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Research paper

HEATING A RESIDENTIAL BUILDING USING THERMALLY ACTIVATED BUILDING SYSTEMS (TABS) AND PARTIAL EARTH-BURIAL: A CASE STUDY

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Abstract

The most significant amount of electrical energy is obtained by burning fossil fuels, which release substantial amounts of harmful gases, that contribute to environmental degradation. Because the most crucial part of the energy produced is used during the construction and operation of buildings, it is necessary to build buildings that can provide the energy needed for heating and cooling through renewable energy sources. Geothermal energy is the clean energy source with the most significant potential for solving this problem. However, the thermal capacity of energy forms and exploitation systems have not yet been sufficiently researched, significantly limiting their application. This paper presents two geothermal energy systems for heating buildings: the passive system, which is burying objects, and the active system, which is the thermally activated building system (TABS). The work aims to highlight the significance and potential of geothermal energy, which can achieve energy independence for the facility. Through a case study of a residential building, based on software simulations conducted in the EnergyPlus program, it has been determined that the total consumption of thermal energy needed for heating is 26,43 kWh/m2. The findings demonstrate that applying the passive and active geothermal strategies can achieve significant energy savings required for heating buildings, thereby mitigating environmental impact. The obtained results will allow for the assessment of the expected impacts of climate change on building energy performance and the adaptation of both passive and active strategies, such as TABS systems and geothermal regulation, to future conditions.

Key words: *Geothermal Energy, Thermally Activated Building Systems, Energy Efficiency, Building Performance Simulation*

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1. INTRODUCTION

In recent decades, most scientific research in architecture and civil engineering has focused on the problems of global warming, air pollution, and the depletion of fossil fuel reserves, as well as potential solutions to these issues. Many researchers emphasize the importance of renewable energy sources and propose various methods for their utilization to reduce energy consumption and, consequently, environmental pollution. Since the largest share of harmful gas emissions in the construction sector is caused by heating buildings through the combustion of fossil fuels, the main objective is to find an alternative energy source that can ensure thermal comfort without negatively impacting the environment. A review of the available literature [1, 2] indicates that, among all renewable energy sources, geothermal energy offers the most significant potential for a long-term solution to this problem. However, this form of energy remains the least explored and underutilized, both globally and in Serbia.

Numerous studies and existing examples worldwide highlight the significant potential of geothermal energy and the substantial energy savings that can be achieved through the implementation of appropriate systems. The most commonly used are active systems, which involve the use of geothermal heat pumps or the direct exploitation of hydrogeothermal energy. By applying these technologies, some countries have enabled the heating of entire cities, significantly reducing both energy consumption and harmful gas emissions, for example, in Reykjavik [3]. Passive use of geothermal energy – such as the burial of buildings into the ground – has also been thoroughly researched. This construction method utilizes the earth's thermal insulation properties, which reduce heat losses from indoor spaces [4, 5]. Given that geothermal systems still require a certain amount of energy to maintain indoor thermal comfort, engineers are developing new technologies and heating systems to reduce the heating demands of buildings further. A review of the literature [6] has shown that the innovative system of Thermally Activated Building Structures (TABS) can significantly reduce energy consumption. According to a study by J. Lind and F. Otterman [7], TABS offers better energy performance compared to traditional heating systems, which is why its application is becoming increasingly widespread worldwide.

This raises the question of the applicability of these systems for heating buildings during the winter season in Serbia. From this, the main objective of the research emerges – to highlight the importance of the underutilized potential of geothermal energy through the application of the TABS system and the construction of earth-burial buildings. The selected location for this study is Vranjska Banja, a settlement renowned for its geothermal springs, which have temperatures exceeding 80°C. The potentials of the TABS system and the passive use of geothermal energy were analyzed in the context of a single-family residential building. The building was modeled using Google SketchUp with the OpenStudio plug-in. To determine the energy savings provided by these systems, heating energy demand and total energy consumption were simulated for three different scenarios. The first scenario represents a standard building without any of the systems applied. The second includes a building equipped with the TABS system, while the third scenario involves a semi-buried building with an integrated TABS system. A comparison of the results, obtained using EnergyPlus software, showed that the most significant energy savings were achieved in the third case.

2. METHODOLOGY

2.1. Heating of buildings using the TABS system

The Thermally Activated Building System (TABS) is a system that utilizes the structural elements of a building to transfer and accumulate thermal energy. In these installations, indoor space heating is achieved by activating the building's thermal mass, which is done by embedding a thermally active barrier into the opaque part of the building envelope. This typically involves pipes carrying warm water embedded within the concrete structure. By integrating the pipes into the structural elements, the temperature difference between the heated indoor space and the structural element is reduced [6]. In this way, the TABS system significantly lowers the building's heat losses. As the temperature difference is reduced – by controlling the fluid temperature within the pipes – the system's heat losses also decrease. This means that heat loss through the building envelope becomes negligible if the water temperature in the TABS system is around 20°C, which corresponds to the standard indoor heating temperature during the winter season [8]. However, maintaining a constant indoor temperature and reducing energy consumption also depend on the type of materials used, as well as, the number and thickness of the layers within the structural elements [9]. Additionally, the thermal performance of a building equipped with a TABS system may be influenced by factors such as pipe positioning, the type of working fluid, and the system's operational method.

The pipes of a TABS system can be embedded in the wall, floor, or ceiling structures of a building. According to scientific studies [9,10], the most effective configurations for space heating are those with floor or wall heating, while ceiling heating provides the least energy savings. However, all of these structural elements provide large heat exchange surfaces, allowing for efficient space heating using low-temperature fluids (up to 30°C). Since lower operating temperatures typically characterize renewable energy sources, this system is ideal for their application.

Higher temperatures of the building's exterior structural elements, although they reduce heat losses from the heated interior toward the building envelope, result in twice as much heat loss to the external environment compared to a building without embedded pipes [8]. This outward radiation of energy from the TABS system can have a negative environmental impact if the thermal energy is produced by burning fossil fuels. However, this issue can be addressed by combining the TABS system with renewable energy sources, as clean energy significantly reduces both the building's energy demand and the emission of harmful gases.

2.2. The impact of building earth-burial on thermal energy savings

Energy savings for building heating, in addition to utilizing renewable energy sources through active systems, can also be achieved by maximizing the use of the site's natural conditions through proper building orientation. Good building orientation can maximize solar gains during the winter period, which positively contributes to reducing energy consumption. However, the most significant energy savings can be achieved by burying buildings into the terrain, which enables the use of the soil's favorable thermal properties. Since this construction approach requires a steeper slope, its potential application is significantly limited.

How does soil, through its thermal properties, enable energy savings required for heating buildings? At specific depths, the earth's temperature remains constant (10–15°C), regardless of the season or time of day [3]. Therefore, by burying a building into the ground, the temperature difference between the interior and exterior is reduced, resulting in decreased heat loss through the building envelope. In addition to providing thermal insulation, the soil also increases the thermal mass of the building's structural elements, thereby helping to maintain a stable indoor temperature. To achieve optimal indoor conditions (20–25°C) in such buildings, it is only necessary to supply additional heating to compensate for the temperature difference (5–15°C), which requires less energy compared to a freestanding building. The reduction of heat loss in earth-sheltered buildings largely depends on the degree of burial, orientation, and the number of exposed facades. According to studies [4, 5], the most significant energy savings are achieved in buildings with openings oriented toward the south and a fully buried north facade, which protects from cold northern winds. In contrast, the lowest energy efficiency is observed in buildings positioned on north-facing slopes, where the southern facade must be buried.

2.3. Model settings

The location selected for this research is in Vranjska Banja, Serbia. The site's most significant advantages are its steep south-facing slope (37%) and the presence of hot water springs (80°C). The conceptual building is positioned so that the northern facade is fully embedded into the terrain, while the lateral sides are partially buried. The southern facade is the only exposed side, allowing for natural ventilation and daylighting of the interior. The building is a single-story structure, with a floor area of 139.57 m² and a ceiling height of 2.60 m. For heating purposes, a TABS (Thermally Activated Building System) was implemented, utilizing the local hydrogeothermal energy as its energy source. TABS requires the installation of pipes within the opaque structural elements of the building. Since heated air rises from the lower to the upper parts of rooms, pipes are installed in the building's floor structure and exterior walls. The windows are double-glazed. The building envelope consists of:

- Green roof: finishing plaster (1.5 cm), reinforced concrete (RC) slab (20 cm), low-grade concrete (5 cm), vapor barrier, EPS insulation (25 cm), SikaPlan membrane, geotextile, barrier layer, drainage layer, filter layer, substrate (10 cm), vegetation
- Ground floor slab: gravel (10 cm), PVC foil, low-grade concrete (10 cm), waterproofing layer, reinforced concrete (RC) slab (40 cm), EPS insulation (10 cm), PVC foil, cement screed for underfloor heating (8 cm), hardwood flooring (2.2 cm)
- External wall 1: reinforced concrete wall (15 cm), waterproofing, EPS insulation (12 cm), cement screed for wall heating (5 cm), reinforced concrete wall (25 cm), finishing plaster (1.5 cm)
- External wall 2: reinforced concrete wall (15 cm), waterproofing, reinforced concrete wall (25 cm), finishing plaster (1.5 cm)
- External wall 3: finishing plaster (1.5 cm), EPS insulation (12 cm), cement screed for wall heating (5 cm), reinforced concrete wall (25 cm), finishing plaster (1.5 cm).

To determine the impact of building earth-embedding and the TABS system on energy savings required for space heating, simulations of the building's heating energy demand were conducted for three scenarios:

- First case – a standard free-standing building without any implemented systems
- Second case – a free-standing building equipped with a TABS system
- The third case – a semi-embedded building fitted with a TABS system.

The modeling of the building with integrated systems was carried out using Google SketchUp along with the OpenStudio plug-in. Simulations were performed in EnergyPlus software based on the following input parameters: indoor design temperature of 23°C, TABS system supply temperature of 45°C, outdoor temperatures were taken from the weather file for Vranje.

The data used in this study covers the period from 2009 to 2023 and represents the most recent available values. Since complete meteorological records for Vranjska Banja are not available, data from the city of Vranje – the closest relevant meteorological station located in the immediate vicinity of the study site – was used. The data were obtained from official meteorological sources and processed to generate a Typical Meteorological Year (TMY). This method uses several years of actual measured data to construct a representative year that accurately reflects average climatic conditions. This approach ensures a consistent and repeatable basis for conducting simulations in software tools such as EnergyPlus.

3. RESULTS AND DISCUSSION

Based on the conducted simulations, the building's energy consumption was determined on a monthly basis for the period from November to March for all three cases. The comparison of energy consumption for buildings with different heating systems is presented in Figure 1. The monthly consumption diagram shows that the application of the TABS system and geothermal energy (second case) results in twice lower energy consumption during the coldest months (December and January) compared to a building with a traditional heating system, while in the remaining months of the heating season, energy consumption is reduced by more than 50%. A comparison between the second and third cases reveals that embedding the building into the ground provides additional energy savings, although significantly lower than those achieved by the TABS system alone.

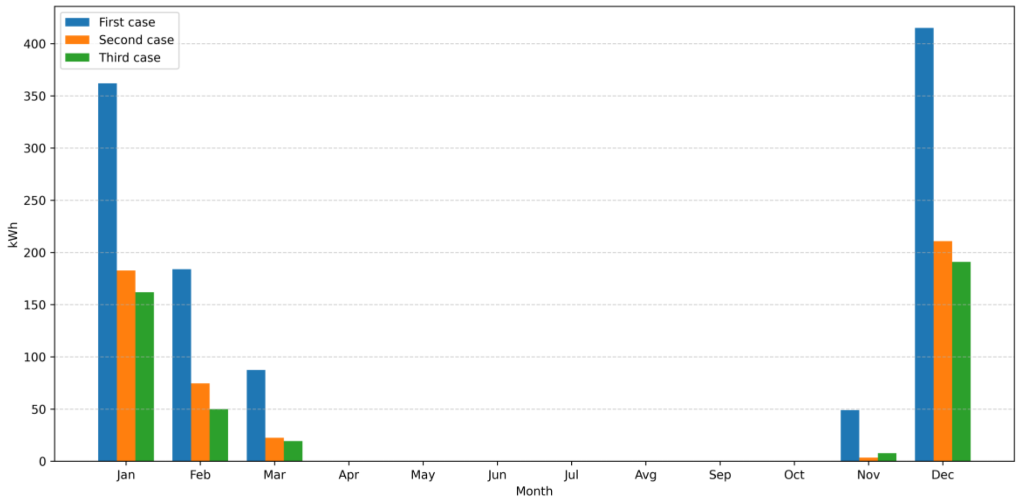

Figure 1. Graphic representation of monthly heating energy consumption, author

The obtained research results show that the highest energy demand was recorded for the building without any applied systems (first case), amounting to 1160.55 kWh. With the application of the TABS system (second case), energy consumption was reduced to 492.23 kWh. In the third case, which included both the TABS system and the earth-embedding approach, the lowest consumption was achieved at 429.97 kWh. Based on these findings, it can be concluded that the application of the TABS system allows for energy savings of 59%, while the combination of the TABS system and building burial reduces energy consumption by 67.5%.

Figure 2 presents a diagram of daily energy consumption during the heating season, illustrating how the application of the TABS system and the principle of earth-sheltering affect the energy required for heating buildings. The ground and the TABS system significantly reduce heat losses from the heated space to the external environment, helping to maintain a constant indoor temperature. By implementing these systems, the cooling of the interior is slowed down, which in turn reduces the need for heating and shortens the heating period. Based on the diagram, it can be concluded that the first case has the most extended heating period and the highest energy demand. The second and third cases are characterized by lower daily energy consumption and a reduced number of days requiring space heating. According to the diagram, in buildings equipped with the TABS system and partially earth-sheltered construction, heating is almost unnecessary during March and November, indicating that the heating period in these cases is significantly shorter.

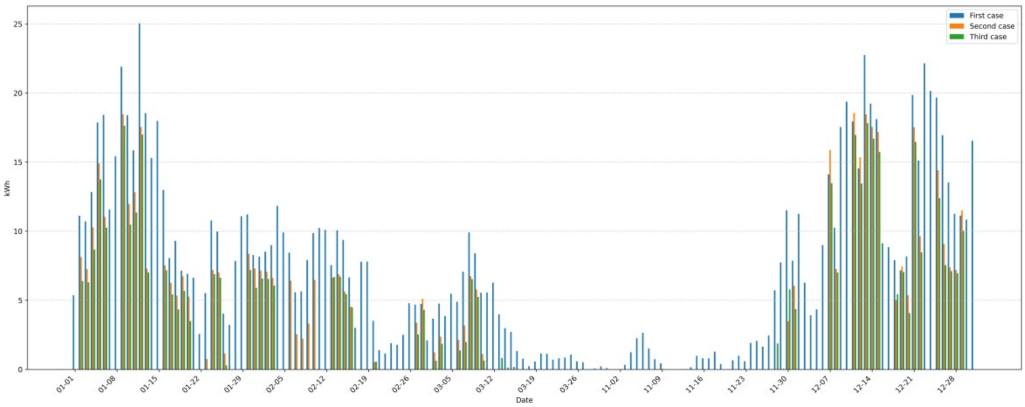

Figure 2. Graphic representation of daily heating energy consumption, author

The simulations conducted in this study were based on a TABS system operating at a heating fluid temperature of 45°C, resulting in a 59% reduction in energy consumption. Although it achieves significant energy savings, a TABS system with a temperature nearly twice that of the indoor air temperature causes greater heat radiation to the external environment compared to low-temperature TABS systems. Numerous scientific studies have shown that the temperature of the fluid in a TABS system has a substantial impact on reducing the energy required for space heating. For example, according to the research by B. Stojanović [8], a TABS system operating at a temperature half that of the indoor temperature achieves considerably lower energy savings than a system with a fluid temperature close to room temperature. He notes that energy consumption for heating can be reduced by up to 75% if a TABS system operating at 18°C is used to maintain an indoor temperature of 20°C. Based on this, it can be concluded that reducing the temperature difference between the TABS system and the heated space can significantly improve the building's energy performance. Although the most significant savings are achieved through the application of the TABS system combined with geothermal energy, the principle of building burial also makes a substantial contribution to reducing energy consumption.

Further development of the research will focus on the study of predictive climate scenarios, including the generation of EPW files for future years (e.g., 2030, 2050) using data from the CMIP6 climate model. This will allow for the assessment of the expected impacts of climate change on building energy performance and the adaptation of both passive and active strategies, such as TABS systems and geothermal regulation, to future conditions.

4. CONCLUSION

Based on the obtained results and discussion, it can be concluded that the application of the TABS system, geothermal energy, and earth-sheltering of buildings leads to significant energy savings for space heating. Although the TABS system has a much greater impact on energy efficiency, the earth-sheltering principle can also considerably reduce energy consumption. By embedding the building into the terrain, the geothermal potential of sloped sites can be fully utilized. The combination of these systems not only reduces energy consumption but also lowers greenhouse gas emissions, which positively impacts the environment. However, the construction of such buildings is limited by high initial investment costs. Therefore, it is essential to emphasize the relatively short payback period and to raise awareness of the importance of applying such systems. Considering that these systems can also be utilized for cooling and combined with other renewable energy sources, the conclusion is that constructing such buildings is justified, as it contributes to sustainable architecture. And this, if done globally, significantly contributes to the reduction of green house gasses, as mentioned in the introduction.

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