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BURIED BUILDINGS AS AN EXAMPLE OF ARCHITECTURE THAT STRIVES TO BE ENERGY EFFICIENT

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Hristina Krstić, Veliborka Bogdanović, Miomir Vasov, Ivana Bogdanović-Protić, Sanja Spasić Đorđević

Faculty of Civil Engineering and Architecture, University of Niš, Serbia

Abstract. *This paper studies the concept of underground architecture in residential houses. The earth (soil) is an element that has some very good features that can be used in order to create a building that is more energy efficient. The most important feature is its good insulation capacity and thermal inertia, which results with constant temperature. By making the home underground, many advantages can be achieved - the land used for the construction is not destroyed and taken away from the nature (the greenery is saved), energy consumption is decreased, the building is more protected from outer influences (storm, vibrations, noise, rain, snow, frost...) etc. The underground houses - earth sheltered houses - represent the passive architecture that can be combined with solar architecture. In this way, earth sheltered houses can be in a great manner energy independent and even considered as self-sustainable structures. The aim of this paper is to find out advantages and possible disadvantages of this type of constructions, through the analysis of few constructed buildings, all with the additional aim to promote the integration of natural conditions that can be found at the location in a design of residential architecture.*

Key words: *solar earth sheltered houses, underground architecture, energy savings, sustainable construction*

1. INTRODUCTION

Energy optimization of buildings and increment of their energy efficiency, as well as the respect of principles of sustainable construction, have become increasingly important elements of architectural and urban design. The optimization of energy consumption in a facility involves the implementation of measures that would reduce the energy demand of this facility, both during construction and during its use and maintenance. In order to

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Corresponding author: Hristina Krstić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: hristinaa@hotmail.com

achieve these goals, the architecture turns to bio-climatic and ecological design principles, which are primarily based on the use of renewable energy sources, the detailed study of natural and generated conditions at the site and their impact on the quality of life, integration of a facility in natural environment, the use of new environmentally friendly materials and technologies etc. Ecological architecture strives to become an integral part of the natural environment and does not disturb its flows. Therefore it insists on the construction method that will not have any negative consequences nor for users, nor for the environment.

The total energy balance of the building is determined by thermal losses and gains of the facility: transmission and ventilation heat losses, heat gains from sunlight, people who stay in the facility and electrical appliances, as well as heat gains from the heating system. Heat losses occur through all the elements of the building thermal envelope such are exterior walls, doors and windows, roof and floor surfaces. According to [2] the greatest heat losses are through the windows (51%) and facade walls (21%), which is together more than 70% of the total heat losses through the building envelope. Heat gains from the solar radiation are dependent on location and micro location, and also on the type of building envelope, where the greatest impact have transparent elements, their surface area and orientation [1]. So the main objectives of energy efficient building should be aimed to the optimization of heat losses and gains, but also to the use of renewable energy sources and the correct choice of thermal energy system in the building.

Significant savings in energy consumption for heating or cooling can be achieved by improving the thermal insulating features of building envelope, which should have a low coefficient of heat transfer U, but also can be achieved by the utilization of natural conditions that exist at the site. And exactly the good use of the natural conditions of the location is a key element for successful and sustainable ecologically oriented architecture. One of the most important factors in design process, in terms of natural conditions of the site, that can in a great manner affect the energy profitability of the facility, is the configuration of the terrain. Besides many generally known positive features, the earth (soil) also has relatively good thermal insulating characteristics. The temperature of the soil at a certain depth is constant and about 12,2^{o}C, regardless of the season, time of the day or the geographic location [3]. According to the Standards for the design of residential buildings, the temperature inside the facilities should be between 20 and 24^{o}C [6], which means that to achieve the desired temperature it is necessary to provide additional heat only to the temperature difference of about 8-12°C. If we add to this the requirements of building's heating in extremely cold regions, where the temperature differences are 30-40^{o}C, and also the requirements of additional energy for building's cooling in summer in the areas where the outside temperatures are very high, it can clearly be understood how big savings can be made.

Thanks to the relatively good accumulation capacity and thermal inertia of the earth, by overlapping the building with earth (soil) at the same time significant thermal insulation and accumulation mass can be achieved. The building protected by earth requires less energy for heating during the winter as well as less energy for cooling during the summer, while creating good quality microclimate conditions in building's internal environment, and all these because the earth's temperature is higher in the winter and lower in the summer compared to the temperature of the outside air of the building on the flat terrain. The difference between the indoor and outdoor temperature is a major factor in heat transfer. By putting the house under the ground, heat losses are reduced, so this subject stands out as a very interesting when it comes to bioclimatic and ecological design and the use of nature to create high-quality microclimate conditions of the internal environment of the building.

The buildings in which the earth (soil) is used as thermal mass for external walls and/or roof are called earth sheltered houses. They are very interesting in terms of energy efficiency in buildings, bioclimatic and ecological design, and will be the topic of this paper. The aim of this paper is to find out advantages and possible disadvantages of this type of constructions, through the study of characteristics of earth shelter houses and analysis of few realized facilities, all this with the additional aim to promote the use of natural conditions in a design of residential architecture. The main focus of the work is on the impact of earth sheltering of structures on heat losses.

2. WHY "GEO-ARCHITECTURE"

The growth of population, the development of industry and technology are leading to expansion of urban areas and the creation of new urban centers. Existing cities are expanding enormously, which entails a number of effects that damage the environment. The nature disappears - forests, meadows, arable land are being lost... Instead of them there rises a " Concrete Jungle " - high-rise buildings, industrial plants, parking lots, bridges, traffic loops, etc. The living space becomes an artificial creation, which gradually loses any form of human character. By working for itself, one actually starts to work against itself. Striving to create an environment clean for living, the man actually makes it dirty. Clean air, water, soil... are becoming a luxury which, if continued in the same way, will become unavailable for many. Thus, the problem of living space becomes an issue of survival and life quality, so this can be listed as the first reason why passive architecture supports geo-architecture, which proposes partially or totally grooving into the earth of various public and residential buildings. The limited surface of the Earth must be kept and used rationally. Many modern city facilities that are not necessary on the surface, could be placed underground. *Lukić M.* gives the quotes from *Fabre-Luce*'s book, ``*Six billion of insects*``: "If we know that the total area of the globe is about seven billion square kilometers, and that only one fifth is suitable for settlement, then how to organize the limited Earth's surface for a huge future human community? In just ten years (1940-1950) the United States population increased for an entire population of Great Britain, and from 2000 to 2059 they will increase for the population China as was in 1950. Demographic expansion, that doubles the population of the Earth every forty years, indicates that in about three hundred years will be seven hundred billion people on Earth. By the year 2260, each inhabitant of the Earth will have only 10 square meters of the earth's surface, and by 2400, only 1 square meter." [3]

Another, equally important reason, for promoting geo-architecture is the fact that buildings are huge energy consumers. It is considered that the energy consumption in buildings is about 50% of total energy consumption in the world. [2] In the United States numerous researches were carried out on the topic of energy savings in earth sheltered buildings. In the areas of relatively dry climate have been achieved savings in heating energy in earth sheltered buildings up to 40% compared to the free-standing buildings of similar size and purpose.

3. Analysis of Examples of Earth Sheltered Houses

The idea of digging the house into the ground is not new. If we look back throughout history, in many stages and in many places man has lived underground. Initially he had used the caves as the shelter, and later, at the beginning of life in a community, he built huts buried in the ground. People have built houses for living underground for more millennia. Cave houses in northern China are dating back to the 2nd millennium BC (Fig. 1a); in Cappadocia in Turkey, residential buildings are carved in soft rocks (Fig. 1b); in Tunisia can be found facilities covered with earth and set around an open courtyard, forming a housing settlements linked by tunnels... and so on there are many other examples of underground structures from the past. Millions of people also today live under the earth, starting from the houses formed in former missile silo, to luxury villas with various program (swimming pools, saunas, bowling alleys, gyms...). The largest number of underground houses exist in America, where, apart from the above mentioned luxury houses, there are several thousand of modest size houses. This trend towards the construction of underground residential structures emerged during the late seventies of the last century, with the beginnings of the development of energy efficiency and sustainability in architecture and construction.

Fig. 1 a) Ancient caves in China, b) Cappadocia, Turkey
Sources of illustrations: http://www.atlasobscura.com/articles/living-underground-a-surprisingly-bright-idea, accessed 15.04.2016; http://www.hrvojeivancic.com/2013/02/kapadokija-vilinski-dimnjaci-u-turskoj/, accessed 15.04.2016.

Self-heating ecological house or solar earth shelter houses is an innovative design principle of passive solar architecture which represents residential building with high energy efficiency, heated by solar energy and designed beneath the earthen layer. There are two types of solar earth shelter houses: fully buried and partially buried. As the name implies, fully buried earth sheltered houses have their whole volumes located completely underground, while the partially buried earth sheltered houses contain openings for introduction of sunlight and air. Protection of exterior walls and ceilings can be achieved by building earthen berm 10-50 cm of thickness, where the penetration of sunlight is made through the south-oriented windows, which are usually buried to a depth of 1.10 m, which is sufficient to significantly prevent heat loss through the parapet wall facade.

This section shows three examples of designs of built solar earth sheltered houses from America and Europe. In contemporary architecture, it is possible to find a large number of similar examples, but for the purposes of this paper are selected only few representative ones. By making analysis of the projects, it is possible to notice common characteristics, advantages and disadvantages, all that with the aim of studying one specific direction in ecological design that becomes more common in architecture.

3.1. Earth-bermed house, arch. Allan Shop

Earth-bearmed House is the design by architect Allan Shop, built on a family farm in Amenia, New York, in America. The main idea in this design is to create a building that will maximally use the advantages of natural environment for its function and will not, in any way, disturb the natural harmony that exist on a location. In these terms, the architect designs one ecologically oriented house, that can, based on its concept, be considered as solar earth shelter. The house has only a ground level, with a very simple shape and a surface of around 176 m^2 in total. The floor plan has a triangular form (Fig. 2), with two sides totally placed under the ground, while the third side is open towards the south garden.

Fig. 2 Photo of the house and sketches of the ground floor level (green-buried part, yellow-free southern facade)
Sources of illustrations: http://www.shopearchitect.com/recent-projects/earth-bermed-house/, accessed 20.04.2016; http://inhabitat.com/nyc/wp-content/blogs.dir/2/files/2012/10/Earth-Bermed-House-Allan-Shope-final.png, accessed 20.04.2016.

This solar earth sheltered house is partially buried, where the roof and front facade are open, while the rest of the building's envelope is covered with earth. Deeply covered by natural soil, the house keeps relatively stable temperature during the whole year.

Thermal insulating capabilities of natural soil enable the temperature difference needed for the achievement of desired inner temperature to be gained from the passive system of sun energy collection. This is due to the fact that the biggest part of the south facade is glazed, so the direct penetration of the sun rays in ensured. The energy that in this way gets inside the house, is collected by the floor made of recycled concrete of around 70 cm of depth. This huge and thick concrete floor surface is able to accumulate a big quantity of heat energy from sunrays, and then, during the night or colder part of the day when the temperature of the inside air goes down, this energy can be emitted back to the interior space. For the additional sun energy collecting, several rows of solar photovoltaic panels are placed on the roof of the house, producing 12 kWh [8] and satisfying all the electrical energy needs. So, the whole energy needed for the function of the house is produced directly on the site (electrical energy, heating energy). In some periods, this solar earth shelter house is able to produce even more energy than needed, so it can be characterized as an energy positive house.

The underground parts of the house are planted with local greenery. In this way, the structure was totally drown in surrounding nature, without making any imbalance.

3.2. Earth- house estate Lättenstrasse, arch. Vetsch Architektur

Earth House Estate Lättenstrasse is a small residential complex in the city of Dietikon in Switzerland. The complex (Fig. 3) consists of nine individual houses organized in a form of U shape around the small artificial lake, placed in the center of the complex [7]. What characterizes the residential complex is its unusual design and tendency to fit in the natural surroundings. The houses are linked together and create a unity, designed in a way that follows organic shapes and contours of the environment.

Fig. 3 Photo and satellite image of the complex
Sources of illustrations: http://www.gizmag.com/earth-houses-hobbit-holes/24534/, accessed 10.04.2016; https://www.google.rs/maps/, accessed 10.04.2016.

The total surface area of the complex is about 4000 m^2 , while the surfaces of each house vary from 60 m^2 to 200 m^2 [7]. Sleeping rooms are placed in the northern part, while dining rooms are oriented towards the southern part. The bathrooms and the stairs that lead to the basement are in the central part of the houses. They are lit from the rooftop. There is also a huge parking space in the basement level. Although built underground, the houses have a very bright interior. The penetration of sunlight inside the house is provided through the glass portals on one free facade, as well as through the openings on the roof. In this way the interiors are do not create an impression of living “inside the cave” and they feature a pleasant atmosphere. Each house has its own part of the garden, oriented towards the central lake. Roofs are passable and are used as garden extensions. They have a soil cover of 40 – 80 cm of depth and are planted over.

The basement and the garages are constructed in the conventional construction system, while the ground floor levels are made of sprayed concrete, reinforced by nets. Although the insulation of the facilities is prevalently achieved by earth sheltering, the additionally insulation is ensured by the layer of foamed recycled glass, and the waterproofing is done on the basis of bitumen placed above the concrete. Other used mater ials are mostly natural, so these buildings are considered as eco friendly and do not affect natural environment.

3.3. Dune house, arch. William Morgan

Dune house is located in Florida, in the sand dunes of the Atlantic coast. It was designed and constructed in 1974/1975, right next to the private house of the architect William Morgan, who designed the house for himself, as a facility for renting. The location is characterized by natural sand dunes created after the hurricane Dora of 1964. Inspired by the natural shapes and stunning views to the ocean, the architect decided to keep the existing natural forms and he decided to have the house dug in one of the sand dunes.

Fig. 4 Photo of the front part of the house, ground plan and section
Sources of illustrations: [4] and https://smallhousebliss.com/2012/08/10/the-dune-house-by-william-morgan/william-morgan-dune-house-exterior-from-street-via-smallhousebliss/, accessed 25.04.2016.

The house consists of 2 mirroring apartments. Each apartment contains the living area with kitchen and dining room, sleeping room, bathroom and balcony, as an extension of the living room that overlooks the ocean. The sleeping zone is organized on the gallery above the kitchen and dining area, also with the stunning views toward the beach and the ocean. The front part of the building is like a grassy knoll that slowly narrows itself and creates two symmetrical wings of the building. The main entrances to the apartments are on the front side and have direct access from the street. Apart from the entrance doors, on the front side there are no other openings. The house fully opens itself toward the ocean, while the front part hides itself from passersby and unwanted views.

In this design, the earth (soil) is primarily used as an insulation material. Cross-ventilation in a combination with earth cover that surrounds the whole building keeps the house from overheating. Inner temperatures of the house are almost constant and are around 20^{o}C.

4. Discussion

On the basis of these examples, certain characteristics of earth sheltered houses can be synthesized and recognized. The chosen examples relate to partially buried earth shelter houses, so this paper mainly studies this type of earth sheltered constructions. It can be noticed that the main advantage of partially earth sheltered houses are greater solar efficiency (because the south openings allow maximal insolation during winter period, that can be mitigated in summer time by the use of different elements for shading – canopies, shutters or similar) as well as visual comfort, i.e. the possibility of views towards the surrounding, which significantly reduces the discomfort that exists during a long stay in underground facilities. Apart from the energy aspect, significant architectonic value and particularity of design concept can also be noticed. All the examples have the same starting point, i.e. they are based on the same conceptual idea, but this idea further develops itself in various ways, which indicates the possible diversity, individuality and originality of solutions.

4.1. Characteristics of solar earth sheltered houses

The most important characteristics of solar earth sheltered houses are reflected through the passive way of energy savings. As it has already be said, earth (soil) has a very good insulation capacity and thermal inertia, which results in the constant temperatures of about 12°C and lead to lower energy needs for heating and cooling inside the house than in traditional houses.

The next important characteristic is the fact that the land above the house is not lost. It can be used as a green area or simply an extention of the yard. The territory that was taken from nature during the construction of the house, in this way is returned back to nature. Further, another advantage is that the house is completely protected from all the atmospheric effects, primarily from the effects of frost and extreme temperatures that can gradually destroy the classical facade and walls of houses. These structures do not require gutters for drainage of rainwater from the roof. Earth absorbs all the water that falls as rain, and drains it. These buildings do not require lightning rods, and are protected in the case of earthquakes and storms. Also, the facilities do not have a problem with noise and vibrations. An example of one company in Kansas City dealing with this issue can be found in the already mentioned book *Solar architecture* by *Lukić M*m, illustrating the claims about elimination of the problem of noise and vibrations. In her book, she writes about the company engaged in the production of optical instruments for the use in outer space. Due to the impact of noise, the company was able to work only in conditions after midnight, when the traffic outside is quiet. In order to solve this problem, the company constructed a new building in a hill about 200m underground. In this new space, which is totally free from external vibrations, people can work in normal working hours and can adjust the instrument without the impacts from the external environment. The company also revealed that this new space requires 3 times less energy for heating and even 10 times less for cooling, while the maintenance costs were decreased 15 times. This experience has shown another advantage of underground living - the silence of inner space [3].

An important feature of underground houses is also their structure, which is in most cases made of reinforced concrete, because it is the only material that can handle the pressure of the earth and the possible groundwater effects. Some says that this is a negative characteristic, because concrete is not considered as eco-friendly material in a way that the basic ingredient of concrete is cement, which requires a lot of energy for its production. But, on the other hand, through a variety of savings, solar earth sheltered houses are able to quickly compensate all the lost energy. Also, nowadays there are many types of recycled concrete whose usage is being increased, so this material is approaching the environmentally friendly materials. Thus, this cannot be fully considered as a negative characteristic.

Some of the negative characteristics of the underground building can be: poor ventilation of underground living space, humidity, protection from water, limited openings, limited material that can be used in construction etc. However, all these disadvantages can be overcome, so they are not crucial for the quality of living in this kind of constructions. Soil cover reduces or completely prevents the effect of wind, so the problem of natural ventilation occurs. This problem is usually solved by the system of tubes, where one tube serves for air intake, while other serves for the evacuation of the used air from the house. In order to protect the building from water, it is necessary to properly perform waterproofing insulation and drainage around the building. Also often used is the waterproof reinforced concrete, which is at the same time the main structural material due to its strength and resistance to humidity. Limitation of the building's openings is caused by a small contact area with the outside space. This is why these buildings are usually designed with smaller depth, in order to allow natural light in all of the rooms. Or, in other cases, the sunlight is provided through the zenithal openings.

Although the increasing number of people is deciding to live in solar earth sheltered houses, which is especially popular in America where there are many companies particularly dealing with this kind of design, on the other hand, to many people the organization of the home underground seems unimaginable. There are many prejudices about underground living, such as claustrophobic and identification with the living inside the holes. The fact is that the psychological aspect is very important for the quality of housing, but unfounded prejudices should be broken down and should be considered all the advantages and disadvantages that this system of construction offers. Malcolm Wells, one of the leaders of what he calls "gentle architecture", the nature-oriented architecture, or the symbiosis of architecture and environment, i.e. green architecture, emphasizes potential of underground construction as one of the strategies to achieve the goals. Although underground architecture is not the only way to build without disturbing the environment, but is, as he would say, just one of the most promising ways.

4.2. Factors that affect the design of solar earth sheltered houses

The design process of solar earth sheltered houses is primarily affected by conditions of the location: soil type, topography, rainfall, the level of underground water, load capacity and stability of the soil etc. The key factor is the configuration of the terrain. The terrain in slope has the advantages over the flat terrain, and these advantages should be used in design process. The slope allows to the building to be partially or completely buried in terrain, using maximally its benefits. The best situation is when the slope is oriented towards the south, because in that case, the building is buried on the north side and the south side is free and can be used for glass openings and solar energy. At the same time, the north part of the building is protected from the impact of northern winds. According to [4] on the south oriented slope, one of the more favorable solutions is inserting the house in the terrain, as much as it is possible, to the practical loss of the northern and half of the side facades, and the eventual roof coverage with a thick layer of earth. In this case the terrain is usually shaped in cascades.

The type and composition of the soil are also very important. The amount of humidity directly affects the thermal conductivity. The thermal conductivity of water is about 25 times higher than the conductivity of air. In other words, if the soil is wetter, its conductivity is higher. The wet soil conducts heat much faster than it is the case with the light and dry soil. The authors of the book *"Bioclimatic Planning and Design - urban parameters"* write about the researches of Basset and Pritchard. [4] They state that if, for example, it is taken that the conductivity of the dry soil has the conductivity factor 1, then the soil that contains 5% of humidity increases the conductivity factor to 1.75, and a soil with 25% of humidity to 2.75. In this regard, it is necessary to take into account the level of humidity when calculating the heat transfer. Therefore, it is always more preferable that the soil that is used for facility is well drained.

4.3. Comparison of conventional and solar earth sheltered house

The charts in Figure 5 show the comparison between the energy required for heating in a commonly built house (with no underground surface) and in a solar earth sheltered house (with north, east, west facades and rooftop under the ground, while the south facade is free). The graphs are derived from the short study on the model of a house. The studied house model is very simple, prismatic in shape, with a square basis of a total net area of 100 m^2. In the first case, the model was observed as a free standing individual house with flat roof. In the second case, the model was observed as a house that has three facades (north, east and west) and roof covered with earth (soil) and one free standing glazzed south facade. The first case represents the common house, while the second one represents the solar earth sheltered house. The structure of the thermal envelope of the house (model) meets the criteria of the maximum values of the coefficients U, established by the Regulation on Energy Efficiency of the buildings in the Republic of Serbia [5]. The study is based on the calculation of the energy required for heating during the year and in the coldest month - January. Calculations were made in the computer program KnaufTermPRO2, for the climatic area of the city of Nis, the internal temperature of 20°C and outdoor average temperature in the heating period of 5,4°C. The results, as is can be seen from the graphs, confirm the statement that solar earth sheltered houses require less energy for heating and are more energy efficient.

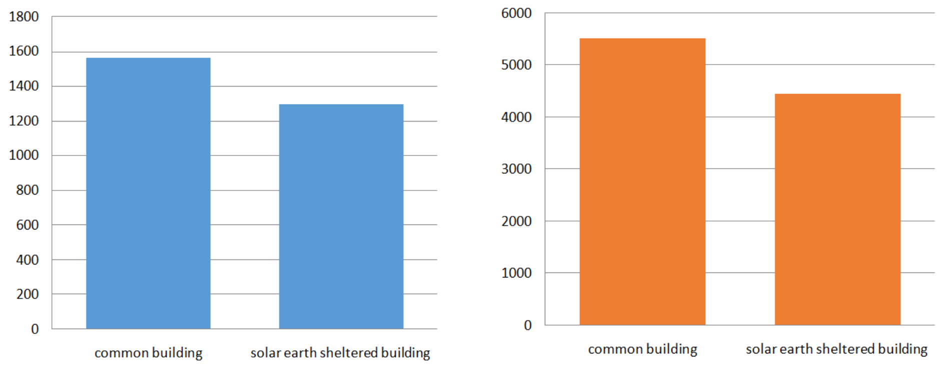

Fig. 5 Charts comparing the total amount of energy required for heating in a commonly built house and in a solar earth sheltered house (left: in January, the coldest month of the year; right: on an annual basis)

5. Conclusions

Advantages of constructing the homes underground are numerous and very significant. Globally observed, the primary reason for the introduction of "geo-architecture" is a space-saving of earth's surface and the increment of green areas. Also, solar earth sheltered houses are great savers of the energy required for heating and cooling of the buildings. The constant temperature of the building, caused by the constant temperature of the soil mostly contribute to these savings. This fact is particularly important and applicable in areas with extreme climates, so the earth sheltered houses are of particular interest in architectural design of buildings in the deserts or in the polar regions.

In terms of total maintenance costs of buildings, earth sheltered houses have a great advantage because they are not affected by any external influences such as snow, rain, wind, thunder, and the like. If there is no influence of the wind, infiltration heat losses are enormously decreased. And also there are no problems with noise and vibrations.

Potential negative characteristics of these facilities can be very easily overcome, so they do not diminish their value. The principle of design that advocates the use of the terrain and the earth sheltering of constructions is directly connected with ecology and is aimed towards the sustainable architecture. Highlighted benefits, i.e. the potentials that offered by the configuration of the terrain and the soil are potential elements that can be incorporated in architectural and urban design. The analyzed examples were used to synthesize the properties of solar earth sheltered houses, as well as the illustration to promote green building and the importance of bioclimatic and environmentally friendly architecture.

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UKOPANE ZGRADE KAO PRIMER ARHITEKTURE KOJA TEŽI ENERGETSKOJ EFIKASNOSTI

Rad proučava koncept podzemne arhitekture stambenih kuća. Zemlja (tlo) je element koji ima jako dobre karakteristike koje je moguće iskoristiti prilikom projektovanja energetski efikasnih objekata. Najbitnije među karakterisikama jesu izolaciona moć tla i njegova termalna inercija, koje rezultiraju konstantnom temperaturom.Ukopavanjem objekta, odnosno kuće, mogu se postići brojne prednosti - zemljište koje se koristi za izgradnju nije uništeno i oduzeto od prirode (sačuvano je zelenilo), smanjuje se potrošnja energije, objekat je zaštićeniji od spoljašnjih uticaja (oluje, vibracija, buke, kiše, snega, mraza...) itd. Ukopane kuće - solarne zemunice - predstavljaju tip pasivne arhitekture koji se može kombinovati sa solarnom arhitekturom. Na taj način, solarne zemunice mogu biti u velikom procentu energetski nezavisne, pa čak i samo-održive strukture. Cilj ovog rada je da istraži prednosti i potencijelne nedostatke ovog tipa građevina, kroz analizu izgrađenih primera, a sve to sa dodatnim ciljem promovisanja integracije prirodnih uslova lokacije i dizajna u stambenoj arhitekturi.

Ključne reči: *solarne zemunica, podzemna arhitektura, uštede u energiji, održiva gradnja*