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Estimation of heating and cooling energy consumption of earth-sheltered buildings due to the hot dry climate changing - case study: Shahdad Desert

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Abstract

One of the main concerns of today's world is the reduction of non-renewable energies and environmental pollution caused by them in buildings, which can be controlled by saving and optimizing energy consumption. On the other hand, global climate change and its local and regional effects are important in buildings energy management policies. To this end, identifying and exploiting passive systems and climate-friendly design strategies are one of the cheap and sustainable solutions in this regard. The present study examined the use of soil thermal potentials and earth-sheltered design as one of the practical solutions for providing thermal comfort and reducing energy consumption in hot and dry climates and case studied "Shahdad Desert". Various active and passive techniques are currently used throughout the world to reduce energy consumption, some of which have been common from the past to the present such as the construction of buildings in the shelter of earth, like the Iranian native architecture. This study empirically and practically investigated the effect of the depth of a building in the soil on the rate of cooling and heating energy consumption. The information required for the construction site of the earth-sheltered building was obtained by conducting a field survey in the Shahdad Desert. It was further suggested to build a tourist residence by taking refuge in the heart of the Kaluts in the hot and dry climates of Shahdad. By moving the designed building inside Kalut, the rate of cooling and heating energy consumption of the building during the year was calculated and the results showed that changing the depth of the earth-sheltered building did not have much effect on heating energy, but as it approached the earth edges, its cooling energy increased. As the building left the earth, the total cooling and heating energy consumption increased dramatically.

Introduction

Due to the energy crisis and the subsequent environmental problems caused by fossil fuels, society's attention was drawn to it which can be controlled by reducing energy consumption and using passive design strategies. One of the passive solutions in native architecture is the use of soil as a controlling factor for cooling and heating losses. Earth, as the first place and material for building shelters, play an important role in shaping architecture, so that in one place (China) it acts as a source of cold and in another place (Cappadocia, Turkey) as a source of heat and another place (Amazon rainforest), on the contrary, is seen as an annoying factor. One of the most important functions of the earth in indigenous architecture is to sink into the heart of the earth. (Barzegar and Mofidi Shemirani 2010). Architecture in the context of nature, according to the mentioned conditions, is the result of sustainable development, and architecture in the shelter of the earth is an example of such architecture in nature (Arab and Farrokhzad 2017). An important advantage of soil is that with its thermal properties and temperature delay, it keeps the shelter warm in winter and cold in summer. The high specific heat of the soil causes the heat transfer in it to be slow and with the penetration into the depth of the earth, the temperature fluctuation is further reduced (Tahbaz 2013). The soil is considered a suitable thermal insulator, temperature fluctuations inside the ground are less and

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fluctuations are trivial in a few meters of the ground depth (Pourdeihimi 2011). A study was conducted on the temperature profile of the adjacent air and its subsoil in the Seabrook, New Jersey, USA, and the temperature was measured at the beginning of winter for 12 consecutive years. It was observed that temperature changes at a depth of 80 cm near the ground are almost zero (Mather 1974). Therefore, the technique of sheltering the soil is an important and inexpensive solution in today's buildings.

The use of "earth shelter" does not necessarily mean that the building should be built under the earth. The referring to such buildings as "earth-sheltered" is a product of how it relates to its surroundings. In other words, the earth-sheltered structure has its common structure, except that part or all of its shell is covered with a thick layer of soil. (Nasrollahi 2015).

A large part of Iran has a hot and dry climate. The unbearable heat, especially in the central plateau of Iran, is one of the factors that, in the absence of necessary measures, sometimes becomes so unbearable that it can endanger the lives of many (Rahimi Mehr 2013). For example, the interest in using passive design is emphasizing that cooling will become an important issue in the Central European buildings due to climate change (STRATEGO 2015). In this way, to face sustainable challenges in terms of climate change, water and energy consumption, the Technical University of Catalonia (UPC) has promoted the culture of energy efficiency in new generations of professionals that will work in the field of building construction (Cantalapiedra et al. 2006). The earth-sheltered architecture was mostly used in the hot and dry climate of Iran to avoid harsh weather conditions (Arab and Farrokhzad 2017). One of the most important advantages of these systems is an adaptation to the environment and the use of the region's potentials, reduction of fossil energy consumption, and the resulting destructive environmental effects (Haeri and Alavi 2012). To control and reduce large fluctuations in daily and annual temperatures, especially on very cold or very hot days, special soil heat has been used by constructing a basement or immersing part of the building in the heart of the soil (Tahabaz 2013). The use of static systems such as the earth sheltering technique to control the heating and cooling of buildings is not a new solution and has been used for many centuries (Haeri and Alavi 2012). Underground spaces have been used from the distant past to the present for various climatic, security, economic, protection, and other purposes, and all or part of them are underground. Wherever the hot and dry climate is the prevailing climate of the region, the earth-sheltered architecture is reflected in it specially. This study mainly aimed to manage the optimal energy consumption and productivity of construction energy in the hot and dry climate of Iran by controlling heat reception and heat loss using soil thermal capabilities and at a suitable depth for designing a passive climate.

Theoretical principles and literature review

To achieve thermal comfort in summer, a multi-stage design solution should be used (Figure 1). In the first stage, heat or cold is removed from the building, and the temperature is controlled in the second stage, and in the final stage, if the further adjustment of climate is required, mechanical equipment is used. But in today's architecture, the final stage is considered as the first stage, and buildings are designed regardless of climate and are built in all regions of the world. With this negligence, the man not only confirms the process of exhaustion of energies but also contributes to the destruction of the environment (Barzegar and Mofidi Shemirani 2010).

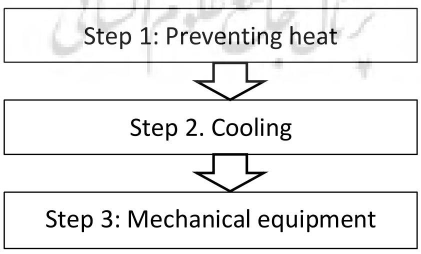

Figure 1.Staging to achieve thermal comfort in summer (Barzegar and Mofidi Shemirani 2010)

One of the most important earth functions in native climate-compatible architecture is the use of soil thermal properties that have been addressed in this study.

The benefits of using a basement in this climate are so great that perhaps research has not yet been able to clarify all its aspects (Barzegar and Mofidi Shemirani 2010). The history of using the basement dates back many years ago. But Privatali believes that the basement rooms were not a living area, and the basement has not been seen in indigenous homes, and the basement seems to be a modern invention. While Talib in his book states that the courtyard in the Sunken courtyard (inside the ground) has been observed in 3000 BC. One of the most famous of these types of yards is in Matmata Village in southern Tunisia. According to the examples presented by Talib, the antiquity of these examples can be understood and doubts can be put aside (Barzegar and Mofidi Shemirani 2010).

Sheltering building in the ground reduces heat reception and loss. Because on the one hand it increases the thermal resistance of the building shell and on the other hand it reduces the temperature difference between inside and outside the building and periodic temperature changes affect it with a delay (Brown and DK 2007). Therefore, soil masses are an effective barrier against high temperatures in hot and dry climates. The depth of the earth is usually close to the average annual temperature of the area. The soil temperature at 2 meters below ground level is very pleasant, while the outside air temperature is sometimes below zero and sometimes very hot. But a house that is located 2 meters underground is much cooler in summer and warmer than the ground in winter (Haeri and Alavi 2012). One of the most important benefits of buildings built in the heart of the soil is thermal comfort and energy savings.

One of the architectural examples of earth-sheltered buildings, located in the hot and dry climate of Kerman, is Dast Kand Village in Meymand (Fig 2). Since the temperature changes in Kerman vary from -15 °C to 38 °C during the four seasons, it can be concluded that the temperature difference between day and night in this climate is very large. By observing the temperature chart of this area and its changes, we find that the main concern of the residents in this area is responding to heat, as most months of the year the weather is hot and dry (Haeri and Alavi 2012). Providing comfortable conditions in the heat of summer noon is done using basements (Tahbaz 2013).

Since the rate of temperature changes during the year at a depth of half a meter is equal to 22 °C and at a depth of two meters is equal to 12 °C, and at greater depths, the rate of these changes decreases, so we find that taking refuge in the earth to protect heat is a correct choice and a useful solution that has been answering the climate issues of this hot and dry zone of Iran for many years (Haeri and Alavi 2012). In this climate, to use the earth's cryogenic properties or cryogenic guidance, the building must be connected to the earth. Thus, the construction of parts of the building inside the soil can be a significant help to provide comfort in this area, because the air inside the ground is cooler in hot weather and warmer than the ground in cold weather (Tahbaz and Jalilian 2008).

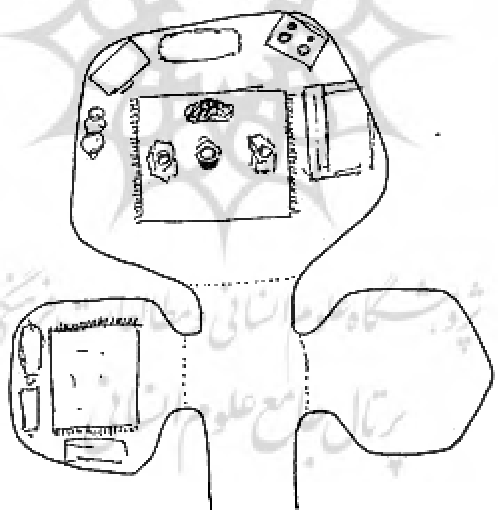

Figure 2. Sample of Dastkand houses plan in Meymand, Kerman (Talib 1984).

In the past ages, according to what can be seen in historical texts, human beings have used the uncreated capacity of nature and have adapted their building to it (Kafar Keli caves, Babol) (Akrami Abarghouei 2016). These natural samples are seldom seen in certain areas where the ground is ready. In unnatural examples, for the construction of such a building, a hole was constructed with the intervention of hands and tools to place the building. The remains of these samples are seen as semi-buried species on the ground. Sunken courtyard in the Central Plateau, as well as Dastkand, Meymand, and Kandovan villages are examples of this. Today's examples have found an easier solution based on the materials of the earth and the location of the construction and with the help of development tools. In these samples, the construction of the building bed is done simultaneously with excavation and embankment. That is, instead of placing the whole land in the excavated area, an embankment is built around the building, which is called an embankment earth shelter sample. Advances in construction technology and various human needs have made it possible to build a variety of uses for the type of earth-sheltered building (Akrami Abarghouei 2016). An underground building can have a completely different internal nature than what exists in a surface building. The location of the building mass below the ground indicates a different type of dealing than conventional buildings (Boyer 1982). In addition to all these issues, when the green space and trees of a region remain intact in the construction due to the use of the earth shelter space (underground), less damage is done to the life cycle of the region and higher levels. Therefore, plant life, animal habitat, and plant respiration and transpiration are more protected than surface construction. This is one of the peaceful ways in which a building coexists with the natural environment that benefits both the building and the surrounding environment (Fairhurst 1976). One issue that needs to be considered is the life of the soil around the building. The type of soil around the building becomes sensitive and may affect ground plants (Carmody and Sterling 1994). Therefore, special care should be taken in strengthening the soil around the building.

One example of indigenous architecture is in Valtierra, in southern Navarre, in an area called La Ribera. Due to its location in the drainage basin, it has a continental climate with sudden changes due to the north wind. The average annual temperature is about 14 °C and it is dry in terms of humidity. Today, more than 300 caves are found in Valtierra, Navarre, Spain. Most of them were excavated in the 19th century and many of them were abandoned in the 1960s. The soil in the caves is made of clay, silt, and gypsum, the softness, and permeability of which, together with the climatic conditions, are suitable for underground constructions. The caves, dug by farmers and workers, are built along the facade of the building to use natural light. In some of these caves, two floors were built to provide more light (Ardanaz Ruiz 2012).

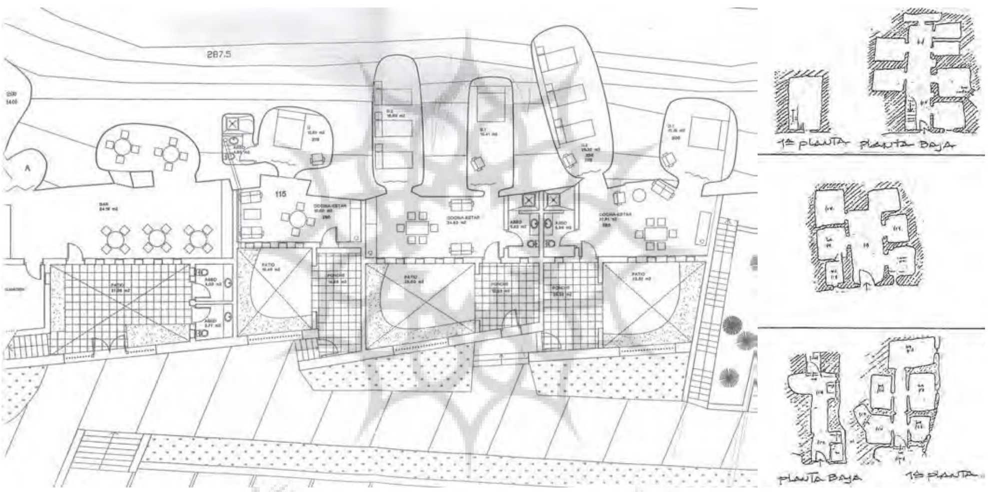

Figure 3. Examples of Valtierra caves (received from City Council 1997).

Figure 4. Panoramic view of Valtierra caves.

Another example of the indigenous earth-sheltered architecture is on the Aegean island in Greece. The features of this island have made it a promising place to display earth-sheltered accommodation. The idea of a semi-underground residence was conceived through the study of biological and indigenous Greek architecture. It aims to create a biologically sustainable, low-energy, and naturally comfortable residence throughout the year. The design used to build modern earth-sheltered residences is discussed and sustainable approaches to achieving a green building are presented and compared to a typical house with similar features. One of the most important parts of this process is site selection. This building is located in a special area of 4000 m^2 in Rodacado. The orientation of the building is southern to enter the building the best natural light of the day and also easier natural ventilation easier. To make a quantitative comparison between this building and a typical house on the ground, energy needs and energy consumption were assessed. It should be noted that the thermal properties of the shell of the earth-sheltered building are much better than the similar building on the ground. The energy performance of the sleeping area in these two buildings was calculated according to EN13790 standards. As confirmed by Greek law abbreviated "K.EM.A.K", energy demand for both heating and cooling is estimated according to the energy costs of the building shell and energy achievements (solar and domestic). The calculations for the earth-sheltered building and the surface building are simulated and the result is as follows (Benards et al. 2014).

Figure 5. Plan and section of the semi-underground residence.

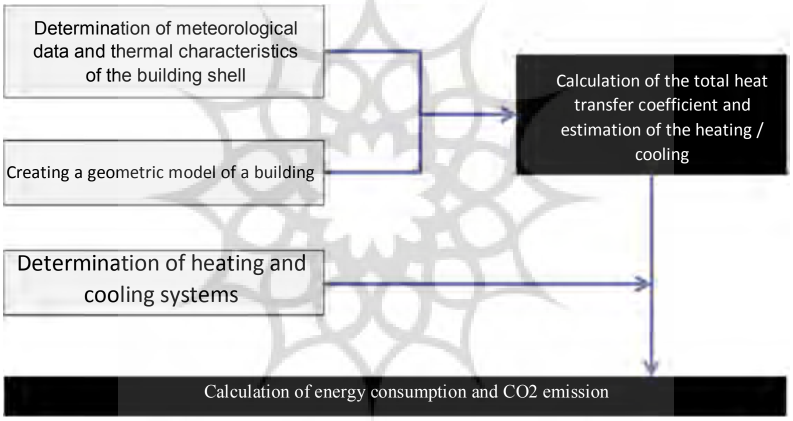

Figure 6. Steps to calculate energy performance by Epa-Cad (Benards et al. 2014).

Another study was conducted in 2017, which was the design of a two-story roadside residence with an earth-sheltered architecture and with an area of m^2 in Shahroud city climate. To use sunlight and sunshine, a sunken courtyard was designed in the center of the residence and its southern wall, this need was met by using the maximum glass surface. Then, thermal modeling of the building was designed and performed in Energy DesignBuilder simulation software, so that the rate of energy consumption of the building in different seasons in Shahroud city was measured in two ways. In the first stage, the building was simulated on the ground, and in the second stage, the same building was simulated without any changes so that its roof and its northern, eastern, and western walls were covered in a mound of soil to a depth of 6 meters (Arab and Farrokhzad 2017).

Figure 7. Left: Perspective of modeling the earth-sheltered roadside residence in DesignBuilder software - Right: View to the south of the roadside residence (Arab and Farrokhzad 2017).

The results of this study show that in the earth-sheltered sample of this building, the annual energy consumption in the heating sector has been saved by about 32% and in the cooling sector by 15%. In terms of lighting, because the architectural structure of both models is the same, but in the studied model of the earth-sheltered building, due to the 6 meters soil on the roof of the building, the amount of light through the sunken courtyard is less than the building model on the ground. It caused an 18% increase in lighting energy consumption in the earth-sheltered model. As a result, the total energy consumption in the earth-sheltered sample compared to the sample on the ground shows 13.7% savings (Arab and Farrokhzad 2017).

Research method

In this research, by referring to the written sources, scientific articles, and dissertations and the researches, the architectural features of the earth shelter are studied. The study aims to determine the optimal depth of an earth-sheltered building and how much depth of earth-sheltered structure can actually affect energy consumption. First, it is necessary to choose a place where the earth-sheltered building could be designed, so the Kaluts of the Shahdad region in Kerman are selected for the design. A field survey is conducted and a sample of the unevenness known as Kalut is selected and then a residential building is designed within the desired Kalut. The building is to be designed in such a way that it has the most benefit from natural factors in such a way that it has an orientation to the east and south for proper natural daylight. In this study, by determining the geographical location and climatic data of the study area in the energy simulator software and then modeling the residential complex designed within the selected Kalut, the building is simulated by DesignBuilder software. To observe the changes in energy consumption affected by the depth of the earth, the designed model is moved from the ground to the outside step by step, for which 79 consecutive simulations are performed.

Site selection

Lut Desert is one of the most impassable places in the world, located in Kerman province. One of the cities of Kerman province is called Shahdad, which is 6000 years old and on the other hand, has special features that have made this region one of the tourism hubs. The unique features of this region include Shahdad Kaluts, Rūdkhāneh-ye Shūr, Gandom Beryan (the hottest spot on earth), Nebkaha Park, and Kashk plain, etc. Therefore, this region is a good place to invest in attracting tourists due to its potential. The Kalut area is located 43 km from Shahdad (Fig 8) and covers an area with an average width of 20 km and an average length of 946 km. The most important wind that erodes the walls of the Kaluts is the 120-day winds that blow from Afghanistan to Zabol (Soroush and Erfanian Salim 2015). Due to the special desert location of this area and the presence of great Kaluts in it, the site is selected to design an earth-sheltered building.

Figure 8. View of Shahdad Kaluts.

The graph of monthly air temperature shows that the maximum monthly temperature is high in the whole year and the difference between the day and night temperature is significantly due to the dryness of the air (Figure 9). The table of climatic needs of this region (Table 1) also shows that due to high heat, active and passive cooling systems are required to work in all seasons, while heating systems are active in 7 months of the year and only in some hours.

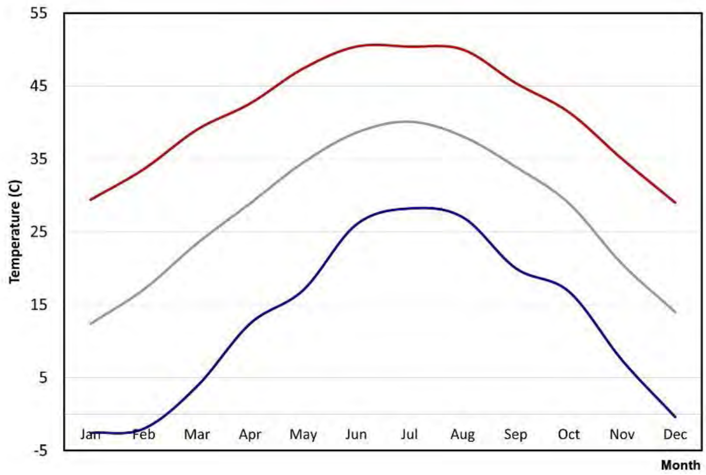

Figure 9. Graph of average, minimum, and maximum monthly air temperature in Shahdad desert/

Table 1. Climatic Needs Table (hourly) of Shahdad region

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.6	7.3	13.7	20.6	26.2	31.9	34.0	31.8	26.9	22.2	13.0	5.9
2	2.1	5.6	12.0	19.1	24.7	30.7	32.9	30.7	25.7	20.9	11.7	4.5
3	0.6	4.0	10.4	17.8	23.3	29.6	31.9	29.6	24.5	19.8	10.4	3.2
4	-0.8	2.4	8.9	16.5	22.0	28.6	31.0	28.6	23.4	18.8	9.2	1.9
5	-1.9	1.2	7.7	15.4	20.9	27.7	30.2	27.8	22.6	17.9	8.3	0.9
6	-2.0	1.0	7.5	15.3	20.8	27.6	30.1	27.7	22.4	17.8	8.1	0.7
7	-0.5	2.8	9.2	16.7	22.3	28.8	31.2	28.8	23.7	19.0	9.5	2.2
8	3.1	6.8	13.2	20.1	25.7	31.5	33.7	31.4	26.5	21.8	12.6	5.5
9	8.3	12.6	18.9	25.0	30.6	35.5	37.3	35.2	30.7	25.8	17.1	10.2
10	14.0	18.9	25.2	30.4	36.0	39.8	41.2	39.3	35.2	30.1	22.0	15.5
11	19.2	24.6	30.9	35.3	40.9	43.8	44.8	43.0	39.3	34.1	26.4	20.2
12	23.2	29.2	35.3	39.1	44.8	46.9	47.6	45.9	42.5	37.2	30.0	24.0
13	26.2	32.5	38.6	42.0	47.6	49.1	49.7	48.0	44.9	39.5	32.5	26.7
14	28.3	34.7	40.8	43.9	49.6	50.7	51.1	49.5	46.5	41.1	34.3	28.6
15	29.2	35.8	41.9	44.7	50.4	51.4	51.7	50.2	47.2	41.8	35.1	29.4
16	28.6	35.1	41.2	44.2	49.9	51.0	51.4	49.8	46.8	41.4	34.6	28.9
17	26.4	32.6	38.8	42.1	47.8	49.2	49.8	48.1	45.0	39.6	32.6	26.8
18	22.7	28.6	34.8	38.7	44.3	46.5	47.3	45.5	42.1	36.9	29.5	23.5
19	18.6	24.0	30.2	34.8	40.4	43.3	44.4	42.6	38.8	33.7	25.9	19.7
20	14.8	19.8	26.0	31.2	36.8	40.4	41.8	39.8	35.8	30.7	22.7	16.2
21	11.8	16.4	22.7	28.3	33.9	38.1	39.7	37.6	33.4	28.4	20.0	13.4
22	9.4	13.7	20.1	26.1	31.6	36.3	38.0	35.9	31.5	26.6	18.0	11.2
23	7.3	11.5	17.8	24.1	29.7	34.7	36.6	34.5	29.9	25.0	16.2	9.3
24	5.4	9.3	15.7	22.3	27.9	33.3	35.3	33.1	28.4	23.5	14.6	7.6

Designing a residential complex

The design of the residential complex requires the adjustment of appropriate environmental conditions to ensure the comfort of residents with reduced energy consumption. Therefore, the plan of the residential complex to reduce the energy consumption of the residential complex is designed within one of the Shahdad region Kaluts that had a regular topography. In locating the residence with an earth-sheltered architecture approach, the main components of the project were easy to access to the road, project scale, direction, slope, geology, and soil type. Considering these components leads to the selection of a site near the Shahdad-Nehbandan road.

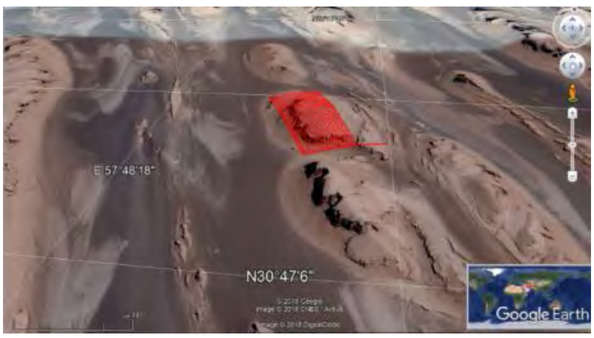

Figure 10. Selected Kalut in Google Earth Pro.

According to the weather data and climatic needs of Shahdad, obtained from Meteonorm, the simulation is done in DesignBuilder software, so that by moving the designed plan inside Kalut, the southern and eastern fronts that need natural daylight, are evaluated at different depths. Since the best orientation in this climate is east and south, so the plan of this complex is designed in an L-shape. Because the west and north directions in this climate have more heat loss, they are not economical to create openings and receive light, and in the design, these two fronts are located inside the Kalut and are considered as adjacent walls in all simulation states. Therefore, heat loss from the roof and north and west directions is minimized.

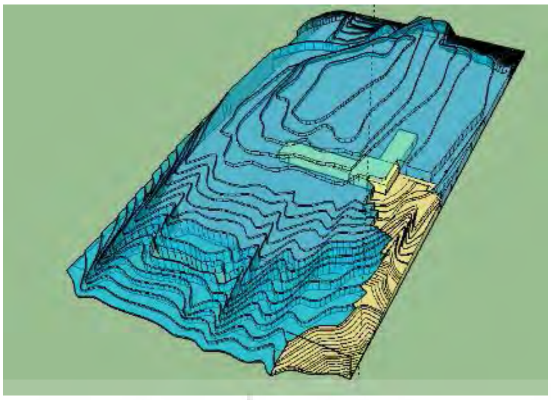

Figure 11. The three-dimensional volume of the selected Kalut along with the plan of the earth-sheltered residence

- The physical plan of the residential complex is as follows:

15 suites with an area of 500 m^2, living space with an area of 130 m, laundry space 110 m^2, staff room 72 m^2, desert climbing products store 72 m^2, cafe 30 m^2, guard room 30 m^2, reception 50 m^2, accounting and management 60 m^2, coffee shop, and restaurant 175 m^2.

Figure 12. Plan of the floors of the designed residential complex.

Energy simulation of the model

DesignBuilder simulation software is an energy simulation tool. This software can model the energy of the building, which includes various aspects such as cooling and heating system, the amount of natural daylight, the amount of air penetration, ventilation, etc. (Moslehi et al. 2016). The designed residential complex was modeled in the simulation software and the main variable studied in this simulation was the distance between the eastern and southern fronts to the outer edges. In fact, the researchers were looking for the best depth of horizontal placement of an earth-sheltered building to optimize energy consumption. DesignBuilder software is applicable for building modeling from various aspects such as building physics (building materials), building architecture, cooling and heating systems, lighting system, etc. and except for modeling the heating and cooling load of the building, it dynamically models different energy uses of the building such as heating and cooling energy consumption, lighting, home appliances, hot water consumption, etc. The software also can calculate daylight and even model the flow and energy in the form of computational fluid dynamics (CFD). Using the climatic file of different cities in Iran, this software performs the calculations of receiving, wasting, and consuming energy exactly based on the climatic conditions of the location of the building.

This residential complex was modeled in the simulation software, and what is important in this simulation is how close it is to the outer edges of the Kalut or how deep it sinks into it.

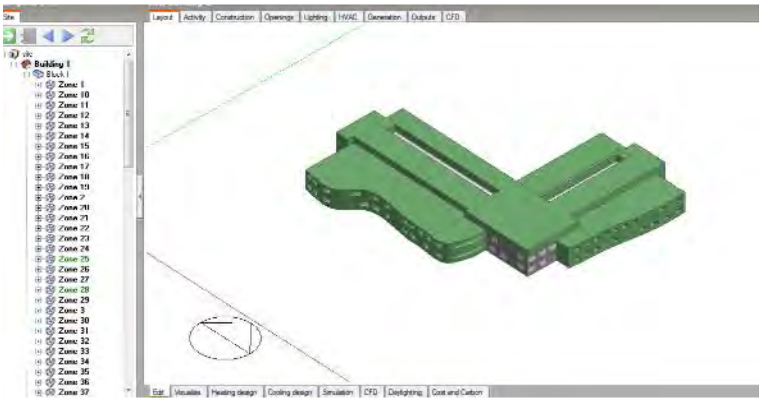

Figure 13. The perspective of modeling the earth-sheltered residential complex in DesignBuilder.

Research variables

Independent research variables include:

1. The climate of region: In this study, the hot and dry climate of Shahdad, Kerman has been considered.
2. Design area: The building is designed on two floors and the infrastructure area is 2200 m^2.
3. Functional specifications and building design include:

- The number of people: The number of people is determined based on the type of use and considering that the research space is residential, the number of people in each space is 0.1000 (people/m^2).
- Cooling and heating system program: The program related to cooling and heating systems is such that the cooling systems are set in the hot months and the heating system is set in the cold months 24 hours a day. The lower limit of comfort temperature for heating (Heating setpoint) is 19 °C and the temperature limit for keeping the heating system (Heating setback) is defined as 14 °C. The upper limit of comfort temperature for cooling (Cooling setpoint) is 25 °C and the upper limit of temperature for cooling system (cooling setback) is defined 29 °C. The fuel type of the building cooling system is electricity and the fuel type is the natural gas heating system.
- Specifications of building walls, doors, openings: The materials used in interior and exterior walls are conventional brick coating and the interior finish is plaster. The materials used in the roofs are concrete slabs. The main floor of the building is located on the ground and is covered with a layer of concrete. Exterior and interior doors are made of wood with two layers of gas as thermal insulation. The windows and skylights are made of double-glazed glass with a middle layer of argon gas.

4. The distance of building from the outer edges of Kalut from the east and south fronts, which this independent variable changes in the course of research.

Dependent variables include:

1. Total annual energy consumption (including cooling, heating, hot water, lighting, and equipment)
2. Annual cooling energy consumption
3. Annual heating energy consumption
4. Annual electricity consumption

Energy simulation and data mining

After locating the plan of the residential building in Kalut, the set of simulations was performed according to the depth of the desired building in the soil and the settings mentioned in the DesignBuilder software. The number of studied and simulated models is 79, each of which is about 25 cm less in-depth than the previous model. The results of the simulation, which included the annual energy consumption in the cooling and heating sections, are extracted from the relevant software and compared by analyzing and drawing graphs in Excel spreadsheet software, these simulated modes are compared. The following diagram shows the location steps of the studied earth-sheltered structure within the selected Kalut topography.

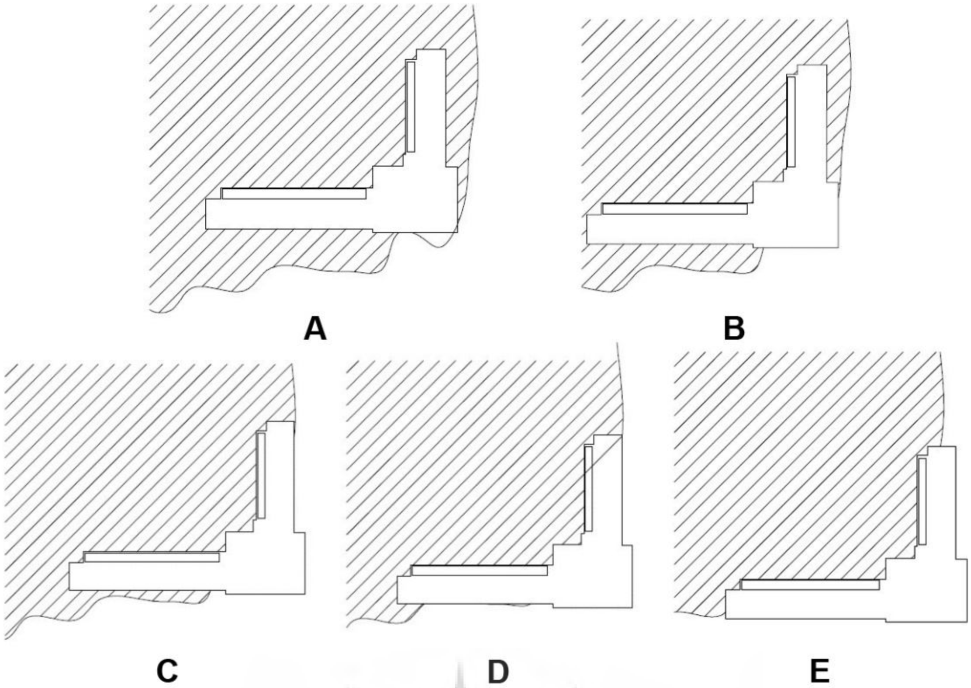

Figure 14. Locations of the earth-sheltered building within the selected Kalut topography.

Figure 14 shows part of the location of the earth-sheltered building within the selected Kalut topography. It should be noted that because the number of simulations performed is large (79 cases), selectively 5 modes are shown in this form:

A. The deepest location (mode 1)
B. Location displacement to the east and south (mode 19)
C. Location displacement until the eastern façade is level with the outer edge of the Kalut (mode 44)
D. Location displacement until the southern façade is level with the outer edge of the Kalut (mode 67)
E. Location displacement with the exit of the roof surface and part of the north and west facades from inside the Kalut (mode 79)

Results

The study mainly aimed to evaluate the rate of cooling and heating energies of an earth-sheltered building concerning its depth. The appropriate depth of the building soil of this complex should be selected so that it has the lowest energy consumption and the rate of cooling and heating does not disturb the thermal comfort. After reviewing the results, it was observed that the most important effect of variables on reducing the consumption of cooling and heating energy is to deepen the location of the building in the soil. The results of modeling and analysis for the earth-sheltered building as well as the desired depth of soil show that the amount of heating and cooling energy consumption of this building has increased significantly since the building came out of the Kalut so that its cooling energy consumption has increased more than its heating energy consumption, which is due to the very hot summers in the hot and dry region of Shahdad.

Consumption of heating system

The first result of the simulation shows that the rate of heating energy does not change significantly until the building is completely inside the Kalut, and the range of change is about 64,000 to 69,000 kWh. Since the residential complex protrudes from the body of the Kalut, the annual energy consumption of the heating system has increased dramatically, so that if the building protrudes 3 meters from the outer edge of the Kalut, the heating energy consumption increases by 11% and reaches from 66,000 kWh to 737,00 kWh.

Consumption of cooling system

The simulation findings show that the annual energy consumption of the cooling system does not change significantly when the building is located in the heart of the Kalut and increases from 17,000 to 23,000 kWh as it moves to the outer edges of the Kalut. But since the earth-sheltered building comes out of the Kalut, the cooling consumption rate has doubled, so that the annual cooling energy consumption has increased by 56% since the building protruded 3 meters from the Kalut and has reached from 23000 to 36000 kWh (Figure 16).

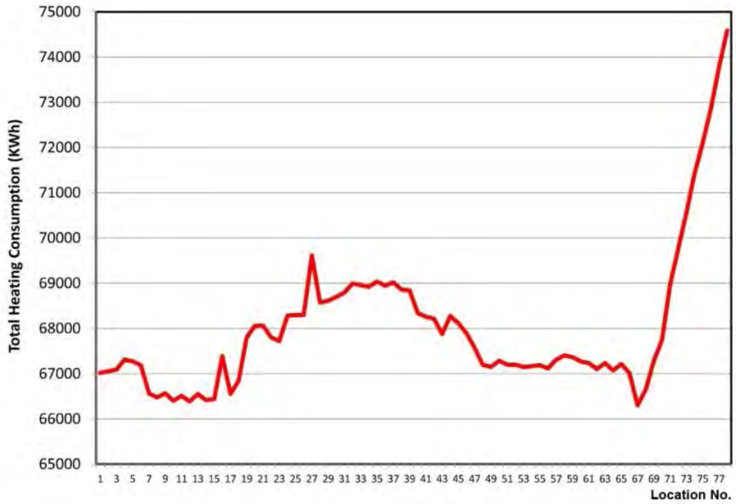

Figure 15. Diagram of changes in the total annual consumption of heating system with location displacement in the soil.

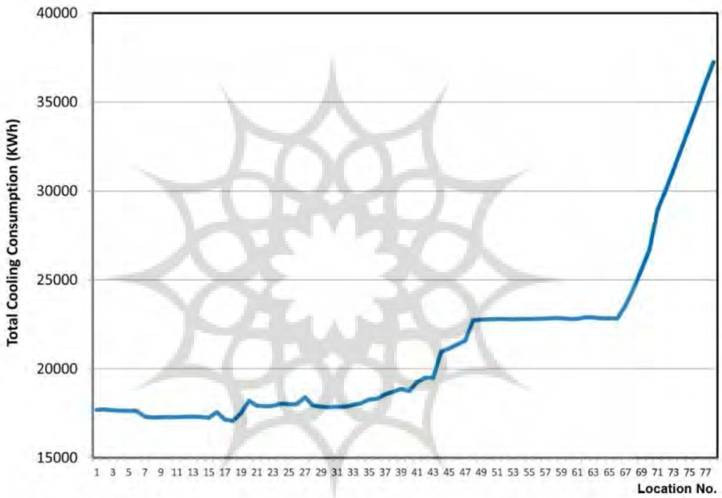

Figure 16. Diagram of changes in the total annual consumption of the cooling system with location displacement in the soil.

Figure 17. Diagram of changes in the total annual consumption of cooling and heating systems with location displacement in the soil.

Total consumption of cooling and heating system

The total annual energy consumption of the building for installation systems (except hot water and lighting) is equal to the sum of the annual consumption of cooling and heating of the building, which is shown in Fig 17. As can be seen in the diagram, the total annual energy consumption when it is at the deepest point of the Kalut until it is aligned with the eastern and southern edges has increased by 6%, from 85,000 to 90,000 kWh. Since the earth-sheltered building came out of the Kalut, it has increased by 22% for 3 m of protrusion, from 90,000 to 110,000 kWh.

Summary and conclusion

Undoubtedly, the location of an earth-sheltered building and the depth of its penetration into the ground affect the heat transfer of its walls. The interaction effects of soil layers on the outer walls of an earth-sheltered building can be due to the thickness of the soil layer that was studied in this study. The researchers calculated the annual energy consumption required for the cooling and heating installation systems by displacing an earth-sheltered building horizontally in Kalut and approaching it to the outer edges of the slope in the east and south views.

This study showed that there was a clear difference between the energy consumption of the building when it was completely inside the ground with the conditions when it came out of the ground. Fig 18 showed that the amplitude of changes in total energy consumption when the building was in the soil (ΔE_{in}) is much smaller than the changes in energy consumption when leaving the soil (ΔE_{out}).

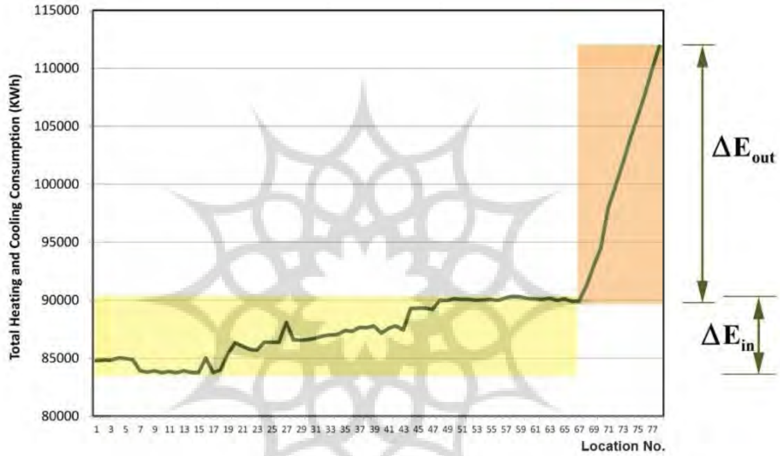

Figure 18. Changes in energy consumption inside and outside Kalut.

On the other hand, it was observed that the rate of increase in energy consumption was directly linearly related to outflow from the soil. However, the relationship between energy consumption and displacement inside the soil was weaker and with a gentler slope (Figure 19).

Figure 19. Regression of heating and cooling energy consumption by changing the depth of placement inside the Kalut.

There was also a direct relationship between earth-sheltered building displacement and cooling energy consumption (Figure 20).

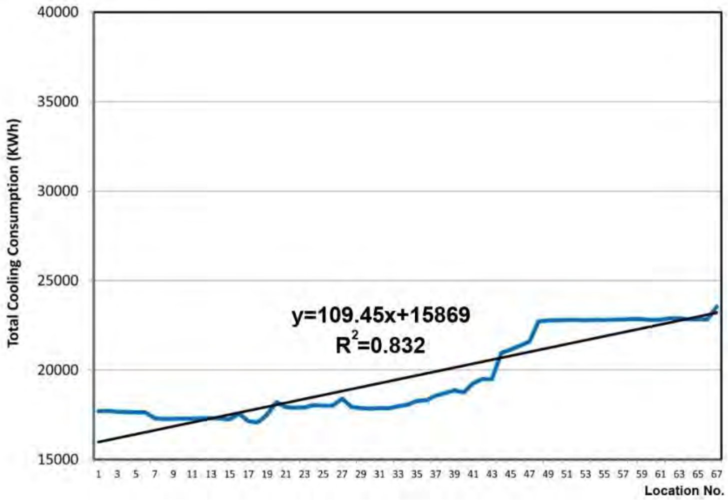

Figure 20. Regression of cooling energy consumption by changing the depth of placement inside the Kalut.

However, a study of changes in heating energy consumption showed that there was no exact relationship between the depth of the earth-sheltered building and heating consumption (Fig 21). This could be due to the predominance of hot climatic conditions in this region compared to cold conditions, so that for heating the earth-sheltered building, displacing the building inside the soil does not have much effect on winter energy consumption.

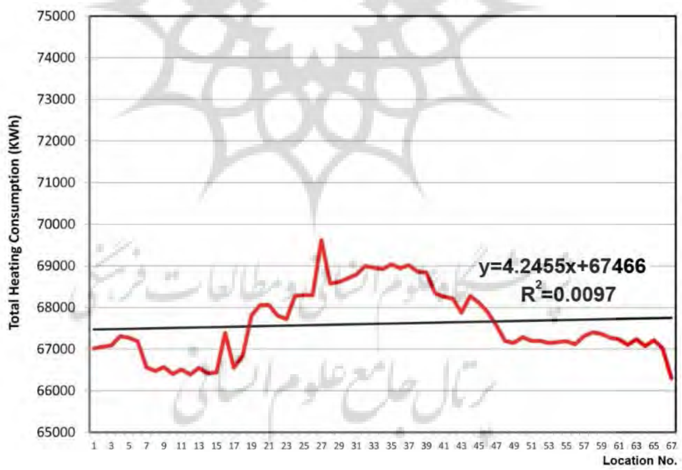

Figure 21. Regression of heating energy consumption by changing the depth of placement inside the Kalut

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