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THERMODYNAMIC BEHAVIOR OF A SOLAR BLOCK OF FLATS WITH A GREENHOUSE AND THERMO-ACCUMULATIVE BRICKWALL

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Abstract. *This paper presents the effects of the passive solar heating of the individual housing unit located in Nis, which are brought about by use of passive solar system made up of glass veranda and thermo accumulative cross brick wall having thickness of d = 20 cm and d = 45 cm. The object is not heated additionally by means of conventional energy sources. On the thermo accumulative wall there are windows for direct absorption of the sun radiation.*
This paper also analyzes the inner temperatures in the room and in the glass veranda, in the thermally isolated object with cross thermo accumulative concrete and brick wall having thickness of 20 and 40 cm. There have been given diagrams of the inner temperatures in the glass veranda and the room of the object for its different orientations: $\psi = 0^\circ$ *(orientation of the glass veranda towards the south,* $\psi = +80^\circ$ *(orientation of the glass veranda towards the east),* $\psi = -80^\circ$ *(orientation of the glass veranda towards the west).*

Key Words: *Greenhouse, Passive Solar Heating of Residential Objects*

1. INTRODUCTION

Depending on how solar energy reaches an object, there are two different manners in which an object can be heated by sunlight: direct and indirect. In direct solar heating, the sunlight directly penetrates the room through a transparent screen (window), whilst in the indirect solar heating the external elements of an object (Tromb's wall, water wall, active

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massive wall, etc.) receive and absorb the sunlight and transmit it to the rooms that are to be heated.

Passive solar collection is made possible by an object with no additional devices that can collect the sunlight and convert it into other forms of energy. In these systems the entire object serves as a solar collector.

Designing energy-efficient residential buildings includes the application of passive systems for solar heating [2,5,8,9].

The paper presents the results of a study on thermodynamic behavior of buildings whose constructive elements (floor, walls, ceiling) have been insulated, in the case when the sunlight is collected through a greenhouse and through thermo-accumulative brick-wall, thickness of d = 20 cm and d = 45 cm. Thermo-accumulative brick wall contains windows (direct intake of sun radiation into the heated object). The object is not additionally heated.

2. Solar Object With a Greenhouse and the Thermo-Accumulative Brick Wall and Windows for Direct Insolation

An object with a greenhouse and thermo-accumulative brick wall and windows for direct insolation is given in Figure 1. A greenhouse is positioned on the southern façade. Coefficient of the glass heat transmission is $U_{window} = 2,5[W/m^2K]$. On the south façade wall there are windows of total surface area $A_{window} = A_3 = 15,72$ m^2. Surface of the thermo-accumulative wall is $A_{wall} = A_2 = 24,96$ m^2 The surface of the greenhouse floor is $A_{gr.house\ fl.} = A_2 = 30$ m^2. Coefficient of the greenhouse floor sun radiation absorption is $\alpha_1 = 0,85$, coefficient of the sun radiation absorption of the thermo-accumulative massive brick wall is $\alpha_2 = 0,80$, coefficient of the absorption of the sun radiation of the room's floor is $\alpha_3 = 0,40$.

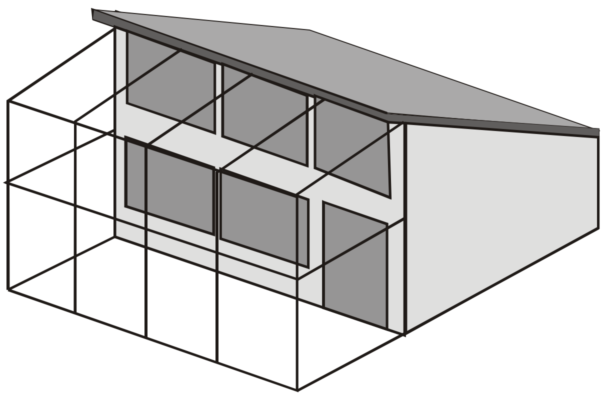

Fig. 1. Acsonometric Appearance of the Object

The structure of the construction parts of the insulated passive solar residential object is given in *Table 1*.

Table 1 Structure of construction parts of the insulated passive solar house with greenhouse and thermo-accumulative massive brick wall

	$d[m]$	$\lambda[W/mK]$	$R = d / \lambda[m^2K/W]$	$\rho[kg/m^3]$	$C_p[J/kgK]$
Construction of the insulated outer wall					
Solid brick	0,300	0.640	0,468	1600	920
Mineral wool	0,080	0,038	2,100	80	840
Façade Brick	0,120	0,640	0,187	1600	920
Construction of the insulated floor on the ground					
Parquet	0,022	0,210	0,105	600	2090
Rabic cement substrate	0,050	1,160	0,043	2200	960
Ferro-concrete	0,150	1,160	0,129	2000	960
PVC foil	0,0004	0,190	0,002	1200	960
Vunizol	0,070	0,041	1,707	150	840
Rabic cement substrate	0,030	1,160	0,026	2000	960
Multi layered bitumen hydroinsulation	0,015	0,190	0,079	1100	1460
Ferro-concrete	0,100	1,160	0,086	2000	960
Ruffle gravel	0,150	0,810	0,519	1700	840
Construction of the insulated slanting roof					
Calcareous mortar	0,020	0,810	0,025	1600	1050
Ferro-concrete plate	0,140	2,04	0,069	2400	960
Steam barrier	0,005	0,190	0,260	1100	1460
Vunizol MP	0,100	0,038	2,631	60	840
Ventilated layer of air	0,020	100	0,000	1,180	1005
Tile	0,012	0,990	0,0121	1900	1460
Construction of glass veranda floor					
Teraco	0,020	0,900	0,022	2000	840
Mortar substrate	0,030	1,160	0,026	2000	960
Multilayer bitumen	0,015	0,190	0,079	1100	1460
Fero concrete	0,180	0,900	0,200	2000	840
Ruffle gravel	0,150	0,810	0,519	1700	840

3. Study Results

The temperatures have been calculated for the rooms and greenhouse of the solar insulated object heated only by means of greenhouse and thermo-accumulative brick wall, (d = 20 cm and d = 45cm). The object was located in Niš, (L = 43°), and $\psi = 0°, \pm 80°$. The room and greenhouse temperatures were calculated by using an original mathematic model [6].

Temperatures in room and greenhouse of a thermally insulated object with a thermo-accumulative brick wall thickness of 20cm

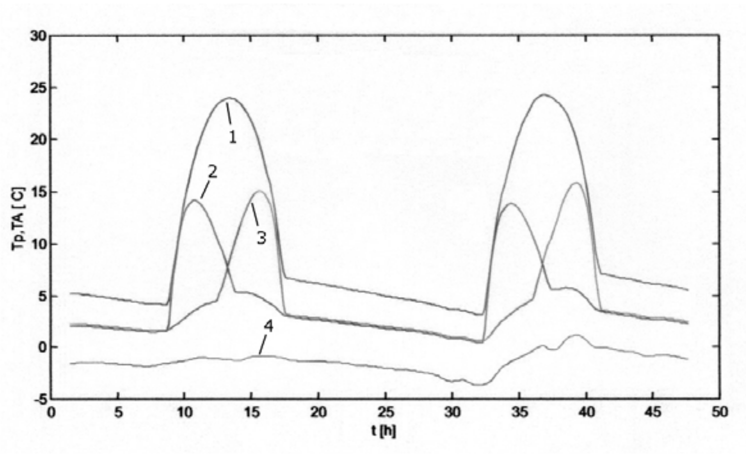

Fig. 2. Room temperatures for (Ap = 15,72 m2; ρ = 0,20; τ = 0,70; Aw = 24,96 m2): 1. Room temperatures for orientation ψ = 0°, 2. Room temperatures for orientation ψ = + 80°, 3. Room temperatures for orientation ψ = – 80°, 4. Ambient temperatures.

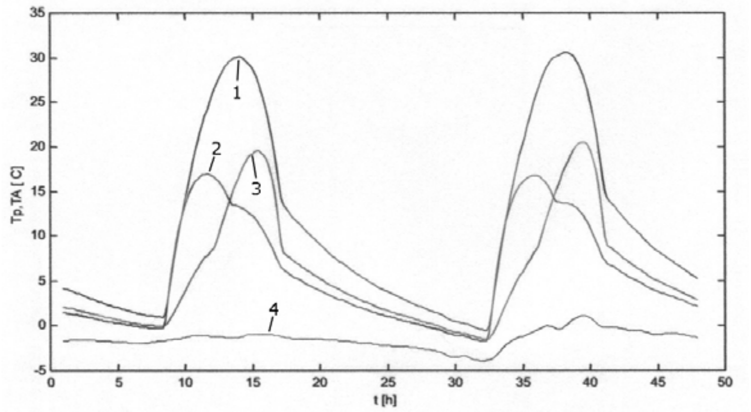

Fig. 3. Greenhouse temperature (Ap = 15,72m2; ρ = 0,20; τ = 0,70; Aw = 24,96m2) for: 1. Room temperatures for orientation ψ = 0°, 2. Room temperatures for orientation ψ = + 80°, 3. Room temperatures for orientation ψ = – 80°, 4. Ambient temperatures.

Temperatures in room and greenhouse of a thermally insulated object with a thermo-accumulative brick wall thickness of 45 cm

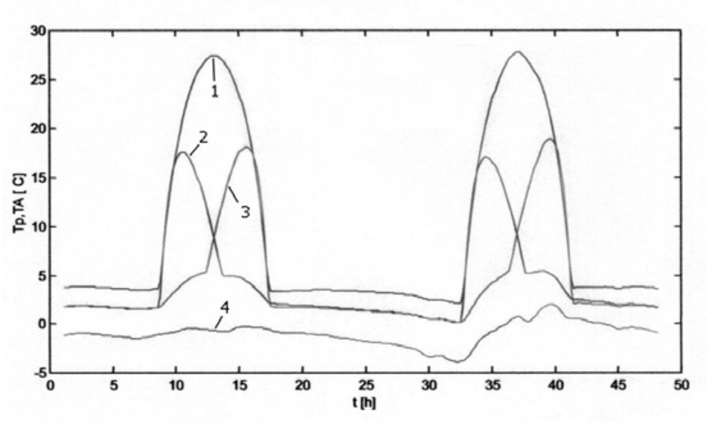

Fig. 4. Room temperatures for (Ap = 15,72m2; ρ = 0,20; τ = 0,70; Aw = 24,96m2): 1. Room temperatures for orientation ψ=0°, 2. Room temperatures for orientation ψ = + 80 , 3. Room temperatures for orientation ψ = – 80°, 4. Ambient temperatures.

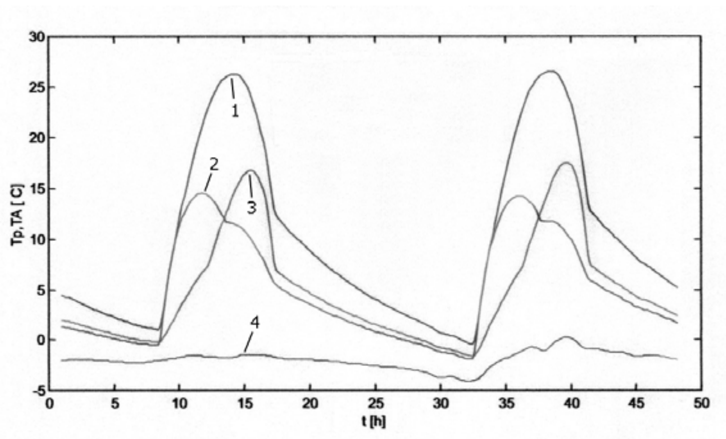

Fig. 5. Greenhouse temperature (A_p = 15,72m^2; ρ = 0,20; τ = 0,70; A_w = 24,96m^2) for: 1. Room temperatures for orientation ψ = 0°, 2. Room temperatures for orientation ψ = + 80°, 3. Room temperatures for orientation ψ = – 80°, 4. Ambient temperatures.

The influence of the object's orientation with greenhouse and thermo-accumulative brick wall upon the air temperature inside the room of ***the insulated object*** has been defined**,** by comparing the inner air temperatures of the object with a greenhouse and the room of the southern orientation (ψ = 0°) with the air temperature of the object with greenhouse and the room of the south or east orientation of ψ = ± 80° (over a time cycle of 24 hours).

The obtained results are as follows:

Thermo-accumulative brick wall thickness of 20 cm

- The greenhouse temperatures (insulated object)) of ψ = ± 80° orientation are lower by 37,2% and 41,3% (Fig. 3) compared to the greenhouse temperatures of southern orientation (ψ = 0°).
- Maximal room temperatures of the insulated southern orientation object during the day is Tp = + 24,8°C, while in the object of the ψ = + 80°orientation TP = + 14,4°C. For the orientation ψ = – 80° TP = + 15,6°C (Fig. 2).
- Maximal greenhouse temperature during the day is:
  TSV = + 27,9°C for ψ = 0°,
  TSV = + 15,9°C for ψ = + 80°,
  TSV = + 19,3°C for ψ = – 80°, (Fig. 3).

Diagrams given in the Figs. 3 and 4 show that:

- In insulated southern oriented object at the sunset room temperature is Tp = + 6,8°C, while in the greenhouse Tsv = + 13°C At the end of the night room temperature is Tp = + 4,02°C while in the greenhouse it is Tsv = + 0,29°C.
- If the object is south oriented (ψ = 0°) room temperatures during 24 hours (15 January) are higher by 15,7% than the greenhouse temperatures. During the day (from the sun rise till the sunset) room temperatures are lower than the greenhouse temperatures by 14,5% while during the night the room temperatures are higher than the greenhouse temperatures by 35,9%.
- ψ = + 80° oriented object has 4% higher room temperatures than the greenhouse temperatures in the 24 hour interval. During the night the room temperatures are higher by 28,7% than the greenhouse temperatures, while during the day the room temperatures are lower by 33% than the greenhouse temperatures.
- For the y orientation of ψ = – 80° the room temperatures (in 24 hours) are higher than the greenhouse temperatures by 2,3%. At night the room temperature is higher by 23,3% than the greenhouse temperature. During the day the room temperature is lower by 29,4% than the greenhouse temperature [2,9].

Thermo-accumulative brick wall thickness of 45 cm

- In the insulated object with a greenhouse and ψ = ± 80° orientation, the room's inner air temperatures are lower by 41,13% and 43,27% compared to the inner air temperatures in the object with a greenhouse of southern orientation (ψ = 0°) (Fig. 5).
- Maximal day temperature in the room of the insulated object and y orientation ψ = 0° is + 22,7°C and for the y orientation ψ = ± 80° is + 14,4°C and + 14,8°C (Fig. 4)
- Maximal temperatures in the greenhouse during the day are: + 29°C, 17°C and 19,6°C for the orientation of ψ = 0°, ψ = + 80° and ψ = – 80° (Fig. 5).
- In isolated object of the south orientation at the sun setting greenhouse temperature is + 13,9°C and in the room temperature is + 2°C . At the end of the night the greenhouse temperature is + 1,2°C and in the room + 2,5°C. After the sun radiation is over the room temperature decreases sharply and is lower than the greenhouse temperature. Greenhouse is not insulated during the night and the heat is transmitted into the surroundings. During

the day massive wall has accumulated the heat and gives it away during the night. Therefore the room temperatures are higher than the greenhouse temperatures at the end of the night. It is necessary after the sun radiation of the thermo-accumulative wall to open the windows installed in it to enable free circulation of the hot air from the greenhouse into the room. Thus one enables shorter period of heating of the room right after the sunset.

- Room temperatures of the insulated object are lower than the greenhouse temperatures. During the day in objects of y orientation ψ = 0° room temperatures (TP) are lower by 33,3% compared to the greenhouse temperatures (TSV). During the night temperatures Tp are lower by 26,7% than the Tsv temperatures. If we observe the 24 hours period (15 January) then the Tp temperatures are lower by 29% than Tsv temperatures. If the object is of ψ = + 80°orientation then Tp temperatures are lower by 49% during the day and by 14% then Tsv temperatures during the night. Within 24 hours room temperatures Tp are lower by 28,4 % than the Tsv temperatures. If the object is of the ψ = – 80°orientation then the day room temperatures are lower by 44,3% than the greenhouse day temperatures, while the room night temperatures are lower by 27,9% then the greenhouse night temperatures. In the 24 hour interval room temperatures are lower by 34,5% than the greenhouse temperatures (Figs. 4 and 5) [2,9].

4. DISCUSSION

- Inner temperatures in the room with a massive brick wall thickness of 45 cm (Fig. 4) are lower by 31,2% than the temperatures of the room with a massive brick wall thickness of 20 cm (Fig. 2) (for the 24 hour interval, 15th January).
- Daily temperatures of the room with a massive brick wall thickness of 45 cm are lower by 23,1% than the obtained inner temperatures of the room with a massive brick wall thickness of 20cm.
- At night air temperatures in the room with a massive brick wall thickness of 45cm are lower by 38,3% than the obtained inner temperatures of the room with a massive brick wall thickness of 20cm.
- For the given variants of the greenhouse and thermo-accumulative wall objects sun radiation part (USE) of the heating of the insulated, non-additionally heated object was calculated. An interval of 24 hours (15th January) was observed. USE was calculated for the orientations of the object: ψ = 0°, + 80° and – 80°, and for the supposed inner designed temperature Tp = + 22°C Calculated values for USE are given in *Table 2.*

Table 2. USE for a greenhouse and thermo-accumulative brick wall objects

Object orientation ψ [°]	Construction variants of the thermo-accumulative brick wall (insulated object)	
	Brick d =20 cm	Brick d =45 cm
	USE [%]	USE [%]
0	67,48	55,33
+ 80	30,85	28,87
– 80	28,92	23,98

Table 2 shows that the highest USE is reached in the insulated object of orientation with a 20cm thick thermo-accumulative brick wall [2,7,8].

CONCLUSION

On the basis of the above-mentioned the following conclusions can be drawn:

1. The positioning of the object in the longer side in the direction east–west allows for a maximum solar collection through greenhouse and the thermo-accumulative brick wall built in the south facade of the object.

2. The energy-independent residential object with a greenhouse provides according to the research up to 51% of thermal energy for heating (in the system with a 20cm thick thermo-accumulative brick wall for instance). As the attained energy level does not fully meet the conditions of comfort, it is, therefore, necessary that the object should be provided with an additional heating.

3. By conducting the energy flow in the object itself (directing the available heat from the sun in north-oriented rooms of the object) a substantially higher percentage can be accomplished in the object's independence of energy.

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TERMODINAMIČKO PONAŠANJE SOLARNE STAMBENE ZGRADE SA VERANDOM I TERMOAKUMULATIVNIM ZIDOM

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U radu su prikazani efekti pasivnog solarnog grejanja individualnog stambenog objekata, koji nastaju primenom pasivnog solarnog sistema, a sastoji se od staklene verande i termoakumulativnog pregradnog zida od opeke debljine d=20 cm i d=45 cm. Objekat se dodatno ne greje konvencionalnim energentima. Na termo-akumulativnom zidu se nalaze prozori za direktan zahvat sunčevog zračenja.

Posebno su analizirane unutrašnje temperature u prostoriji i staklenoj verandi, u toplotno izolovanom objekatu, sa pregradnim termoakumulativnim zidom od opeke debljine 20 cm i 45 cm. Dati su dijagrami unutrašnjih temperatura u staklenoj verandi i prostoriji objekta za njegove različite orijentacije: $\psi = 0^\circ$ *(orijentacija staklene verande prema jugu),* $\psi = +80^\circ$ *(orijentacija staklene verande prema istoku),* $\psi = -80^\circ$ *(orijentacija staklene verande prema zapadu).*

Ključne reči: *Staklena veranda, pasivno solarno grejanje zgrada.*