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TRADITIONAL SERBIAN COUNTRY COTTAGE EQUIPPED WITH THE PASSIVE TROMBE WALL

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Abstract: This paper investigates the passive use of solar energy in a traditional Serbian country cottage (<100 m^2) in the vicinity of the city of Kragujevac – the implementation of the passive Trombe wall. Through a seven-month (from October 1 to April 30) comparison with a classic cottage (without the passive Trombe wall), the benefits of mentioned solar systems are determined. Both country cottages (created in the Google SketchUp program), and in the EnergyPlus program, are equipped with central heating systems with coal boilers (heat energy generators). The results showed that the consumption of useful (thermal) energy can be reduced from 4823.97 kWh to 3923.22 kWh, final energy from 7836.21 kWh to 6372.99 kWh, and primary energy from 10187.07 kWh to 8284.89 kWh. Environmental and economic indicators are also on the side of a country house with the passive Trombe wall: CO_2 emission is reduced by 0.61 t, and financial investments for heating during the analyzed period are reduced from 312.49 € to 254.14 €.

***Keywords**: Country cottage, energy-eco efficiency, passive Trombe wall, simulation, traditional Serbian architecture.*

INTRODUCTION

The latest studies show that over a thousand village (rural) settlements in Serbia are on the verge of survival, even though they have a large energy and ecological potential, in addition to agricultural, tourist, and economic ones.

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The existence of a homestead, the main characteristic of a traditional rural household, greatly reduces the density of construction, thus providing a whole spectrum of possibilities for using renewable energy sources, such as solar energy.

Unlike cities, where solar energy, due to the high density of buildings, is mainly focused on the active solar systems (solar thermal collectors [1], photovoltaic panels [2], and photovoltaic-thermal collectors [3]), villages are much more suitable for implementing passive solar systems, as the Trombe walls [4], etc.

The Trombe wall is an interesting green architectural concept that, in combination with other HVAC and solar (active) systems, can in some cases reduce the annual consumption of final energy in buildings by over 30% [5].

In the literature, there is a large number of papers (analytical, software, experimental, and combined) with emphasis on different elements of the Trombe walls: geometric characteristics (relation between glazing and non-glazing [6], the thickness of the massive wall [7], the thickness of the air layer [8], the thickness of the glazing [9], etc.), use of the different colors coatings [10], use of the insulating materials [11], use of the glazed materials [12], implementation of the natural and forced ventilation [13], sizing of the fan units [14], etc.

Serbian scientific literature also records a large number, mostly numerical (in the use of various software packages: EnergyPlus and jEplus [15, 16], RMSun and InSunTr [17], MATLAB [18, 19], only EnergyPlus [20-22], TRNSYS [23]) papers in which various aspects of the Trombe wall are expressed. Bojic and colleagues from Lyon [24] used EnergyPlus software to apply the Trombe wall to two Mozart house model types: the original Mozart house model and the modified Mozart house model.

In the mentioned papers, the building models were: educational building located in Niš [15], rectangular single-store building located in Belgrade [16], residential building located in Niš [17], one-zone residential building located in Niš [20], modern residential building located in Belgrade [21], and modern residential building located in Kragujevac [22].

In this paper aspects of the Trombe wall are numerically investigated on the model of the traditional Serbian country cottage in the vicinity of the city of Kragujevac. Kragujevac is located in a belt of moderate continental climate with distinct seasons, so the focus is on a seven-month period that includes the heating season (from October 15 to April 15) and two transition periods (October 1 to October 14 – the first transition period, April 16 to April 30 – the second transitional period). The research mostly focuses on the energy performance of the Trombe wall, then on the ecological and economic ones. Through this work, the authors want to promote rural settlements in another way, reminding them of their ancient national importance.

MATERIALS AND METHODS

RESEARCH SUBJECT

The 3D model of a traditional Serbian country cottage (TSCC) in the vicinity of the city of Kragujevac is shown in Fig. 1a. A family of four has 6 rooms at their disposal, i.e. thermal zones (TZ). Children use room TZ4, while parents stay in multifunctional room TZ3 (Fig. 1b).

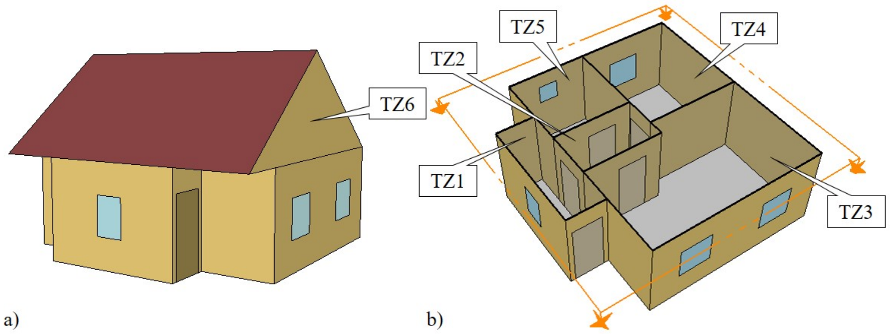

Figure 1. 3D model of the TSCC (a) and room layout (b): TZ1 – Hall 1, TZ2 – Hall 2, TZ3 – Multifunctional room (Living room, Kitchen, Dining room, Bedroom), TZ4 – Children's room, TZ5 – Bathroom, TZ6 – Attic.

The TSCC has been designed following the regulation on energy efficiency of buildings [25]. The maximum permitted heat transfer coefficients U_{max} [W/(m^{2}K)] of the external construction elements for the new buildings are presented in Tab. 1.

Table 1. The maximum permitted U_{max} values of the external construction elements for the new buildings, [25].

Construction building element	Mark	U_{max} value [W/(m^{2}K)]
Ground floor	GF	0.3
External wall	EW	0.3
Intermediate construction above the open passage	IC	0.2
Slope roof	SR	0.15
External window	EW	1.5
External door	ED	1.6

The net area of the TSCC is 89.72 m^2 (TZ1 is 4.32 m^2, TZ2 is 3.75 m^2, TZ3 is 18 m^2, TZ4 is 10.5 m^2, TZ5 is 6.25 m^2, and TZ6 is 46.9 m^2). The central heating system (with coal boiler as heat energy generator) is used to heat TZ3, TZ4, and TZ5 (34.75 m^2, i.e. 38.73% of the TSCC).

THE PASSIVE TROMBE WALL

The Trombe wall cleverly combines two fields: architecture and mechanical engineering. In the first place, the Trombe wall represents an external building element (external wall, EW) that separates the interior space of the building from the external environment. Due to its specific design (Fig. 2a, Tab. 2), which implies the installation of glazing (1) in front of the massive southern facade wall (2), which is coated with a selective coating (3) on the side of the glazing, the Trombe wall has another, indirect, role – reducing the final energy consumption for heating, through the following stages: absorption of solar energy, conversion of solar energy into thermal energy, accumulation (storage) of thermal energy, delivery of thermal energy to the thermal zone by the basic principles of heat energy transfer (conduction through the wall, convection and radiation from the wall).

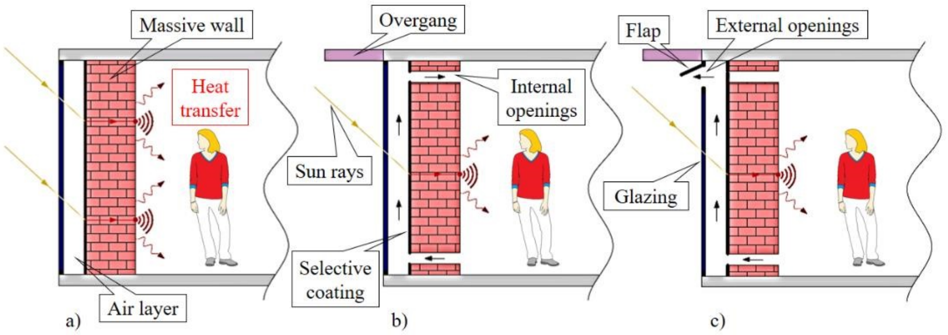

Figure 2. Types of the Trombe walls: the passive (a), the active with internal openings (b), and the active with internal and external openings (c).

The mentioned variant (Fig. 2a) represents the basic variant of the Trombe wall. As, over time, these constructions were improved with various additional elements (overhangs, curtains, openings, fans, etc.), it is clear that over time the classification of the Trombe walls was established in the literature, namely into the following two categories: the passive Trombe walls (Fig. 2a) and the active Trombe walls (Fig. 2b, Fig. 2c).

The following figures show the southern facade of the TSCC before (Fig. 3a) and after (Fig. 3b) the installation of the passive Trombe wall.

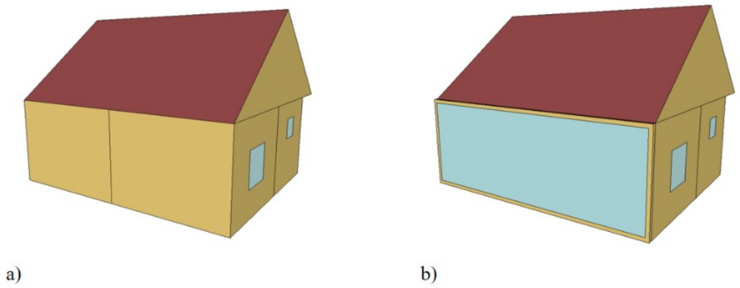

Figure 3. The southern facade of the TSCC before (a), and after (b) the installation of the passive Trombe wall.

Table 2. The geometric-thermal performance of the passive Trombe wall [26].

Description	Unit	Layer			
		Glazing	Air layer	Selective coating	Massive wall
Thickness	[m]	0.003	0.1	0.0016	0.4
Thermal conductivity	[W/(mK)]	0.9	-	393	1.73
Density	[kg/m^3]	-	-	8907	2242
Specific heat	[J/(kgK)]	-	-	370	837
Solar transmittance	[-]	0.899	-	-	-
Solar reflectance	[-]	0.079	-	-	-
Absorptance	[-]	-	-	0.94	0.65
Emissivity	[-]	-		0.06	0.9

ENERGY AND ENVIRONMENTAL INDICATORS

Total useful heat energy consumption E_{USE} [kWh] in the TSCC is the sum of the thermal zones (for TZ3 E_{TZ3} [kWh], TZ4 E_{TZ4} [kWh], and TZ5 E_{TZ5} [kWh]) useful heat energy consumption Eq. (1):

$$E_{USE} = \sum_{TZ=3}^{5} E_{TZ} = E_{TZ3} + E_{TZ4} + E_{TZ5} \quad ....(1)$$

Total final energy consumption E_{FIN} [kWh] in the TSCC in that case is Eq. (2)

$$E_{FIN} = \frac{E_{USE}}{\eta_{PN} \cdot \eta_{RS} \cdot \eta_{CB}} \quad ....(2)$$

where [25]: η_{PN} [-] is the pipe network efficiency (η_{PN}=0.95), η_{RS} [-] is the regulation system (η_{RS}=0.9), and η_{CB} [-] is the coal boiler efficiency (η_{CB}=0.72).

Total primary energy consumption E_{PRY} [kWh] in the TSCC depends on the primary energy transformation coefficient for coal R_{PRY}=1.3 [25] Eq. (3):

$$E_{PRY} = R_{PRY} \cdot E_{FIN} \quad ....(3)$$

In the end, CO_2 emission can be determined as Eq. (4):

$$M_{CO2} = m_{CO2} \cdot E_{PRY} \quad ....(4)$$

where m_{CO2} [kg/kWh] is the specific CO_2 emission (m_{CO2}=0.32 kg/kWh [25]).

RESULTS AND DISCUSSION

The next figure (Fig. 4) shows the monthly total useful heat energy consumption in the TSCC before and after the passive Trombe wall. In the same figure, for the same analyzed cases in TSCC, the monthly total energy savings e_{USE} [%] is also shown.

The monthly total useful heat energy consumption, in the TSCC before the passive Trombe wall, were (Fig. 4): 265.35 kWh (October), 612.04 kWh (November), 1026.36 kWh (December), 1283.73 kWh (January), 819.48 kWh (February), 546.60 kWh (March), and 270.40 kWh (April).

Conversely, the monthly total useful heat energy consumption, in the TSCC after the passive Trombe wall, were (Fig. 4): 136.53 kWh (October), 434.17 kWh (November), 938.40 kWh (December), 1206.97 kWh (January), 668.94 kWh (February), 350.28 kWh (March), and 187.92 kWh (April).

Based on all of the above, the monthly total energy savings were (Fig. 4): 48.55% (October), 29.06% (November), 8.57% (December), 5.98% (January), 18.37% (February), 35.92% (March), and 30.50% (April).

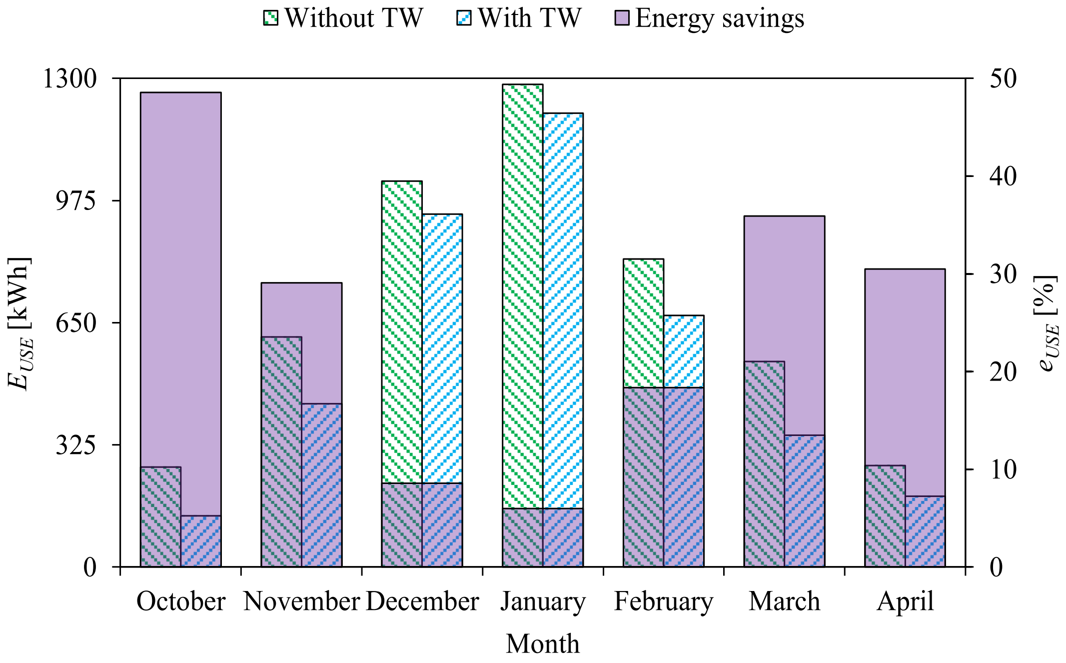

Figure 4. Monthly total useful heat energy consumption and energy savings in the TSCC before and after the passive Trombe wall.

The highest percentage savings were achieved at the beginning and end of the analyzed period (October, March, and April) when the weather was on the side of the passive Trombe wall. The external ambient temperature is higher. The same goes for the solar radiation (direct, diffuse, and reflected). In that case, the passive solar design reaches its full expression, because the accumulated heat energy is higher (on the one hand), and the heat losses through the glazing are lower (on the other hand). In the winter months, although the Sun elevation angle is more favorable due to the passive Trombe wall (solar incidence angle [27]), the intensity of the solar radiation is much weaker and the external ambient temperatures are often below zero. Due to the mentioned effects, the energy savings are less than 10% (8.57% in December and 5.98% in January).

If it is accepted that the thermal power of coal is 18.5 MJ/kg (5.14 kWh/kg) [28], and the price of coal is 205.13 €/t, the annual financial costs can be reduced by almost 20% (18.67%).

CONCLUSION

Energy consumption in the residential sector, both globally and nationally, is very high. An increasing number of people live in cities, and fewer live in the countryside. In the EU, around 72% of the human population lives in urban areas. This share is assumed to reach around 80% in 2050.

The way out can be seen in increasing the energy efficiency in cities, but we should certainly work on their deurbanization. The authors believe that promoting countries (and raising energy efficiency in them) is a long-term solution that needs to be worked on.

Following that, in this paper, the energy, ecological, and economic aspects of the country houses in Serbia (small net areas built in accordance with traditional principles) were investigated. The consumption of useful, final, and primary energy was analyzed on the case study model of the traditional Serbian country cottage equipped with a modern passive solar system – the passive Trombe wall.

The results of the numerical research (Google SketchUp software package is used for building design, EnergyPlus software package is used for simulation thermo-technical systems) showed that in an economic sense, costs for heating in the traditional Serbian country cottage equipped with the passive Trombe wall can be reduced up to 20%.

Serbia is a country rich in natural resources and landscapes, and this should be used in the best way: responsible politics, infrastructure projects, clear goals, engagement of scientific and professional people (multidisciplinary approach), even greater participation of state bodies and all citizens.

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TRADICIONALNA SRPSKA SEOSKA KUĆA OPREMLJENA PASIVNIM TROMBE ZIDOM

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Rezime: U ovom radu istražuje se pasivno korišćenje solarne energije u tradicionalnoj srpskoj seoskoj kući (<100 m^2) u okolini Kragujevca – implementiranjem pasivnog Trombe zida.

Kroz sedmomesečno (od 1. oktobra do 30. aprila) poređenje sa klasičnom kućom (bez pasivnog Trombe zida) određuju se prednosti korišćenja ovakvih solarnih sistema.

Obe seoske kuće (kreirane u programu Google SketchUp), u programu EnergyPlus, opremljene su sistemima centralnog grejanja sa kotlovima na ugalj (generatori toplotne energije).

Rezultati su pokazali da se potrošnja korisne (toplotne) energije može smanjiti sa 4823.97 kWh na 3923.22 kWh, finalne energije sa 7836.21 kWh na 6372.99 kWh, a primarne energije sa 10187.07 kWh na 8284.89 kWh.

Ekološki i ekonomski pokazatelji takođe su na strani seoske kuće sa pasivnim Trombe zidom: emisija ugljen-dioksida redukovana je za 0.61 t, a troškovi grejanja za analizirani period umanjeni su sa 312.49 € na vrednost 254.14 €.

Ključne reči: *Energo-eko efikasnost, pasivni Trombe zid, seoska kuća, simulacija, tradicionalna srpska arhitektura.*

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