Investigating effect of using earth-sheltered architecture on energy conservation in cold and mountainous climate; case study: Yakhchal-e Qaem Maqam, Basement of Sharbat Oqli House, and Cistern of Parvin Etesami House

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The limitation of energy resources is becoming a serious crisis in the world. Considering the energy and environmental crises caused by the excessive consumption of energy in the world, it is necessary to revise design methods and use sustainable and valuable models in the design of buildings in order to provide thermal comfort. Architecture in the shadow of the earth is a valuable and sustainable model which has high energy conservation capability acts along the protection of the environment via energy conservation and adapts with the needs of the era. The present research is aimed to explain the concepts of earth-sheltered architecture and determine the effect of design and use of underground spaces in environmental sustainable design, architectural harmony with the climate, and energy conservation. In this research, using descriptive-analytical research method based on library and documentary studies as well as field survey, the earth-sheltered architectural concepts are explored and successful samples of the world and valuable models in Iranian traditional architecture are introduced. In the case study, the physical features of a few samples of underground spaces in Tabriz as well as heat waste or absorption from walls are examined at different depths. The results of the study indicate that heat waste or absorption rate via walls depends on the underground physical properties, contact of walls with the outside air, and burial level of buildings. Benefiting from the potential of underground spaces and use of ground depth in architectural design has led to developing relatively stable conditions against adverse conditions of climate and environmental balance. Utilizing the values of experiences could provide a solution for solving a part of the current energy crisis and creation of responsive environments in terms of climate and application.

keywords: *Earth-sheltered architecture, Sustainable, Energy conservation, Climatic comfort, Energy consumption.*

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1. INTRODUCTION

Construction of a place with climatic comfort and creation of thermal comfort in buildings are specifically important. The issue of thermal comfort is one of the significant subjects due to its role in the optimization of the environment. In human settlements, paying attention to the climate with heating and cooling mechanisms could increase sense of relaxation and promote quality of life as well as sustainability.

In today's architecture, buildings are built and designed regardless of the climate. In fact, construction for the purpose of construction, not for living, has left no opportunity for paying attention to important and deep issues such as thermal comfort, architectural body, and building substrate [1]. According to the current issues, energy crisis, considerable consumption of fossil fuels, and end of fossil energies, humans require a fundamental change in the manner of energy consumption in order to survive [2]. If no change is made in the human behaviors and no solution is sought in this regard, hazardous environmental consequences are expected. Therefore, following appropriate energy strategies for saving in different energy consumption parts is one of the necessities of today's world [3]. This issue is very important due to high growth rate of energy consumption in Iran.

Paying attention to local and traditional houses in different parts of the world and Iran shows that valuable experiences and solutions inherited from the past, local and indigenous capabilities of each region, and natural energy resources can be used to convert external incompatible conditions into comfortable spaces with minimum energy consumption. One of these experiences is the use of ground depth and underground spaces in Iran and the world. The ground as the first location for shelter construction plays a special role in the formation of architecture. The idea of architectural in the shadow of the earth is specifically considered a sustainable model for energy conservation via the creation of energy crisis. Underground spaces with great potentials have significant impacts on the creation of responsive environments in terms of function and climate, but due to the improper mentality related to earth-sheltered architecture, which indicates the basement space, there are some obstacles against the application of this idea and, despite its climatic advantages and its prevalence in the past Iranian architecture, its usage is limited in Iran. A review on the history of using underground spaces in the past and contemporary periods shows that these spaces had various residential, administrative, educational, religious and other applications, but today most of the underground spaces are used with a different approach in terms of communication, transportation within the city, storage (such as constructing oil and gas reservoirs in the underground), urban infrastructure facilities, mineralization, etc [4].

Some studies have been performed on the issue of earth-sheltered architecture. In a number of books and articles on underground spaces, some texts have been written. In this regard, previous studies are the books and articles written about the historical background of underground spaces and their classifications. The next category includes the documents that examine different dimensions of these spaces and their role in the climatic design and construction of buildings in harmony with climate as well as the position of earth-sheltered architecture in the sustainable urban development. The most important studies include the examination on how to use climatic conditions in design, use of radiant cooling, radiant evaporation, and classification of various underground spaces in terms of contact with the ground [5], typology of underground spaces [6], operation manual of underground space as well as people-oriented planning and design in underground spaces [7] According to the historical background of underground spaces in local architecture, examination and presentation of solutions for today's architecture could be favorable.

In the present study, a response can be found for these questions: What are the most important effective factors for heat loss reduction in winter and heat absorption in underground buildings? What is the dominant factor for the reduction of U-value and increase of R-value in buried walls? How much is the heat loss in winter and heat absorption in summer in the studied buildings? Which of the studied buildings is closer to the comfort zone in terms of temperature?

Hence, this research will introduce earth-sheltered architecture with the aim of determining the effect of design and use of underground spaces on the environmentally sustainable design and energy conservation. In addition to the brief overview on the valuable models of underground buildings in traditional architecture in Iran and the world, the environmental values of earth-sheltered architecture in achieving the objectives of sustainable development are considered while assuming the effect of local architecture review and use of architecture in the shadow of the earth for the environmentally sustainable design, energy conservation, and energy consumption reduction in order to emphasize the use of underground spaces in future developments.

2. RESEARCH METHOD

In this manuscript, "descriptive-analytical" and "library literature review" research method is used and data are collected in the context of field studies. In general, data collection methods are direct and indirect: First, written resources, data banks, and the available maps, works, and documents related to the underground spaces which are available in East Azerbaijan Province Cultural Heritage Organization are used as reliable resources for examining these spaces. Then, field observations are done to prepare photos and physical data. By examining and collecting physical data of a few samples of underground building in city of Tabriz and the comparison of their physical properties, particularly determining U-value and R-value of buried and non-buried walls using SBCE web-based software, heat loss and absorption of these spaces are classified to consider the utilization of ground depth and energy in the contemporary design for achieving sustainable architecture, because earth-sheltered architecture can act as a model for using new energies, sustainable design, and creation of responsive environments in terms of climate.

3. CONCEPT OF UNDERGROUND SPACES AND DIFFERENT SPECIES OF EARTH-SHELTERED ARCHITECTURE

"Underground spaces" are the spaces that have been used from distant past to the present era by placing all or a prat of spaces in the underground for different climatic, security, economic, protective, or other purposes. Thus far, there have been different species of construction in the underground and various contact with the ground form in this type of architecture. In different climates, various techniques are observed in terms of using the ground and contact with ground in different forms. There are different species of these spaces in the world, which have made the best use of heat mass of the earth and its resulting cooling. "Underground spaces" have different classifications in different resources, some of which are presented below (Tables 1 and 2 and Fig. 1).

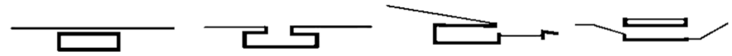
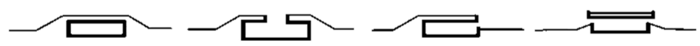
Sterling and Carmody (1993) classified underground spaces based on 5 principles (Fig. 1).

Golani (1996), classified underground spaces and earth-sheltered Architecture into five categories (Table 2).

4. VALUABLE MODELS OF UNDERGROUND SPACES IN TRADITIONAL IRANIAN ARCHITECTURE

Use of underground spaces is considered one of the conventional methods in some climatic areas of Iran. There are several species of underground spaces for using the available static heating and cooling in Iran, which aim to provide sustainable and favorable environment and conditions in adverse weather conditions. Iranian architects have great innovations in order to make coordination with the nature and climate of each region and cisterns, underground Yakhchal, Kariz (Qanat), Cellar(Sardab), shovadans, and underground bathrooms are among the prominent samples of underground climatic favorable spaces in traditional Iranian architecture (Fig. 2 and Tables 3 and 4).

Table 1. Classification of different types of underground spaces in terms of contact with the ground [5].

Various underground spaces	Drawings
Integrated in the ground	
Built in the ground form	
Contact with the ground	

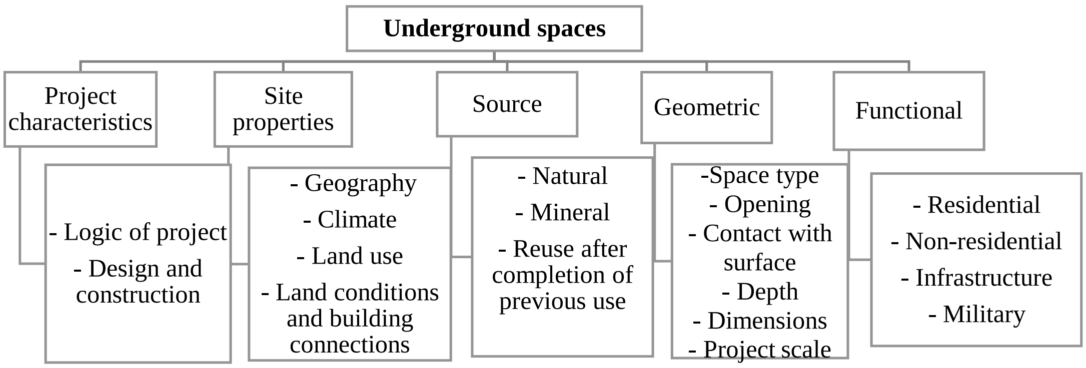


Fig. 1. Classification of underground spaces from Sterling's viewpoint [7].

Fig. 2. Location of some underground spaces on the map of Iran.

5. ADVANTAGES AND DISADVANTAGES OF USING UNDERGROUND SPACES

Underground spaces have many advantages. Although the operation of underground has some problems, its advantages area considerable (Table 5):

At one point, the ground acts as a source of coldness and, at another point, it is the source of heat, yet it is seen as a disturbing factor in another place. It is different in each climate (Fig. 3).

6. EARTH-SHELTERED ARCHITECTURE AND ENERGY CONSERVATION

In most areas of the world, stone and soil temperature at lower depths shows a neutral and constant thermal environment compared to the maximum difference in the surface temperature and the constant and neutral temperature of the underground – with low temperature fluctuations - provides an appropriate condition for energy conservation and storage.

Heat mass of the ground moderates and delays the annual cycle of temperature fluctuations and, below the depth of 45-61 cm, many temperature changes cannot be felt [5]. The ground temperature at the depth of 1.82 m, which is usually considered constant, is not in fact constant, but it is generally changed with the difference of 5.5 to 6°C with the average temperature of the ground [5]. The image of the annual changes in ground temperature for the conventional soil in terms of depth and range of variations in the surface temperature is shown in Fig. 4.

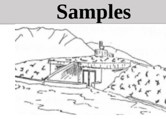
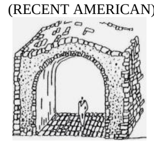
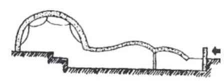
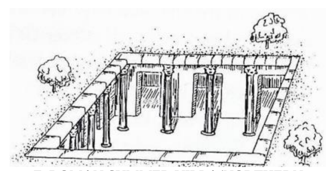
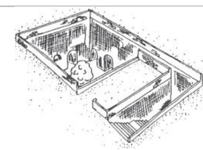
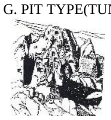
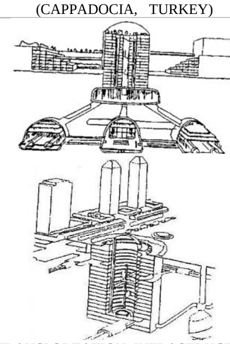
According to Fig. 3, the annual fluctuation in ground temperature is decreased with the increased depth. Most of the temperature fluctuations are eliminated at the depth of 6.1 m. "From the depth of 6.1 m on, the ground temperature is almost constant and equal to the average annual temperature in the external space" [8]. At such depths, the thermal resistance and capacity of the ground layer reaches infinity; as a result, the temperature of the outer space is not transferred through conduction into these spaces. In winter, with decreased flow of the outside air, reduced air infiltration, and decreased heat conduction flow, the heat loss is prevented. These spaces help temperature balance and climatic comfort via decreasing the flow of heat conduction, air infiltration, solar heat absorption, and use of ground cooling [5].

7. RESULTS

In the research on the underground buildings of Yakhchal-e Qaem Maqam, Basement of Sharbat Oqli House, and Cistern of Parvin Etesami House in Tabriz (Fig. 5), considerable results are achieved on the reduction of energy consumption and decreased heat loss of buildings according to the physical properties and temperature difference between the outside and inside air.

Yakhchal-e Qaem Maqam: Yakhchal-e Qaem Maqam has

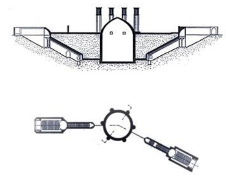
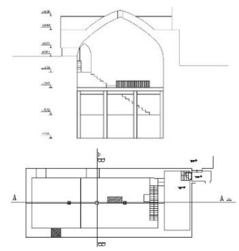
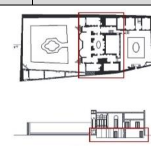
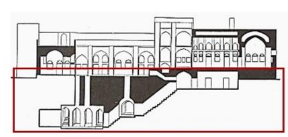
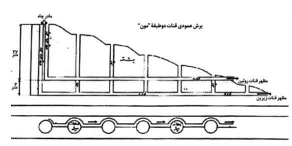
Table 2. Typology of underground spaces and earth-sheltered Architecture [6].

Types and features	Samples
Earth-sheltered Habitat This type of space is conventionally used to describe a type of housing in the USA, which is located on the ground and protected by a layer with the thickness of 0.5 m. This method is a response to high energy consumption for heating and cooling, particularly in incompatible climates.	 A.EARTH-ENVELOPED HABITAT (RECENT AMERICAN)  B. INDIGENOUS JERUSALEM HOUSE
Semi Below Ground A semi-belowground dwelling is a unit constructed partly below and partly above ground. This is one of the most common human-made housing forms and was used in Neolithic village communities in China, Japan, and other places of the ancient world (Fig. C). It is still in use in rural communities in Africa. The basement form, which also falls within this category, is commonly used throughout the world. A similar functional form in northern China and in southern Tunisia is the terraced cliff, where part of the house is built below ground and part is built above (Fig. D) Another example is the Eskimo winter igloo and summer semi-belowground house (Fig E)	 C. NEOLITHIC(CHINA AND JAPAN) D.TERRACED(MEDITERRAN)  E. IGLOO, ESKIMO
Subsurface House A subsurface house is a shallow belowground level dwelling with a short distance between its celling and the soil surface, usually about one-half meter or less. This subsurface type of house was used in ancient times by the romans in the city of Bulla Regia in northern Tunisia (Fig. F). The Romans built a large number of peristyle subsurface summer villas to escape the intense heat of north Africa. This design form was before the Romans arrived. In some modern houses, basement units are built subsurface style.	 F. ROMAN SUMMER VILLA(NORTHERN TUNISIA)
Below Ground (SUBTERRANEAN) Belowground or subterranean space has been the most common form of earth – integrated space developed below ground at a reasonable depth- usually about three meters from the ceiling to the soil surface. Because of the soil thickness, the belowground space is usually created by the «cut- and – use» method is used on flat topography for a pit-type design (Fig. G), as well as for a terraced form on cliffs (Fig H). It is typically developed in limestone or in tufa because cutting is relatively easy, as in Cappadocia(Fig. I), or in loess-type soil, which is firm and holds its shape when dry, as was the case in cave dwellings of northern China.	 G. PIT TYPE(TUNISIAN AND CHINES STYLE)   H. CLIFF TYPE (CHINA) I.NEST TYPE (CAPPADOCIA, TURKEY)
Geo-Space(JAPANESE CONCEPT) The term geo – space is currently used by the Japanese designers have introduced some innovative and pioneering concepts of geo-space forms for multipurpose human activities at depths of 50 meters or more (Fig. J). The renewed interest in the use of earth – enveloped space of this type originated primarily among the technologically advanced counties of the world. Another example of deep geo – space usage is the Ran fast project on Norway's southwestern coast. The project comprises two undersea fjord crossings, and provides mainland connection for all of the major islands in Rennesoy County. The longest tunnels among this network are the Byfjord Tunnel (5860 m) and the Mastrafjord Tunnel (4405 m).	 J. TRANSPORTATION, INFRASTRUCTURE, SHOPPING, AND HOUSING

been designed and built with a rectangular plan and the approximate dimensions of 32*13 m and buried depth of 9 m. Currently, the materials used in the wall, ceiling, and floor are rubble stone, brick, and ceramic brick, respectively (Table 6).

Calculating U-VALUE of the buried wall and floor in Yakhchal-e Qaem Maqam In order to calculate U-VALU of the buried floor and walls in the soil, the web-based simulation software of Swedish Building Code Energy Calculation (SBCE) [10] is used. According to the physical data obtained from Yakhchal-e Qaem Maqam and

Table 3. Sample of using underground spaces in traditional Iranian architecture [8].

Space name	Cistern	Main components: Water storage source, source cover, aspirator or windward, staircase and pashir, entrance	Sample	Six-windward cistern in Yazd
A cistern is an indoor pool or pond which is usually built for water storage underground; Water is usually stored in winter and used in summer; Source or reservoir is the main part of cistern in cubic, rectangular, octagon, and cylindrical forms; All or the major part of the source is dug under the ground; The ceiling cover is in domed, conical, and flat forms. Materials used in the construction of cisterns include stone, brick, lime, and mortar.				
Space name	**Underground refrigerator**	**Main components: Reservoir, shadowing wall, crete or ice hole**	**Sample**	**lale Beig Yakhchal**
A yakhchal has been a hole for ice conservation. Ice has been prepared during the cold months of the year and has been stored and used during warm seasons up to the beginning of the next winter. This type of yakhchals has been made in the north-central and north-western areas of Iran. A major part of the body of these yakhchals has been inside the ground. Yakhchals often have a vault brick ceiling, groin, and ceiling Materials used in the construction of its thick walls have been rubble stone, water mortars and bricks such as lime, sand, mortar, and saruj.				
Space name	**Cellar and pool house**		**Sample**	**Company house**
A cellar is a basement that is usually located under the summer room and has a pool. In warm and dry areas, the length of wind-wards reaches the cellar and wind blowing above the pool water generates a fine weather. In cities such as Tabriz which lack summer rooms, pool houses are located under the main space of winter rooms.				
Space name	**Shovadan**	**Main components: Courtyard (main hall), kat (more private spaces in Shoadan), derizeh (a window to provide light and vertical ventilation), stairs**	**Sample**	**Moein-o-Tojjar House in Shoushtar**
It is also called Shabadan, Shababik, Kheshian, or Badkash and exists in the southwest of Iran. It is a basement with the immense depth of about 9-11 m under the ground. Shovadan's temperature is constant between 22 and 25°C. Shovadan usually lacks construction materials and, only in some cases, its walls are covered with plaster. Its ceiling is dome-shaped. There is a hole on top of the ceiling that usually leads to the courtyard. Its lighting is provided by small windows in its ceiling (which are usually located on the floor of the courtyard).				
Space name	**Kariz (Qanat)**	**Main components: Opening, horizontal hole, vertical holes (well)**	**Sample**	**Two-story Qanat of Mun in Ardestan**
A qanat is a type of underground drainage and the water collected by this drainage is brought to the ground surface. Qanats collect water with the gravity, without using tension force and electrical or heat energy, by the natural flow Qanats are divided based on placement site, construction location, discharge, structure, and application. Raw materials used in qanats include kools, tanbushe, lime, and sealing materials.				

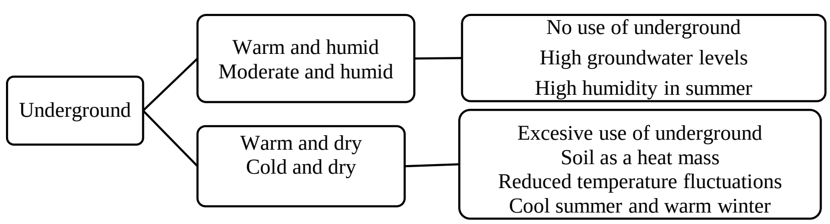
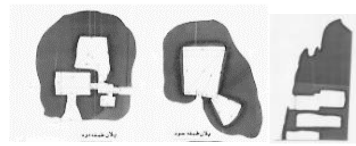
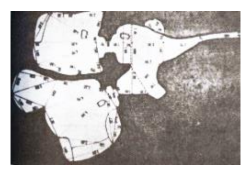


Fig. 3. Advantages and disadvantages of using underground spaces in different climates.

using SBCE web-based software, the U-VALUE values of the floor and buried walls are 0.13 $W/(m^2.K)$ and 0.22 $W/(m^2.K)$, respectively (Fig. 6, Tables 7 and 8).

Based on the studies and calculations in Yakhchal-e Qaem Maqam, heat exchange in winter through the walls with contact to open air is 12373 w, through the buried wall adjacent to soil

Table 4. Sample of using underground spaces in Iranian villages [8].

Element	**Cave**	**Sample**	**Kandovan Village**
Physical properties and features			
It is located in Eastern Azerbaijan Province on the slope of Mount Sahand. Buildings are completely formed inside the rocks and the rocks themselves act as the heat mass. The houses are usually made of different stones.The height of these stones, called Karaan[1], is 10-15 m and their diameter is 5-8 m. Sometimes, a house has two or three stories. Rooms are relatively small with 2 m height inside Karaans. The diameter of walls is 2-3 m, which is very appropriate for the cold weather of this area and a large energy storage resource, but lack of light and ventilation is a challenge.		 	
Hilehvar Village is located in Eastern Azerbaijan Province, in city of Osku, central part. Houses are dug inside the ground and, due to the coverage by rocks, cannot be observed from afar, even from not too close distance. The architecture of this village is unique and its houses are dug inside the ground as rock Karaans and slums using the tools of that era and excellent architectural style. Some of these houses are two-story. The extent of some rooms is more than 50 m^2, the slums are connected through corridors, and the inhabitants communicate with each other under the ground. The height of the rooms is 150-170 cm.		**Sample**	**Hilehvar Village**
		 	
It is one of the unique models of Iranian local architects in the south of Kerman Province. Houses are completely under the ground and on the slope. The entrance door is the only connection between the inside and outside of the building. This door is the place of entrance and exit and also provides light and ventilation. Ventilation of the houses is not appropriate and their natural lighting is not enough. These buildings are very sustainable in terms of heat comfort and their body is monolithic rock. They are very cold despite the high temperature of the region.		**Sample**	**Dastkand Village in Meymand**
			

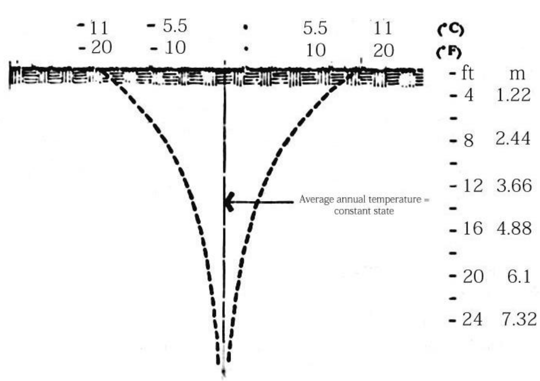


Fig. 4. Reduction of annual temperature fluctuation with increased depth [5].

Fig. 5. Location of the study cases on the map of Tabriz (Author).

is 1548 w, through the floor is 474 w, and through the ceiling is 9549 w; in total, it is equal to 19890 w, which is equivalent to 7.91 $\frac{W}{m^2}$. In contrast, the heat exchange rate in summer through the walls with contact to open air is equal to 11135 w, through the buried wall adjacent to soil is 1184 w, through the floor is 362 2, and through the ceiling is equal to 8594 w; in total, it is equal

Table 5. Advantages and disadvantages of underground spaces.

Advantages	Disadvantages
Environmental and climatic balance and decreased influence from external factors and unfavorable climatic conditions (minimum permeability, reduction control, air leakage and infiltration control, reduction of temperature fluctuation) Excellent compromise with the environment and less pressure and damage to the region’s ecosystem compared whit the building above the ground Geothermal energy source, **energy conservation**, saving in the heating and cooling energy consumption due to the approximately constant temperature and energy economy Heat comfort, increased comfort and mental vitality, and decreased anxiety Reduced noise, visual, and air pollution, and minimization of visual and auditory chaos Soil conservation and erosion control Resistance against fire Resistance against earthquake	Not enough natural lighting Lack of appropriate ventilation Moisture and dirt, efflorescence of walls Sense of darkness, fear of closed spaces, getting lost

Table 6. Physical properties of Yakhchal-e Qaem Maqam.

Properties		
Burial rate	%80	
Temperature (Winter)	Inside*	Outside
	+8 ° C	-6 ° C
	281.15 °k	267.15 °k
Temperature (Summer)	+25 °C	+37.6 °C
	298.15°k	310.75 °k
Length (m)	33	
Width (m)	13	
Area (m^2)	429	
Perimeter	92	
Buried depth (m)	9	
Wall materials	Rubble stone	
Ceiling materials	Brick	
Floor materials[2]	Ceramic brick + uncrushed gravel + elongated gravel + uncrushed gravel	
Walls thickness	Northern	1.4
	Southern	0.8
	Eastern	1.8
	Western	2.4
Average thickness [3]	1.34 m	
Ceiling average thickness [4]	0.68 m	
Walls materials R -value $\frac{(m^2.K)}{W}$	$R=\frac{d}{\lambda}$ $R=\frac{1.34}{1.7}=0.79$	
Floor materials R -value $\frac{(m^2.K)}{W}$	$R=\frac{0.1}{0.25}+\frac{0.1}{0.77}+\frac{0.04}{0.25}+\frac{0.04}{0.4}=0.79$	
Ceiling materials R -value $\frac{(m^2.K)}{W}$	$R=\frac{0.68}{1.08}=0.63$	
Ground type	Clay and mud	
Soil temperature at depth of 9 m according to the diagram (Fig 4)	Summer	TX $TX^5+1=18.5^\circ C$ $273.15+18.5=291.65^\circ K$
	Winter	$TX-1=16.5^\circ C$ $273.15+16.5=289.65^\circ K$

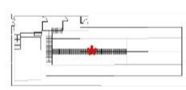
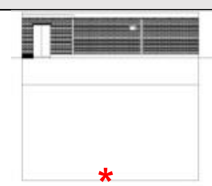
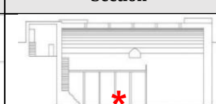
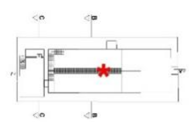
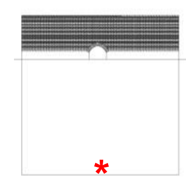
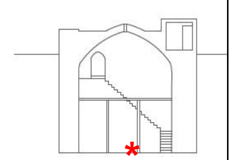
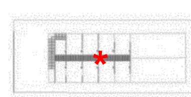
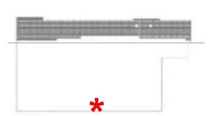
Drawings[9]		
Plan	Elevation	Section
 Ground floor	 Southern Elevation	 Section A-A
 Half floor basement	 Northern Elevation	 Section B-B
 Basement	 Western Elevation	 Section C-C

Table 7. Properties and wall area, R-VALUE, U-VALUE, and temperature difference in Yakhchal - e Qaem Maqam(Author).

Element name	Position	Wall properties	Wall area m^2	R-VALUE $R=\frac{d}{\lambda}$ $\frac{(m^2.K)}{W}$	U-VALUE $U=\frac{1}{R}$ $\frac{W}{(m^2.K)}$	ΔT Winter	ΔT Summer
Ceiling	-	Brick	$33 \otimes 13 = 429$	$R=\frac{0.68}{1.08}=0.63$	$\frac{1}{0.63}=1.59$	$281.15=-14-267.15$	$310.75-298.15=+12.6$
Floor	-	Ceramic brick, uncrushed gravel, elongated gravel, uncrushed gravel	$33 \otimes 13 = 429$	-	0.13	$281.15=+8.15-289.65$	$291.65-298.15=-6.5$
External wall	Northern	Rubble stone	$13 \otimes 9 = 117$	$\frac{1.4}{1.7}=0.82$	$\frac{1}{0.82}=1.22$	$281.15=-14-267.15$	$310.75-298.15=+12.6$
	Southern	Rubble stone	$13 \otimes 9 = 117$	$\frac{0.8}{1.7}=0.47$	$\frac{1}{0.83}=2.12$	$281.15=-14-267.15$	$310.75-298.15=+12.6$
	Eastern	Rubble stone	$33 \otimes 9 = 297$	$\frac{1.8}{1.7}=1.05$	$\frac{1}{1.875}=0.95$	$281.15=-14-267.15$	$310.75-298.15=+12.6$
	Western	Rubble stone	$33 \otimes 9 = 297$	$\frac{2.4}{1.7}=1.41$	$\frac{1}{1.41}=0.71$	$281.15=-14-267.15$	$310.75-298.15=+12.6$
Buried wall	-	Rubble stone	$2 \otimes (13 \otimes 9)+$ $2 \otimes (33 \otimes 9) = 828$	-	0.22	$281.15=+8.15-289.65$	$291.65-298.15=-6.5$

Table 8. Heat power transmitted from the walls in Yakhchal-e Qaem Maqam (Author)

Formula	Calculation (Summer)	Calculation (Winter)
$QC = UA\Delta T$	$Q1=[1.22\otimes(13\otimes 9)+2.12\otimes(13\otimes 9)+0.95\otimes(33\otimes 9)$ $+0.71\otimes(33\otimes 9)]\otimes 12.6=883.8\otimes 12.6=11135.88$ $Q2=0.22\otimes(828)\otimes(-6.5)=-1184.04$ $Q3=0.13\otimes(33\otimes 13)\otimes(-6.5)=-362.505$ $Q4=1.59\otimes(33\otimes 13)\otimes 12.6=8594.58$ $Qtotal=Q1+Q2+Q3+Q4=$ $QC=18183.46w$	$Q1=[1.22\otimes(13\otimes 9)+2.12\otimes(13\otimes 9)+0.95\otimes(33\otimes 9)$ $+0.71\otimes(33\otimes 9)]\otimes(-14)=883.8\otimes(-14)=-12373.2$ $Q2=0.22\otimes(828)\otimes(+8.5)=+1548.36$ $Q3=0.13\otimes(33\otimes 13)\otimes(+8.5)=+474.04$ $Q4=1.59\otimes(33\otimes 13)\otimes(-14)=-9549.54$ $Qtotal=Q1+Q2+Q3+Q4$ $QC=-19890.70w$
$\frac{\sum UA\Delta T}{\sum A}$	$\frac{18183.46}{2514}=7.23W/M^2$	$\frac{-19890.70}{2514}=-7.91W/M^2$
QC: Absorption or heat loss rate via walls (Q1: Upper wall with contact to open air, Q2: Lower wall without contact to open air, Q3: Floor, Q4: Ceiling)		

to 18183 w, which is equivalent to 7.23 $\frac{W}{m^2}$ Slight difference is observed in the comparison of heat loss or heat absorption in summer and winter.

Basement of Sharbat Oqli House: Basement of Sharbat Oqli House has been designed and built with a rectangular plan and the approximate dimensions of 26*12 m as well as buried depth of 2.6 m. Currently, the materials used in the wall and ceiling is brick and the floor is made of ceramic brick (Table 9).

textbf Calculating U-VALUE of buried wall and floor in the basement of Sharbat Oqli House: According to the physical data obtained from the basement of Sharbat Oqli House and using the web-based software (SBCE) [10], the U-VALUE of the floor is 0.25 W$/(m^2.K)$ and that of buried walls is equal to 0.52 W$/(m^2.K)$ (Fig. 7, Tables 10 and 11).

According to the studies and calculations on the basement of Sharbat Oqli House, the heat exchange rate in winter due to the lack of contact of the walls with open air is 0 w, through the buried wall adjacent to soil is 236 w, through the floor is 179 w, and through the ceiling is 4088 w; in total, it is equal to 3672 w which is equivalent 4.47 W$/(m^2)$. In contrast, the heat exchange rate in summer due to the lack of contact of the walls with open air is 0 w, through the buried wall adjacent to soil is 304 w, through the floor is equal to 230 w, and through the ceiling is 4218 w; in total, it is equal to 3683 w, which is equivalent to 4.48 W$/(m^2)$. Heat loss or heat absorption in summer and winter are equal to each other and no difference can be observed.

Cistern of Parvin Etesami House: In the third sample, 100% of the building is located under the ground. Cistern of Parvin Etesami House has been designed and built with a rectangular plan and the approximate dimensions of 12*6.5 m and buried depth of 3.9 m. Currently, the materials are brick and rubble stone in the walls, brick in the ceiling, and ceramic brick in the floor (Table 12).

Calculating U-VALUE of buried wall and floor in the cistern of Parvin Etesami House: According to the physical data obtained from the cistern of Parvin Etesami House and using the web-based software (SBCE) [10], the U-VALUE of the floor and buried walls is 0.18 W$/(m^2.K)$ and 0.39 W$/(m^2.K)$, respectively (Fig. 8 and Tables 13 and 13).

Based on the studies and calculations on the cistern of Parvin Etesami House, the heat exchange rate in winter due to the lack of contact between the walls and open air is 0 w, through the buried wall adjacent to soil is 213 w, through the floor is 53 w, and through the ceiling is 1609 w; in total, it is equal to 1342 w which is equivalent to 4.47 $\frac{W}{m^2}$. In contrast, the heat exchange rate in summer due to the lack of contact between the walls and open air is 0 w, through the buried wall adjacent to soil is 337 w, through the floor is 84 w, and through the ceiling is 1067 w; in total, it is equal to 1498 w which is equivalent to 4.99 $\frac{W}{m^2}$. Slight difference is observed in the comparison of the heat loss or heat absorption in summer and winter.

Table 9. Physical properties of Basement of Sharbat Oqli House (Author).

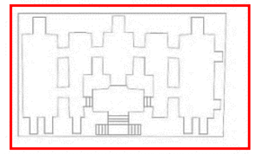
Properties						Drawings[11]
Burial rate			%100			
Temperature (winter)	Inside (basement)	Outside	Temperature (summer)	Inside (basement)	Outside	 Basement plan
	+12.5 °C	-5.1°C		+23.16 °C	+37.4 °C	
	285.65 °k	268.05 °k		296.31 °k	310.55°k	
Temperature of room above basement (winter)	+ 6.2 ° C 279.35°k		Temperature of room above basement (summer)	+29.7° C 302.85°k		
Length (m)	26		Width (m)	12		
Area (m^2)	312		Perimeter	76		
Buried depth (m)	2.6		External walls height	0		
Walls thickness(m) (average thickness)	0.6		Ceiling material	0.52		 Elevation -section
Walls material	Brick	R-VALUE $\frac{(m^2.K)}{W}$ $R=\frac{d}{\lambda}$ $\frac{0.6}{1.08}=0.55$	Ceiling material	Brick	R-VALUE $\frac{(m^2.K)}{W}$ $R=\frac{d}{\lambda}$ $\frac{0.52}{1.08}=0.48$	
Floor material	Ceramic brick + uncrushed gravel + elongated gravel + uncrushed gravel	R-VALUE $\frac{(m^2.K)}{W}$ $R=\frac{0.1}{0.25}+\frac{0.1}{0.77}+\frac{0.04}{0.25}+\frac{0.04}{0.4}=0.79$	Soil temperature at a depth of 2.6 m according to the diagram (Fig 4)	Summer	$TX+2.7=20.2^{\circ}C$ $273.15+20.2=293.35^{\circ}K$	
				Winter	$TX-2.7=14.8^{\circ}C$ $273.15+14.8=287.95^{\circ}K$	
Ground type	Clay and mud					

Table 10. Properties and wall area, R- VALUE, U-VALUE, and temperature difference in the surfaces of Basement of Sharbat Oqli House (Author).

Element name	Wall properties	Wall area	R-VALUE $R=\frac{d}{\lambda}$	U-VALUE $U=\frac{1}{R}$ $\frac{W}{(m^2.K)}$	ΔT Winter	ΔT Summer
Ceiling	Brick	$26 \otimes 12 = 312$	$\frac{0.52}{1.08}=0.48$	$\frac{1}{0.48}=2.08$	$279.35-285.65=-6.3$	$302.85-296.31=6.5$
Floor	Ceramic brick + uncrushed gravel + elongated gravel + uncrushed gravel	$26 \otimes 12 = 312$	-	0.25	$287.95-285.65=+2.3$	$293.35-296.31=-2.96$
Buried wall (adjacent to soil)	Brick	$2 \otimes (26 \otimes 2.6) = 135.2$ $2 \otimes (12 \otimes 2.6) = 62.4$ $135.2+62.4=197.6$	-	0.52	$287.95-285.65=+2.3$	$293.35-296.31=-2.96$

8. DISCUSSION

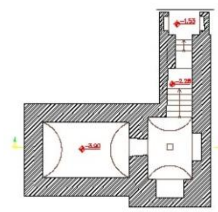
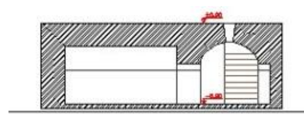
Issues discussed in the findings section indicate that (Table 15):

- Heat loss or absorption through the wall depends on the physical properties of the underground including the underground space volume, materials type of wall and floor,

Table 11. Heat power transmitted via the walls in the Basement of Sharbat Oqli House (Author).

Formula	Calculation (Summer)	Calculation (Winter)
$QC = UA\Delta T$	$Q1 = 0$ $Q2 = 0.52 \otimes 197.6 \otimes (-2.96) = -304.15$ $Q3 = 0.25 \otimes 312 \otimes (-2.96) = -230.88$ $Q4 = 2.08 \otimes 312 \otimes (+6.5) = +4218.24$ $Qtotal = Q1 + Q2 + Q3 + Q4 = 3683.21$ $QC = 3683.21w$	$Q1 = 0$ $Q2 = 0.52 \otimes 197.6 \otimes (+2.3) = +236.33$ $Q3 = 0.25 \otimes 312 \otimes (+2.3) = +179.4$ $Q4 = 2.08 \otimes 312 \otimes (-6.3) = -4088.45$ $Qtotal = Q1 + Q2 + Q3 + Q4 = -3672.72$ $QC = 3672.72w$
$\frac{\sum UA\Delta T}{\sum A}$	$\frac{3683.21}{821.6} = 4.48 \frac{W}{M^2}$	$\frac{8462.834}{821.6} = -4.47 \frac{W}{M^2}$
QC: Absorption or heat loss rate via walls (Q1: Upper wall with contact to open air, Q2: Lower wall without contact to open air, Q3: Floor, Q4: Ceiling)		

Table 12. Physical properties of Cistern of Parvin Etesami House.

<table>
<tr><th colspan="6">Properties</th><th>Drawings[9]</th></tr>
<tr><td colspan="3">Burial rate</td><td colspan="3">100%</td><td rowspan="11">
Plan

Section</td></tr>
<tr><td rowspan="3">Temperature (winter)</td><td>Inside</td><td>Outside</td><td rowspan="3">Temperature (summer)</td><td>Inside</td><td>Outside</td></tr>
<tr><td>+11.2 ° C</td><td>-6 °C</td><td>+26 °C</td><td>+37.5 °C</td></tr>
<tr><td>284.35 °k</td><td>267.15 °k</td><td>299.15°k</td><td>310.65°k</td></tr>
<tr><td>Length (m)</td><td colspan="2">12</td><td>Width (m)</td><td colspan="2">6.5</td></tr>
<tr><td>Area</td><td colspan="2">78</td><td>Perimeter</td><td colspan="2">37</td></tr>
<tr><td>Walls thickness (m) (average thickness)</td><td colspan="2">0.82</td><td>External walls height</td><td colspan="2">0.9</td></tr>
<tr><td>Walls material</td><td>Brick and rubble stone</td><td>R-VALUE $\frac{(m^2.K)}{W}$
$R1 = \frac{0.82}{1.08} = 0.76$
$R2 = \frac{0.82}{1.7} = 0.48$
$R = \frac{0.76 + 0.48}{2} = 0.62$</td><td>Ceiling thickness (m)</td><td>Brick</td><td>R-VALUE $\frac{(m^2.K)}{W}$
$R = \frac{d}{\lambda}$
$\frac{0.9}{1.08} = 0.83$</td></tr>
<tr><td rowspan="2">Floor material</td><td colspan="2" rowspan="2">R-VALUE $\frac{(m^2.K)}{W}$
$R = \frac{0.1}{0.25} + \frac{0.1}{0.77} + \frac{0.04}{0.25} + \frac{0.04}{0.4} = 0.79$</td><td rowspan="2">Soil temperature at a depth of 3.9 m according to the diagram (Fig 4)</td><td>Summer</td><td>$TX + 2.5 = 20.00^{\circ}C$
$273.15 + 20 = 293.15^{\circ}K$</td></tr>
<tr><td>Winter</td><td>$TX - 2.5 = 15.00^{\circ}C$
$273.15 + 15 = 288.15^{\circ}K$</td></tr>
<tr><td>Ground type</td><td colspan="5">Clay and mud</td></tr>
</table>

thickness of walls and ceiling, depth of buried space, burial rate and external contact, and geological properties of the studied regions.

- Considering the thickness of the walls and ceilings, thick walls have higher heat capacity. Such thickness causes the buildings to naturally keep heat inside, has less heat transmission from the external wall to the inside, and suffers less temperature fluctuation. In fact, providing a heat mass such as thick ceilings and walls can prevent from temperature fluctuations. Thus, the internal temperature of the building is relatively independent from the external temperature.
- Using the web-based simulation software (SBCE), the U-value resulted from the floor and walls buried in the soil in Yackhchal-e Qaem Maqam, basement of Sharbat Oqli House, and cistern of Parvin Etesami House is 0.13, 0.24, and 0.18 W/(m^2.K) and 0.22, 0.59, 0.39 W/(m^2.K), respectively. According to the studies and comparison of the resulted values, U-value is decreased with the increased depth. In fact, due to the effective factors in U-value, burial rate in the soil is the dominant factor for the U-value reduction.
- In the comparison of the internal and external temperature differences, maximum temperature difference is observed in Sharbat Oqli House than cistern of Parvin Etesami House and Yakhchal-e Qaem Maqam. Considering the heat comfort range in Olgyay's method and the favorable weather

Table 13. Properties and area of wall, R- VALUE, U-VALUE, and temperature difference in the surfaces of the cistern of Parvin Etesami House.

Element name	Wall properties	Wall area	R-VALUE $R=\frac{d}{\lambda}$	U-VALUE $U=\frac{1}{R}$ $\frac{W}{(m^2.K)}$	ΔT Winter	ΔT Summer
Ceiling	Brick	$12 \otimes 6.5 = 78$	$\frac{0.9}{1.08} = 0.83$	$\frac{1}{0.83} = 1.20$	$267.15 - 284.35 = -17.2$	$310.65 - 299.15 = +11.5$
Floor	Ceramic brick + uncrushed gravel + elongated gravel + uncrushed gravel	$12 \otimes 6.5 = 78$	-	0.18	$288.15 - 284.35 = +3.8$	$299.15 - 293.15 = +6$
Buried wall (adjacent to soil)	Brick + rubble stone	$2 \otimes (12 \otimes 3.90) = 93.6$ $2 \otimes (6.5 \otimes 3.90) = 50.7$ $93.6 + 50.7 = 144.3$	-	0.39	$288.15 - 284.35 = +3.8$	$299.15 - 293.15 = +6$

Table 14. Properties and area of wall, R- VALUE, U-VALUE, and temperature difference in the surfaces of the cistern of Parvin Etesami House.

Formula	Calculation (Summer)	Calculation (Winter)
$QC = UA\Delta T$	$Q1 = 0$ $Q2 = 0.39 \otimes 144.3 \otimes (+6) = +337.66$ $Q3 = 0.18 \otimes 78 \otimes (+6) = +84.24$ $Q4 = 1.20 \otimes 78 \otimes 11.5 = 1076.14$ $Qtotal = Q1 + Q2 + Q3 + Q4 = 1498.04$ $QC = 1498.04w$	$Q1 = 0$ $Q2 = 0.39 \otimes 144.3 \otimes (3.8) = 213.85$ $Q3 = 0.18 \otimes 78 \otimes (3.8) = 53.352$ $Q4 = 1.20 \otimes 78 \otimes (-17.2) = -1609.92$ $Qtotal = Q1 + Q2 + Q3 + Q4 = -1342.71$ $QC = -1342.71w$
$\frac{\sum UA\Delta T}{\sum A}$	$\frac{1498.04}{300.3} = +4.99 \frac{w}{m^2}$	$\frac{-1342.71}{300.3} = -4.47 \frac{w}{m^2}$
QC: Absorption or heat loss rate via walls (Q1: Upper wall with contact to open air, Q2: Lower wall without contact to open air, Q3: Floor, Q4: Ceiling)		

conditions in the summer, the basement of Sharbat Oqli House is closer to the comfort range among the three buildings, the main reason of which is the lack of wall contact to the open air and its 100% burial rate.

- According to the research findings, heat loss from the walls in winter in the three buildings of Yakhchal-e Qaem Maqam, basement of Sharbat Oqli House, and cistern of Parvin Etesami House is equal to 19890, 3672, and 1342, respectively. Considering the area of the walls, which is equal to 2514, 821, and 300 m^2, respectively, the heal loss in each of the buildings is 7.91, 4.47, and 4.47 w. In contrast, the heat absorption in the studied buildings in summer is equal to 18183, 3868, and 1498 w, and heat loss in each of the buildings is equal to 7.23, 4.48, and 4.99 w, respectively.
- In the comparison of these three buildings, basement of Sharbat Oqli House and cistern of Parvin Etesami House have less heat loss due to the buried depth of the basement of Sharbat Oqli house (2.6 m), which is less than the buried depth of the cistern of Parvin Etesami House (3.9 m), but equal values are obtained in the heat loss from the walls, the reason of which is the complete burial of the basement of Sharbat Oqli House and lack of contact via walls, and very weak contact with the outside. However, in the cistern of Parvin Etesami House, despite the buried depth of 3.9 m and more depth than the basement of Sharbat Oqli House, owing to the contract via the ceiling to the external environment, heat loss is higher than that of the basement of Sharbat Oqli House. In Yakhchal-e Qaem Maqam, with buried depth of 9 m, due to the 20% contact of the walls and 100% contact the ceiling with the outside, higher heat loss can be seen than the two other studied samples.
- In the comparison of heat loss and absorption in summer and winter, the loss and absorption difference in the basement of Sharbat Oqli House is 0 and a slight difference can be seen in heat absorption in summer and heat loss in winter in Yakhchal-e Qaem Maqam and cistern of Parvin Etesami House. The reason may be related to the very low ceiling contact to the outside in the basement of Sharbat Oqli House and its 100% burial, which could less affect the temperature fluctuations of the building. In the two other studied buildings, due to the contact of the walls and ceiling to open air, the temperature fluctuations affect the building and the heat loss and heat absorption are different in summer and winter.
- It should be noted that, due to the examinations, Yakhchal-e Qaem Maqam, similar to other buildings, has less internal

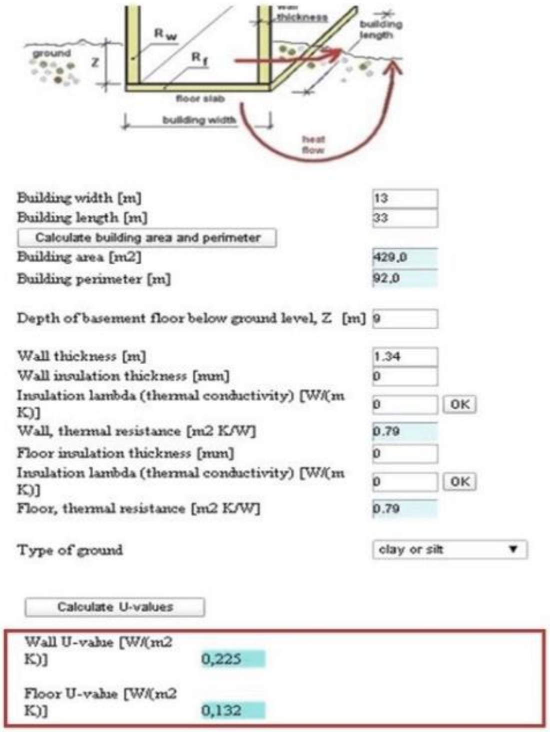


Fig. 6. Calculating U-VALUE of buried wall and floor considering the physical properties of Yakhchal-e Qaem Maqam in the web-based software «SBCE».

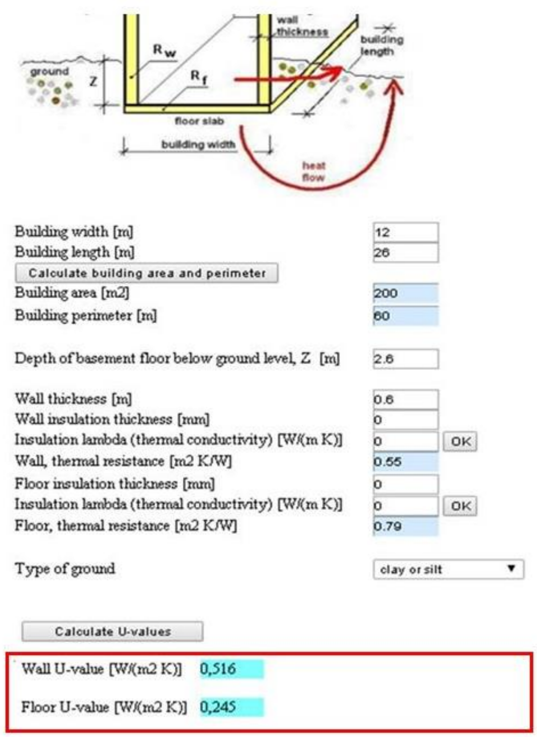


Fig. 7. Calculating U-VALUE in buried wall and floor considering the physical properties of Basement of Sharbat Oqli House in the web-based software «SBCE».

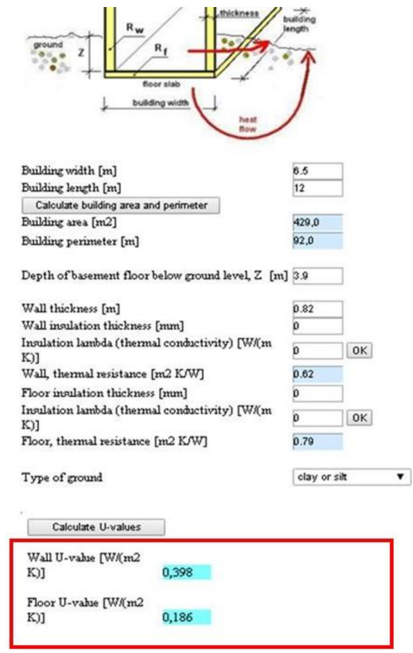


Fig. 8. Calculating U-VALUE of buried wall and floor considering the physical properties of the cistern of Parvin Etesami House in the web-based software «SBCE».

and external temperature difference in the case of no contact to open air through the surfaces. Also, its heat difference is very lower than that of other buildings and its internal temperature is much closer to the comfort range compared with other studied samples. These factors could have a great impact on the energy conservation than other buildings.

9. CONCLUSION

Below, the results of some discussed issues that can be considered due to the valuable role of earth-sheltered architecture are briefly presented:

- Underground spaces are valuable sources and can be used for sustainable development. In fact, such architecture has a great potential for stepping toward sustainable architecture.
- Living in an underground building has higher heat comfort than living on the ground. In fact, buildings in the shadow of the earth as the sustainable model can have their own unique microclimate. Independent from the external microclimate, their microclimate is almost constant in both daily and seasonal conditions. One of the cases that causes thermal suitability and environmental balance is essentially the dependence on the existence of great mass of soil, the surrounding or protective state of the ground, lack of wall contact or low wall contact to open air, and reduction of heat conduction flow through walls, and decrease of the outside uncontrolled air intrusion, burial depth, type of materials, and thickness of walls, which are less affected by the outside weather fluctuations and develop appropriate conditions and more balanced heat environment than the adverse and unfavorable external weather. Therefore, the use of buildings from the adjacent soil and ground as

Table 15. Comparison of physical characteristics of the studied buildings and the amount of heat loss and absorption from the walls in summer and winter.

Name	Buried depth (m)	Walls area (m2)	Walls and Ceiling contact to open area		U-VALEU (W/m^2)		Season	Heat loss and Heat absorption (w)	Heat loss and Heat absorption (W/m^2)
Yakhchale Qaem Maqam	9.00	2514	Ceiling	100%	Floor	0.13	Winter	19890	7.91
			Wall	20%	Buried wall	0.22	Summer	18183	7.23
Basement of Sharbat Ogli House	2.60	821	Ceiling	0%	Floor	0.24	Winter	3672	4.47
			Wall	0%	Buried wall	0.51	Summer	3868	4.48
Cistern of Parvin Etesami House	3.90	300	Ceiling	100%	Floor	0.18	Winter	1342	4.47
			Wall	0%	Buried wall	0.39	Summer	1498	4.99

the heat mass not only causes heat comfort for humans, but also can store a great amount of energy and considerable decrease in the temperature fluctuations inside of the building and, as a result, in energy consumption. In fact, it will significantly decrease the extent of using measures for achieving heat comfort, which is one of the best static heating and cooling techniques.

- In the design of earth-sheltered architecture in city of Tabriz, climatic conditions and features as well as the use of environmental conditions for creating favorable conditions inside buildings are considered. The studied earth-sheltered architecture are responsive and effective environments in terms of climate and energy, respectively, reduce the use of mechanical heating and cooling, and save energy consumption.
- In this regard, essential to pay attention to natural capacities of the earth in thermal balance in different conditions. Although it is not claimed to be perfect, just like any other approach, with the accurate examination of building type, function, location, and the issues related to the building during the design, this architectural idea can be used as a highly efficient and favorable sample of sustainable architecture.

NOTES

[1] In Azerbaijan, the lahar and inemberiate classes are called Karaan.

[2] The floor details from the bottom to top are: virgin soil, uncrushed gravel (10 cm), elongated gravel (5-10 cm), uncrushed gravel (3-4 cm), paving brick (4 cm).

[3] $\sum \frac{((W1L1)+(W2L2)+(W3L3)+(W4L4))}{(L1+L2+L3+L4)} = \frac{((13\otimes 1.4)+(13\otimes 0.8)+(33\otimes 1.8)+(33\otimes 2.4))}{((2\otimes 13)+(2\otimes 33))} = \frac{167.2}{125} = 1.34$

[4] $\sum \frac{((W1L1)+(W2L2))}{(L1+L2)} = \frac{((0.93\otimes \pm 1.27)+(0.35\otimes 0.9))}{(1.27+0.9)} = 0.68$

$R = \frac{d}{\lambda}, U = \frac{1}{R}$

[5] Average annual temperature of the ground from the surface to the depth of the first hundred feet is constant. By measuring the well water temperature, its approximate temperature can be obtained (Watson & Labs, 2006). Considering the sensors located at 10 m depth in city of Tabriz, the well water temperature is 17.5°C

[6] Energy indices (heat transfer coefficient) and calculation method: Heat transfer coefficient of a substance is its heat conductivity coefficient K for a standard unit of thickness d. This coefficient is defined as the duration of temperature passing from a unit area and a thickness unit in a homogeneous material and steady state when there is one unit of temperature difference between the surfaces. Heat resistance R is the opposite of heat transfer coefficient U. Thus, heat transfer coefficient is obtained by dividing the thickness of materials by heat transfer coefficient $R = \frac{d}{\lambda}$, $U = \frac{1}{R}$.

Heat transfer coefficient of the materials used in underground buildings are brick (clay and gravel) 1.08, ceramic brick 0.4, stone 1.7, elongated gravel 0.77, and uncrushed gravel 0.25.

[7] Olgyay has suggested the temperature of 21.1-27.8°C for summer and 20–24.4°C for winter and the relative humidity of 30-65% as favorable weather conditions.

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