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Using Thermal Potential Of The Earth To Optimize Energy Consumption In Architectural Structures

Parisa DORAJ[1] , Mine BARAN [2] , Omid HOSSEIN ESKANDANI[3]

[1]Faculty of Architecture and Design, Department of Architecture, Ataturk University, Erzurum, Turkiye
ORCID ID: 0000-0001-5954-0173

[2]Faculty of Architecture and Design, Department of Architecture, Dicle University, Diyarbakır, Turkiye
ORCID ID: 0000-0002-9012-9603

[3]Faculty of Architecture and Design, Department of Architecture, Ataturk University, Erzurum, Turkiye
ORCID ID: 0000-0002-0218-4187

Abstract: Architecture used to have its foundations on a thoughtful interaction with nature surrounding it. Utilizing the earth as an almost infinite source of energy with somehow stable temperature at certain depths is one of the manifestations of this interaction in creating comfort for humans and eluding severe climatic bottlenecks. The earth is the best thermal mass that could act as a reservoir for heat; thus, maximizing surfaces subject to earth's thermal masses, its cooling capacity could be used in its maximum. Needless to say that earth could not be used as the only material to build walls and barriers, however, structures could benefit from thermal reservoir walls like brick, concrete etc. In fact, using earth's topography and its form could be of a huge significance in designing contemporary structures. The concept of "Earth-Shelter Architecture" with its roots in traditional architecture is currently a solution for many of the challenges faced in several countries. However, this concept has not been investigated in developing countries; thus, the present paper intends to accumulate data, promote "earth-shelter architecture" and investigate methods to utilize thermal stability of the earth. In order to do so, after a brief glance at the background of this architecture and its pros and cons, a professional view is taken toward various aspects of thermal stability of the earth and the factors influencing the temperature on the surface and different depths of the earth are scrutinized. Finally, referring to some relevant cases, solutions are proposed to utilize the potentials of thermal stability of the earth to create thermal comfort.

Keywords: Earth-shelter architecture, Thermal stability of earth, Thermal comfort, Earth temperature

Introduction

Nowadays, energy crisis is among the most widespread discussions and numberless studies are being conducted throughout the world. However, studies on wind and solar power are more prevalent and earth as an important element of nature is generally neglected in most of these studies. This negligence is even worse in case of some other problems like environmental destructions induced by modern architecture. Nevertheless, traditional architecture and its use of the earth and its benefits have gained attention from scientific forums of the world and scholars around the world(Doraj et al., 2021).

Considering the role traditional architecture plays in leaving parts of land, preserving thermal stability and its several other benefits, it is worth to go deeper into various methods of utilizing earth along with its pros and cons so that architects consider it while designing their structures. In this regard, first, the background of earth-shelter architecture is reviewed. Then its advantages and disadvantages are scrutinized and later a more professional approach is taken to thermal stability aspects of the earth. Finally, methods and solutions are proposed to better use earth's thermal stability (Sterling et al., 1982).

Life in bigger cities increases pressure on downtown area and increases the need for further developments in dense and high rise constructions. On the other hand, this intensifies the need for open spaces to fill up leisure time and protect the quality of environment. In cities with high population density, earth-shelter architecture could bring open spaces back to city centers. This becomes more significant in case of public buildings with a large area like movie theatres, shopping centers, museums etc. where light is not very important and earth shelter developments have indispensable outcomes. One prominent example of these structures is the UNESCO headquarters in Paris where pit yards and green roofs are the concept behind their structures (Figure 1.).

The concept of underground constructions in building design of some countries have come into existence since 1940. However, the idea was intensified after 1973 energy crisis so that energy consumption was economized and climate is considered further in architectural designs. Instances of modern large scale pit yards could be found in UNESCO Headquarters building in Paris, underground library of the University of Illinois and expanded areas of Louvre Museum in Paris. Several other instances in residential scales could be found in other regions of the world (Al-Mumin, 2001).

Figure 1. UNESCO Headquarters building in Paris (Al-Mumin, 2001).

Material and Methods

Current trends in using the earth as an effective factor in thermal control of a construction go back to 1973 when energy crisis became an international challenge. It should however be noted that many civilizations had underground structures as a natural solution to control thermal conditions of the environment in dry and hot climates.

The most prominent instances of using earth to form social communities are found in northern China, Göreme in central Turkey, Kendovan and Meymend in Iran,Matmata in Tunisia and Colorado in America. All these regions are commonly located in hot and dry climates and have extreme diurnal and seasonal temperature variation.

Traditional architecture on the other hand has excellent samples of underground structures. In fact, these structures are among most popular methods of tackling severe heat and cool in different climatearound the world. A closer look at traditional architecture in the world in different climate especially in hot and dry and hot and subtropical climates demonstrates that previous generations knew about thermal stability of the earth and utilized it in its best and diverse ways(Jefari, 2008).

Pros and Cons of Earth Shelter Architecture

A historical review over earth-shelter architecture and its contemporary instances reveal that it is an efficient alternative to common methods of designing residential complexes in order to reduce energy consumption especially in very hot climates. Due to the relatively cooler temperature of the surrounding soil, compared to the hot weather of hot season, underground structures could dramatically reduce the amount of energy required for cooling due to reduction in thermal transmission through outer walls. According to Sterling and Carmody, even in shallower depths, in a very hot summer day, temperature of the earth seldom reaches that of the outside. Thus, less heat is transferred to inside of the structure (Carmody & Sterling, 2009). In fact, many scholars have concluded that underground structures consume much less energy compared to common structures through lowering heating and cooling loads (Khair-el-Din, 2006). Carpenter, for instance, claims that earth-shelter structures have the highest potential to minimize energy consumption compared to any other design. Not only does temperature difference between outside and inside decrease, but the walls are not directly exposed to sunlight as well (Carpenter,1994).

Thermal efficiency of these structures is remarkably lower for they eliminate direct exposure of their walls and roofs to sun, reduce unpleasant penetration of air and block absorption of heat through roof and walls (Al-Mumin,2001). Presence of soil on the roof of these structures, create further capacity for greener spaces which could be a great advantage for underground structures. Since these structures are built inside the earth, they provide a more comfortable atmosphere for their residents and are less affected by noise pollution compared to over-the-ground counterparts (Emadian & Ayetollahi, 2012). Since most parts of the outer surfaces of the structure, its crust is damaged by natural events like, frost, wind, extreme sunlight, hail etc. less than those built on the surface. Meanwhile their maintenance is easier. Another important fact about these structures is their resistance to natural disasters like gales, thunderbolts, earthquakes, hurricanes etc. Last but not in any way least is the role underground structures play in passive defense mechanisms in case of war or any kind of unrest (Boyer & Grondzik, 1983).

In spite of all these advantages, earth shelter architecture and going deeper into earth has its own disadvantages and limitations. One of the most challenging ones is to overcome social and psychological difficulties (Gideon Golany, 1982). Designers assume that people will not accept living in underground houses even though they strongly believe that elaborating on benefits of these houses will encourage a lot of people to accept them. Lack of windows or their limited number gives a sense of isolation, claustrophobia and an anxiety of difficult access to exits in case of emergencies coupled with other problems intensify these disinterests (Emadian Razavi, 2008). The second barrier to promoting these structures is the limited data we have on “energy behavior” in earth shelter structures. Predicting overall performance of underground structures is difficult mainly due to complicatedness of soil temperature changes over a long period and transmission of heat from walls to the soil (Sterling & Tingerthal, 1981).

Another point worth mentioning is the higher costs of building underground structures compared to typical houses. However, this raises discussion in scientific forums. Some scholars claim that primary costs of building earth shelter houses are higher than common wooden structures with similar size and quality (Sterling et al. 1982). They believe that higher costs come from extra materials needed to strengthen rooftop to tolerate weight of soil. Nevertheless, this could be simply challenged. Several other scholars believe that costs of building a house under the ground is compatible with building a house over the ground(Baggs et al. 1991). On the other hand, some scholars go even further and believe that these structures cost less than their over-the-ground counterparts for extra costs of construction are compensated by lower costs in other areas including designing mechanical systems. Furthermore, lower thermal load on a structure decreases insulation costs of the building. Moreover, the more the contact surface of a building with the soil, the less its façade will cost. In fact, economizing the façade, will simply make up for extra costs induced by strengthening rooftop resistance to soil weight (Carpenter, 1994). Table 1 summarizes the advantages and disadvantages of earth shelter structures(Emadian & Ayetollahi, 2012).

Table 1: Summary of pros and cons of earth shelter structures

Advantage	Disadvantage
Thermal efficiency	Lack of acceptability from people
More privacy	Lack of view to surrounding landscape
Increased open spaces	Insufficient data on thermal behavior
Decreased noise pollution	High digging and earth reinforcement costs
Decreased maintenance costs	Drainage problems
Improved safety against natural disasters	Ventilation problems
A decent passive defense strategy	

Thermal variations at different depths of earth

Thermal efficiency of these structures comes from “thermal stability” of the earth in contrast to considerable fluctuations in environmental temperature. In fact, thermal mass of the earth balances the range of fluctuation of temperature and delays it. In this section, the factors affecting temperature above and under the surface of the earth briefly and then results from investigations on several underground spaces are presented(Watson&Labs, 1983).

Temperature of the surface of the earth has a diurnal and annual temperature variation determined by the level of solar energy absorbed by the surface and environmental temperature. Diurnal temperature is generally determined by region’s vegetation (soil free of vegetation, greenery and trees), soil moisture and Albedo of the surface. Furthermore, thermophysical properties of soil and particularly heat transfer coefficient and penetration ratei.e. the ratio of heat transfer coefficient to specific heat capacity. The higher the penetration rate, the easier the heat transfers from surface to lower levels. This reduces fluctuation in surface temperature. Wet soil has indeed got higher heat transfer coefficient and penetration rate compared to dry soil(Givoni,1994).

Methods of Utilizing Thermal Stability of Earth

Various methods of utilizing thermal stability of earth are somehow dependent on the contact between structure and soil. Wherever the structure and mass of earth i.e. soil are interconnected, are in direct contact or separate from each other, the contact is indirect. In this case, the building is cooled through thermal convertors like pipes or air ducts buried in the soil. In this section, a few examples are presented from various relationships a building has with the soil.

Direct Contact between Structure and Soil

Direct contact between soil and building occurs when the outer walls or the rooftop are in direct contact with the soil. In this case, soil is considered to be the surrounding environment of the building. In this conductive condition, temperature of the inner side of the outer crust approximates the temperature of the earth. Combination of structure with earth is accessible through various methods ranging from a typical cellar, a house with greenery on rooftop and/or a yard dug deep in the earth (Figure 2).

In regions with relatively hot or even hot weather in winter (average minimum temperature of over 10 degrees Celsius), it is recommended that direct thermal contact of the building with soil be formed with minimum thermal resistance(Emadian & Ayetollahi, 2012). In other words, structural elements in direct contact with cold soil should be made of materials with high thermal conductivity like concrete and compact bricks and without any thermal insulation. In fact, adding a water-resistant layer to the surfaces which are in contact with soil suffices. On the other hand, in regions with minimum temperature of 5 degrees Celsius and average diurnal temperature of 10 degrees Celsius in winter, thermal resistance has to be increased in the outer crust so that heating load of the building is minimized (Givoni, 1994).

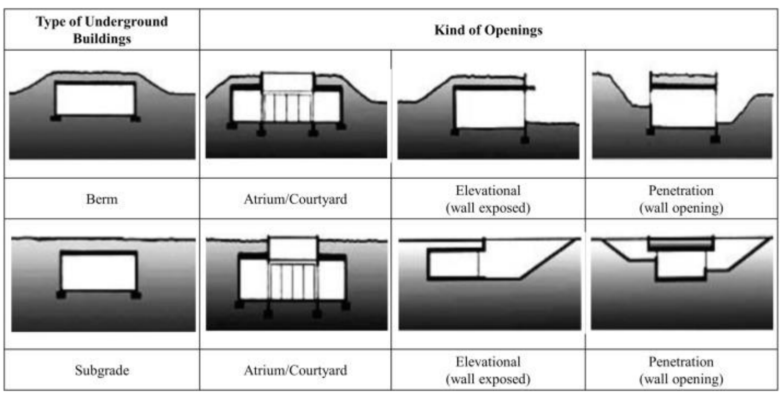

Figure 2. Various methods of combining structure with earth (Mukhtar et al., 2019)

Indirect Contact between Structure and Soil

In regions with severely cold climates, buildings have to be insulated. Due to high rate of heat loss, direct contact between inner spaces and surrounding soil through walls, floor and rooftops with high thermal conductivity is not recommended. In this condition, a pleasant system is the one in which the contact between building and soil is on in the summer and off in the winter (Bina, 2008). Thermal transmission between building and soil is done though active techniques and through obligatory flow of water or air. In this technique, convey of heat to the soil is done using a network of pipes. In another technique, walls in contact with cold soil are built through double-layer walls with a layer of air in between. In this state, the outer layer is built with water-resistant materials (concrete) with high thermal conveyance capacity in direct contact with soil and the inner layer is insulated. There is air between two layers. The outer layer has a temperature close to the earth surrounding it (Doraj et al.,2021). Its temperature will be lower in the summer and higher than average environmental temperature and is on the other hand protected from direct sunlight in the summer. During the summer, the air inside the building is exchanged through a closed system with the air from between two layers and provides a convection cooling for the interior space. In the winter, the inner layer and the air layer act as an insulation against cold air outside through preventing the air flow. This could be applicable in areas with hot summers or rather cold winters (Givoni, 1994).

Figure 3 demonstrates the contact between soil in the Cincinnati House designed by Moore. As it could be seen, a hybrid cooling system is utilized in this house with underground canals (PVC pipes buried underground). During winter, cold winter air is fanned though underground canals and finally is discharged outside the structure. This “discharge” cycle in wintercools the soil mass to levels cooler than soil temperature and prepares it for the summer. In the summer, however, it blocks the pores, pushes room air downward and flows it through canals using the same fan and returns it to the house after it has cooled down.

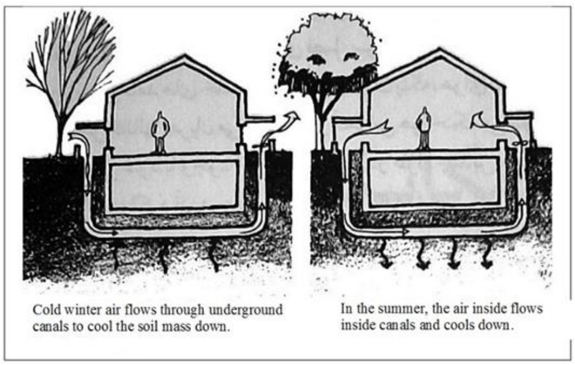

Figure 3. The Cincinnati House cooled with underground canals (Moore, 2003)

Sample Houses Designed Using Thermal Capacity of the Earth

There are several cases of these houses in the world and use an optimum use of earth’s thermal mass and its coolness. Some of them are totally dug into the earth and others are in slopes and rocks with small parts inside earth. From the point of view of material, these houses are made of soil and particularly the Loess and are buried inside it. However, some of these houses are made of stone and are either completely or partially located in rocks. Loess is a silt-sized sediment that is formed by the accumulation of wind-blown dust. Since it is general soft and porous with almost 45% air inside, it could be a feasible option for building shelters and residences (Moore, 2003). From spatial arrangement perspective, these houses sometimes form ornate courtyards; yet, some have no yard and are individual houses with independent entrances.

Sample Houses Designed in Eastern Asia

One of the nicest examples of advanced underground houses could be seen in China and in a Loess Belt. Natives in the region call these Loess Houses Yaodong (Figure 4). These houses have been present for thousands of years and could be an answer to local culture, lifestyle, topography and climate of Loess plains and some 40,000,000 people lived in these underground houses in 2002 (Wang et al., 2014). In provinces of Hainan, Shanxi and Gansu of China, over 10% of people live in underground houses dug into Loess (Moore, 2003).

Summers in these regions are hot but short; yet, the winter is long, dry and cold (Wang et al.,2014). Huge mass of soil in these houses protect them from heat of sunny summers and cold of dark winters; therefore, thermal variation could be controlled. This is in fact one of the efficient techniques of static cooling (use of heat exchange in earth) in these regions of China. In northern China and Korea, these houses are built in groups (Crouch & Johnson, 2001). In other words, each three or four houses are located around a rectangular square or yard,this yard is larger than 100 m^2 and are some 9 meters deep (Figure 4, 5).

Figure 4. Underground dwellings in Loess regions of Northern China (Crouch & Johnson, 2001)

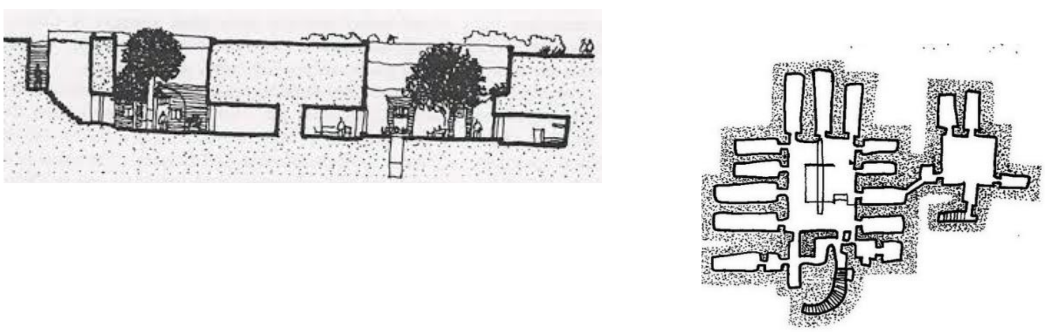

Figure 5. Schematic plan and section of underground dwellings in Loess regions (Crouch & Johnson, 2001)

Another form of underground houses combining house and yard is an underground yarded house (Figure 6). These houses preserve heat in the winter and cold in the summer. The reason for this is the thickness of the soil layer around them. In some cases, this thickness reaches 1.5 to 2 meters. Thus, earth masses absorb heat and give it to the house in the cold. Nevertheless, there are several imperfections as well. These houses general have little natural light and air ventilation. In fact, there is a limited number of doors and windows in the façade (Wang et al., 2014).

Yards in this region, balance winds and reduce absorption of heat in the summer while increasing it in the winter. The yard in fact becomes a microclimate and alleviates negative impacts of the climate (Ayetollahi, 2006). Since these yards and all their elements are located at a lower level, they join the surface through a ramp. Besides, being built in groups brings numerous cooling and heating advantages to them. Common shadows created by these groups of houses acts as a static cooling technique in these shelters.

Figure 6. A traditional cave dwelling in shuangshui village (Wang et al., 2014)

Inside these houses have a great temperature variation compared to the outside. For instance, when the temperature outside is - 6.43 degrees Celsius, it is 12.94 degrees Celsius inside; thus, outside heat penetrates inside the house with a 0.58-hour delay. This temperature variation between inside and outside house has three main reason: Absorption of heat during the day, impact of being surrounded by soil, storing heat in underground houses. Moreover, presence of yard is of a crucial importance in underground houses. The houses with yard preserve the temperature at 16 degrees Celsius during winter days and 11 degrees Celsius during summer days (Wang et al., 2014).

Samples of Underground Houses Designed in Africa

These residences like China, are completely underground at depths of 7 to 10 meters and protect their residents from extreme sun and severe storms (Figure 7). The height of these yards with their pleasant shadows in the summer inspires the cooling they provide (Crouch &Johnson, 2001).

There is a particular type of underground houses like what could be found in Loess regions of China is found in Matmata, Tunisia. The soil in this region is similar to that of Loess region in China. Climate is dry and hot in this region and the buildings are protected against humidity. They have an area of about 100 square foot including the central yard and the rooms around it (Moore, 2003). Yards are deep, either rectangular or circular and are also connected to the surface through ramps (Figure 8). Underground systems have in fact a long history in northern Africa so that Tunisian designers devised this method to counter impacts of dry and hot climate about 2000 years ago (Boukhchim ,2017).

Figure 7. Underground houses in Matmata, Deep central courtyards (Crouch &Johnson, 2001)

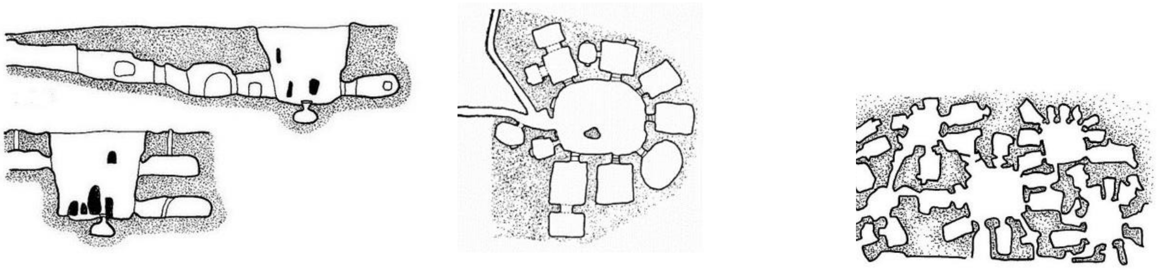

Figure 8. A typical plan and section of Matmata'scave dwelling (Boukhchim et al., 2017)

Samples of Underground Houses Designed in Turkey

In Cappadocia, Turkey, thousands of houses and churches have come out of volcanic tufa cones over the past 2000 years. Many of these sites are still residential for they are great protection against heat and cold (Lechner, 2001). In fact, a short cut through the very few windows seen on the rock faces, a city could be seen with an organized system built into rocks. Houses of several floors are inside the earth and each of them are connected to the upper one through ramps. All houses have common kitchens and used underground water reservoirs through vertical canals (Figure 9,10). Houses in this region are also suitable for both very cold winters and somehow hot summers. Rocks play a key role in creating enough shade to provide a pleasant weather in the summer. On the other hand, awning windows open to outside so that they create shade in the summer and prevent snow and rain from entering the room. Windows were small as well (Carmody &Sterling, 1984).

Figure 9. Multistory houses inside rocks, Cappadocia (Lechner, 2001)

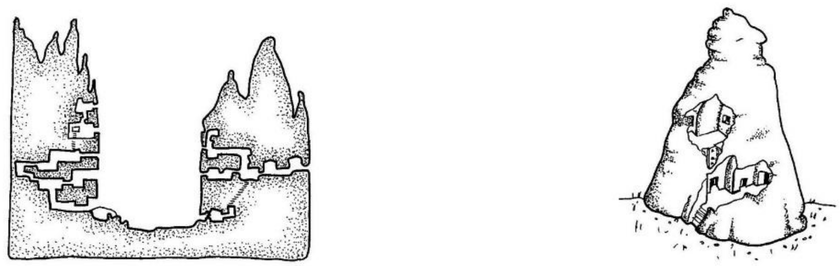

Figure 10. A typical section of Cappadocia'sunderground multistory houses (Lechner, 2001)

Samples of Underground Houses Designed in Iran

Kendovan village on the slopes of Sahand Mountain is very similar to Cappadocia, Turkey. Houses in this village are dug into the rocks. These rocks, also known as slope, are 10 to 15 meters in height and 5 to 8 meters in diameter (Figure 11). The slopes are located between hills and rivers and the main axis of village is over south west. These slopes provide an excellent resistance against sunlight, wind and rain along with humidity, snow and even earthquake (Yılmaz et al., 2020). The rooms dug into slopes are rather small in size with almost 2 meters of height,some houses have two or three stories. Diameter of the houses reach up to 2 or 3 meters in some cases and this is proper for the cold weather of the region (Figure 12). These walls in fact act as huge reservoirs of energy. However, these houses lack proper light and ventilation (Emadian Razavi, 2011). In this region, some houses are multistory houses and are formed around a yard.

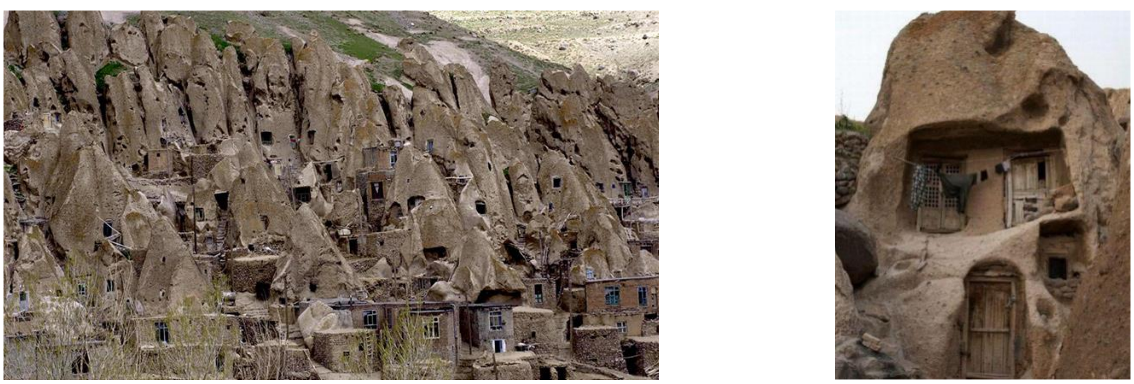

Figure 11. Dwelling inside rocks, Kendovan (Ghobadian, 2012)

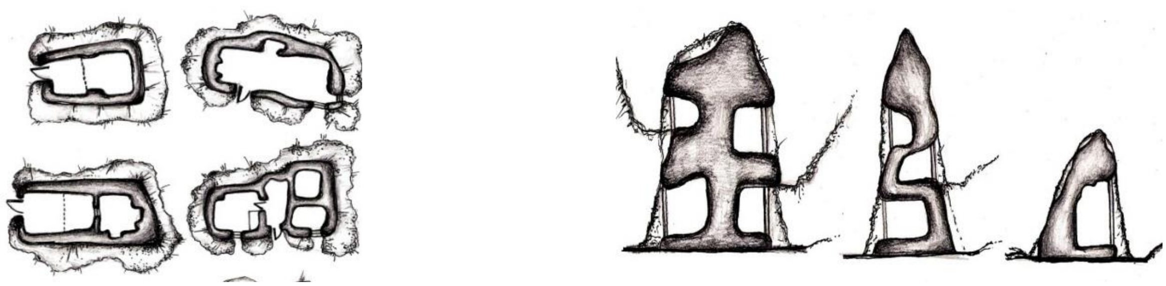

Figure 12. Schematic typical plan and section of cave dwelling in Kendovan (Doraj et al.,2021)

Another example of these houses could be found in Dastkand village of Meymand. However, there is a difference in their location and they are built into slopes (Figure 13). All these houses in the village are dug like huge caves and the only link they had to the outside is their entrance. This entrance was in fact the only source for light and ventilation and provide a channel for entering and leaving them (Jefari, 2008). These houses are properly stable in their provision of thermal comfort for their body is made of one-piece rocks. Diurnal temperature variation in these houses is very little and no rain and wind could go inside them. They are fire-resistant as well. In contrast, air ventilation in these houses is not proper and their natural light is not sufficient (Ghobadian, 2012). Due to the slope around the valley of Meimand, houses are built with four or five stories. The inner height of these houses was 2 meters and was of an area of 16 to 20 square meters. Yet, in spite of the heat, houses are extremely cool.

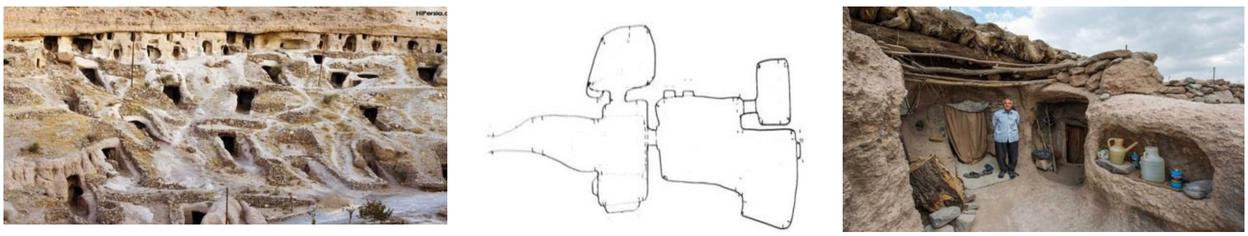

Figure 13. Position of houses in the slope of inner mountain, Meymand (Jefari, 2008)

Samples of Underground Houses Designed in America

Pueblo houses in Long House, Mesa Verde, built into Colorado rocks, use heat absorption capacity of rocks and masonry stone walls perfectly, these houses have southward holes created through a natural process on rock faces (Figure 14). In fact, southward rocks get more shade during summer days. In regions where there is no rock, thick soil walls were built. Inhabitants of drylands of southwestern America built cottages with thick soil walls and roofs so that they could act as thermal insulation (Lechner, 2001).

These houses were built between 1100 and 1500 AD. the form of these houses built of rock and soil of the region is a combination of a few rooms organized in a way that their roofs act as a terrace for the upper house and this gradually continues until it reaches ceilings of deep caves. This arrangement provides maximum sunlight in the winter and its thermal effect benefits the house and the rocks surrounding it (Boyer & Grondzik, 1983).

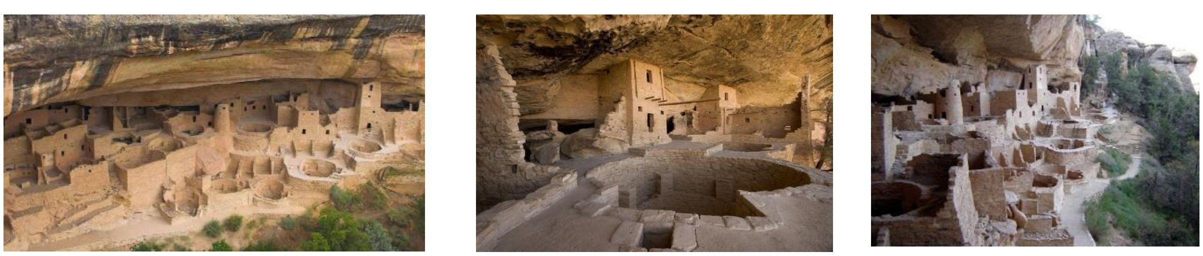

Figure 14. The houses in rocks, Colorado (Doraj et al.,2021)

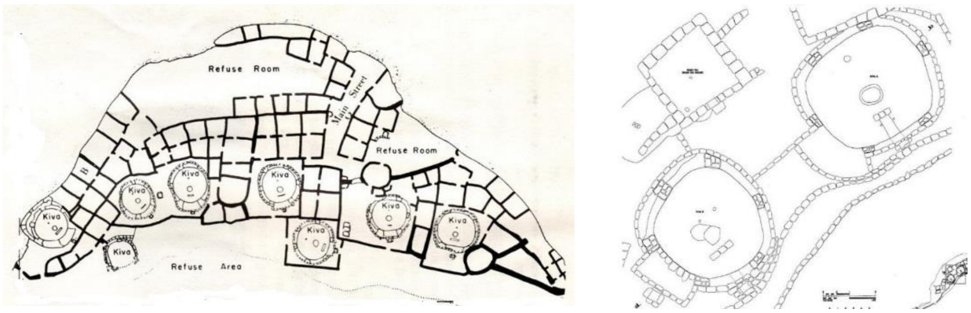

Figure 15. Plan of houses in rocks, Colorado (Boyer & Grondzik, 1983)

Conclusion and Suggestions

Historical study on "earth-shelter architecture" reveals that not only it is not a novel concept, but also it has a long and precious history. Considering remarkable advantages this architecture has in reducing energy consumption and opening spaces up, using thermal stability of earth could be on the agenda for architects, contractors and investors in construction business.

However, a few points have to be taken into account:

Designing earth-shelter structures have to be done with architectural considerations. Any general concept in architectural design in the field of earth-related structures have particular characteristics. In fact, following a systematic protocol in the designing stage could end in pleasant solutions. This protocol requires the following strategies:

- Evaluating users' attitude toward earth-shelter structure is a primary stage in the process of design. Decisions have to be made based on psychological needs of humans. These decisions have to take the desires of residents and requirements of structural usage (residential, official, educational etc.) into account. Requirements individuals have of natural light, natural ventilation and visual interaction with the environment have to be all observed.
- Site analysis to define the interaction between structure and earth helps significantly and has to be conducted according to special needs of these structures. Proper considerations have to be made in decisions made for pedestrian and car access of the building.
- In order to design primary model of the building, climate analysis is obligatory beside site analysis. In fact, climate analysis has to be done during the summer and winter. Designer has to determine the building's need for heating in winter and the rate of sunlight along with the need for cooling in the summer and natural ventilation. Last but not least is to consider overall energy consumption of the designed model or models.
- Technical and structural issues like pressures imposed by earth, moisture insulation and drainage have to be taken into account.
- Costs of construction, energy consumption, maintenance etc. are all equally important as well as post construction costs over time.
- Selection from among various earth-shelter structures have to be done based on climate analysis, site analysis and analysis on anthropological factors as well.
- In order to complete static cooling technique, the surfaces like the windows causing penetration of hot air and increase in the temperature have to be minimized. In other words, radiative thermal exchange through windows has to be reduced. Another benefit of using rocks and earth is the use of

shades present in these sites. Designing structures in these areas has to be done considering the fact that shades are increased and direct sunlight is minimized.

Nowadays, most countries have the potential for using thermal stability of earth as they mostly have proper soil and dry and hot climates. In these regions, a very high percentage of residences are single-household ones with maximum two floors over the ground. Thus, it is recommended that vertical migration be considered as a requirement of modern life and cellars be an alternative for the summer or other times of the year.

Considering the fact that there is a possibility of using thermal stability of earth either directly or indirectly at various depths according to their temperature, any research or design process on earth-shelter structures have to be conducted after calculating and measuring depth of earth in particular climates and the insulation, interaction with the earth and possibility of utilizing thermal stability of earth have to be predicted.

Having discussed the above facts, it could be said that one of the most economic cooling techniques in native architecture around the world is the use of earth in its full (underground) or in parts (slopes). In fact, considering geographical location of a site, optimum use could be realized. Sadly enough, earth-shelter structures of the past are ruining and not enough effort has been put to revive them. It is occurring in spite of the fact that a deeper understanding of these spaces and their capacity to cool the environment could be the motive to take practical steps to revive and reactivate them.

References

Al-Mumin, A. (2001). Suitability of sunken courtyards in the desert climate of Kuwait, Energy and Buildings Journal,33, 103-111.

Ayetollahi,M.H. (2006). Five-Year Evaluation of Solar House Efficiency. Soffeh Journal, (43), 72- 91.

Baggs, S., Baggs J, Baggs W, (1991) Australian Earth-Covered Buildings, Intl Specialized Book Services Press, 184, 56-72.

Bina, M. (2008). Analyzing Shovadons in Dezful's Houses. Fine Arts Journal of University of Tehran, 33 (1), 37- 46.

Boukhchim, N., Ben Fraj, T. Reynard, E. (2017). Lateral and "Vertico-Lateral" Cave Dwellings in Haddej and Guermessa: Characteristic Geocultural Heritage of Southeast Tunisia, springer, 119-131.

Boyer, L. L., Grondzik, W.T. (1983).Habitability and energy performance of earth sheltered dwellings, Third Miami İnternational Conference, Alternative Energy Sources,United States, Hemisphere Press, Miami Beach, United States, 7, 39-64.

Carmody, J., Sterling, R. (2009). Underground Space Design:Part 1: Overview of Subsurface Space Utilization Part 2: Design for People in Underground Facilities. Wiley Publisher, 328, 245-257.

Carpenter, P. (1994). Sod It : An Introduction to Earth Sheltered Development in England and Wales, Coventry University.

Crouch, D. P., Johnson, J. G. (2001). Traditions in Architecture: Africa, America, Asia, and Oceania, Oxford university press, 433.

Doraj, P., Aluclu, I., Hossein Eskandani, O.(2021). The Impact of Architectural Structures from Past to Present on Developing Tourism (Example of the City of Paris), International Journal of Scientific and Technological Research (JSTR), 7 (9), 8-19.

Emadian Razavi, S.Z. (2011). Thermal Stability of Earth and Thermal Behavior of Building. Thesis for Phd in Architecture. Faculty of Architecture and Urbanization. Shahid Beheshti University, Tahran.

Emadian, S. Z., Ayetollahi, M. H., 2012, Utilizing the thermal stability of the earth in creating thermal comfort, Soffe Journal, 64,33-42.

Ghobadian, V. (2012). Clamatic Investigation of Traditional Buildings in Iran. University of Tehran press. 265, 98-112.

Gideon Golany, S. (1982). Earth Sheltered Habitat, History, Architecture and Urban Design,Van Nostrand Reinhold, 240.

Givoni, B. (1994). Passive Low Energy Cooling of Buildings, Wiley Press, 272, 166-187.

Hossein Eskandani, O., Doraj, P. (2021). Redevelopment of Brownfields, an Approach toward Sustainable Local Development, Turkish Journal of Computer and Mathematics Education (TURCOMAT), Research Article, 12 (13), 4808-4815.

Jefari, S.(2008). Sheltered by Earth. Thesis for Master's in Architecture, Faculty of Architecture and Urbanization, Shahid Behshti University, Tahran.

Khair-el-Din, A.M. (2006). Earth sheltered housing: An approach to energy conservation in hot arid areas, Ekistics Journal, 4 (25), 73.

Lechner, N. (2001). heating cooling lighting design methods for architects, Wiley Press, 696, 437-461.

Moore, F. (2003).Environmental Control Systems: Heating, Cooling, Lighting, McGraw-Hill, Inc. New York Press, 544, 133-154.

Mukhtar, A., Yusoff, M. Z. (2019). The potential influence of building optimization and passive design strategies on natural ventilation systems in underground buildings: The state of the art, Tunnelling and Underground Space Technology, 92.

Sterling, R., Tingerthal, M. (1981). Building Costs and Construction Problems in the Minnesota Earth-Sheltered Housing Demonstration Program, Underground Space, 6 (1), 13–20.

Wang,Z., Li, A., Ren, J., He, Y.(2014).Thermal adaptation and thermal environment in university classrooms and offices in Harbin, Energy and Buildings Journal,77, 192-196.

Watson, D., Labs, K. (1983).Climatic Design: Energy-Efficient Building Principles and Practices, McGraw-Hill Press, 280, 189-204.

Yılmaz, S., Doraj, P., Hossein Eskandani, O., 2020. Concepts in Sustainable Architecture and Critical Approaches On The Ecological Effect, The Journal of International Social Research, Vol. 13, Issue 69, pp. 695-703.