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Underground and Semi Underground Passive Cooling Strategies in Hot Climate of Iran

Fereshteh Beigli*

PhD Candidate, Department of Engineering, La Sapienza University

Rome, Italy

E-mail; febe201415@gmail.com

Ruggero Lenci
Professor Associate
Department of Engineering, La Sapienza
Rome, Italy
ruggero.lenci@uniroma1.it

Abstract— Climate change is one of the most significant threats facing the world today. Buildings are one of the largest energy consuming sectors in the world. Most contemporary buildings are highly dependent on air conditioning systems and electricity, reliant on fossil fuels and increasingly unable to adapt to a warming climate. Iran's hot and cold climatic regions are vast, and significant amount of energy is consumed in these areas for heating, cooling, and ventilation. However, in the same climatic conditions in the past, numerous effective strategies had been used in vernacular residences to confront the harsh circumstances. Traditional buildings in Iran have employed some ingenious passive techniques especially in hot regions in order to restore thermal comfort and coordinate with the local environment and climate. A comprehensive overview of Iranian vernacular architecture principles, in addition to comparative analysis of its elements, shows the dominant effects of natural environmental factors. It is important to note that Climatic issues are considered as the most significant factors in architectural design and have an important influence on architectural development of Iran.

These creative passive techniques have a high potential for today's architecture getting revived to decrease the fossil energy consumption. The main purpose of a research is describing and analyzing the principal and methods of vernacular architectural designs in Shavadan and Shabestan and also sunken garden which are kind of underground and semi-undergrounding building in dry and hot area. The three case studies analyzed in this paper could increase designer's awareness toward environmental sustainable contemporary architecture.

Keywords—passive design, Underground and semi Underground

I) Introduction

Global warming is one of the most critical components of environmental degradation. Global temperature which has risen by over 0.7°C in the last 300 years is predicted to rise by up to 8°C by 2050 in the worst global warming scenario (IPCC, 2007).The building sector is one of the major energy consumers in the world. The proportion of total energy use attributable to buildings generally ranges from 10 - 15% in undeveloped countries to more than 40% in the developed countries.

In Iran statistics show that buildings account for about 39% of total energy consumption (IFCO, 2007). According to a report in "The 2nd conference of Fuel Conservation in Buildings" in Tehran (2003), the amount of energy consumed in buildings in Iran is equal to 30% of its annual oil income (equivalent to US$15 Billion in 2005), with 50% of this being wasted. Using and wasting energy, air-conditioned energy-dependent buildings result in more emissions of green-house gases that drive global warming [8].

Climate has a significant impact on the performance of the building and its energy consumption. Reducing energy consumption, using natural resources and providing comfortable, healthier and sustainable living spaces are the aims of a climatically responsive sustainable building design [7].

A general overview of Iranian traditional architecture values, furthermore comparative analysis of its origins, indicates the prevailing effects of natural environmental factors. In this regard, Climatic factors, considered as the most significant component in natural environment, have a leading influence on the formation of Iran's architecture. As in some cases, forming factors merely serve as a climatically responsive function and have been shaped according to natural

environmental conditions. In Iranian architecture, consistent with the global trend for sustainable architecture, passive architectural strategies, and the maximum use of renewable energies have been used to provide thermal comfort. That being said, passive cooling strategies play an outstanding role in the hot-arid climate of Iran in order to moderate the severe environmental conditions for interior living spaces.

In hot dry area of Iran, Climate had a major effect on the performance of the traditional building architecture and its energy consumption Lack of water and energy sources in these areas forced people to build their houses with some strategies based on minimum energy consumption. Persian vernacular architecture shows the effectiveness and productively of limited sources to gain sustainability faced with severe climate condition. These solutions are remarkable and they are coming from long term experiments [9].

When sustainable design and construction strategies of Iran's traditional architecture are under scrutiny, then it is possible to observe how traditional buildings and settlements in this region were designed in harmony with the local cultural, topographical and climatic conditions and how their design and construction could be integrate in today's design practices. In these regions we can find various strategies and methods which are used in a creative ways to use natural sources for sustainability. Their responses to prevailing climatic conditions have been favorable, like narrow paths and covered passages and underground and semi-underground spaces [7].

These teachings are even more expressive in the contemporary Iranian context with low energy resources and the unremitting escalating needs of an exploding population and also needs for residential building. Moreover learning from the Iranian vernacular have also established their effective thermal performances with respect to existing environments especially the hot-dry and warm-humid climates.

This research focus on underground and semi underground strategies which are call "Shavadan", "Gowdal Baqche" Shabestan in three different cities which are located in hot-dry and hot-humid climate areas of Iran.

A. Underground passive cooling strategy

The various underground building can be seen almost in each part of the world. Significant examples of underground structures used for housing are also found in Asia, some of them are as fallow where the Yaodong cave houses in the Loess Plateau area (China) have a history of more than 4000 years, The Kandovan rock houses are found in Tabriz Iran, [6].

Earth sheltered homes have provided shelter, warmth and security for mankind. They have provided a safe haven for people. Protection from predators and climatic conditions, were among the reasons for going underground Apart from the energy values which the subsurface climate of the earth provides, the other significant characteristics beneficial to earth shelters includes a major goal of recycling surface space by relocating functions to underground. In this way, earth shelters liberate valuable surface space for other functional uses and improve ground surface visual environment, open surfaces for landscaping and thus a greener atmosphere [1].

Earth-sheltered buildings offer also other benefits, such as:

- Lower building maintenance costs (smaller surface area of exposed building envelopes)
- better noise and vibration damping (earth dampens well the amplitude of acoustic waves)
- An earth-sheltered home is less susceptible to the impact of extreme outdoor air temperatures [15].
- Other advantages cited by the DOE include protection against the extremes of Mother Nature, such as high winds, hailstorms, tornadoes, hurricanes and earthquakes; less susceptibility to fire; lower insurance premiums; less maintenance; natural soundproofing; conservative use of land and natural resources[12].
- Non-governmental groups usually add a few more advantages. Most say that a buried house provides maximum protection from not only natural disasters but man-made ones, such as explosions, nuclear accidents, burglaries and break-ins. Many claim that earth-sheltered homes are the only way to gain total privacy. Still others like having the ability to grow your food on top of your house

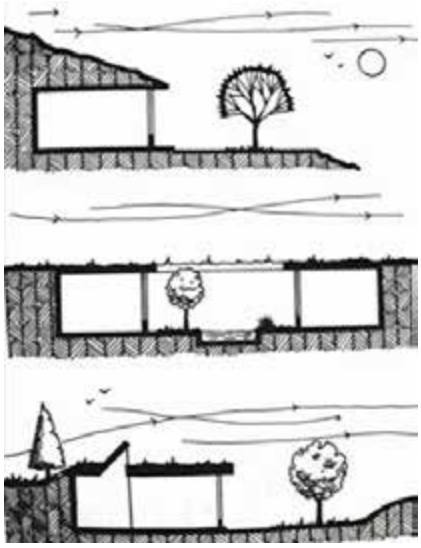


Fig.1 the placement of building inside the ground [4]

Providing thermal comfort to their inhabitants is the main function of these underground buildings. Although it would be difficult to maintain thermal comfort without using mechanical equipment, in Earth-sheltered buildings this problem has been solved The underground buildings are one of the vernacular methods which used in hot-dry and warm-humid to solve this conflict by reaching high thermal comfort with minimal use of energy consumption.in "Fig. 1,"shows some sample of building which located inside the ground.

II. *Shavadan*

The harsh ecological conditions in some parts of Iran have made past architects emphasize the harmony between the buildings and nature and design the buildings based on ecological foundations. The architects in Dezful and Shooshtar, which located in hot and semi humid regions, need to battle the common summer conditions of fifty degree temperature and fifty percent relative humidity to reach thermal comfort, for solving this problem digging rooms as deep as 5–12 meters that one can accesses through many stairs was a suitable option for settlements and was in harmony with the ecology of the region [15].

Fig.3. Shavadan in Moinotojar's house

These parts of houses "Fig. 2," in some Iranian old houses allow people to live in different seasons of the year. Because Shavadan has been used in winter for heating and in summer for cooling purposes when the ambient temperature is 8℃ during winter and 47 ℃ in July, Shavadan average temperature is 17 ℃ and 23 ℃, respectively. The suitable Shavadoon temperature range proves the ability of this space in for saving energy.

This underground strategy is one of the most innovative types of sustainable architecture in Iran which has been heavily used inDezful [9].

The history of Shavadoon can be recognized simultaneously with the appearance of the first signs of civilization in Dezful (Sassanid era – AD 224).

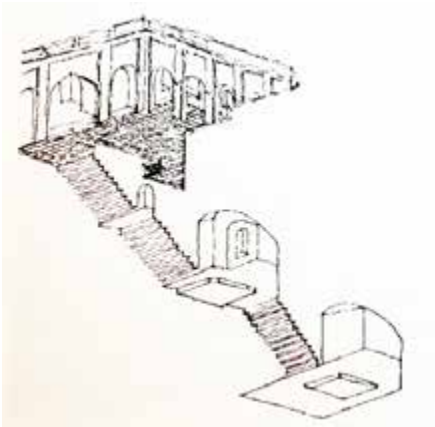


Fig.2. Shavadan in Dezful [10]

According the researchers the Qajar and Pahlavi eras (1785–1979) are in the peak of using of Shavadoon, But with increasing urbanization and technological developments this space has been left abandoned. In the late 1970s Shavadoon construction was not seen anymore. As the war started in 1980 and missile attacks on Dezful began, the role of Shavadoon was changed and they were used as civil defense shelters but after that they fell into disuse again.

The efficiency of the shavadan is deeply depended on their volume and depth. For instance increasing their volume and depth will help to be more efficient in term of sustainability [3].

A. *Different componenets of shavadan*

Shavadan consists several parts such as: entrance, stairs, main hall, kat (Sahn), stairs, main hall, kat (Sahn)

Fig.4 entrance of shavadan [3]

- Entrance: Shavadan has a relatively wide entrance(1.8m-1.2m) which is generally situated in corner of the yard and commonly it does not have

door so for providing security it is Surrounded by walls.(parapet)

- Stairs: Shavadan can be accessed by stairway "Fig. 4," which is situated in Shavadan's entrance corridor and continued the Shavadan's floor and its slope is more than nowadays stairways [3].

- Sahn:(MainHall) Sahn is the main part of the Shavadan and has a squar shape plan and in some cases has polygon plan.In large Shavadans the diffrence level of floor with other part create new identity with different function. Generally as a unifying factor Sahn connects different parts of the Shavadan.

- Kat: Except for one wall which is connected to the stairway, the other three walls are linked to small rooms which are called kats and separated with a maximum of the one stair from the floor. These are considered more private parts of Shavadan.

- Tal: In some cases Kats are connected by a tunnel or gate to the neighboring Shvadan which is named Tal. These tunnel not only connect different shavadans together but also cause air flowing in this places.

- Darize: "Fig. 5," without exeption in some roof of Kats or Sahns small window is situated in the roof of Kats and Sahns in order to ventilation which is named darize(small door).

Fig.5.Darize

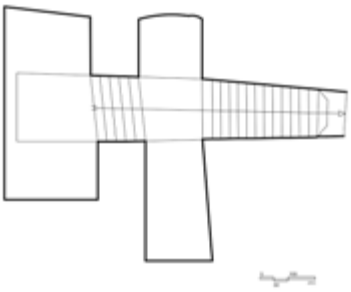


Fig.9.plan of Shavadan-Shayegan House

Fig.6.Shavadan plan in Seyed Sadr House[20]

Fig7.section of Shavadan-Seyed Sadr House

Fig.8.section of Shavadan-Sadr House

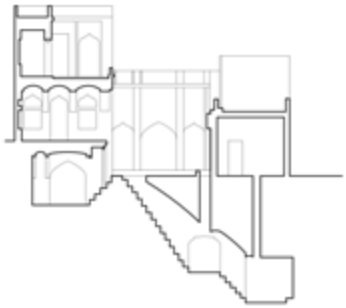


Fig.10.Section-Shayegan House, Dezful

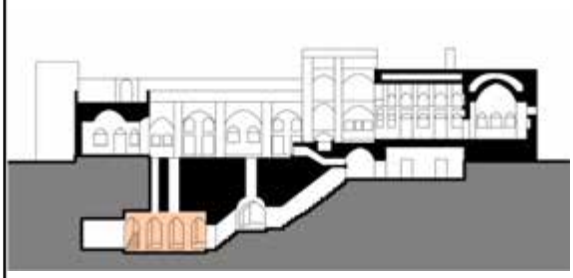
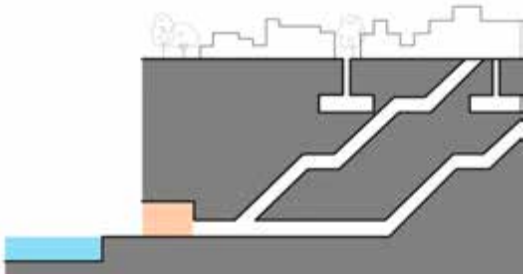
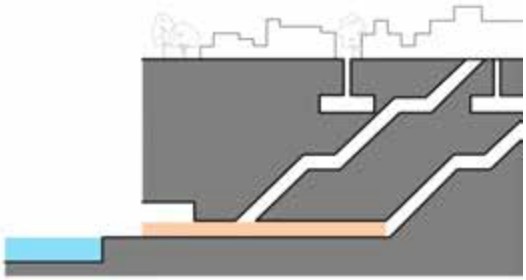
Stairway	• Shavadan can be accessed by stairway which is situated in Shavadan's entrance corridor • its slope is more than nowadays stairways	
	• Sahn is the main part of the Shavadan and usually has a square shape • Sahn connects different parts of the Shavadan together • Most activity of occupants happen in this part	
Vertical Canal Si-Sara	• placed in the level of yard • Using as air ventilation inside the shavadan • Providing the light	
Kat	• small rooms which separated with a maximum of the one stair from the floor. • These are considered more private parts of Shavadan	
Underground passage	• Horizontal narrow canals connect neighboring Shavadan to each other • Make connection between Shavadan • Improve air following	

Fig.12Components of Shavadans

B. analyzing the temperature of the shavadan in summer

Table I indicates information about five different houses which located in different part of the city and also shows depth of the Shavadan in these houses.

Table 2 provides information about the average of the temperature in different month of the summer. Glance at five types of Shavadans, on average, the temperature is around 25℃ however, the lowest degree temperature in five warmest months of the year is recorded for A3.

This reduction of the temperature and more comfortable thermal condition can be attributed to two main reasons first for high depth and second for city location which is situated in old historic center. By contrast the highest degree is recorded for A2 and A4 which their entrances do not have direct access to outside [3].

Table II: Samples temperature in summer

Date	A1	A2	A3	A4	A5	Average
22-Jun	25	25.3	24.5	25	24.5	24.86
23-Jul	25.5	25.8	25.5	25.7	25	25.5
23-Aug	26.5	26	26.2	26.5	26	26.24
23-Sep	26.5	26.5	26.2	26.5	26	26.34

TableIII. Inside and Outside Temperatures of Shavadan in Summer

Date	*inside temperature*	Outside temperature		
		Minimum	*Maximum*	*fluctuation*
22-Jun	24.86	25.25	45.5	20.25
23-Jul	25.5	27	46	19
23-Aug	26.24	28.5	45.5	17
23-Sep	26.34	21	40.5	19.5

It can be clearly seen that, although the temperature of the outside increase dramatically during summer and reach to 45℃ on June, the inside temperature remain relatively unchanged. It is obvious that stability of temperature helps occupants stay more comfortable. Accurately in this case inside temperature was cooler during summer without using any mechanical systems.

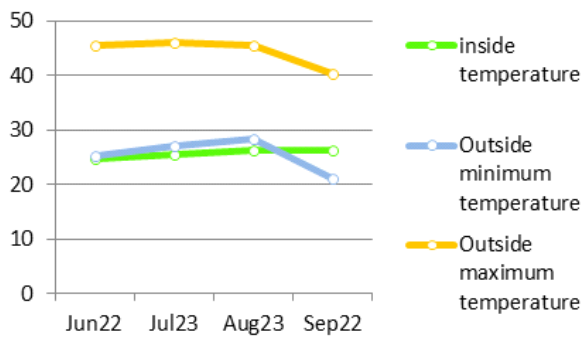
Moreover, the depth of the Shavadan has significant effect on inside temperature.

According to the table, the highest depth was recorded for A3 which has coolest temperature during summer.

Table I. Case Studies

code	Owner name	Depth (m)	Location
A1	Mohammed Hussain Bina	7	on the border of the old urban texture North of City
A2	Mohsen Bina	7.30	out of the old urban texture, North East of city
A3	Tizno	11	In the center of the old urban texture, City center
A4	Dideban	7.70	on the border of the old urban texture, City center
A5	Seyed Mehdi Purmusavi	8.50	out of the old urban texture, South of city

Chart1: Comparison between outside and inside temperatures of Shavadan in summer



C. *analyzing the temperature of the Shavadan in winter*

The table shows that there is significant change in the temperature of the Shavadan during the winter. Because of the cold weather however the internal temperature of it is only 3°C under thermal comfort .it is evident that in this situation it does not need to use mechanical heating [3].

Table IV. samples tempretures in winter

Date	A1	A2	A3	A4	A5	Average
22-Dec	18.5	19.2	18	19	19	18.75
21-Jan	17.2	17.8	17	18	18	17.6
20-Feb	19.5	19.5	18.2	19.5	19	19.18
21-Mar	20.5	20.5	19	20	20	20

TableV. Inside and Outside Temperatures of Shavadan in winter

Date	*inside temperature*	Outside temperature		
		Minimum	*Maximum*	*fluctuation*
22-Dec	18.75	10.5	16	20.25
21-Jan	17.6	5	12	19
20-Feb	19.18	7.5	14.5	17
21-Mar	20	9	14.5	19.5

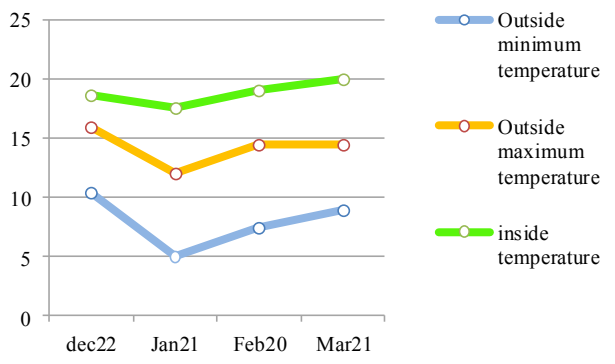


Chart2: Comparison between outside and inside Temperatures of Shovadan, in winter.

D. Analysising passive cooling strategies in shavadan

- *Ground stable temperature*

the desirable thermal conditions in the Shavadan is due to different factors, one of the important one is temperature stability of the ground on an annual cycle, and also the thermal mass of the ground to store the cool of the night and use it during the day to adjust the temperature of the Shavadan.
The temperature of the lower regions of the earth crust is about 800C, and for each 100 m increase of the height, the temperature drops 3°C and this temperature reduction continues until the temperature of the earth outer crust reaches the ambient temperature. This part of the crust is the part that we live on. As the depth is increased below the ground surface, the daily temperature change which is 17°C aboveground is reduced to only one degree at a depth of only affects one degrees on the 1 m underground and, at a depth of 5.6 m, the annual temperature change does not affect the ground temperature .So, we can store the coldness of the winter and the warmness of the summer for 6 months, a delay which in the summer season can use this coldness for providing the thermal comfort .To gain a better picture of the actual conditions, Fig. 5 shows the temperature difference in Shavadoon space and living space aboveground over an annual period.[15].

- *Natural ventilation*

Natural ventilation is the supplying and removing air through an indoor space without using mechanical systems. It refers to the flow of external air to an indoor space because of pressure or temperature differences. There are two types of natural ventilation occurring in buildings: wind driven ventilation and buoyancy driven ventilation. While wind is the main mechanism of wind driven ventilation, buoyancy-driven ventilation occurs as a result of the directional buoyancy force that results from temperature differences between the interior and exterior [15].

In Shavadans vertical canals, “Si-Sara” which are used more often in order to get light. These canals enter the light into the space, indirectly; the skylight of the canal is placed in the level of yard. (Figure 6) Furthermore, canals have been using as air ventilation inside Shavadan through arising warm air to the outside and using chimney property .Vertical air shafts or Si-Sara are placed in Sahn or Hojreh[16].

According to environmental conditions, house position and architect’s solutions, different ways are chosen for excavated air shafts in order to ventilate. Some Shavadans have been ventilating through wind catcher; natural ventilation of the building in traditional buildings of Iran has had many applications that the most evident one of them is wind catcher. Wind catcher enters the desired wind into the underground spaces and transfers undesired air to the outside. Ventilation in Shavadans also causes temperature decrease in warm months and temperature increase in cold months. In fact, the relation of Shavadans with outside depends on the placement site of the building.

III. Shabestan

There is an underground space in some hot arid area of Iran as well as Dezful and Shushtar which was called "Shabestan", Shabestans depth is just 3-5 meters under the ground level comparing with Shavadan, part of the building is under the ground.''Shabestan'' is a space in the basement floor, which is half height and located under the ground level.

A) Passive cooling strategies in Shabestan:

Fig.13.Tiznoo House in Dezful

Location of the building:

The Height of this place is about 3 meters. One third of it is above the courtyard and rest of it is in the ground. Even located part of the building in the ground helps to create convenient and appropriate place during the year. One of the important factors like previous strategy, high thermal mass materials conducts a significant proportion of incoming thermal energy deep into the material then re-radiates heat at a lower temperature so this is the best option in hot climate that have large swings of temperature from day to night. Like other vernacular techniques traditional builder used limited resources to achieve maximum comfort.

Fig.14.Tiznoo House

Fig.15. entrance of Shabestan

Fig.16.View of the windows in Shabestan

B) Ventilation:

Lighting and ventilation in the ''Shabestan'' room are provided through windows located between the courtyard and the ''Shabestan'' [18].

Although in the hot summer days the ''Ivan'' space is completely shadowed, it is not useful in the day and since it is not always possible to sleep on the roof during the night, residents go to ''Shabestan''. However, if they cannot bear the temperature of the ''Shabestan'', the ''Shavadan'' is a more comfortable and cooler place [5].

It is usually a few degrees colder than the ambient temperature and two or three degrees warmer than the deep Shavadan's surface temperature. Usually its

entrance is located at the staircase, but in some cases, such as Azar-Abad house, it is located outside [15].

IV. sunken Garden

Fig.17.Sunken Garden Abbasian house

Fig.18. View of Sunken Garden- Abbasian house

Gardens are inseparable cultural elements of the cities in hot and dry cliamete . Beside the courtyard there are different kind of yard in hot climate city like Kashan, Naeen, Yazd which called "Sunken Garden .In Persian language "sunken" means fossa and "Baqche" means small garden. The Sunken Garden was a distinctive yards designed as a living space in hot arid area of Iran. It is surrounded by rooms in four side of the yard and predominant terraces or porches in ground floor level. This kind of houses with sunken garden has wind catcher located in one side of it. There is no valid evidence to show the first creation of Gowdal Baqche but it was popular in Safavid era.The Abbasi House is a large traditional historical house located in Kashan, Isfahan Province, Iran in which selected as a case study for analyzing Sunken Garden. This house has two courtyards (Sunken garden) which are illustrated in "Fig.14"and "Fig15".

Fig.19. Sunken garden view from ground floor- Abbasian house

Fig. 20.Abbasian house plan

It is evident that these types of buildings provide appropriate temperature condition some of them are as follow:

- protecting house from the harsh winds of desert
- providing cooling space
- Decreasing temperature fluctuation of internal space

Fig.21.Sunken Garden of Abasian House

The entrance usually consists of stairways or graded tunnels leading to the interior courtyard with L-shaped corridor to insure privacy. The vernacular rooms in sunken courtyards are usually raised out from the courtyard surfaces, and are usually long and narrow in the lower level, and smaller in the upper level. The ceilings are usually vaulted to accommodate day lighting and ventilation needs. The typical dimensions of the rooms are 4-5 m wide and 8-10 m long with a height of about 3 m for the large rooms, and between 3-4 m wide and 4-5 m long with a height of 2-5 m for the smaller ones. The soil cover from the ground level reduces the heat gain and heat loss in to and out of the building. For vernacular buildings this meant thermal stability which led to thermal comfort.

Fig.22. Ground floor plan of Abbasian House

A. Thermal benefits of sunken courtyard buildings

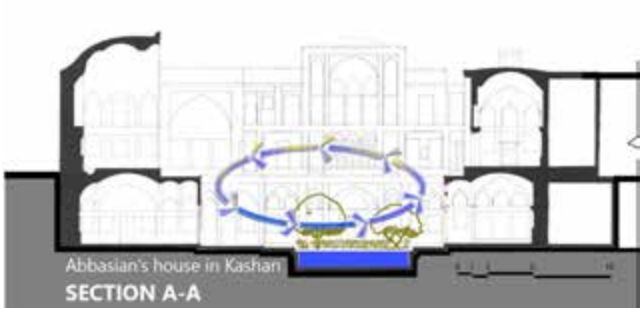


Fig.23

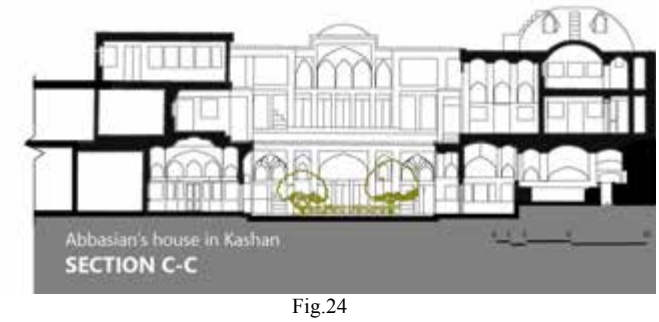


Fig.24

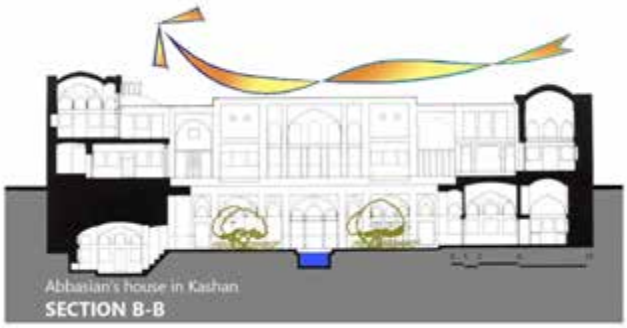


Fig.25

The courtyards as one concept, and underground as another, each possess unique means for modifying the climate to a certain extent, but when they are integrated as in the sunken courtyard building their combination provides integrated thermal interaction which is highly effective in modifying the climate.

1) Thermal advantage of sunken courtyard

- The elimination of the solar radiation from reaching the roof and all embedded walls thus reducing the effect of one major heat gain sources in desert buildings.
- Second advantage is the reduction of infiltration rate which is another major heat gain source in desert buildings. The joints between cladding components and around frames are major sources for infiltration in a typical aboveground building, however, infiltration rates are significantly reduced in earth-sheltered buildings, thanks to its buried walls.
- Third, heat gain through the embedded walls and roof is also greatly reduced since the temperature of the surrounding environment (soil) is lower than the air temperature of the outside in the summer season.

- Placement of tree and planet beside the pool or pond keep the building cool in other ways beside offering shade they create a cool microclimate that can dramatically reduce the temperature.

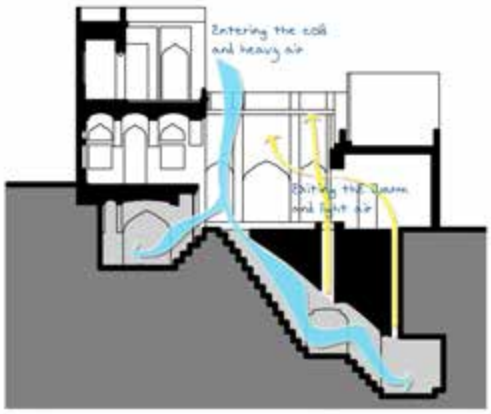


Fig.26. Ventilation in Sunken Garden

2) Important factors of passive cooling strategiy

- Soil : While the soil covers most of the building envelope and isolates the building from the direct impacts of the stressful desert climate, the courtyard becomes a source of light, fresh air, and interaction to the outside environment without the extreme conditions. Although the solar radiation is not completely eliminated as in the case with soil cover, the courtyard geometry itself shades at least two of the courtyard wall surfaces and part of the courtyard floor surface.
- Most of the courtyard designs in were noticed to incorporate some tree planting in the courtyard which further improves the cooling effect as illustrated in"Fig.23".
- Pool: the placement of a pool of cool air contained within the courtyard. The modified air, due to the garden and water fountain located in the courtyard, cannot escape anywhere except to the interior rooms resulting in a lower heat gain rates to the courtyard surfaces. This integration between earth-shelter and courtyard concepts, which exist in sunken courtyard design, provides an effective climate control system.

V) Result:

This paper discussed the suitability of Shavadan, Shabestan and sunken Garden concept in the hot and hot humid climate using Iran as a case study. It demonstrated investigated different forms of underground vernacular architecture.

The research should help to increase concerns and awareness of energy efficiency in vernacular architecture and it is expected that the results will contribute positively to design in Hot and humid climates by providing useful ideas for applying vernacular passive technologies. Vernacular passive-cooling technologies can provide us with the inspiration for new and innovative approaches to the design of adaptive and appropriate dwellings for hot and humid climates and give us an indication of our ability to survive in such regions without using mechanical systems By investigating the factors affecting the success/failure of vernacular building strategies, it should be possible to propose the means for successful future implementation of energy impressive community-based housing programmers. It can be claimed that in terms of today's sustainable technologies and people's request, vernacular climatic strategies can influence declining natural ventilation. Vernacular techniques can be revived, modernized altogether and get involved with new

technical passive and active sustainable strategies, and help to reduce fossil energy usage.

the study indicates that these strategies would be suitable alternative for modern contemporary building because shortage of land to accommodation and energy saving purpose and sustainability.

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