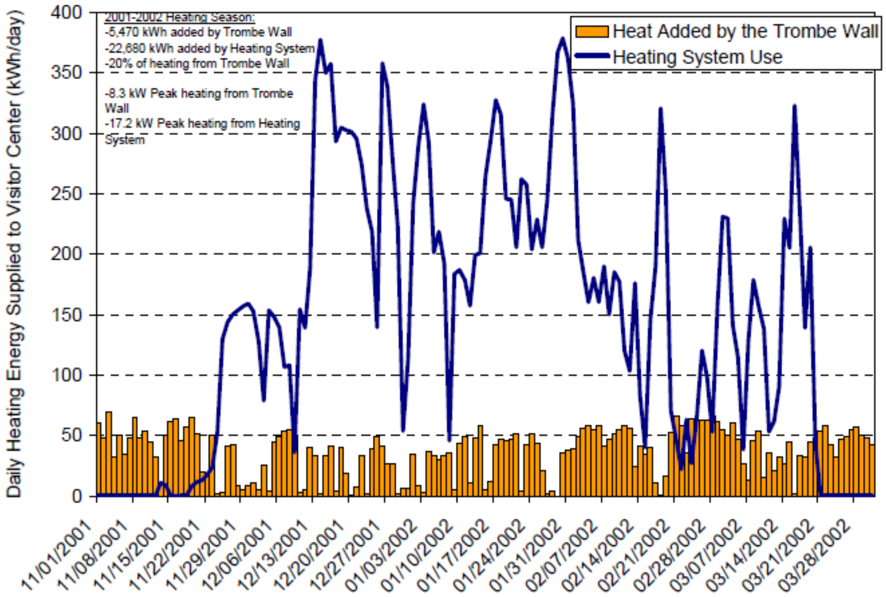

Figure 1. Heat contribution generated from the Trombe wall (yellow bars) and the convectional HVAC system (blue line)[1]

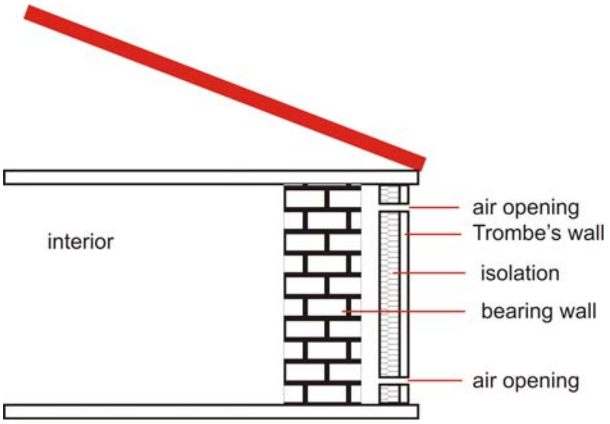

Figure 2. Active insulation model with bridging of heat

2. HEAT CONDUCTION EQUATION – ONE DIMENSIONAL APPROXIMATION

The temperature field is generally time and space depended, i.e. $T = f\left(x, y, z, t\right)$, and it is described with the mathematical model of partial differential equations, derived from the energy balance through the Trombe wall with active insulation[1] [4,5].

To simplify the problem, we will calculate heat transfer along one direction only (for example *x* – direction), assuming there is no heat generation in the interior, and that the values of density (ρ), specific heat (c) and heat conduction coefficient (λ) remain constant. In that case we can define the input amount of heat:

$$Q_{ul} = -\lambda \frac{\partial T}{\partial x} S , \tag{1}$$

while heat amount which goes through different small thickness of the wall (*dx*) is equal $Q_{iz} = Q_{ul} + dQ$, where:

$$-dQ = d\left(-\lambda \frac{\partial T}{\partial x} S\right) = -\lambda d\left(\frac{\partial T}{\partial x} S\right) = -\lambda \frac{\partial^2 T}{\partial x^2} dxS \tag{2}$$

---

[1] Energy balance formulation implies: Input energy – Output energy + Generated energy = Energy accumulated in system.

represents a change of the heat during heat-transition trough the differential small thickness of the wall (*dx*). Accumulated heat is:

$$\frac{dmc\Delta T}{\Delta t} = \rho c \frac{\partial T}{\partial t} dV = \rho c \frac{\partial T}{\partial t} S dx, \qquad (3)$$

and after re-organizing energy balance equation we obtain the expression $\lambda \frac{\partial^2 T}{\partial x^2} = \rho c \frac{\partial T}{\partial t}$, which can be written in a simplified form:

$$a \frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t}, \qquad (4)$$

where term a represents heat diffusion coefficient i.e. $a = \lambda / \rho c$. Expression (4) is a partial differential equation of 2nd order over the space and first order over time, so to obtain a solution we would need two boundary conditions over space coordinate (for *x=0* and *x=L*) and one initial (time) condition (for *t=0 ; T(x,0)=f(x)*).

3. SIMULATIONS OF TEMPERATURE FIELDS

We have used a simple sinus function over the temperature to simulate external conditions. This is a rough but good approximation, although we have used extreme changes in external temperatures (starting temperature 15 °C with 20°C amplitude). For computing and simulations we used MatLab program package [6], with space step of 1 pixel=1 [cm] and time step of 30 minutes. We performed calculations with iterative procedures, with previously calculated temperature field as input parameter in the next iterative time step. Total time for simulations was 96 hours. Also, we used commercially available material in all simulations, with their properties given in Table 1.

Table 1. Properties of building Materials used in simulations

Material	λ [W/mK]	ρ [kg/m^3]	*c* [J/kgK]	a[10^{-7} m^2/s]	Rel. diffusivity
Lime mortar	0,85	1700	1050	4,76	1
Solid brick	0,61	1900	920	3,49	0,73
Hollow brick	0,42	1600	920	2,85	0,60
Giter block	0,22	1200	920	1,99	0,42
Plastic matter	0,06	120	1400	3,57	0,75
Cork plate	0,04	200	1670	1,20	0,25

3.1. Non-insulated wall

To determine the influence of a type or thickness of insulation (or the bearing wall), we will first calculate the temperature field for a non-insulated wall[2]. We have changed different types of bearing walls: a) solid brick, b) hollow brick, and c) Giter block, all with the same thickness of 15 [cm], and with the coefficient of relative diffusivity of 0,73, 0,6 and 0,4 respectively. Every wall has an inner and external layer of lime mortar 3 [cm] thick. Figures 3 – 5 show temperature profiles inside the walls and in interior for three specific (and characteristic) moments: when the external temperature is at the maximum; equal to the interior temperature; and when the external temperature is at the minimum. All three moments are chosen in the last (fourth) day, i.e. near the very end of the whole simulation process. Green and purple colors represent lime mortar; yellow color is for the bearing wall, while the blue color represents interior air. As mentioned above, we have simulated a case of active insulation, when the air behind Trombe wall[3] circulates only if air temperature is higher than the temperature of non-insulated wall, otherwise the air circulation stops. The process of air circulations is determined with the computer with thermometers (sensors). Thus, Trombe walls with active insulation combine their characteristics – Trombe wall with relatively easy heat generation, and good insulation characteristics of various materials.

One can see that Giter blocks have much better insulation properties compared with solid and hollow bricks. Also, Giter blocks have significant heat inertness, and this material manifests the lowest deviation (or temperature oscillations) from the starting temperature. The bearing wall made of solid brick shows the lowest heat inertness. In Figure 4

---

[2] Although this type of wall has formally insulation layer (usually lime mortar), common name for this wall in civil engineering is non-insulated, because none of the bearing wall sides have a layer of insulation material with relatively (enough) small heat conduction coefficient λ.

[3] Trombe wall is not shown here in Figures, but we presume its presence on the left of non-insulated wall.

heat accumulation inside the bearing wall is shown – the quantity which is very important especially in the heating systems with discontinuation. Figure 6 presents a change of interior temperature in total simulation period of time (96 hours), where blue curve indicates external temperature oscillations (sinusoidal function).

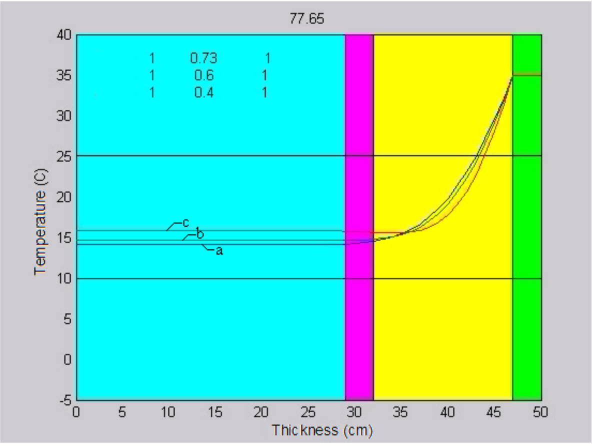

Figure 3. Temperature profile for non-insulated wall and maximum external temperature with the bearing wall made of: a – solid brick; b – hollow brick and c – Giter block

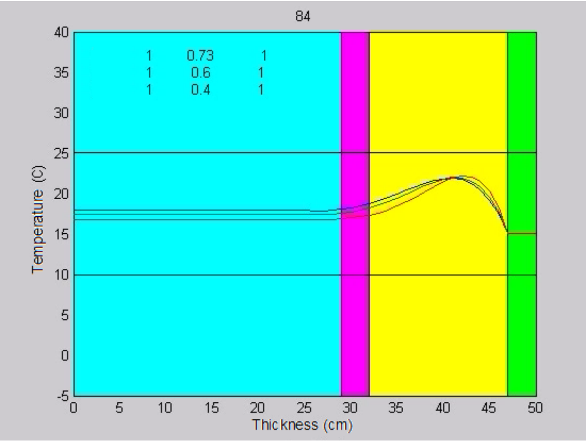

Figure 4. Temperature profile for non-insulated wall and equal interior and external temperatures

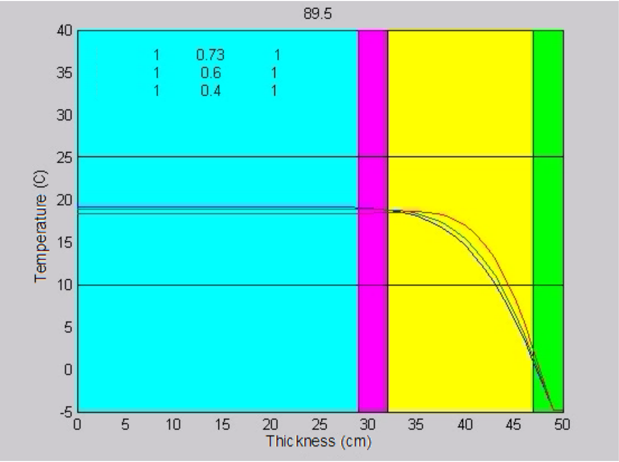

Figure 5. Temperature profile for non-insulated wall with minimum external temperature

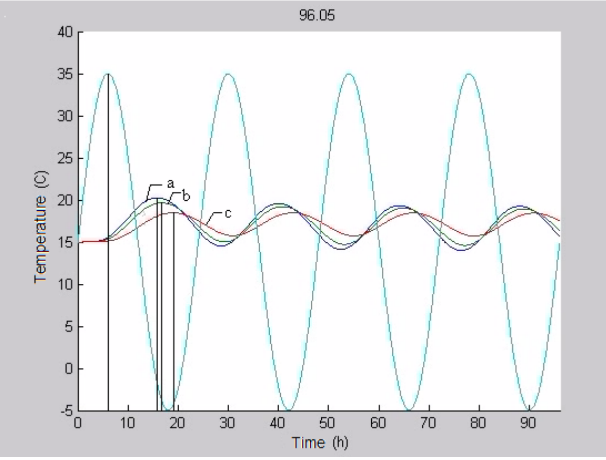

Figure 6. Temperature profile of interior compared with external temperature for non-insulated wall

This figure shows that the phase difference (i.e. delay of maximum interior temperature compared to external temperature) ranges from about 10 hours (for a bearing wall made of solid brick), up to 15 hours for a bearing wall made is decreasing function in dependence of relative heat diffusivity.

3.2. Insulated wall

We have calculated temperature distributions for insulated walls, with various insulation layers placed on the external side of the wall. Results are shown in Figure 7, where a non-insulated wall is shown by two walls insulated in different ways, to make it easier to compare. The curve “c” represents a non-insulated wall, while curve “a” represents the wall insulated with 6 [cm] thick cork plates and curve “b” represents the wall insulated with 2 [cm] thick Durisol.

One can see that the highest interior temperature can be achieved with the wall insulated with cork plates, which is an expected result because cork has the lowest heat conductivity coefficient (λ). Additionally, active insulation system (automated blowing of air when the temperature of air is higher than the interior temperature) in combination with Trombe wall leads to faster warming-up of the interior temperature, compared with the passive wall insulation systems. Figure 8 shows a change of interior air temperature over a total simulation time.

From Figure 8 one can see that the existence of insulation layers does not affect the phase difference (heat inertness) and in all cases time delay is about 11 hours. Also, the influence of insulation thickness has been investigated and the conclusion is that the thickness of the embedded insulation layer has no influence on phase difference. However, the insulation layer is directly connected with heat accumulation in such a way that interior air temperature increases with time, while non-insulated wall cannot contribute to an increase of interior air temperature – where temperature oscillates around the some equilibrium temperature with an approximate 2°C amplitude. Obviously, the densest part of the wall has the greatest impact on heat inertness, which is in our case the bearing wall, while the insulation layer has a negligible influence on heat inertness, regardless of the type or thickness of insulation layer. This is a fact that could be very important in heating systems with discontinuation, where delivery of heat could be time shifted, i.e. delivered from the bearing wall.

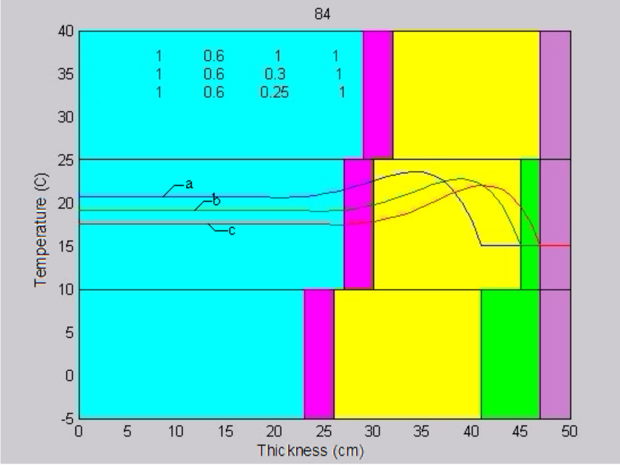

Figure 7. Temperature profile for: non-insulated wall (curve c); wall with insulation layer of 2 [cm] thick *Durisol (curve b) and wall with insulation layer of* 6 [cm] thick cork plate *(curve a)*

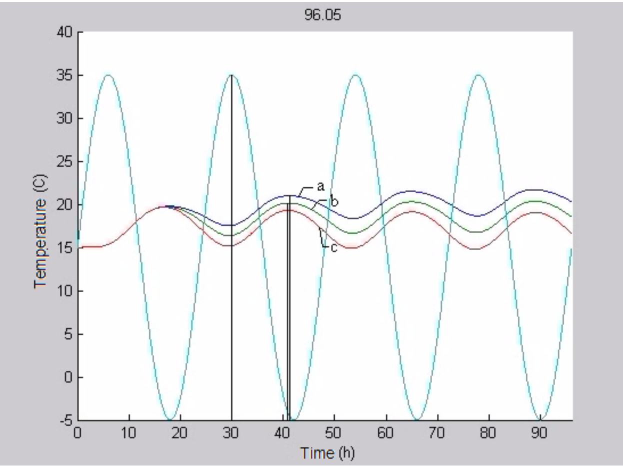

Figure 8. Interior temperature profile for: non-insulated wall (curve c); insulated with 2 [cm] *thick Durisol (curve b); insulated with* 6 [cm] *thick cork plate (curve a)*

3.3. Influence of thickness of the bearing wall

We have selected one type of the bearing wall (for example hollow brick) and simulated the influence of various thicknesses on interior air temperature. Figure 9 shows 3 combinations of walls, each with two layers of 3 [cm] thick lime mortar (both on external and internal side of the wall), an insulation layer of 6 [cm] thick bulrush, and the bearing wall made of hollow brick a) 15 [cm]; b) 19 [cm] and c) 25 [cm] thick.

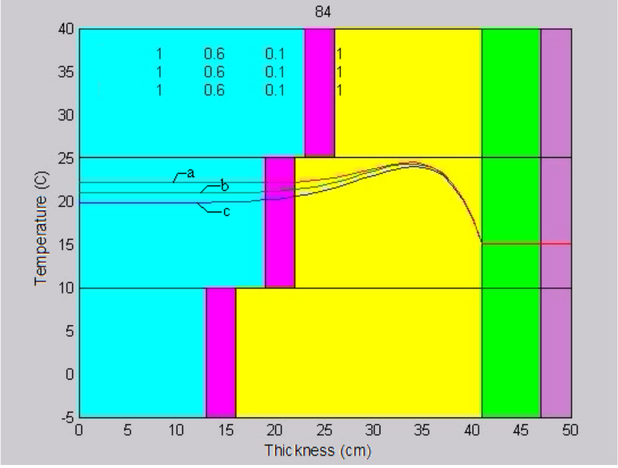

Figure 9. Temperature profile wall with thermal insulation, and with bearing wall thickness of: a) 15 [cm]*; b)* 19 [cm] *and c)* 25 [cm]

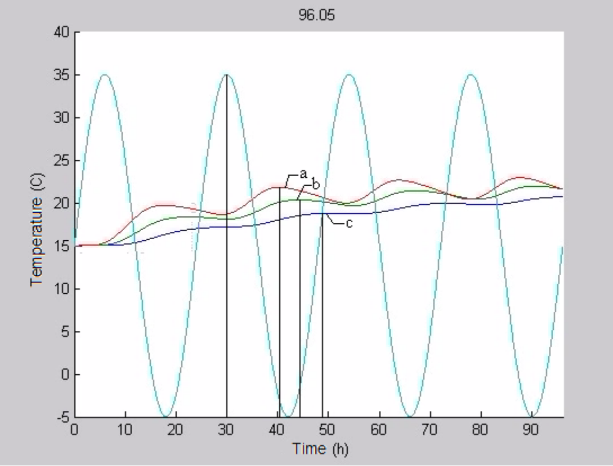

Figure 10. Change of the interior air temperature for the insulated wall, with thickness of the bearing wall of: a) 15 [cm]*; b)* 19 [cm] *and c)* 25 [cm]

Maximum interior air temperature is obtained with the lowest bearing wall thickness, which is an expected result, while the heat transition coefficient ($K = \lambda / x$) inversely depends on thickness of the wall. It can be concluded that the heating (or cooling) rate of interior air will be the highest with the smallest thickness of the bearing wall. Figure 10 shows how temperatures change with various thicknesses of bearing wall in total simulation time. The value of phase shift increases with thickness of the bearing wall, but the amplitude of temperature oscillations decreases (the thickest bearing wall has the smallest amplitude of interior air temperature oscillations). However, the interior air temperature increases for all three thicknesses of the wall. From these facts we can conclude that the temperature field will be most balanced (i.e. without higher oscillations in temperature) for the thickest bearing walls. From the point of view of heat transfer and accumulation, as well as heat inertness, thick and thin bearing walls have both their pros and cons. But, primarily, thickness of the bearing wall will be determined by the required strength and mass load of the building. Taking into account the economic issues (besides the heat and strength issues, although all issues can fall under economic issues), it is necessary to conduct an assessment regarding optimum thickness of the wall.

4. CONCLUSION

In this paper we have presented a theoretical model of simulation of Trombe wall coupled with active air flow, where (in winter time) heat (produced from the Trombe wall) is conveyed to the bearing wall, and then with the heat conduction mechanism trough the bearing wall into the interior air. In summer time flow of the heat has an inverse direction. All simulations have been conducted using MatLab software. Using this type of active insulation a negative side of Trombe wall could be relatively reduced, especially during the summer days where, due to additional heat more expenses are incurred for cooling the facilities. In the simulation of 96 hour time period and extreme sinusoidal change of external air temperature, we conclude that:

− Active insulation has advantage over passive insulation, because heat transfer is supported with the air flow (i.e. heat flow – convection of heat) mechanism, beside heat generation by Trombe wall (heat radiation). Air flow could be used both for heating and cooling the object.

− Setting up of the insulation layer on the external side of the wall results in increasing the interior air temperature. Type and/or thickness of insulation material (with as low as possible heat conduction coefficientλ) is directly proportional to the interior air temperature, although only insulation layers do not have significant impact on heat inertness of the object (i.e. on the phase difference in oscillations between external and interior air temperature), remaining almost the same as for non-insulated walls.

− Type of and/or thickness of bearing wall has a significant impact on heat inertness of the object, and this is due to the fact that bearing walls are made of material with the highest values of density and specific heat. The thinnest bearing walls have the highest temperatures and maximum heating rates, but also have a maximum cooling rate. On the other hand, thicker bearing walls result in a balanced interior air temperature and the highest heat inertness, making those walls a sort of heat accumulators. Considering economic and constructional requirements of each building, the final thickness of a bearing wall must be properly optimized. Nevertheless, passive heating effects remain a wise solution for all combinations of bearing walls.

5. REFERENCES

[1] P. Torcellini, S. Pless, *Trombe Walls in Low-Energy Buildings*, NREL/CP-550-36277, Denver (2004)

[2] M. Muravljov, *Građevinski materijali* [Construction Materials], Beograd: Građevinska knjiga (2007)

[3] R. Trbojević, *Arhitektonske konstrukcije, masivni konstruktivni sklop,* Novi Sad: Stylos-print (2003)

[4] W. S. Janna, *Engineering heat transfer*, New York: CRC Press (2000)

[5] D. W. Mackowski, *Conduction Heat Transfer – Notes for MECH 7120*, Mechanical Engineering Department, Auburn University (http://www.eng.auburn.edu/~dmckwski/mech7210/condbook.pdf)

[6] http://www.mathworks.com/help/techdoc/matlab_prog/briz6wl.html

* * *

АКТИВНА ИЗОЛАЦИЈА – ВАРИЈАЦИЈА ТРОМБОВОГ ЗИДА

Сажетак: Тромбов зид, који је као рјешење за додатно загријавање објеката предложен 60-их година прошлога вијека, данас постаје поново актуелан. Основни проблем код употребе Тромбовог зида јесте чињеница да се ради о пасивном елементу, те се овај проблем настоји превазићи увођењем различитих модела активне изолације. Овај рад представља модел активне изолације објекта, у којем се контрола изолације врши методом премошћења. Модел је симулиран у програмском пакету MatLab у условима нестационарног топлотног провођења, као што и јесте у реалним условима. Прорачунавали смо утицаје различитих комбинација и врста изолационих слојева и носивих зидова, као и њихових дебљина, на температурну дистрибуцију како унутар система изолациони слој – носиви зид, тако и ваздуха у унутрашњости објекта. Испитали смо и временско кашњење у процесу загријавања ваздуха у унутрашњости објекта у зависности од температуре спољашњег ваздуха, тј. термичка инертност ових система.

Кључне ријечи: Тромбов зид, активна изолација, термичка инертност.

* * *