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Zero Carbon & Low Energy Housing; Comparative Analysis of Two Persian Vernacular Architectural Solutions to Increase Energy Efficiency

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***Abstract*—**In order to respond the human needs, all regional, social, and economical factors are available to gain residents' comfort and ideal architecture. There is no doubt the thermal comfort has to satisfy people not only for daily and physical activities but also creating pleasant area for mental activities and relaxing. It costs energy and increases greenhouse gas emissions.

Reducing energy use in buildings is a critical component of meeting carbon reduction commitments. Hence housing design represents a major opportunity to cut energy use and CO_2 emissions.

In terms of energy efficiency, it is vital to propose and research modern design methods for buildings however vernacular architecture techniques are proven empirical existing practices which have to be considered. This research tries to compare two architectural solution were proposed by Persian vernacular architecture, to achieve energy efficiency in hot areas.

The aim of this research is to analyze two forms of traditional Persian architecture in different locations in order to develop a systematic research and sustainable technologies on adaptation to contemporary living standards.

***Keywords*—**Comparative Analysis, Persian Vernacular Architecture, Sustainable architecture.

I. Introduction

PERSIAN vernacular architecture shows the effectiveness and productivity of limited sources to gain sustainability faced with severe climate conditions. These solutions are remarkable as there were no modern technology to make the life pleasant.

These techniques vary with materials, construction methods and the style of architecture. Architecture structure is a beauty component while added strength and stability and accounted sustainability. They are coming from long term experiments therefore tracking them has not been limited for one region or same type of architecture.

The severe climate condition of hot located in most part of Iran. According to their climate charts, mild weather and thermal comfort may only occur for a short term of year.

Ecological condition of this region requires dense architecture context and shadow design with air currents. Traditional cities were fully designed by narrow lanes and covered passages. "Shavadan" and "Gowdal Baqche" were the solutions which were found in hot-humid and hot-arid area of Iran.

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II. Climate of Iran

As it was mentioned the climate of Iran is varied according to the vast geographical locations, Fig. 1. Iran is basically divided into four climatic regions:

- Mild – Humid Climate
- Cold Climate
- Hot – Humid Climate
- Hot – Arid Climate [1].

Hot-arid Climate prevails in most parts of the central Iranian plateau, it receives almost no rain for at least six month of a year, and hence it is very dry and hot. In this climate, summer is very hot and dry and winter is very cold and hard. In this area, there are very few clouds in the sky for most of months of a year hence there is almost no humidity [2]

Fig. 1 Climatic zone

Iran's Hot-humid region lies along the narrow 2000km littoral strip on the Persian Gulf coast. In this area they have long summers and long winters. There are very high levels of evaporation and air humidity because of its proximity to the sea and there is high vertical solar radiation in both spring and summer [3].

Shushtar and Dezful are two cities located in hot-humid climate. Their humidity varied from 42% to 21% in summer. The maximum temperature reported during last 10 years in Dezful is 48°C and the minimum is -3°C comparing to Shushtar with 52°C maximum and -6°C minimum temperature [4].

Kashan and Yazd are two cities in the middle of Iran with Hot-arid climate. The maximum temperature reported during last 10 years in Kashan was 45°C and the minimum was -10°C comparing to Yazd with 46°C and the minimum of -20°C. Their relative humidity typically ranges from 8% (very dry) to 85% (very humid) over the course of the year, rarely dropping below 8% (very dry) [5].

III. Shavadan

"Shavadan" or "Shadan" is a deep underground space (5-12 meter depth) in Persian traditional houses of some Iranian cities which was created during Safavid era[1]. It was utilized sustainable heating and cooling from the earth [6].

It should be noted that there was an underground space in some hot arid area of Iran as well as Dezful and Shushtar which was called "Shabestan", Fig. 2. Shabestans depth is just 3-5 meter under the ground level and higher than Shavadan [7].

Fig. 2 Shabestan, Iran

There is some definition for the word of "Shavadan". Among all of the definition, Dr Pirnia's definition makes more sense and seems much more reasonable. In local dialects of Iran, Shavadan means a place (space) which is underground [8].

There is no valid evidence of first Shavadan emersion in Iran. According to the history of the cities and its historical buildings, such as the Cathedral Mosque of Dezful and its Shavadan, historians and researchers believed that the first Shavadan might be born during Sassanid Empire2 [ibid].

Most of Shavadans were highly in used until the invention of air conditioning systems then they were abandoned for a while. In 1980 and during the Iran and Iraq war, they were reused as a trench and shelter when airstrikes took place. After the war in 1988, some of these Shavadans were closed and some others were used as storage [9].

The level of subterranean water is low in two cities of Dezful and Shushtar and it gives deep space to the formation and expansion of a Shavadan under the earth. In other cities of Khuzestan County such as Ahwaz and Khoramshahr, it is impossible to dig down Shavadan because they are so close to the sea level. The cities of Dezful and Shushtar are 140 and 150 meters above the sea level and 2-30 meters higher than Dez River, Fig. 3.

[1] Was one of the most magnificent dynasties of Iran(1501-1722)

2 was the last pre-Islamic Iranian Empire, ruled by the Sasanian Dynasty from 224 CE to 651 CE

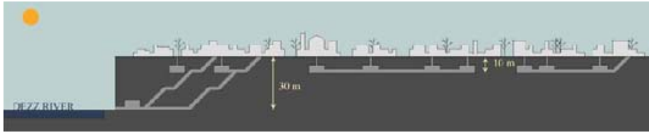

Fig. 3 The level of Shavadan and Dez River in Dezful

As Geology science, the conglomerate texture of the earth enable these cities to deeply excavate however "Dezful" has a rubble bed, and can provide an appropriate substrate for installation of Shavadan compared to Shushtar. Furthermore the ventilation is performed easily by the pore of the earth. Therefore the Shavadan space is more chilly, dry and functional. However Shushtar with rock and clay soil seems to be hard to create a Shavadan space under the earth, then it was necessary to be roofed properly [10].

IV. Shavadan Structure

Each Shavadan space has the following component, Fig. 4:

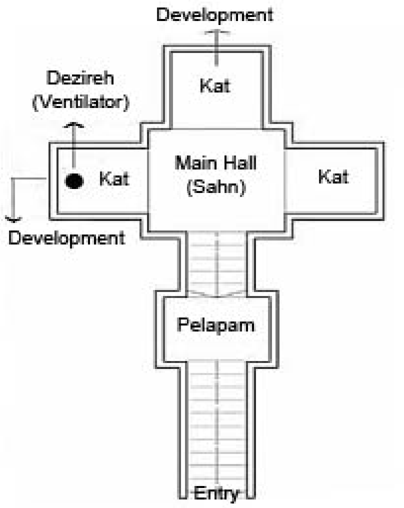

Fig. 4 General plan of Shavadan

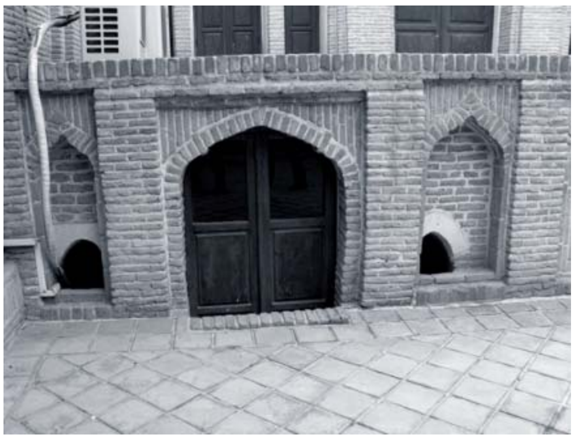

Fig. 5 Entry of Shavadan from the Yard

The function of Shavadan based on two principles: utilizing the geothermal energy and natural ventilation, Fig. 6.

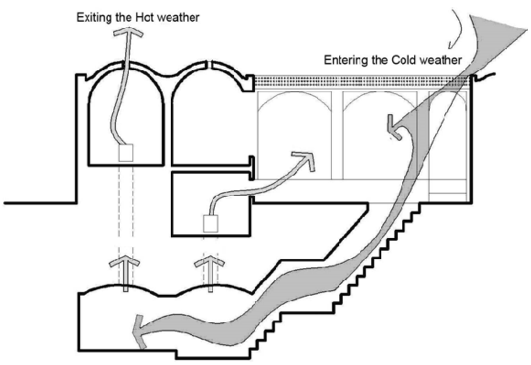

Fig. 6 Air movement in houses with Shavadan

It has to be considered that Shavadans are also following the basic rules of Persian vernacular architecture such as Space hierarchy and could create a hetero place with different temperature and function.

V. The Study of Shavadan Temperature

For optimum result, five Shavadan were selected from different places with deferent depth in Dezful city, Table I. The average temperature of Shavadans on the 1st day of each month of summer is registered. The table shows that the third Shavadan (S3) and the fifth one (S5) are colder than others. The coldness of S3 might be referred to its depth and location which is inside the traditional part of the city. In contrast, the S5 located in contemporary context and it is not as deep as S3. Therefore it can be concluded that depth is as important as location.

The second Shavadan (S2) is the hottest one during the first and second month of summer. However on 23 August, the S1 and S4 had the highest temperature of the whole summer. The conclusion is: A shallow Shavadan in comparison to the deepest one are hotter. Further research showed that S2 and S4 have not been connected to outdoors directly and it might be critical reason for highest temperature.

TABLE I
Average Temperature of Shavadan, 2006

Shavadan	Location	Depth (m)	Average temperature (°C) 22 June	Average temperature (°C) 23 July	Average temperature (°C) 23 August
S1	Border of traditional context North	7	25	25.5	26.5
S2	Contemporary context in N-East	7.3	25.3	25.8	26.2
S3	Traditional context in Centre	11	24.5	25.5	26
S4	Border of traditional context Centre	7.7	25	25.7	26.5
S5	Contemporary context in South	8.5	24.5	25	26
Average temperature			24.86	25.5	26.24
The temperature of the city (outside of Shavadan) (°C)		highest	45.5	46	45.5
		lowest	25.25	27	28.5
		fluctuation	20.25	19	17

Also we can conclude from Table I: Average temperature of all Shavadans is lower than the lowest temperature of the city in spite of high fluctuation of temperature during a day.

The stability of the temperature in Shavadans is the most interesting point. The fluctuation temperature for a month is less than 1°C.

Table II shows the temperature of the same Shavadans during winter time. The table shows that the third Shavadan (S3) which is deeper is colder than others. And the warmest one are the second (S2) and the fourth Shavadan (S4). The same result comes out of the table for the winter time. It means the inside temperature does not influenced by outside climate change.

We can conclude that the temperature of Shavadan is similar in summer and winter, means a Shavadan is usable and available for four seasons.

TABLE II
Average Temperature of Shavadan, 2006

Shavadan	Location	Depth (m)	Average temperature (°C) 22 Dec	Average temperature (°C) 21 Jan	Average temperature (°C) 20 Feb
S1	Border of traditional context North	7	18.5	17.2	19.5
S2	Contemporary context in N-East	7.3	19.2	17.8	19.5
S3	Traditional context in Centre	11	18	17	18.2
S4	Border of traditional context Centre	7.7	19	18	19.5
S5	Contemporary context in South	8.5	19	18	19
Average temperature			18.75	17.6	19.18
The temperature of the city (outside of Shavadan) (°C)		highest	10.5	12	14.5
		lowest	10.5	5	7
		fluctuation	5.5	7	7

Table II also shows the average temperature of Shavadans is also higher than the maximum temperature of outside in winter time.

VI. Persian Sunken Garden (Gowdal Baqche)

“Gowdal Baqche” or Sunken Garden is a formal yard was constructed below ground level (one floor) in Persian traditional courtyard houses which was created during Safavid era3. It was utilized sustainable heating and cooling from the earth in hot arid area of Iran, cities of Yazd, Kashan and Nain [11].

“Gowdal” in Persian language means fossa and “Baqche” means small garden.

Fig. 7 The Sunken garden in Abbasian house, Kashan, Safavid era

The Sunken Garden was a typical yards designed as a living space in hot arid area of Iran. It is surrounded by rooms in four side of the yard and normally has wind catcher (Badgir) located in one side, Fig. 8.

There is no valid evidence to show the first creation of Gowdal Baqche but it was popular in Safavid era [12].

Fig. 8 The Sunken Garden and Badgir

The yard is located on basement rather than ground floor and was surrounded by predominant terraces4 or porches in ground floor level. The terrace was roofed in some houses.

Deep garden yard helps to move air and cool the house. In the other word, garden yard as a 3D space was a main element of designing a house [ibid].

Houses with “Gowdal Baqche” usually were constructed in three floors: Ground floor, basement with The Sunken Garden and in some cases lower basement. But some of posh traditional houses belonged to the rich or famous people in ancient time, had more than one floor on top of the Garden such as Abbasian house in Kashan, Fig. 10 [13].

3 Was one of the most significant ruling dynasties of Iran(1501-1722)
4 Called “Mahtabi”

In Kashan city, the Sunken garden is a typical space for every house. In luxury houses it was changed by the size and ornaments such as painting and Stucco.

Fig. 9 View from Terrace in ground floor to the Sunken Garden, Abarghoo, Yazd

Fig. 10 Abbasian House, Kashan, two floors on top of basement

In hot arid area of Iran, the underground water was too deep therefore the Sunken garden on basement increases accessibility to the underground water. Garden yard normally has a small pool in the middle and watered down with conduit passages from one house to another and creating a pleasant space [ibid].

In city of Nain, where water was supplying with deeply underground channels5, Sunken gardens designed by a pool and water flowed over channels. Pomegranate trees, Pistachio and fig trees were the most popular plant in Sunken gardens adapted to the climate.

[5] More than 3,000 years ago the Persians learned how to construct aqueducts underground (***Qanat*** or in Persian *Kariz*) to bring water from the mountains to the plains. In the 1960's this ancient system provided more than 70 percent of the water used in Iran and Nain is one of the best places in all the world to see these Qantas functioning

Fig. 11 Rigareh water channel, 28 meter under the ground

In conclusion, subterranean geothermal and moisture, water and green spaces were zero carbon solutions not only cool the house in hot season but also warm the house in winter. In addition it caused a building to be soundproof and Earthquake resistant.

Besides, the soil from digging was transformed to brick as a sustainable material to build the house.

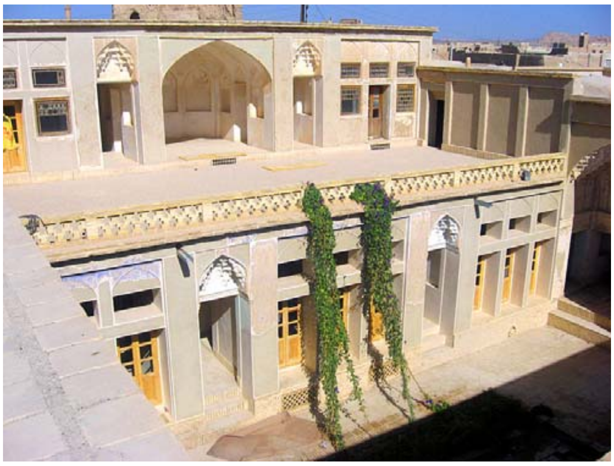

Fig. 12 Fatemi House in Nain, Safavid era

The difference between the levels of alley to the Sunken Garden is 7-10 meters in Kashan houses and the temperature difference is between 15-20 degrees [14].

The sunken garden was not designed just for the houses; it was also constructed in public houses such as Mosque, Caravanserai Fig. 13.

The formal shape of the Sunken garden is square and it was designed in octagon shape in few cases.

Fig. 13 Aqa Bozorg Mosque in Kashan (1778)

Fig. 14 Square shape of Sunken Garden, Aqa Bozorg Mosque in Kashan (1778)

Fig. 15 Olya religious School, Ferdows city in Khorasan estate (Safavid era)

Some of the rooms in basement level adjacent to the Sunken garden was hollowed the earth deeply and has long length Fig. 17.

Fig. 16 Abbasian House, Kashan, view from inside room of basement

Fig. 17 Balal House, Kashan, Pahlavi era, 12m length of the room in basement floor

VII. THE TEMPERATURE STUDY OF THE SUNKEN GARDEN AND ATTACHMENTS

For optimum result, two houses with the Sunken Garden were selected in Kashan city. The average temperature of the rooms attached to the Sunken garden was registered on three months of summer and winter (Tables III and IV).

TABLE III
TEMPERATURE TABLE IN SUMMER 2009

	Average temperature in June	Average temperature in July	Average temperature in August
The temperature of the city	45	48.5	43
The Sunken Yard	32	33.5	31.5
Case study 1	23.15	25.35	23.55
Case study 2	25.25	26.25	25.25
Average temperature	24.2	25.8	24.4
The difference between adjacent rooms in average of case studies with the temperature of the city	-20.8	-22.7	-18.6

TABLE IV
TEMPERATURE TABLE IN WINTER 2009

	Average temperature in December	Average temperature in January	Average temperature in February
The temperature of the city	4	1	7
The Sunken Yard	14	12	19
Case study 1	9.25	7.55	11.35
Case study 2	11.25	10.5	14.15
Average temperature	10.25	9.025	12.75
The difference between adjacent rooms in average of case studies with the temperature of the city	6.25	8.025	5.75

Table III shows the dropped temperature at rooms adjacent to the Sunken garden varied from 18.6 to 22.7 degrees in summer as well as decreasing temperature inside the sunken garden from 12 to 15 degrees.

However the difference temperature between inside the basement level and the city is varied from 5.75 to 8.025 degrees in winter but the higher temperature in the Sunken garden is considerable.

VIII. CONCLUSION

While the world is facing crises of energy, utilizing renewable energy in building is preventable. Applying and developing the current vernacular techniques such as Shavadan and the Sunken garden are not only useful for Iran but also it is capable to apply for many other countries with some changes. They are multipurpose spaces which are suitable for four seasons.

Although the slight difference temperature in winter is not enough to create pleasant space, there is potential to apply other techniques for passive heating.

REFERENCES

[1] M. H. Ganji, *The Atlas of Iranian Climates.* Tehran: University of Tehran, 1964, pp. 15–64.
[2] H. Fathi, "Natural Energy and Vernacular Architecture" Chicago: The university of Chicago, 1986.
[3] M. Kasmaee, *The guide of designing in Iran climate conditions,* Tehran: University of Tehran, 2001.
[4] M. Robobi, F.Rahimi, "Shavadan and Shabestan", *Asar, vol.2, 3, 4*. Tehran: Iran Statistic Centre, 2009, p.192-208.
[5] M. Bina, "Analysis of Shavadan in Dezful houses", *Fine Arts, vol.33.* Tehran, 2008, p.37-46.
[6] N. Pigulevskia, *Iranian cities during Partian and Sasanid,* Ed: R.Ayatollah, Tehran, 1998.
[7] L. Zamani, N. Barshadat, "Architecture through the Earth", Iran National Convention of culture and sustainability: Kermanshah, 2011.
[8] M.M. Safaee,"Sustainable city of Dezful", Tehran, 2008, p. 10.
[9] M. Robobi, F.Rahimi, "Shavadan and Shabestan", Asar, vol.2, 3, 4. Tehran: Iran Statistic Centre, 2009, p.195.
[10] M. Pirnia, *Iranian architecture*, 2009, p.36-48.
[11] S. Majidi, "Persian traditional sustainable construction", Tehran: Iranian architect convention, 2011, p.601.
[12] Q.M. Memarian, *Iranian Housing architecture*, 2006, p.115.
[13] A. A. Helli, "Traditional Houses in Kashan (Taj House)", *Culture & People, vol. 19, 20*, 2006, p.169-173.
[14] M. Jamshidi, N. Yazdanfar & M. Nasri, "Increasing of Energy Efficiency Based on Persian Ancient Architectural Patterns in Desert Regions", *World Academy of science, Engineering and Technology, vol. 5,* 2011, p.331.

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