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

N. Poorang

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 CO2 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.

Fig. 1 Climatic zone

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].

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].

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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. 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].

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 Empire [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 Khormamshahr, 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.

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:
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](image)

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>
<thead>
<tr>
<th>Shavadan</th>
<th>Location</th>
<th>Depth (m)</th>
<th>Average temperature (°C)</th>
<th>Average temperature (°C)</th>
<th>Average temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Border of traditional context North</td>
<td>7</td>
<td>25</td>
<td>25.5</td>
<td>26.5</td>
</tr>
<tr>
<td>S2</td>
<td>Contemporary context in N-East</td>
<td>7.3</td>
<td>25.3</td>
<td>25.8</td>
<td>26.2</td>
</tr>
<tr>
<td>S3</td>
<td>Traditional context in Centre</td>
<td>11</td>
<td>24.5</td>
<td>25.5</td>
<td>26</td>
</tr>
<tr>
<td>S4</td>
<td>Border of traditional context Centre</td>
<td>7.7</td>
<td>25</td>
<td>25.7</td>
<td>26.5</td>
</tr>
<tr>
<td>S5</td>
<td>Contemporary context in South</td>
<td>8.5</td>
<td>24.5</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Average temperature</td>
<td></td>
<td>24.86</td>
<td>25.5</td>
<td>26.24</td>
</tr>
</tbody>
</table>

The temperature of the city (outside of Shavadan) (°C)

<table>
<thead>
<tr>
<th></th>
<th>average temperature</th>
<th></th>
<th>highest</th>
<th>45.5</th>
<th>46</th>
<th>45.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lowest</td>
<td></td>
<td>25.25</td>
<td>27</td>
<td></td>
<td>28.5</td>
</tr>
<tr>
<td></td>
<td>fluctuation</td>
<td></td>
<td>20.25</td>
<td>19</td>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Shavadan</th>
<th>Location</th>
<th>Depth (m)</th>
<th>Average temperature (°C)</th>
<th>Average temperature (°C)</th>
<th>Average temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Border of traditional context North</td>
<td>7</td>
<td>18.5</td>
<td>17.2</td>
<td>19.5</td>
</tr>
<tr>
<td>S2</td>
<td>Contemporary context in N-East</td>
<td>7.3</td>
<td>19.2</td>
<td>17.8</td>
<td>19.5</td>
</tr>
<tr>
<td>S3</td>
<td>Traditional context in Centre</td>
<td>11</td>
<td>18</td>
<td>17</td>
<td>18.2</td>
</tr>
<tr>
<td>S4</td>
<td>Border of traditional context Centre</td>
<td>7.7</td>
<td>19</td>
<td>18</td>
<td>19.5</td>
</tr>
<tr>
<td>S5</td>
<td>Contemporary context in South</td>
<td>8.5</td>
<td>19</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Average temperature</td>
<td></td>
<td>18.75</td>
<td>17.6</td>
<td>19.18</td>
</tr>
<tr>
<td></td>
<td>highest</td>
<td></td>
<td>10.5</td>
<td>12</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>lowest</td>
<td></td>
<td>10.5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>fluctuation</td>
<td></td>
<td>5.5</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
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 era 3. 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.

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].

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.

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].

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.

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

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

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

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

TABLE IV

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

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


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Isfahan, Iran/1979. She studied architecture and graduated from Isfahan Azad University in Iran and gained master degree of Architecture in 2006. Then she was accepted as a PhD student in Strathclyde university of Glasgow, UK and was awarded from Scottish overseas research student award scheme (SORSAS) in 2010. Her research is about environmental sustainability in architecture and urban design.

She started working in architecture while she was an undergraduate student. In 2002 joined a well-known architecture company in Isfahan as an architect and continued her work as a project manager and designer for 5 years. After her graduation in master degree, she joined Azad University as a lecturer and became a full time member of academic board of the university.

During her PhD research, she was working as a team member of Mayfair club project in Burrell architecture, BCA, in London, 2012. Her current job is sustainable manager in Mezo Ltd, London.

She started her cooperation with Iran tourism Organization by writing of Isfahan tourism attraction book in 2002. Then she pursued her interest in Isfahan Engineers Magazine (Nama) as a journalist. She also has some papers and translation in Persian language and her papers accepted and published for the 6th International Seminar on Vernacular Settlements, 2012 (ISVS-6) and ENEFM 2013 (International Congress on Energy Efficiency and Energy related Materials).