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INVESTIGATING DIFFERENT STRATEGIES FOR LIGHT AND VENTILATION PROVISION IN VERNACULAR UNDERGROUND ARCHITECTURE AND THEIR INTEGRATION WITH UNDERGROUND MUSEUMS ARCHITECTURE - A CASE STUDY IN IRAN

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Abstract- Nowadays, with regard to environmental problems, environmental sustainability as well as previous vernacular buildings and methods have been specially paid attention. In old Iranian vernacular architecture and in some regions by merging in the heart of the ground, it was possible to provide comfort for residents and optimal condition followed by reduction of energy demand in direction of temperature increase or decrease. The present paper describes significance of environmental sustainability by vernacular underground architecture in Iran based on an analytical method. It is recommended the content be used in creation of underground museums due to its various advantages. Since light and ventilation are two important factors inside museums, in order to maintain invaluable historical and cultural works and also merging at the heart of the ground provides the light required for a museum due to indirect natural and local light with sustainable environmental condition and optimal sufficient ventilation, identification of different kinds of vernacular. Underground architecture in Iran can present different strategies in designing contemporary underground museums. In addition, invaluable works will be more effectively protected. Finally, different kinds of vernacular underground architectures in Iran will be compared and studied based on two factors of light and ventilation through a comparative-analytic method. In conclusion, an ideal underground space that meets requirements of an underground museum is obtained. Its aim is to bring about higher environmental sustainability within larger scales.

Keywords: Vernacular Underground Architecture, Natural Light, Sustainable Environmental Condition.

I. INTRODUCTION

Rapid and irregular growth of technology generates changes in human life, his habits, and his surrounding environment. However, it is not recognized as the only reason for environmental disturbance. Ever increasing population and concentration on urban life have caused a considerable increase in the population of city inhabitants followed by increased demands and requests in areas. The listed areas such as housing, energy, etc. that altogether cause air pollution, global warming, destruction of large areas of green spaces, irrational uses of nonrenewable sources, and greenhouse effects ergo perforation of the ozone layer [1-2].

The progress of the current conditions will confront human with more serious environmental problems, lack of non-renewable energy sources, etc. Human approached environmental sustainability as an act in line with maintaining the natural environment around him as well as improving his life conditions on earth [2]. Simos Yanas [3] believes, "The aim of bioenvironmental sustainable design is to achieve visual and thermal comfort in building by using natural energy supplies through architecture. It is expected that a building with low dependency on engineering systems and non-renewable energy sources have the following features:
- can respond to various conditions
- can provide appropriate environmental conditions for inhabitants' activities
- can include both simplicity and robustness
- can be well representative of their designers' architectural expression and innovations.

The following general items in the field of sustainability must be considered in all related projects
- Thermal comfort as well as indoor and outdoor air quality
- Inhabitants needs as well as possibility of compatibility with changes
- Passive design techniques for heating, cooling, ventilation, and use of daylight
- Urban environment including streets, squares, thresholds, transition centers, and transportation paths
- Past and contemporary similar vernacular buildings" [3].

All the above-mentioned points must be considered so that environmental sustainability will be achieved, steps to meet human demands will be taken, a desirable proper path will emerge, and environmental problems will be mitigated. By having a look at the rich vernacular Iranian architecture during the past and by analyzing its positive aspects, one can learn more about the process of appropriate designing of spaces, appropriate construction, and optimal environmental and thermal condition inside the buildings.

Spaces created at the heart of the ground, within old Iranian vernacular architecture, can be considered an efficient suitable solution for higher environmental sustainability due to their providing thermal comfort, optimal climate for inhabitants and passive design for suitable heating, cooling, ventilation and light. Those buildings that enjoy natural ideal thermal and environmental condition consume half of building energy and apply different systems to create optimal condition.

It shows that creation of suitable environmental condition and thermal comfort with the least energy consumption and in the most natural way possible will be very effective on protection of the environment and environmental sustainability, i.e. in past, human communities paid more attention to natural environmental sources [4-5]. Paying attention to past architecture and using it in present and future, which is common nowadays, does not mean that principles of past designs are being imitated, rather, past invaluable principles should be appreciated, and their integration with contemporary conditions taught. One must, indeed, analyze, ergo learn more about, philosophy of these principles and designs [6].

In recent studies of the International Conference of Green Buildings and Sustainable Cities in 2011, it was specified that the excavated old cities had shown to be desirably able to meet weather problems and energy supply needs [7]. In addition, in a paper in 2009, it has been mentioned that underground architectures surrounded by soil, in comparison with normal architecture, better-kept buildings away from natural disasters and environmental problems such as humidity and temperature, and that underground spaces are environmentally sustainable and can well keep historical structures [8].

The advantages and disadvantages of underground architecture have been specified in a research in 2004 [1]. In addition, a paper presented in 2011 showed that Iran's traditional sustainable solutions, with all its different climates, could provide human comfort ergo solution of energy problems. It seems that, due to museums' need of indirect natural light, proper ventilation, and sustainable consistent conditions, constructing underground museums is a proper solution to stability as well as provision of proper light and ventilation.

If this assumption is right, how can one provide appropriate natural light and ventilation for museums? The main purpose of the present paper is to get familiar with underground architecture as well as with different methods in provision of museums' ventilation and lighting by offering different performed models of vernacular underground architecture with more emphasis on environmental sustainability at larger scales. To do so, a comparative analytic methodology is used. Information has been gathered from papers of famous journals and magazines, different field observations and studies as well as several high-validity databases. The obtained data were then analyzed based on qualitative methods.

In order to reach environmental sustainability through underground architecture and underground museum building, the present study investigates, through content analysis, the capabilities of underground architecture and significant factors in museums' inner spaces, then it gives reasons, through logical reasoning, why to integrate the two. Methods of ventilation and lighting in different vernacular underground architectures in Iran analyzed and represented through a comparative analytic method later.

Different vernacular underground architectures are finally compared with each other so that research information is analyzed and results are represented through a comparative analytic method, ergo an ideal strategy is introduced in underground museums architecture which well enjoys underground characteristics and can well respond to different emerging needs.

II. REVIEWING OF MUSEUM AND UNDERGROUND ARCHITECTURE CAPABILITIES IN ORDER TO EXPLAIN WHY THESE TWO CASES ARE COMBINED

A. Underground Architecture

Soil can provide an impenetrable and insulated space in the earth against heat and cold by increasing thickness and it can delay fluctuations of annual temperature due to its high thermal mass [9]. The daily fluctuation of temperature is negligible in depths over 0.6 m (2 feet) [10], in a few meters under the ground level, air temperature is constant during the year, which provides a warm space in winter and a cold space in summer. Therefore, there will be reduced energy demand in increasing or decreasing space temperature and providing comfortable conditions for human without much energy consumption.

Furthermore, vaster spaces left on earth allows the emergence of more green spaces and more integration and coordination with the environment. Generally compared with on-ground architecture, which is confronted with hard weather conditions, fluctuations of air temperature, the effects of humidity on materials, and unstable or unusual conditions, underground architecture can provide safe spaces with thermal comfort for human beings as well as stable spaces with temperature and thermal consistency to preserve invaluable works vulnerable to ever-changing environmental conditions.

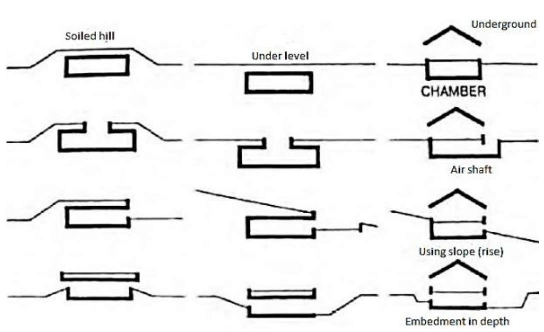


Figure 1. Different forms of underground architecture [9]

Underground architecture is observable in different forms such as in a usual underground, earthy hills with specific thickness of soil on their tops, and the structures completely inside the ground (Figure 1) [9].

B. Underground Architecture - Advantages and Disadvantages

Besides its different advantages and benefits, underground architecture has its own disadvantages and problems as well. The advantages include more moderate and desirable weather conditions than on-ground spaces, decreasing cooling energy requirements of building, energy reserve, increasing green spaces on earth, decreasing noise and acoustic pollution penetrating into the building, and creating a calm environment.

In addition, it decreases weather fluctuations, thus causes less contraction and expansion of buildings materials. Ineffective UV rays, no extinction, change of color in materials, etc., longer materials life expectancy, more resistance against wind, storm, earthquake and so on, prevention from direct radiation of sun are among the other advantages. On the other side, the disadvantages include social and psychological problems within underground spaces that compel most people to ignore these spaces as habiting areas.

In addition, lack of stimulation from changing weather conditions and sun light can create a sense of confinement. Increasing primary ventilation and lighting costs are the other problems of such spaces [1]. Due to uncountable advantages that this architecture can bring and its effectiveness on proceeding of sustainability goals, reviewing, and solving problems of this architecture are allowed to use it more and more. Two main problems in this architecture i.e. light and ventilation, as well as light supply methods and ventilation were dealt with by offering different models and samples of underground space.

C. Methods to Provide Light and Ventilation within Underground Spaces

Light can enter underground spaces from different ways, it can be supplied from ceiling light, an inner yard or atrium, and/or from one or more sides of the building, sufficient ventilation is also very important for removing additional humidity and heat. The Figure 2 shows different approaches for supplying proper lighting and ventilation [10]. These make passive heating and cooling possible without much energy consumption and provide balanced desired air within underground buildings without any additional noise.

D. Investigating Museums' Capabilities as well as Some Significant Factors within Inner Space of Museums

Environmental parameters such as air pollution, light, humidity, and temperature of the exhibition site can have destructive harmful effects on culturally valuable works in the inner space of museums. Environmental problems should be paid enough attention at the beginning of designing so that culturally invaluable objects are well kept, preserved, and protected from any kind of destruction.

For example, increased temperature causes humidity loss of the works ergo their dryness [11], UV rays of sun change color of the works, destruct them and cause some other harmful effects which exterminate cultural works of a nation, works for preservation of which stabilizing standard inner conditions is necessary within museums.

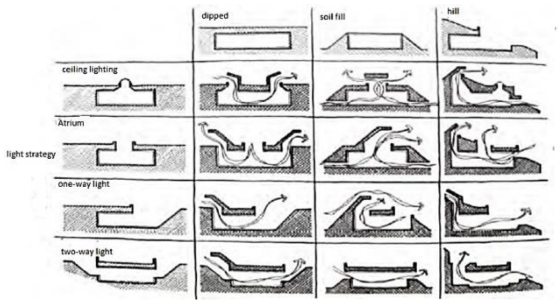


Figure 2. Lighting and ventilation strategies for different samples of sheltered buildings within the ground [10]

In the case of the problems associated with museums' lighting, both natural and artificial lights can cause these destructive reactions, controlled natural indirect light, however, causes much less increased temperature inside the museum when compared with artificial light. Though UV rays of artificial light is less than those of natural light, using some special filters is necessary when using artificial lights such as fluorescent lamp [11].

Therefore, the absorbed light can destruct the works while at the same time it is a vital element of museums, lack of light weakens precise recognition of colors and dimensions, ergo comprehensive accurate understanding of the work. Therefore, the problem with damaging works cannot decrease the importance of the need for light in museums [12]. Light must be, therefore, controlled inside museums so that no harmful effects is caused for works while at the same perfect light for perfect seeing is provided, natural lighting, also, decreases electricity ergo energy consumption.

One of the approaches inside museums is classification of exhibited works based on their sensitivity to light, generally, however, direct light of sun must be prevented in museums. Some previous performed models show that ceiling light with moving or fixed protectors can act more effectively and efficiently in conduction of indirect light into museums [12]. Sunshades may also be used to prevent from increasing heat in the space. Another problem inside museums is ventilation and creating balanced, constant weather conditions.

Minimum fluctuations of room temperature in the museums, (21±3) centigrade degrees, relative humidity (55%±5%), annual air flow as well as least light and UV rays radiation must be taken into account when planning for least destruction to museum works. Movement and change rate of air is decreased by insulating and blocking the pores, so higher thermal and temperature consistency will be generated inside the space, ergo, keeping culturally invaluable works within museums will be more efficient, while at the same time ventilation rate and energy consumption will be decreased in the space [11-12].

In order to provide proper light and ventilation and with accordance to the high performance standards, low energy innovative methods and programs can be good solutions to environmental sustainability [12].

E. Integration and Combination of Underground Architecture and Museum Architecture

As said before, underground spaces can provide sustainable environmental conditions and decreases in temperature fluctuations. In addition, indirect natural light and reduction of the effects of UV rays, which are both associated with underground architecture, can provide better conditions for protection of historical works when compared with ordinary architecture.

Considering long history of Iran in different kinds of vernacular warm, dry climates, especially underground architecture and its ability in creation of sustainable environmental architecture, studying vernacular underground architecture in Iran can offer different principles and strategies for designing contemporary underground museums. With regard to this and considering abovementioned methods for ventilation and light in underground spaces, two parameters are studied in different kinds of Iran's vernacular underground architecture so that a proper model for underground space is obtained in terms of ventilation and light.

F. Iran's Vernacular Underground Architecture

In a country like Iran with different climatic regions, vernacular creators have presented some reasonable solutions for increased human comfort. Since Iranian vernacular architecture has, for a very long time, responded well to environmental problems and as it has been formed based on climatic factors and local constructional materials and in fact, its features have been in line with principles of sustainable architecture, it can be considered as a sustainable architecture [13].

One of the most considerable strategies in Iran's vernacular architecture with regard to improved environmental condition for the inhabitants is architecture at the heart of the ground. Considering the long history of Iran's underground spaces (which will be presented in the following), ventilation, and light will be studied within different vernacular architectures based on classifications mentioned for underground architecture.

III. INVESTIGATING LIGHT AND VENTILATION IN DIFFERENT UNDERGROUND ARCHITECTURES

Here, different samples of past Iranian vernacular underground architecture are offered in accordance with the mentioned classification for underground architecture.

A. Usual Undergrounds - Cellar

Traditional houses in hot dry areas often have undergrounds, these are mostly used in warm seasons. Cellar or hall that is same as underground is found and not only in houses but in mosques, schools, etc. Sometimes, the undergrounds covered the whole surface under the first floor or they even went beyond proprietary scope.

The ceiling of the underground was one meter above the yard level and the remaining went to the underground itself. One of the important reasons in using undergrounds, besides their being warmer, is their proper soil and excellent composition. These spaces in the heart of ground are protected by the thick earth crust surrounding them so that outer heat cannot much affect them. In these underground spaces, natural light is indirectly supplied by dome ceilings (windows between the yard and the hall). Furthermore, ventilation is as well provided by the rising warm air, which later goes out from through the windows.

In many buildings, however, ventilation is provided through wind catchers. Height and direction of the wind were very important in designing of wind catchers, wind catchers were very common since old ages in Iran. Wind catchers are designed to absorb the desired wind, enter it to the canal, which is connected to the cellar (underground) and finally bring fresh cool air [14]. In hot dry areas, where air humidity is very low, there was usually a small pool designed in the underground of many buildings where desired air could pass over water, get some humidity, and bring cool humid air into inner spaces at end (Figures 3-4).

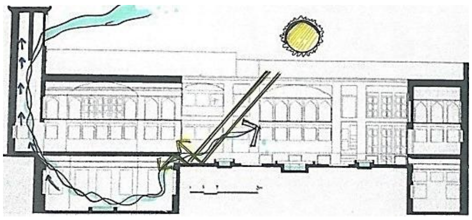


Figure 3. Natural lighting and ventilation of the cellar in an old house located in Yazd Province [15]

Figure 4. The entrance of indirect light into the underground [15]

There is another method of evaporative cooling, which is using a small garden above wind catcher canals, from where the humidity penetrates into canal body by irrigated small gardens which in turn causes cooler desired wind enter wind catcher (Figures 5 and 6) [16].

Figure 5. Small garden in body of the wind catcher for evaporative cooling [16]

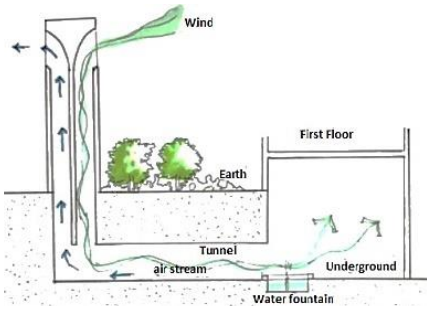


Figure 6. Cooling mechanism of wind catchers

B. Under the Ground Level

B.1. Shovadan

There are places in some old Iranian houses in which people could live during all different seasons of the year, "Shovadan" is one of such places. These places are thoroughly placed under the ground and include room or rooms, which have been placed at about 5 to 12 meters under central yard, the proper soil characteristics of these warm areas allow deep excavations. Undesired, and sometimes unbearable, air conditions in Iran warm areas, where temperature sometimes reaches 45 degrees or higher in summer, make underground spaces, with a temperature of 25 centigrade degrees during the year, a proper refuge from conditions that are not tolerable for human beings.

Air temperature in such underground spaces is less than outside temperature in summer and more than that in winter. In fact, the deep excavation (insulation layer) does not allow heat conduction into ground and consequently, there is cooler summer air in Shovadans in comparison to that of outside environment. Access to vast spaces of Shovadans is provided through stairs in the central yard or in the rooms (Figure 7) [14-17].

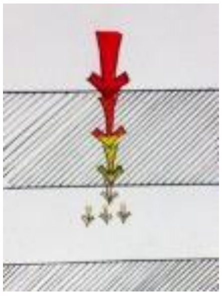


Figure 7. Insulation layer (the ground) and decreasing conducted heat into the ground

According to performed measurements, the summer temperature in Shovadans is even lower than the minimum temperature in outer space and there is no need for cooling systems. Furthermore, earth temperature is almost constant in depths over 6.1 m and almost equal to average annual outside heat of that specific site, consequently, there is no need for heating systems in winters as well [14-17]. Besides decreasing consumption of nonrenewable energies, this innovative traditional solution, therefore, fulfills heating and cooling needs of inhabitants as well.

Here, with regard to the desired air conditions needed for human comfort within Shovadans, which is 20 and 23 centigrade degrees in warm and cold seasons, light and ventilation are investigated in these underground spaces and the corresponding more environmentally friendly elements are introduced. Shovadan, as shown in Figure 8, has comprised of elements including Sahn, Hojreh, Si-Sara, and furnace. The main part of Shovadan is called Sahn and rooms interrelated to it are called Hojrehs [18].

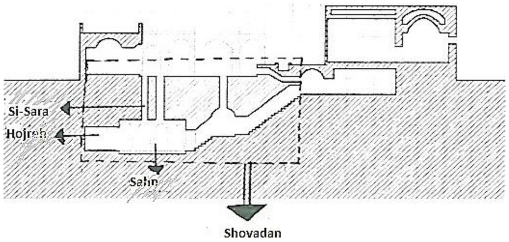


Figure 8. The elements of a Shovadan

Shovadans have vertical canals, called Si-Sara, which are often used for lighting. These canals bring indirect light into space, the skylight of the canal is placed at the surface of the yard. Canals are also used for air ventilation inside Shovadans, arising warm air gets out of the room through them [14]. Vertical airshafts or Si-Saras are placed in Sahn or Hojreh (Figure 9).

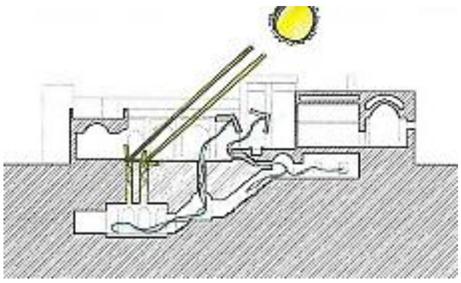


Figure 9. Natural lighting and ventilation of Shovadans (a cross-section of Moein-al-Tojar's house) [17]

Figure 10. The exhibition of old pictures of Shooshtar in a Shovadan

Different methods are chosen for excavated ventilating airshafts according to different environmental conditions, different house positions, and differing architects' solutions. Some Shovadans have been ventilated through wind catchers, natural ventilation has been very common in old Iranian buildings, the most evident example of which is wind catchers.

Wind catchers bring the desired wind into the underground spaces and transfer undesired air to the outside [14-17]. Ventilation in Shovadans also causes decreased temperature in warm months and increased temperature in cold months [18]. Horizontal canals are also excavated so that better air cycling and better ventilation are reached inside Shovadans, in the case of close relationship between neighbors, the neighbor Shovadans were also connected to each other. In some houses, horizontal canals reached rivers and benefited from the desirable air around the river, which brought life to Shovadans with itself [14-17]. In fact, the relation of Shovadans with outside depends on the placement of the building (Figure 11).

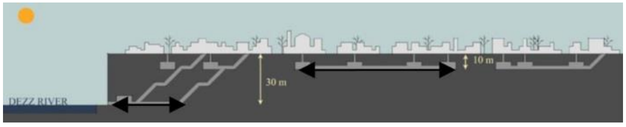


Figure 11. Connector horizontal canals of Shovadans

B.2. Small Garden Pits

In some Iranian traditional houses, the yard and/or some rooms are lower than the natural ground level of the house and alley, this deep hollow yard is called small garden pit. In some houses, the yard has been built one floor deeper and has been dipped into the ground, many advantages were provided by having more connections with the earth. Deep hollow yard provides central order of the building and makes distinction between up and down spaces, its soil could be used for constructing the building, underground waters were used for irrigating yard plants and trees as well as filling water storages, furthermore, the increased humidity and shade in the yard brought desired cool air with itself.

Higher resistance of theses building against earthquake, decreased heat exchange between outside and inside of the building, and decreased thermal fluctuations are among some other advantages of buildings with dipped small garden pits [14, 15, 19]. Lighting of lower spaces is provided naturally and desirably by created fractures at the surface of the yard which have continued downward. Furthermore, one can enjoy the view of small garden pits, the ventilation of spaces is provided by arising warm air going far away from garden pits. In fact, small garden pits provide not only indirect proper light for museums but also natural desirable ventilation (Figure 12).

C. Soil Hills - Buildings Covered by Soil in Historical Village of Meimand

Perhaps the best example of buildings covered by soil in Iran is Meimand village in Kerman province near Shahr-e-Babak. All buildings of this village are like carved caves in the heart of mountains. As all these buildings are placed in the ground and as the soil on the roof acts as a natural insulation and finally as their bodies are integrated stone. Fluctuation of temperature is very low during day and night in these buildings, it helps much in terms of inner spaces heating and cooling, wind and rain don't penetrate into the buildings and they are resistant to fire.

The birth of these buildings goes back to around twelve thousand years ago, and they are not dead yet (Figure 14).

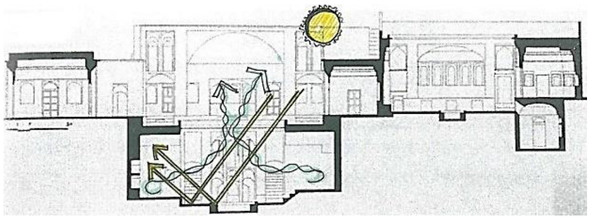


Figure 12. Natural lighting and ventilation through small garden pits (Oloumies' house) [15]

Figure 13. Small garden pit (Oloumies' house) [15]

Figure 14. Faraway view of the village

One of the other most important, useful features of these underground buildings is that because of their placement in heart of ground, a thick layer of earth keeps buildings within itself and repels side energy of earthquake away from inhabitants. Large-scale earthquakes, which occurred in this village many years ago, show strength of this feature of Meimand buildings [14]. Since this village is placed on the slope of a mountain, its lighting and ventilation are provided from only one side.

In fact, one-way lighting is used and the openings, which are placed on the front, are both entrance, exit sites for inhabitants, and provide both light and ventilation, ventilation is, as a result, not of good quality and natural light is, therefore, not enough. Furthermore, spaces in further distances from the openings cannot enjoy proper light and ventilation (Figures 15 and 16).

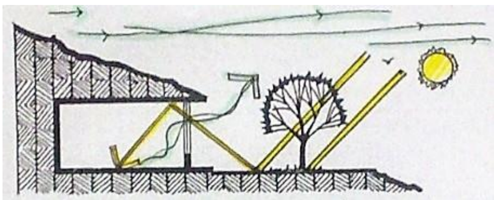


Figure 15. Natural lighting and ventilation of soil-covered buildings [14]

Figure 16. One-way lighting of the buildings in Meimand village

However, the problem of light and ventilation can be well solved by excavating the ground and adding windows and/or skylights. Natural light can indirectly enter the spaces through skylights. The warm air in warm days can also exit from the open skylights, ergo fresh cool air is provided (Figure 17).

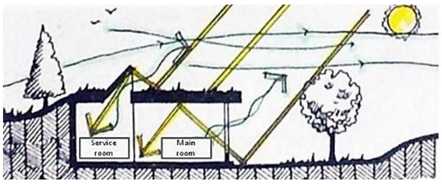
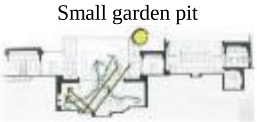
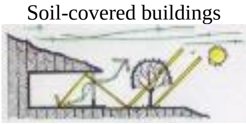


Figure 17. Ceiling light (with the main rooms at the right and the services at the left) [14]

Table 1. Comparison of the underground vernacular architecture samples

Different kinds of underground buildings	Consistency of inner air conditions	Thickness of thermal insulation	The rate of indirect natural light	Natural lighting	Required artificial light during day	The rate of natural ventilation	Natural ventilation method	Required artificial ventilation
Cellar 	Relatively low temperature consistency	Relatively low	Relatively strong	One- way and two-way	It is possible in the case of large areas.	Enough and proper ventilation	Wind catchers + windows between the yard and the hall	No
Shovadan 	Very high temperature consistency	High	Weak	Ceiling	Yes	Proper ventilation	Si-Sara (vertical air shaft) + interrelated horizontal canals + wind catchers	No
Small garden pit 	Moderate temperature consistency	Relatively low	Moderate	Atrium	No	Proper and enough ventilation	Middle yard + wind catchers	No
Soil-covered buildings 	High temperature consistency	Moderate	Weak	One-way	Yes	Improper ventilation	Outward one-way openings	Yes

IV. DISCUSSIONS AND CONCLUSIONS

In design and creation of some spaces, the presence of some particular problems and factors, which are imposed from outside, leads to taking refuge in underground spaces, where buildings are protected by layers of soil. Since underground conditions are different from those of the ground in terms of temperature, especially in depths of 5 to 6 m, underground spaces can be used in summer and winter. In the past, when there were no electrical systems, such as electrical coolers, to bring desired air into building, the excavated spaces in the heart of the ground, including Shovadans, acted as sources of fresh cool air with no need for electrical energy or energies from fossil fuels. In addition, Exploitation of these spaces is still possible.

Ground is, therefore, such a proper source of energy, the value of which becomes even more evident when having a comparison between outdoor and indoor temperatures of the underground spaces. Carved spaces in the heart of the ground not only follow the sustainability of the environment but will also have ideal conditions for underground museum exploitation due to their fixed thermal conditions inside the space, entered indirect weak natural light, proper and natural ventilation, etc., the placement of such buildings itself is as well a perfect item for exhibition. Consequently, responding to some problems in the past vernacular architecture has led to the creation of architecture that is proper for a performance like museum and supplier of its needs, especially in terms of natural light and ventilation.

Comparing different samples of Iranian vernacular underground architecture, one may hopefully conclude with a novel ideal model for underground museums which are environmentally sustainable at large scale as well.

- Excavating underground interrelated canals results in better air ventilation, and using them at large-scale projects is possible as well.
- In a museum, the less the valuable works are affected by unstable outside conditions, the more their life would continue and the more effectively they will be protected. Dipping into the heart of the ground decreases extreme temperatures for the inhabitants. From this point of view, Shovadan is a very proper desired option for underground museums, for seasonal temperature changes effect on its temperature is only about 1 centigrade degree during different months.
- In a Shovadan, although the reinforcement of the entered weak light is possible through use of modern technologies such as light pipes, a proper combination of natural and artificial light can be created in the museums where local and artificial light is also necessary and applicable in addition to natural indirect light.
- Building Shovadans is not possible in areas where underground waters are high or where the weather is very humid, since dipping deep into the ground is necessary for their building.
- In soil-covered buildings, because of constant internal conditions but one-way improper lighting and ventilation, inhabitants' needs are not desirably and ideally satisfied, combining soil-covered buildings with central yards where the spaces are excavated around the yard in the heart of the ground and using skylights, are among the methods that not only bring environmental sustainability but also are very efficient in terms of exploitation of these spaces for museum and proper natural lighting and ventilation. Furthermore, a combination of skylights with modern technologies can be used, skylights act as light sources and cooling systems in sciences academia in California which are opened and closed automatically in warm days and warm air can exit from the building. Not only can one have insulated skylights but also they can be used in combination with central yards.

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