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IMPACT OF TROMBE WALL CONSTRUCTION ON THERMAL COMFORT AND BUILDING ENERGY CONSUMPTION

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Abstract. *Energy consumption has reached its highest level globally. Buildings have the largest share in total energy consumption, so designers must take into account their functioning and the consequences that can arise. Passive solar design is an imperative in modern architecture, and Trombe wall, as one of the principles of this design, is certainly distinguished. The paper presents an overview of the characteristics of the construction of the Trombe Wall in order to improve thermal stability and reduce energy consumption in buildings. Starting from the consideration of climatic influencing factors, through the heat capacity of the materials applied and their thickness and color of the thermal mass, it is very important to know in detail all the factors that can lead to the improvement of the efficiency of this system. The specific heat of the walls in the building, the time delay, the decrement factor and the influence and position of the thermal insulation were also taken into account. The effect of glazing as well as the influence of the ventilation openings were highlighted as significant elements. On the basis of the analysis of the above components, the conclusions and guidelines for designing this type of constructions were made in order to improve the efficiency and reduced energy consumption while providing adequate comfort in the facility.*

Key words: *Climate conditions, Heat accumulating materials, Insulation, Glazing, Ventilation, Final Energy Use*

1. INTRODUCTION

The house has always been a place for a man to feel safe and secure. In the earliest periods of human civilization, the role of the house was only to physically protect the host, but in time, parallel to the greater needs of people and finding new materials, its role changed significantly. Over time, the house became a hallmark of not only individual users but also of

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the whole settlement and sometimes of the whole village. People have always adapted to climatic conditions and environment as evidenced by traditional ways of building in different geographical locations and in different natural conditions. External influences (climate, wind speed and their dominant direction, sunshine, precipitation, built environment and accessibility of building materials, etc.) defined the designs, and gave architects constraints or freedom in their design. Thus, favorable microlocation and thermal performance of the building envelope can significantly contribute to the energy efficiency of buildings, as a building capacity to consume less energy, which is imposed as a necessity in the aspiration for sustainable construction [1]. If decisions made in conceptual and project phases are compatible with sustainability requirements, many negative outcomes can potentially be prevented or at least minimized [2] In situations where the potential of the thermal coating is not used, it is possible to intervene later in order to improve energy efficiency, which has been shown in many works, such as [3].

There is a large number of scientific papers related to the concept of green buildings [4]. Ali and Al Nsairat [2] in their research attempted to contribute to a better understanding of the concept of green building assessment. They have developed tools and their importance in achieving sustainable development through energy efficient green buildings, as well as the housing appraisal system in Jordan. The development of such systems is necessary due to significant ecological, social and economic problems worldwide. Passive solar design represents a real challenge for architects and contributes to the improved energy efficiency of the projected objects. O'Brien, Kesik and Athienitis [5] have provided guidelines for a correct passive solar design. There is a number of structures that are internationally recognized and represent pioneers in the application of modern solar design. The challenges in building passive solar houses are in innovative materials and techniques, knowledge, information, education, new design and construction process, as well as quality control [4]. In 1881, French scientist Edward S. Morse first patented the Trombe Wall. He noticed the potential of using solar energy by thermal heat accumulation through a massive wall. Accumulating solar energy contributes to heating, ventilation and improved heat comfort within the rooms. In this way, savings in the consumption of energy for heating and cooling are achieved. This construction began to be widely known and gained significance thanks to French engineer Felix Trombe and French architect Jacques Michel who further developed this system. The principle of functioning of the Trombe wall is shown on Fig. 1.

It is extremely important to take into account the economic aspect and the cost of construction as well as the savings during the lifetime of the facility (Life cycle costing - LCC) [7]. It is recommended to use passive solar systems regardless of their price, as this reduces energy consumption, preserves the natural environment and reduces the emissions of gases which contribute to the greenhouse effect [8]. Many studies have shown that the combination of multiple strategies is generally more effective than applying one strategy. However, the mixed effects of different strategies make it

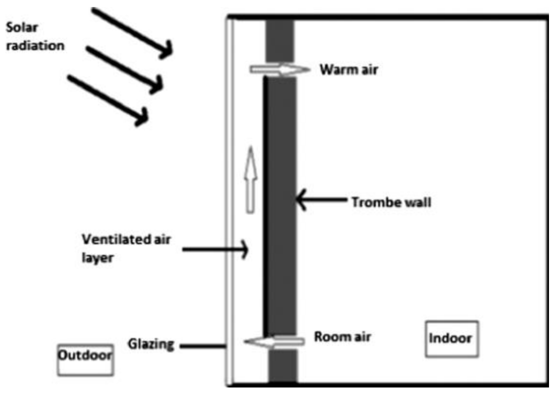

Fig. 1 The way the Trombe wall works [6]

difficult to determine which strategies actually contribute to the overall effect of the improvement. The most important advantages of applying this constructive element are the possibility of its integration with new technologies such as Photovoltaic (PV) systems, reduced energy consumption, reduced humidity of the interior, improved thermal stability, preventing the excessive decrease of solar radiation into rooms, relatively low cost, time delay of amplitude oscillations of daily temperature, improvement of comfort (not only directly but also indirectly in adjacent rooms). When innovative systems are used, it is possible that they will not work just as intended. They must be carefully monitored and evaluated in order to take their advantages and also improvements should be made where necessary. There is a mistaken belief that the construction of the Trombe wall must be of full height and width, as well as that it with its structure completely blocks the light and direct solar gain within the building. On the contrary, the Trombe wall can only partially cover the room in which it is built which contributes to accommodating the needs of tenants. Reducing the dimensions of this structure simply reduces the surface absorbing the sun's radiation, but at the same time this surface blocks direct sunlight and heat in the structure [9]. Balcomb [10] in the book *Passive Solar Design Handbook* gave specific guidelines for designing of this system, which significantly contributes to making the right decisions when designing energy efficient buildings.

2. Analysis of the Trombe Wall Construction Aimed at Improving Efficiency of this System

The Trombe wall is also known in the literature as Trombe-Michel wall, solar wall, thermal storage wall, collector storage wall, or simply a simple storage wall. In order to fully use the potential of this system, it is important to fully understand the functioning of the Trombe wall, as well as the role of all of its components. Various additions such as ventilation openings and insulation, its dimensions, thickness and colors of thermal mass, applied materials, finishing layer and type of glazing significantly affect the efficiency of the Trombe wall [6]. The Trombe wall contributes both to the reduction of energy consumption and to the reduction of the negative impact on the environment compared to buildings without a Trombe wall [11]. The appearance of the computer model of the Trombe wall is illustratively shown on Fig. 2.

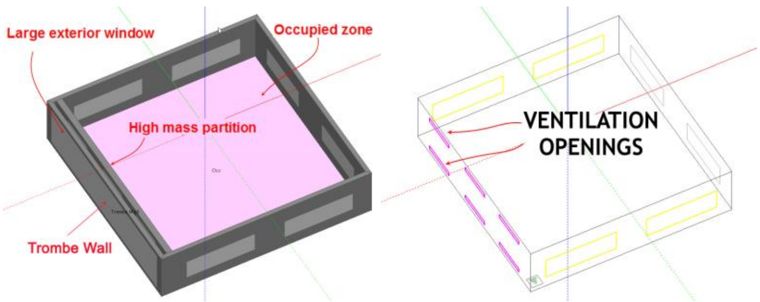

Fig. 2. The appearance of the computer model of the Trombe wall [12]

2.1. The influence of climate factors

Strategies of energy efficient passive design are largely dependent on meteorological factors, and therefore designers require a wider understanding of climate factors. Depending on the climate, the time of day and outside temperatures, efficiency of this system can significantly oscillate. The application of the Trombe wall system provides significant benefits in the Mediterranean climate region. The benefits are reflected in the lesser need for energy systems and reduced fuel consumption [7]. Based on the research in the Greek region (mild Mediterranean climate) that Kontoleon and Eumorfopoulou [13] carried out for the cooling period and the influence of the wall orientation and the solar absorption of the outer surfaces, for the time delay and the decrement factor of several isolated wall systems, it is concluded that the effect of the external absorption coefficient in combination with the effect of solar radiation on the air temperature within the building, for each wall and orientation, factors must be seriously taken into account in order to get the best possible time delay of thermal waves and reduce the decreasing relationship of the internal temperature. Bojić, Johannes and Kuznik [11] state that a building with a Trombe wall in Lyon, France, while using solar energy saves about 20% of operational energy during heating season compared to the buildings that did not use the Trombe wall system.

In order to adapt this system to different climatic conditions and user needs, we distinguish various forms of the Trombe wall. Namely, Saadatian and others [6] state that in addition to the basic variant (Classic Trombe wall), there are Zigzag Trombe wall, Water Trombe wall, Solar transwall, Solar hybrid wall, Trombe wall with phase-change material, Composite Trombe wall, Fluidised Trombe wall, PV Trombe wall. The potential for the application of solid heat-storage constructions in order to save energy for heating and cooling is a well-known and scientifically proven principle. A wall with potential for heat storage represents a great potential for reducing heating needs (40-50%). This technology is sufficiently developed, and there are European and international standards for calculation and analysis of their heat behavior in SRPS EN ISO 13790:2010[14]. This standard gives the calculation methods for estimating annual energy used for the spatial heating and cooling of residential buildings or their parts, or "buildings".

The most developed thermal storage system is the wall and its variants. Thermal accumulation walls are considered constructions in which the thermal mass is located on the inner or outer side in relation to the insulating layer. The thickness of the thermal mass (L_{mas}) varies between 0 and 50 cm keeping the Rn-value constant. Investigations show that for the given critical thickness of the thermal mass, greater potential energy savings are obtained with: walls of solid concrete blocks, walls with the lower absorption surface, and walls within the heat mass.

Knowing the thermal characteristics of all elements of the building envelope can significantly contribute to the improvement of the dynamic thermal characteristics of the building. By adding high thermal capacitance materials from the inside of the building envelope, the amount of accumulated heat or cold increases, which reduces the amplitude of oscillation of the temperature, and therefore reduces the amount of energy consumed. In this way, the influence of variations in the outside temperature during day and night on the heat comfort inside the object is reduced. The optimization of the building envelope implies the optimization of the thermal properties of building materials. Thermal rehabilitation implies a properly designed wall structure. Attention should be paid to the calculation of the thermal conductivity of all materials in the wall.

Al-Sanea, Zedan and Al-Hussain [15] carried out research under constant periodic conditions using the Riyadh climate data. The concept of potential energy savings has been developed using thermo-massive constructions and for the first time a diagram for determining L_{mas} is needed to obtain the desired percentage of energy savings for any thickness of the insulation. The results have shown the following:

- Daily transmission losses during the summer and winter months do not depend on Lmas
- For average months, the daily need for cooling and heating decreases with the increase in Lmas regardless of whether it decreases to zero or decreases asymptotically to constant values.
- The annual need for cooling and heating decreases with increasing Lmas and achieves asymptotically constant values.
- As the Lmas increase, the greatest cooling and heating requirement and decrement factor are reduced, while the time delay increases with the increase in Lmas.
- While the nominal resistance (R_n-value) is constant, the dynamic resistance (R_d-value) of the wall changes with the amount and position of L_{mas} and represents the actual variations in the transmission load.

Relations between the critical value of the thickness of the thermal mass ($L_{mas,cr}$) and potential energy savings by thermal mass (Δ) were obtained [15] by means of heavy concrete (in which a heavy natural aggregate was applied) it was found that:

- $L_{mas,cr}$ increases with higher Δ.
- For given L_{mas}, the potentials for energy saving on cooling and heating are the same.
- For Δ in the range of 70-99%, $L_{mas,cr}$ varies between 6 and 30 cm.
- For given Δ, $L_{mas,cr}$ is less for a wall with an external insulation compared to a wall with internal insulation. In contrast, for the given $L_{mas,cr}$ of a wall with an external insulation a larger Δ was obtained.
- The maximum savings for annual transmission loads are about 17% for cooling and 35% for heating as a result of optimization of thermal mass.
- For a given thermal mass, the wall with external insulation gives better overall heat performance compared to the wall with internal insulation.
- It is recommended that the walls should contain a minimum critical amount of heat that corresponds to potential energy savings in the range of $90\% \leq \Delta \leq 97\%$, and that the insulation layer should be placed on the outside for situations with continuous operation of the air conditioner.

The most benefits in terms of thermal properties and heat transfer through convection can be achieved only with the appropriate amount of thermal mass, together with appropriate external climate factors. Anđelković and others [16] based on the conducted computer simulations, have shown that the addition of a thermal mass has a greater impact on the requirements for heating and cooling of space and energy in buildings with conditioned radiation than those caused by convection. It is thus proven that heat transfer by radiation plays an important role in the behavior of thermal mass. An analysis carried out by Florides and associates [17] have shown that, in relation to the heat mass, the increase in the thickness of the walls and the roof and the use of night ventilation is not enough to reduce the house temperature to acceptable limits during summer.

Jeanjean, Olives and Py [18] suggest tools for the selection and comparison of construction materials, and above all materials with high heat capacity. Andjelkovic and others [16] conducted a research in which they studied the relationship between increasing the amount of thermal mass in the building and its energy performance. The study focused on the analysis of the performance of the building with passive systems and the annual energy needs for heating and cooling the space for a building where several different applications of heat were applied. Since the coefficient of heat transfer within the structures for the most commonly used building materials is small, the effect of convection cannot be neglected. For the storage of heat, concrete and steel are better than wood, but the steel is not far superior to concrete if the effect of convection is taken into account [19].

Thermo - massive wall systems are too expensive to be competitive on the market. Al-Sanea, Zedan and Al-Hussain [15] have developed concepts of potential energy savings by applying thermal mass (Δ) and critical thickness of thermal mass ($L_{mas,\ cr}$) in order to determine the thickness of the thermal mass (L_{mas}) needed for the selected percentage of energy savings. The results show that L_{mas} does not affect the daily load transfer for representative days of the month and years and in winter. By examining the construction materials as a thermal mass, and not just as a structural material, Ma and Wang state in their research [19] that there is no reason to use thicknesses greater than the optimal thickness of the thermal mass. The capacity of the heat accumulation of the inner thermal mass reaches the maximum value for the optimal thickness of the thermal mass. There is a big difference between materials, not only in volumetric specific heat but also in optimal thicknesses of the thermal mass.

Another way of using thermal elements is by using water. Water retains heat that accumulates during the day very well, and when the nights are cooler, this heat can be used in several ways. The simplest way are tin cans, painted in black, filled with water, exposed to sunlight through windows, or a hothouse. In the evening, these elements can be moved to other rooms in the facility, where heating is required. A more complicated system contains pipelines that conduct heated water into other rooms in the house. They are regulated by means of a valve so that users have control of which rooms will be heated and which will not. In this case, we do not need to use a regular barrel, but a pipeline that extends over the entire length and width of the wall exposed to solar radiation.

Building thermal elements in the floor of the building accumulates heat during the warm part of the day, while in cooler periods, excess heat is released inside the building. This type of heating is perhaps the most comfortable one for housing, because it is similar to the floor heating effect. It is only necessary to take into account that enough mass is exposed to solar radiation and that there is a system that will prevent the warming of the floor during warmer days. If solar energy is used for passive cooling, only solar chimney is more efficient from the Trombe wall, but although similar to the Trombe wall, the solar chimney is less advanced technology. Although some energy gains are expected, however, there is still significant potential for optimizing this system.

2.2. Influence of applied materials, thickness and surface color of material used

People have built thick walls (primarily of stone or brick) since ancient times to keep the sun's heat during the day. This heat is then slowly and evenly released during night, which would further contribute to heating of rooms inside the building. Today's low-energy buildings are improving this ancient technique using a system called the Trombe Wall that allows storage and distribution of heat. Named after the French scientist Felix Trombe, the Trombe wall serves as an effective component of a passive solar design since late 1950s [6].

Andjelkovic and others [16] conducted a study in which they studied the relationship between increasing the amount of heat in the building and its energy performance. The study focused on the analysis of the performance of the building with passive systems and the annual energy needs for heating and cooling the space for a building where several different heating applications were applied. The results of the simulation show that with the use of heavy massive structures for analyzed climatic conditions in Belgrade, the capital of Serbia, there is potential for reducing energy needs for heating and cooling of space [16].

For the same wall thickness, high-density materials have a higher thermal capacity compared to low-density materials. This means that high-density materials can accumulate more solar energy than low-density materials, which allows more solar energy to be used to heat the object instead of using operational energy [11]. Anđelković and others [16] conducted a research in which they concluded that the addition of thermal mass has a greater impact on the requirements for heating and cooling of space and energy consumption in buildings conditioned by radiation than those caused by convection. It is thus proved that heat transfer by radiation plays an important role in the behavior of thermal mass. The heat accumulation capacity of the internal thermal mass reaches a maximum value for its optimum thickness. There is a big difference between the materials, not only in the volumetric specific heat but also in the optimal thicknesses of the thermal mass [19].

Any materials that have a high thermal capacity can be used in the Trombe wall [6]. The high degree of heat accumulation has concrete, stone, earth, but also water, so they are most suitable for making such heating elements. Concrete and steel are better for storing heat than wood, but steel is not far superior to concrete if the effect of convection is taken into account [19]. Concrete, terracotta and limestone are the most advantageous inertial materials for use in housing: they offer simultaneously a fairly high thermal storage capacity, low energy consumption during the production process and low cost [18]. To accumulate heat during the day it is recommended to orient concrete, stone or brick walls, to the most exposed side to the sun during the year. Accumulated heat is emitted into rooms during cooler nights. This transmission does not have to be direct, but the natural character of the air can be used, due to which the warmer air rises, and the cooler descends.

In the case of electric heating, the optimum thickness of the layer (clay-brick) is about 0.35m, and in the case of natural gas heating, about 0.25m [11]. If the Trombe wall is of extremely high thickness, heating by natural gas can even lead to the loss of primary energy. Saadatian and others [6] state that the massive Trombe wall of 30-40cm thick concrete in many geographical locations works well. The finishing of the Trombe wall is very important for the efficiency of this system. Coating materials with a high degree of absorption contributes to the improved storage of heat in the Trombe wall. However, when designing these systems, particular care must be taken to avoid unwanted overheating during the summer period. Dark colors are recommended because they absorb much more energy. The bright colors reflect solar radiation, while the darker surfaces absorb much more sunlight. The white absorption coefficient is 20-30%, while for black it is 90-100% [20]. The dark-colored modified Trombe wall surface of $2m^2$ with 14cm of space between glass and thermal mass can induce $20\text{-}90m^3/h$ ventilation [6].

Abbassi, Dimassi and Dehmani developed a numerical model of the Trombe wall system, and the results were confirmed by the experimental study [21]. Thermal insulation of buildings and optimal surface of the Trombe wall can significantly reduce the annual consumption of heat energy. Insulation of the inner surface of the Trombe wall contributes to the increased degree of ventilation in the summer period, which reduces the amount of energy spent on cooling. In this way, it also prevents unwanted overheating of the internal air due to heat transfer from the wall through convection and radiation [22]. Strictly, correct insulation from the inside of the wall is recommended in order to avoid the reverse heat transfer. Insulation not only increases the efficiency of the solar system by up to 56%, but also reduces the size of solid walls, which reduces the weight of the entire building [6].

The greatest need for heating and cooling is less in the cases having a thermal mass on the inside of the insulating coating [16]. Jaber and Ajib [7] recommend the use of blinds in order to prevent the penetration of solar radiation into the building, as well as insulation curtains between glass and wall layers to avoid heat transfer to the building during summer. Moreover, the foundations must be protected in the usual way by rigid insulation, in order to reduce heat losses between the solar wall and the foundation.

2.3. Specific heat of the walls in the building

Zeng and others [23] provided new concepts and approaches for the development of energy-efficient buildings. As an initial step, the ideal specific heat of the walls in the building is determined. The results have shown that:

- For analyzed cases, the ideal specific heat of the walls in the building consists of the baseline values and ideal excess values. The ideal excess heat is approaching the δ function.
- The critical values of the extreme volumetric enthalpy are different in different climatic conditions, but the corresponding characteristic temperatures of the ideal thermal mass are in the Chinese region closer to one another. They fall in the temperature range of about 18.3°C - 19.3°C in winter and around 26.5°C -26.7°C in summer.
- The ideal excess volumetric specific heat of the thermal mass over the whole year is in the close superposition of the thermal mass in the winter and summer periods.

2.4. Time delay and decrement factor

Since the increase in the thermal mass does not increase the phase shift of the system an appropriate amount of thermal mass should be used in the passive solar design.

Buildings of solid constructions generally have less oscillations of the interior air temperature than buildings with lightweight structures, but there is a time lag and reduced maximum cooling requirements [24]. For locations with high daily temperature fluctuations, this process can significantly reduce the energy consumption of mechanical cooling systems. This technique refers more to offices and other buildings that are empty during the night, so the room can be cooled by the use of night ventilation. The air-conditioned building can also be pre-cooled during a period when no one was in them, which leads to significant energy savings. Small variations of interior temperatures in the rooms also have a positive effect on the user's thermal comfort [24].

The thermal mass has the ability to store heat during the day and release at night. In desert climatic conditions with all-day high room temperature and intense sunlight, resulting in increased heat storage during the day compared to heat release during the night. As a result, the use of cooling energy will increase. Florides and associates [17] conducted the analysis which have shown that, in relation to the thermal mass, the increase in the wall and the roof thickness and the use of night ventilation is not enough to reduce interior temperature to acceptable limits during summer. In cases where space heating is intensified during the day, it is necessary to try to use walls with a lower thickness of thermal mass [8].

Buildings of solid constructions generally have less oscillations of the interior air temperature than buildings of light structures, but there is a time lag and reduced maximum cooling requirements [24]. Asan [25] investigated the time delay and decrement factor for real building materials. Twenty-six different construction materials were selected for the analysis. The calculations were repeated for each material for eight different thicknesses and the effect of thickness and he studied type of material on the time delay and decrement factor. The results of this study are useful for making more efficient passive solar buildings. The use of different materials results in different time delays and decrement factors. The thickness of the material is also determined by time delays and decrement factor [25]. The heat is distributed to the interior in the afternoon, and the effect of air heating is even more pronounced through the ventilation holes during the day [12]. In Fig. 3 - A time delay in the zone of residence occurs as a result of the Trombe wall effect it is clear that there is a time delay in the zone of residence resulting from the effect of the Trombe wall.

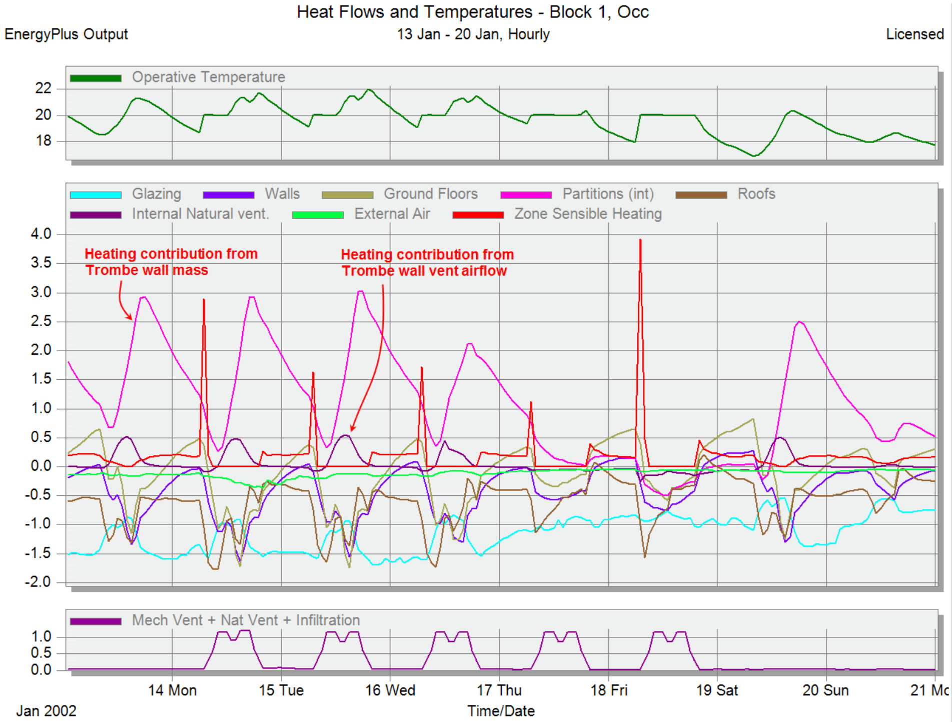

Fig. 3 A time delay in the zone of residence occurs as a result of the Trombe wall effect [12]

2.5. The effect of glazing

There is data on the wide application of glass in architecture, as well as on its characteristics in many papers, such as [26]. The thickness and type of glass significantly affect the performance of the Trombe wall. The Trombe wall, due to glass main characteristic of letting through the short-wave solar radiation, and of retaining radiation (which is the main carrier of heat) for a long time, is functionally based on the effect of the hothouse. The effect of glazing also depends on the geographical characteristics of the site, as well as on the orientation of the wall [27]. The energy collected by applying a low-emission double and standard double glazing varies greatly depending on the thermal mass, as well as the type of wall. Glazing in front of solid elements is designed to prevent heat loss, while helping to accumulate it. The use of a double instead of a single glazing for the Trombe wall system not only reduces the heat losses in the winter, but also improves the passive cooling in summer [22]. The distance between the glass and the thermal mass is usually between 3-6 cm. From the economic point of view it is justified to use a double glazing in combination with a 30 cm thick thermal mass. It is also preferable to apply a combination of 20 cm thick thermal mass and a single glazing compared to a 10 cm thick wall with a triple glazing. The thermal mass made of 45 cm thick wall in combination with single glazing is also a better option compared to a 20 cm thick thermal mass combined with a triple glazing [8].

The main characteristic of passive houses is the maximum utilization of solar energy for the achievement of high-quality heat comfort. In contrast to active systems, passive systems do not require additional electricity for their functioning. Using only location natural conditions contribute to the improvement of comfort within the facility. The fundamental principle of passive use of solar energy is that the building is oriented towards the Sun and uses its energy. The moment the Sun is no longer functioning and when the external conditions become unfavorable, it should be protected from heat losses by closing it to the environment. The Trombe wall provides passive solar heating without the negative impact of light and reflection in the building. In order to reduce unwanted summer gains, it is necessary to design permits to prevent overheating. The use of the Trombe wall increases if a curtain is placed over its outside to prevent heat loss overnight. For an average well-insulated 100 m^2 house, the Trombe wall can save up to 30% energy for heating. This constructive improvement contributes to increasing the efficiency of the implemented system primarily in the summer period of the year.

2.6. Influence of ventilation openings and ventilation

In order to allow air flow, this system originally has ventilation openings in the lower and upper part. This flow can be natural, but sometimes it also provides forced air flow (by installing a fan). The efficiency of this system decreases with the increase in the input air temperature in the input channel. Due to constant solar radiation, with increasing air speed in the inlet channel, solar walls increase efficiency. This simplified method allows users to evaluate the efficiency of the heating system, as well as to perform comparisons and predict the behavior of thermal behaviors under working conditions.

Dragićević and Lambić [28] conducted a numerical analysis of the efficiency of the modified Trombe wall with a double glass and a solid wall with an opening and a central channel in it with forced convection (flow). In order to increase efficiency, a fan is provided in the lower part of the wall. This system is more advanced compared to the simple Trombe solar wall with relatively low thermal resistance, which is taken as a reference in experimental analysis. In Fig. 4., solar thermal accumulation of different variants of Trombe wall are shown.

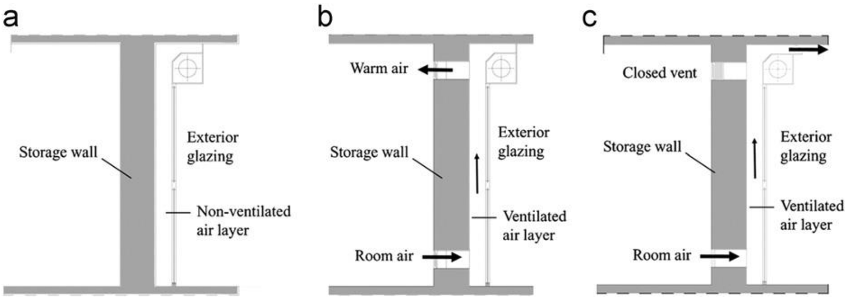

Fig. 4 Solar thermal accumulation of different variants of Trombe wall:
a) without ventilation b) winter mode with thermo-circulation
c) summer mode with ventilation [27]

Ventilation openings, ventilation and insulation are three components of the Trombe wall which have a significant impact on its efficiency. The dimensions of the inlet and outlet openings are increased by changing the width of the channel, while increasing the distance between the wall and the glazing also increases the ventilation rate [22]. Liu and others [29] have experimentally and numerically determined that the optimum time to open the ventilation ducts on the Trombe wall is 2-3 hours after sunrise, while the optimal closing time is 1h before sunset. Trombe wall reaches the maximum value of the capacity of the heat accumulation at 16h, while the minimum value is recorded at about 7-8 o'clock in the morning. The research results provide a reference basis for optimization and operational management in passive solar houses with a Trombe wall.

3. Conclusions

Based on the literature review and characteristics of the elements of the Trombe wall, it can be concluded that the implementation of this construction positively influences the reduction of the total amount of heat needed to heat the object. Concrete walls thicker than 15 cm do not conduct heat from one side to another, they provide some kind of insulation, and the excess heat accumulated during the day, the walls emit inside the building. Regardless of the fact that along with the increase in the degree of coverage of the southern facade with the Trombe wall proportionally reduces the required amount of heating energy, the most optimal variant does not always have to be the one with the greatest coverage with this massive construction. Orientation also plays an important role, and along with reducing the amount of energy required to heat the building, the degree of total energy savings is changed.

The application of the Trombe wall represents a good choice in order to passively reduce the consumption of energy. A number of constructive elements of a structure as well as behaviour of its users, can significantly affect the efficiency of this system. The benefits of using this system are primarily reflected in saving energy needed for heating and cooling the space, which is mostly contributed to heat accumulation during the day and distribution of this heat during the night. The application of this system is possible in various climatic conditions, but the most favorable ones are the regions with high temperature fluctuations during the day and night. The greatest disadvantages of applying this system are the degree of efficiency depending on the external climatic conditions (in the summer when temperature periods are too high the problem with room cooling can exceed the benefits achieved in the winter period). Cloudy weather periods can also be a major problem that could contribute to unwanted heat transmission losses. Low thermal resistance of this system affects the increase of heat flux, and the gain is difficult to predict.

It is important to point out that the best values of dynamic thermal characteristics of the walls also depend on: building types (public or residential) and occupancy (permanent or occasional) of the facility or part of the building. The desired level of internal temperatures, as well as the tolerance to temperature oscillations, presence or absence of air conditioners, existing glazed surfaces and external environment also play significant role. Adaptive approach and level of tolerance of the users of space related to thermal comfort in the interior plays a major role in the final energy consumption. By lowering the temperature in the apartment by only 1^o, the cost of heating will be reduced by about 7% [30]. Interaction with objects in the environment, as well as potential obstructions by surrounding structures, then the configuration of terrain and the complexity of design in order to enable all the necessary comfort in the facility, are the constraints that must be considered. Changing the temperature at the very construction of the Trombe wall is a very important parameter. Computer analysis of the thermodynamic properties of this construction, and experimental research confirm the importance and advantages of using this system. Aesthetic aspect can sometimes play a significant role in deciding whether and how to apply this system. Architects and engineers must be aware of all possible positive and negative consequences of the application of this system.

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UTICAJ TROMBOVOG ZIDA NA TOPLOTNI KOMFOR I SMANJENJE POTROŠNJE ENERGIJE U ZGRADAMA

Potrošnja energije je na globalnom nivou dostigla svoj maksimum. Zgrade imaju najveći udeo u ukupnoj potrošnji energije, pa se mora povesti računa o njihovom funkcionisanju I posledicama koje mogu nastati. Pasivno solarno projektovanje predstavlja imperative u modernoj arhitekturi, a kao jedan od principa ovog načina projektovanja se svakako izdvaja Trombov zid. U radu je dat pregled karakteristika konstrukcije Trombovog zida u cilju poboljšanja toplotne stabilnosti i smanjenja potrošnje energije u zgradama. Počev od sagledavanja klimatskih uticajnih faktora, preko toplotnog kapaciteta primenjenih materijala, ali I njihove debljine i boje termičke mase veoma je važno detaljno poznavati sve faktore koji mogu dovesti do poboljšanja efikasnosti ovog Sistema. Specificna toplota zidova u zgradi, vremensko kašnjenje i dekrementi factor i uticaj i položaj termoizolacije su takođe uzeti u obzir, a kao značajni elementi su se izdvojili I efekat zastakljenja, kao I uticaj ventilacionih otvora. Na osnovu analize navedenih komponenti izvedeni su zaključci I date smernice za projektovanje ovakvog tipa konstrukcija u cilju poboljšanja efikasnosti I smanjenog utroška energije uz obezbeđivanje adekvatnih komfora u objektu.

Ključne reči: *klimatski uslovi, termoakumulacioni materijali, izolacija, zastakljivanje, ventilacija, finalna potrošnja energije*