IMPROVING THERMAL STABILITY AND REDUCTION OF ENERGY CONSUMPTION BY IMPLEMENTING TROMBE WALL CONSTRUCTION IN THE PROCESS OF BUILDING DESIGN: The Serbia Region

by

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This paper analyzes the impact of Trombe wall construction on heating and cooling demands of building with form (rectangular single-store building of about one hundred square meters area) which is common for individual residential buildings in the Republic of Serbia. Trombe wall, as a representative of a passive solar design, was installed on the south wall of the building. Model of the building was made in the Google SketchUp software, while the results of energy performance were obtained using EnergyPlus and jEplus. Parameters of thermal comfort and climatic data for the area of city of Belgrade, Republic of Serbia, were taken into account. Coverage of the south façade was varied, as well as the thickness of the thermal mass and orientation. Energy consumption of the object is discussed, based on obtained results of the analysis. According to comparative analysis of the above mentioned models it can be concluded that the application of the Trombe wall structure on south side may lead to savings of 33% on heating, but also the higher energy consumption for cooling. Total energy consumption on an annual basis is reduced by using this system.

Key words: *Trombe wall construction, EnergyPlus, energy consumption*

Introduction

Regardless of the fact that environmental designing dates back to the earliest ages, the green building concept has been gaining an increasing importance in recent years. A number of factors are important for determining the future levels of energy production and consumption in the country. Primarily, these are changes in population numbers, economic performance, technological development, government policy and the relationships between the energy sector and events in the global energy market [1]. If the most efficient energy saving measures is not implemented in the near future, the electric power demand will increase by as much as 100%, and the fuel demand would increase by around 23%. Accordingly, as a consequence of activities in the housing sector, the predicted increase in GHG emissions will be 59%. However, it is predicted that the gradual implementation of the proposed measures would affect a slower increase of electric power and fuel consumption and greenhouse gas emissions [2]. Dincer and Rosen [3] expounded a comprehensive discussion on the future of energy use, and the consequences for

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ecology, reflected in acid rains, destruction of the stratospheric ozone layer and various GHG. Due to the complexity of the energy behavior of buildings, and uncertainty of influential factors, the study [4] proposed several models for predicting the energy consumption in buildings in a precise, robust and straightforward way.

Swan and Ugursal [5] in their paper provided a review of various modeling techniques used for modeling of energy consumption in the housing sector. Two distinct approaches were identified. The first treated the housing sector as an energy funnel and did not relate to the individual consumption. It employed historical values of energy consumption and reduces the housing stock energy consumption in the function such variables as macro-economical indexes (for instance, gross domestic product, unemployment and inflation), energy costs and general climate. The second approach assessed the energy consumption using a representative set of individual houses at a regional and national level. The latter approach comprised two different methods: statistical and engineering methods.

Passive solar designing represents a veritable challenge for architects and contributes to an enhanced energy efficiency of designed buildings. O'Brien *et al.* [6] in their paper solar design days: A tool for passive solar house design provided specific guidelines for effective passive solar designing. One of the well-known principles of passive solar designing is the Trombe wall. The subject of this paper is an analysis of the Trombe wall implementation effects on the building heating and cooling energy consumption. A series of simulations conducted on the modeled structure yields important information as to what extent, if any, implementation of this system contributes to the improvement of building energy performance.

The Trombe wall was first patented by Morse [7] as early as in 1881 who acknowledged the potential of using the solar energy by thermal accumulation of heat using a massive wall. In this way, savings can be made in using the heating and cooling energy. This structure gained importance and became widely known owing to the French engineer Felix Trombe (and it still bears his name) and the French architect Jacques Michel who further enhanced it [8, 9]. The Trombe wall is known in literature variously as Trombe-Michel wall, solar wall, thermal storage wall, collector storage wall, or simply storage wall. Trombe wall is a proven effective passive energy use design for the current environmental and energy crisis [10]. This thermal storage structure provides energy saving by storing energy during the sunny days in the winter season and by releasing the heat into the structure overnight. A house with Trombe wall is a complex thermodynamic system, and this system allows indirect gains. By storing solar energy, one contributes to heating, ventilation and improved heat comfort in the rooms.

In order to fully use the potential of this system it is very important to fully understand the Trombe wall functioning as well as the role of all of its elements. The efficiency of Trombe wall is affected by various elements such as apertures, ventilating fans and insulation, but the most important elements comprising the Trombe wall structure are its size, thickness, color, materials, finishing layer and type of glazing [10]. Bojić *et al.* [11] provided a comparison of energy consumption and environmental impact of the buildings with and without Trombe wall. The indicator for measuring the environmental impact is the sum of primary operative heating energy in the winter and the consumption of energy necessary for the functioning of Trombe wall at the annual level. The adaptive approach and the level of tolerance of the residents related to the thermal comfort in an interior plays an important role in the total energy consumption. By lowering the temperature in a flat for only 1 °C, the achieved heating cost reduction is around 7% [12].

Originally, this system comprised ventilation openings in the upper and lower parts, so as to provide air circulation. This circulation can be provided naturally, but is sometimes forced (by installing ventilating fans). Ventilation openings, ventilation and insulation are three components of Trombe wall which have a considerable effect on its efficiency [10]. Gan [13] analyzes the function of the Trombe wall system for cooling of buildings in summer. Namely, dimensions of inlet and outlet openings increase with the change of the duct diameter, while with the increase of the distance between the wall and the glazing increases the rate of ventilation. Dragićević and Lambić [14] provided a numerical analysis of the modified Trombe wall efficiency with forced convection (air-flow). The analyzed system had a double glazing, and a massive wall with an opening and the central duct in it. In order to increase efficiency, a fan in the lower part of the wall was provided. This system is more advanced in comparison with a simple Trombe solar wall with a relatively low thermal resistance, which is assumed as the reference one in the experimental analysis. In fig. 1 are presented various variants of solar thermal storing Trombe wall.

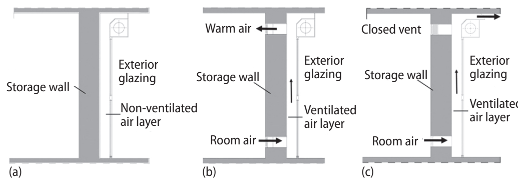

Figure 1. Various variants of the solar wall: (a) without ventilation, (b) winter mode with thermocirculation, and (c) summer mode with ventilation [10, 15]

The software used for simulation

Considering the low likelihood of performing experiments and their complexity, cost and duration, empirical or intuitive designing is often prevalent in practice. This problem has been overcome by the development of modern software, which leads to the precise assumptions about future design. Numerous contemporary software solutions for simulation of energy behavior enable modeling of Trombe wall, primarily BLAST, DOE-2, TRNSYS, SUNREL, ESP-r, as well as EnergyPlus. Buildings represent a complex system with a lot of variables, so approval of the used tools is extremely important in order to obtain accurate results. Heat transfer represents the main component in the research of these systems. The level of complexity increases if the effects of conduction through the walls, transfer of solar energy through the glass, exchange of long waves by radiation, thermal loss, *etc.* are taken into account. The exact model of Trombe wall system developed for the popular software EnergyPlus represents a reliable component which designers can safely employ in their work [16]. Ellis [16] in his thesis developed and validated the Trombe wall model in the EnergyPlus software. In this way, variation of physical parameters was enabled, providing optimum designing. For this reason, for modeling the analyzed housing building thee Google SketchUp software was used, while for the energy analysis the EnergyPlus software was used (build 8.6). This software ensures a comprehensive analysis and inclusion of various factors such as accurately defined climate characteristics, structure, human presence, lighting, thermal mass, electrical appliances, usage time, insolation effects, shading, wind, infiltration, *etc.*, and all of this for the precisely defined time period. The Trombe wall model in the EnergyPlus software comprises inclusion of all the mentioned phenomena for the walls and windows. The only phenomenon characteristic of this system exclusively is certainly convection occurring in the space between the glass and the massive wall structure.

The Trombe wall model is based on the thermal equilibrium method. This method assumes the following:

– interior surfaces temperatures are equalized,
– surfaces radiate diffusely,
– inlet air is momentarily mixed with the existing air,
– air in the entire room has equal temperature, and
– heat transfer is 1-D.

Description of analyzed/simulated model

From an architectural point of view it is very important to provide enough natural light as well as adequate vistas and ambient comfort. Regarding that in designing it is very often necessary to make different compromises, in this case also the results need not be the only correct decision, but they should serve as guidelines for designing and as an aid to the designers in the selection of the optimum design.

A large number of papers indicates the irrefutable efficiency of this system implementation, so the main focus of this paper is to assist in defining guidelines for designing and implementation of this system with a goal of energy saving, through a number of simulations for concrete climatic conditions. Climatic and geographic characteristics of the site have an effect on which materials and principles will be applied. Diversity of materials which can be used, methods for their usage, climate and construction conditions provide for a combination of various materials and principles. These systems represent only auxiliary systems and they can not maintain a constant temperature in the building on their own, but they can help in reducing the heating energy consumption. The design is done for the climatic area of the city of Belgrade, for interior design temperature of 26 ºC in the cooling period, *i. e.* 20 ºC in the heating period. The building is considered a detached family house with natural ventilation, with an open building position and more than one façade exposed to wind.

The energy simulation of the modeled structure with or without the Trombe wall analyzes the decrease of heating and cooling energy at the annual level in Serbia. There is a potential to reduce heating and cooling energy demand by implementing heavy massive structures in the analyzed climatic conditions in Belgrade, capital of Serbia [17]. The research is performed on the model of a one store building, with 100 m^2 net surface area of simple prismatic form. The authors have applied this particular geometry for analysis because this type of geometry is common for individual residential buildings in Serbia [18]. The building has a square layout 10.0 × 10.0 m and height of 3 m, fig. 2. The northern façade has no openings, while the western and eastern façades have designed openings occupying 25% of wall surface area. Construction of the Trombe wall is planned on the south side because of the favorable orientation and maximum use of solar energy for thermal gains.

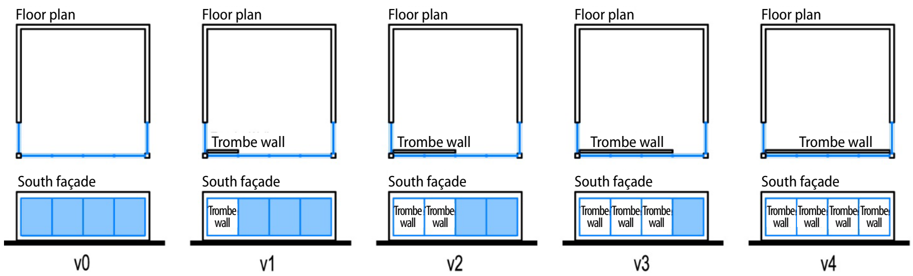

Figure 2. Variants of the basis and the south façade of the objects on which the simulations were conducted

The Trombe wall is usually made of masonry blocks or concrete 20-40 cm thick. Glazing is situated at a distance of 2-10 cm in front of the wall. In practice, two structural variants of the Trombe wall are used: without openings and with openings at the base and top of the wall. After passing through the glass, solar radiation hits the Trombe wall and heats it up. The heat is transferred from the exterior to interior side of the wall by conduction. The rate of heat transfer through the Trombe wall depends on the material it is made of and its thickness [19].

The surface area of the Trombe wall is expressed in percent's as ratio of the Trombe wall surface area to and the surface areas of other walls in a room [20, 21]. Saadatian *et al.* [10] quoted that the optimum value of the Trombe wall surface area is $\alpha = 37\%$. It is most efficient to have it face the south (on the northern hemisphere) in order to provide the best possible efficiency in solar energy usage, with overhangs protecting the building from overheating in the summer season. The paper varies the degree of the Trombe wall coverage of the southern façade. Namely, 5 variants of the Trombe wall structure are modeled, whereby the degree of coverage is varied from the model without the Trombe wall (v0), followed by ¼ of the surface area (v1), ½ of the surface area (v2), ¾ of the surface area (v3), as well as with the entire south façade covered with the Trombe wall (v4). The effects of positions and dimensions of the Trombe wall are observed through the total energy for heating and cooling throughout the year.

All the elements of the envelope structure, tab. 1, satisfy the regulations (excluding the southern wall – Trombe wall) defined by the Code of energy efficiency of buildings [22] in terms of maximum permissible values of thermal transmittance coefficients (for walls and bottom floor $U_{max} = 0.3$ W/m^{2}K, for a flat roof $U_{max} = 0.15$ W/m^{2}K, for the glazed part of the façade $U_{max} = 1.5$ W/m^{2}K). The structure of the building is made of the following materials (inside to outside):

Table 1. Elements of the building envelope

	Construction	U-Factor [Wm^{-2}K^{-1}]	Area [m^2]	Azimuth [°]
East wall	Outside wall	0.269	30.00	90.00
North wall	Outside wall	0.269	30.00	0.00
Western wall	Outside wall	0.269	30.00	270.00
South wall – Trombe wall	Trombe wall (d0 = 0.10 m)	2.343	30.00	180.00
	Trombe wall (d1 = 0.15 m)	2.174	30.00	180.00
	Trombe wall (d2 = 0.20 m)	2.028	30.00	180.00
	Trombe wall (d3 = 0.25 m)	1.901	30.00	180.00
	Trombe wall (d4 = 0.30 m)	1.788	30.00	180.00
Roof	Flat roof	0.136	100.00	–
Floor	Floor	0.207	100.00	–

Exterior walls: mortar 1.5 cm thick, reinforced concrete 15 cm thick, polyurethane 12 cm thick, and reinforced concrete 6 cm thick. Thermal transmittance coefficient $U = 0.269$ W/m^{2}K.

Flat roof: mortar 2 cm thick, reinforced concrete 15 cm thick, layer for inclination 5 cm thick, vapor dam 0.5 cm thick, polyurethane 24 cm thick, PVC soft foil 0.01 cm thick, bitumen roofing paper 1.3 cm thick, dry sand 4 cm thick, concrete with stone aggregate 2.5 cm thick. Thermal transmittance coefficient $U = 0.136$ W/m^{2}K.

Floor: stone wool 15 cm thick, reinforced concrete 25 cm thick. Thermal transmittance coefficient $U = 0.207$ W/m^{2}K.

Trombe wall: concrete material (thickness varies from 10 cm to 30 cm) with a solar absorber surface as the innermost layer of the wall. The absorber is a selective surface material with very high absorptivity and very low emissivity – copper with a special black surface treatment. Modeled Trombe wall is sealed (unvented) with a single pane window 0.6 cm thick. which covers all of the wall area and has a very high transmissivity to allow the maximum amount of solar flux into the Trombe zone. Thermal transmittance coefficient U varies from 2.343 W/m^{2}K to 1.788 W/m^{2}K.

The applied materials used for the building structure are primarily selected in accordance with the current Regulations on energy efficiency of buildings [22] regarding the maximum allowed U-value. Reinforced concrete material is imposed because it is one of the most flexible materials, and in addition it can satisfy all architectural constructive requirements, such as burial in the ground, bridging large ranges, variety of form and actuality in contemporary design.

Balcomb *et al.* [23] quoted that ventilation ducts neutralize the stored head which reduces the efficiency of this system. For this reason, designing of a closed – non-ventilated space between the glazing and thermo-storing mass is favored in recent time. On the other hand, if nights are warm, it should be arranged that the excess heat is dumped, via ventilation, outside and not inside. In the hot climates, it best to use this effect by constructing thick, massive walls which would store all the external heat, but will not emit it inside buildings [24]. The Trombe wall is modeled using the standard EnergyPlus model. A ventilated Trombe wall is more complex for design because of air-flow, but even though that model also is a part of EnergyPlus, this research analyzes only a non-ventilated Trombe wall. A special *Trombe zone* is defined in the space between the glass and the Trombe wall. Glass and wall represent standard EnergyPlus surfaces. Wall is connected to the main zone as an interior surface. Glazing is a large glass surface covering a part of the external surface of the southern wall. Concrete was used for construction of the Trombe wall as thermo-storing massive structure. There is a natural convection occurring in the air space of the non-ventilated Trombe wall. Regardless of the low external temperature, sunrays that pass through the glass heat up the massive wall structure. Then ensues a complex convection process in the special *Trombe zone*. The main difference between the special *Trombe zone* and *normal zone* is primarily in geometrical characteristics. The *Trombe zone* is characterized by a large ratio of height and width (from 10 to 100), while in case of the *normal zone* this ratio is around 1 or less. Exactly of that reason, special algorithms for convection are used for design of this zone.

Results and discussion

The complete study results are graphically represented, fig. 3. The total required amount of energy for heating and cooling per m^2 at an annual level is presented. On the basis of the clustered columns in the graphs, one can analyze the relation of the cooling and heating energy demands at an annual level, in case when the Trombe wall faces true south.

Comparative analysis of the results leads to the conclusion that the total necessary amount of heating energy at the annual level varies depending on the position and dimensions of the Trombe wall. Based on the conducted simulation and the obtained results it can be concluded that the analyzed model demands the least heating energy in case when 75% of the southern wall is covered by the Trombe wall structure (v3), with the thermal mass thickness of 25 cm (d3) and facing true south, while the least cooling energy demand is found in the case without the Trombe wall (v0). On fig. 4 comparative analysis of maximum and minimum values of energy consumption for heating, (a) and cooling, (b) for all model variants are presented.

If we compare the percentage ratio of energy consumption for heating and cooling in relation to the reference model without the Trombe wall (v0), we can find out the optimum values. Accordingly, the biggest heating energy savings in percent is in the case when 75% of the southern wall is covered by the Trombe wall structure (v3), with a thermal mass of 25 cm (d3). On the other hand, the smallest savings for heating energy in percent is achieved in the case when 25% of the southern wall is covered by the Trombe wall structure (v1), with the thickness of 10 cm (d0) which is shown in tab. 2.

The energy demand for cooling is increasing when compared to reference model – without the Trombe wall (v0). The highest energy demand for cooling in percent is achieved in the case when 75% of the southern wall is covered by the Trombe wall structure (v3), with a ther-

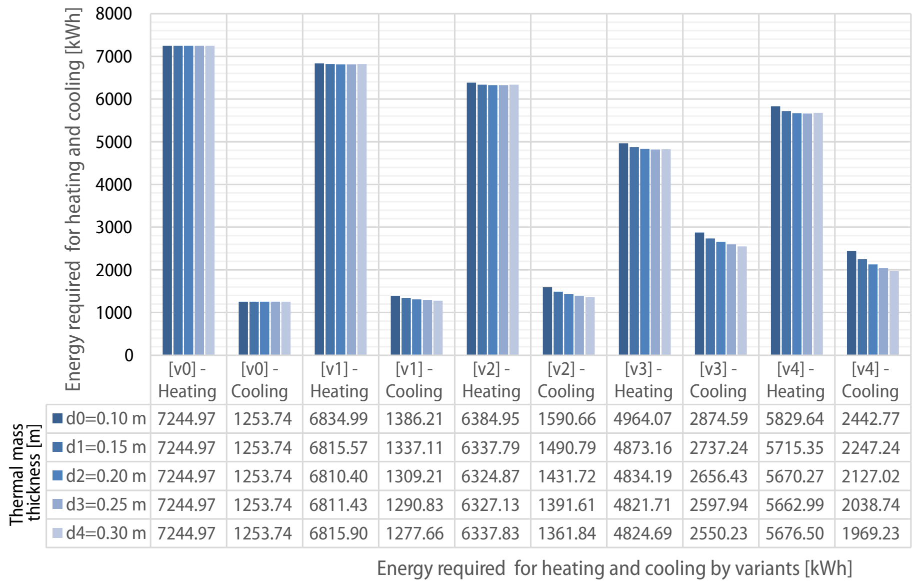

Figure 3. The total required amount of energy for heating and cooling depending on the change in the thickness of the thermal mass

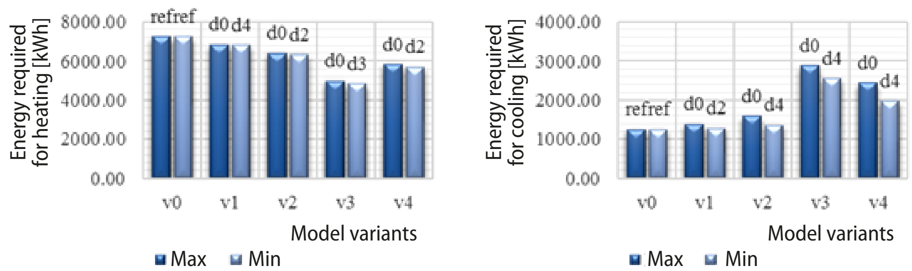

Figure 4. Comparative analysis of maximum and minimum energy consumption for heating (a) and cooling (b) for all model variants

mal mass of 10 cm (d0). On the other hand, the least increase for energy for cooling in percent is achieved in the case when 25% of the southern wall is covered by the Trombe wall structure (v1), with the thickness of 30 cm (d4). Although in other circumstances it would be expected that cooling energy is reduced by the use of passive systems, the contradictory nature of this passive system leads to increased energy consumption in cooling, which is best seen in tab. 3.

Table 2. Comparative review of reduction of heating energy consumption for different model variants compared to the referent model [%]

	d [cm]	v0	v1	v2	v3	v4
d0	0.10	Referent model	5.66	11.87	31.48	19.54
d1	0.15	Referent model	5.93	12.52	32.74	21.11
d2	0.20	Referent model	6.00	12.70	33.28	21.74
d3	0.25	Referent model	5.98	12.67	33.45	21.84
d4	0.30	Referent model	5.92	12.52	33.41	21.65

Table 3. Comparative review of increasing of cooling energy consumption for different model variants compared to the referent model [%]

	d [cm]	v0	v1	v2	v3	v4
d0	0.10	Referent model	10.57	26.87	129.28	94.84
d1	0.15	Referent model	6.65	18.91	118.33	79.24
d2	0.20	Referent model	4.42	14.20	111.88	69.65
d3	0.25	Referent model	2.96	11.00	107.22	62.61
d4	0.30	Referent model	1.91	8.62	103.41	57.07

It is clear that for the analyzed climatic conditions in the summer period, the construction of the Trombe wall must have adequate protection against unwanted thermal gain and direct sunshine. This can be accomplished by applying overhangs or by introducing of elements of shaded exterior glazing in combination with natural ventilation and passive cooling [25-27].

Figure 5 shows the percentage ratio of energy savings using Trombe wall for all analyzed variants and for different thickness of thermal mass relative to the reference model (without Trombe wall). Based on this, it can be clearly seen that the biggest save is recorded when the percentage of coverage is 75% (v3), with a wall thickness of 0.3 m (d4), while the smallest save is recorded in the case of 25% (v1), for wall thickness of 0.1 m (d0).

The biggest heating demand is in the case without the Trombe wall (v0), with such orientation of the building that the entire eastern façade is glazed, while the highest cooling energy demand is found in case when entire surface of the wall is covered by the Trombe wall structure having thermal mass thickness of 10 cm and when the building faces 60° southwest.

The least demand for heating and cooling energy is found in the case when 75% of the southern wall is covered by the Trombe wall structure (v3) having thermal mass thickness of 30 cm (d4) and facing true south. On the other hand the highest demand for heating and cooling energy is found in the case when 100% of the western wall is covered by the Trombe wall structure having thermal mass thickness of 10 cm (d0) and facing true west.

Column 1	v1	v2	v3	v4
d0	3.27	6.16	7.77	2.66
d1	4.07	7.89	10.45	6.31
d2	4.46	8.73	11.86	8.25
d3	4.66	9.18	12.70	9.38
d4	4.77	9.40	13.22	10.04

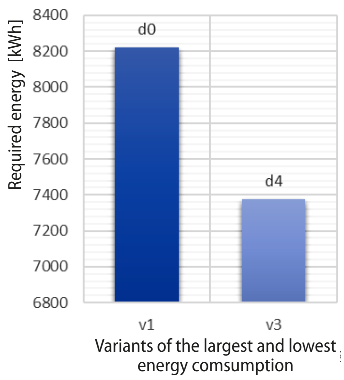

Figure 5. Percentage ratio of energy savings using Trombe wall

Further analysis confirms that with further alterations of the model, it is possible to additionally optimize the buildings, so another 175 simulations are done, for the variants without lateral glazing (5 basic models are simulated with variations of thermal mass thickness and Trombe wall orientation) and another 175 simulations for the variants without any glazing.

Based on the conducted additional simulations and obtained results, it can be concluded that the least heating energy demand of the analyzed models is found in case when 75% of the southern wall is covered with the Trombe wall structure (v3) having thermal mass thickness of 20 cm (d2) and facing true south when there are no additional windows on the building.

On the other hand the highest heating energy demand is found in case without the Trombe wall, with such orientation of the building that the entire eastern façade is glazed, while the highest cooling energy demand is found in case when the entire surface is covered by the Trombe wall having thermal mass thickness of 10 cm when the building faces 60° southwest.

The least demand for heating and cooling energy is found in the case when 75% of the southern wall is covered by the Trombe wall structure (v3) having thermal mass thickness of 30 cm (d4) and facing true south without any additional windows on the building. On the other hand the highest demand for heating and cooling energy is found in the case without the Trombe wall structure and facing true west.

The previously presented discussion indicates the specificity and a typicality of the application of this passive system. The most specific guidelines for designing of the Trombe wall system were provided by Balcomb and Jones [28] in the Passive Solar Design Handbook. Besides, in practice is often posed the question whether the implementation of the Trombe wall is justifiable and what surface area it should cover, and what it is most adequate and efficient, and thus the most justifiable, implementation should be. One of the biggest advantages is that it is possible to combine Trombe wall with other energy systems in the building such as solar greenhouse and other passive systems [29-31]. Often, and the issue of esthetics can sometimes affect the investors or deciding whether to implement this system or not [32].

Conclusions

This paper provides an answer to what extent Trombe wall contributes to enhancement of energy efficiency of buildings using solar energy. Such buildings are often constructed using installed reflector surfaces around window frames (primarily near the Trombe wall structure) for the purpose of amplifying the solar gain, *i. e.* amount of heat entering the house. Based on the research carried out on a simple building model, it has been proven that the implementation of the Trombe wall has beneficial effects on reducing the need for heating. Although it is true that concrete walls thicker than 15 do not transmit heat from one to another side, but offer a kind of insulation, and emit inside the excess heat stored during daylight, on the basis of the conducted study it is confirmed that at an annual level, the highest thermal energy saving can be achieved using the thermal mass thickness of 25 cm (d3). Required heating energy decreases proportional to the increase of the degree of coverage of the southern façade using the Trombe wall. Yet, the optimum variant proved to be the one with ¾ of coverage by the Trombe wall (v3). Orientation also plays an important role, so the energy saving degree varies in terms of reduction of the necessary heating energy demand. On the basis of the research conducted on the model of the building having simple form, it is proven that construction of the Trombe wall has beneficiary effects on reduction of the total quantity of heat required for building heating.

The advantages of using this system are manifold and very significant. The most fundamental reason for introduction of this system is saving of energy required for heating but it should be stated that there is no energy saving for cooling. However, from architectural point of view during the design process architects take into account energy needs and therefore the model is considered without thermos-technical systems. This certainly does not represent a limitation for the implementation of the conventional thermo-technical systems in the building. The disadvantages of using Trombe wall system primarily reflect in limitations and dependence on the external climatic conditions (when the temperatures are excessively high in summer, the cooling problem may negate the benefits acquired in the winter season). A large problem can be also posed by the periods of overcast, so these details can be spots of additional transmission heat losses. Low thermal resistance of this system increases the heat flux, and the gains are difficult to predict. Based on the research carried out saving is mostly contributed by the heat storage during the day, and release of that heat overnight when the external temperature drops below the one defined as a comfortable one in a specific time of year. This type of thermal storing structure is particularly important in the regions with high temperature oscillations during the night and day, but based on the conducted simulations, it can be concluded that its implementation is possible in the climate conditions of Serbia. According to research and literature on the evaluation of Trombe and thermal storage walls [33-35], the most effective combination for Mediterranean climate conditions (Belgrade solar data for summer are quite similar to those of Mediterranean) is to use shading to reduce overheating.

Finally, the Trombe wall is suitable for Belgrade weather conditions, and it leads to overall energy consumption reduction. The limitations that must be mentioned, and which can be further researched concern interaction with the buildings in the environment, and possible obstructions by the surrounding structures, and the land configuration and complexity of designing, with an aim of providing all the necessary comforts in the building. A detailed analysis of the temperature variation on the very Trombe wall structure is a very important parameter, so a detailed analysis of thermodynamic properties of this structure is recommended, as well as an experimental confirmation of the obtained results. At this stage of the research, the economic aspect of the application of this system was not considered. This segment is extremely important in design process, so it will definitely be an object for future research. For future research, it is recommended to analyze ventilated Trombe wall system and solar radiation protection measures during summer, in order to obtain optimum solution.

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