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Impact of Hot and Arid Climate on Architecture (Case Study: Varzaneh Jame Mosque)

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Abstract

Generally, in architectural literature, scholars argue that there are lots of factors that affect on type of architecture. One of the most important factors is impact of kind of climate on architecture type. The purpose of this article is to evaluate the effect of climatic factors on construction and local architecture in hot and arid regions with special focus on Varzaneh city. A Jame mosque, which is the most important building in the city, is selected for case study. According to the findings in this study, this mosque was climatically designed in accordance with the economic and social context of the region.

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1. Introduction

How a building takes advantage of sun, breeze, vegetation, and creates a unique microclimate is one of the subtle but enduring measures of the designer's skill. Climatic design is the one approach by which to reduce the energy cost of a building comprehensively: the building design is the first "line of defence" against the stress of outside climate. In all climates, building built according to climatic design principles reduce the need for mechanical heating and cooling by using "natural energy" available from the climate at the building site. The resulting long-term energy cost makes climatic design techniques the best financial investment for any building owner. Many are "no cost" techniques, requiring only climatic design knowledge. Other techniques are easily incorporate into conventional construction [1].

Traditional Iranian architecture has changed a lot during different time periods, but architectural design respects nature in all durations. Lots of factors have an effect on traditional design, factors like religion, cultural and social issues, political decisions, the context of the city and climate and so on. In every climate, we have some positive and negative conditions. Traditional designers attempted to improve the positive aspects of climate to better the lives of inhabitants and confront with harsh conditions. Other goals of traditional architects were to maximize the conservation of resources (energy, land, water,

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materials) and reduce pollution. Most parts of Iran are located in hot and arid regions often face with limited water resources and green spaces but contain many ancient settlements. The design and construction of these settlements are based on the environmental issues from small details to the whole.

Many hot climates have a need for winter heating, which can be achieved by connecting passive systems for heating and cooling to the building. These are called passive plant and equipment because they use natural forces, such as temperature differences, radiation, convection and conduction, with no mechanical systems such as electric fans or pumps. The advantage of these systems is that they can be self-regulating and use no electricity; but they are often complicated to design since the dynamics of the systems are difficult to predict. A level of experimentation and empirical work is needed to optimize these systems. Active systems involve the use of mechanical devices such as electric motors and fans to drive heating and cooling systems. These can be used in combination with passive systems, creating hybrids.

Air-conditioning systems are increasingly seen as a part of the climate change problem, as well as its solution, as the yawning gap grows between the amounts of fossil fuels used in the world and the falling amounts of fossil fuels that are available to run these machines. Not only is the rising cost of energy a problem, perhaps least to those who could not afford air conditioning anyway, but the fact that the energy used to run these systems is a major contributor to greenhouse gas emissions. We now have no option but to adapt the actual fabric of our buildings to withstand higher temperatures [2].

This paper is done by the "case studies and combined strategies" research method. It uses analytical and description techniques, data collected from field studies and library documents [3].

2. Literature review

It could be said that birth of climatic design coincided with human development itself. Man's first shelters were caves, inside which the external conditions were tempered producing a high level of internal stability. Right back as far as prehistoric times, prehistoric man used his intuition to position his dwelling. As far as we can tell, he even seemed to use these dwellings to regulate some of the adverse effects of Nature [4].

Ancient builders were aware of the need for human-centered climatic design. Traditional building design took the climatic "given" as the starting point and derived not only building forms and practices but also generated cultural attributes. Over centuries, this-trail-and-error evolution was able to produce "traditional" design solutions that are climatically appropriate, culturally relevant and aesthetically pleasing. Unfortunately modern societies seem to have forgotten this art [5].

This type of architecture aims when designing obtain conditions of internal comfort, and so substantially increase our standard of living. This can be achieved by making the most of our surroundings, using climate, microclimate, positioning, winds, humidity and of course a good choice of materials to give us a personalized solution for a building integrated into its environment, cheaper, more pleasant and above all "healthier". Using only architecture and without any additional complex systems we can obtain a level of comfort which in many places would be sufficient without having to resort to using conventional, or in the best cases, alternative energy supplies [6].

So the architectural design of the building is one of the factors that affect the thermal comfort within. The architectural elements play a great role in influencing the thermal comfort of the building [7].

3. Climate of Varzaneh city

Varzaneh city, a small city on the edge of the central desert of Iran, is located southeast of Esfahan province. The origin of this city, which has the population of 13000 and an area of 2300 km^2, trace back to a pre-Islamic era. This city has been laboured sometimes during hot and arid weather in summer and sometimes during very cold winter [8] Fig. 1.

Fig.1.Varzaneh city (municipality of Varzaneh)

Maximum temperature is mostly more than 42°C in July while the minimum temperature in winter falls bellow -5.6°C in December in some years. The yearly fluctuation in temperature is more than 38°C. The temperature fluctuation between day and night is rather high in all seasons because of the lack of the humidity in the air and distance from the sea and ocean. Its average rainfall is about 80mm per year. Also, green spaces are very rare because of low rainfall. Varzaneh city suffers from drought and dusty typhoons. The wind brings the sand from high sand dunes which are located 10 km to the southeast of Varzaneh city. These dunes occupy an area of 17,395 hectares and extend up to 45 km. This unfavourable wind plays a major role on the orientation of the buildings [9].

In this city, people built their living area as compressed as possible, with minimal surface toward the external area, to be protected from undesirable winds and the influence of hot and cold weather. As a whole, the city's structure resembles a battlement fully enclosed from all directions which prevents the invasion of enemies from any side [10]. Most of the sidewalks in this city are built in the east-west direction to protect people from heat.

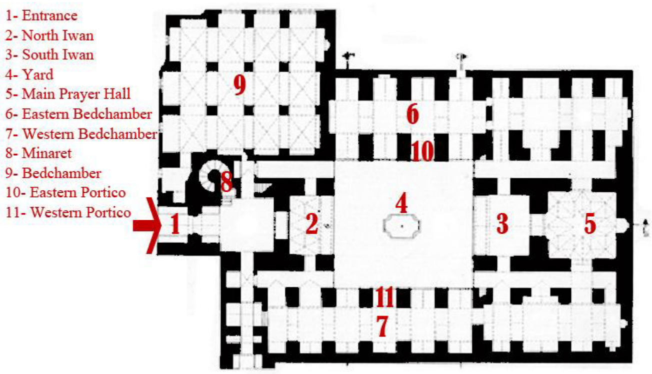
The narrow and disordered sidewalks with high walls are accompanied with roofed places in some parts that control the speed of desert wind and provide great shadow for passengers so the desert wind cannot penetrate into the city district [11]. Also, the temperature difference between the shadow and sunshine in arid places cause cool breeze, so the travellers forget that they are walking in the desert. This article cannot explain all of the traditional buildings in this city, so Varzaneh Jame mosque has been selected as case study to analyze.

4. Introduction to the Varzaneh Jame mosque

According to existing documents, the Varzaneh Jame mosque was built on remnants of the fire temple dating back to the Sassanid era. However, the present structure of the mosque had been renovated in the Timurid era (about 580 years ago) [12]. Builders have repaired this mosque in different periods. For example, the different appearance of north Iwan results from 17th century Safavid repair. According to the inscription on the head of the mosque's entrance door, it was built by Mahmood Mozafar. The mosque has two Iwans (north Iwan and south Iwan), a prayer chamber, two brick colonial's porches around the court, east and west bedchambers and a minaret Fig.2. (b).

The main prayer chamber, as the most significant part of the mosque, has a very beautifully tiled mihrab and minbar on an inside wall indicating the direction of Mecca. This prayer chamber is connected to the west and the east bedchambers and to the south Iwan. The dome placed directly above the main prayer chamber may signify the vaults of heaven and the sky. Both the west and east bedchambers are covered with an arched roof of brickwork. This mosque has 3 mihrabs, or prayer niches, two of which were originally set into the Qibla wall in the east and west bedchambers and one in the prayer chamber. Also, there is an indicator minaret near the entrance door that is about 20 meters high and is accessible through a set of spiral stairs that runs from the circular base[13] Fig. 2(a).

(a)



(b)

Fig.2. (a) Plan of the Varzaneh jame mosque (municipality of Vazaneh). And (b) Varzaneh Jame mosque's entrance and minaret (Author)

In this part of the article, some devised strategies used in the Varzaneh Jame mosque to deal with harsh conditions are listed.

4.1. Introversion and central courtyard of the mosque

The courtyard is the heart of the mosque spatially, socially and environmentally. It creates enclosure for security and privacy, and can establish its own interior thermal environment. The square courtyard of the mosque is surrounded with two Iwans in the south and north and simple brick colonial's porches in the east and west.

The dimensions of the yard are 11m × 11m which is narrow enough to maintain shadow area during the heat of the day in summer but wide enough to receive solar radiation in winter. A water pool in the centre of the courtyard causes increases in moisture in the hot and arid climate in the mentioned region. Water in this pool is used as thermal mass. The heat of direct solar radiation during day time is stored in water for night time. Also the sprinkler on top of the pool kept the yard cool through evaporative cooling in summer time.

This enclosed space is protected from sandstorms and unfavourable winds and creates a pleasant microclimate which provides comfort for worshipers. All of the openings of this mosque, except the entrance door open to this controlled courtyard in order to get enough light and ventilation [14]. Dimensions and locations of the openings are strongly influenced by hot climate and material use. Colonial's porches in front of windows avoid direct light to the interior space. The courtyard is like a hole that traps the cool night air and stores it for day use [15]. This cool air also flows into surrounding colonial's porches. Even without modern and mechanical heating or cooling systems, the courtyard provides a comfortable and healthy place to use during the hot seasons [16].

4.2. Climatic analysis of the main prayer chamber and south Iwan

The south main prayer chamber is a square space with dimensions of 7 m ×7 m that is roofed with a double-shelled dome. The dome is placed upon an octagonal base forming the star. The transitional space under the dome is composed of two floors. The mihrab and arches in this place are decorated with glazed tile. Prayers use this place the most due to its cool air.

One of the design techniques which is a creative method to achieve climatic design is the height of the building. The architect needed to cool the building so he designed a high and bulky space [17].

The form of the dome also causes an increase in the high of the ceiling for the prayer chamber below, providing more space for the hot interior air to rise and exit through the roof. The hot air (higher pressure) moves upward because of light weight and cool air (lower pressure) moves downward and substitutes the warm air. This phenomenon is called chimney effect Fig. 3. Pressure differences, inertia and friction tend to produce turbulence so the air does not move smoothly along straight path [18]. So, high spaces which have an air displacement provide a suitable place for worshipers in hot seasons.

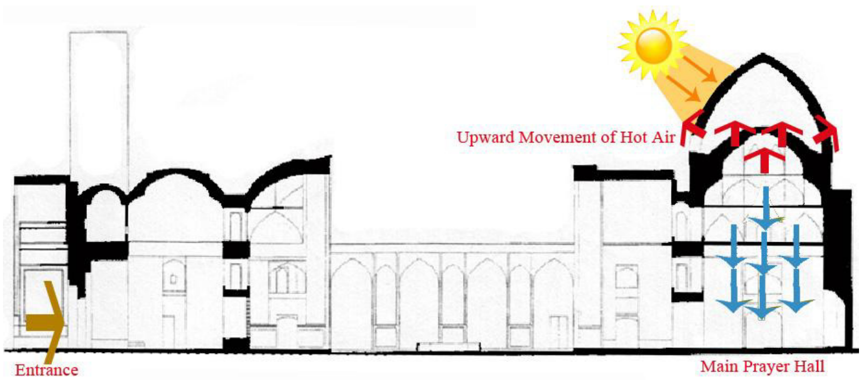


Fig.3. Chimney effect in the prayer chamber (municipality of Vazaneh).

The design of the dome as double-shelled (one dome inside another) is a climatic solution. The external dome, which receives sun's energy, prevents heat gain to the interior dome. Also, the air between the two domes functions as a thermal insulator. So the inner dome is protected from the heat outside and its degree is less than an outer dome. Less heat is absorbed, which causes less heat radiation into the main prayer chamber and this reduces the degree of interior space.

Roofs are mainly made of sun-dried bricks. For the hot and arid regions of Iran, sun-dried bricks domes function more effectively than flat roofs in term of reducing solar heat. The form of the dome increases the total surface area of the roof, resulting in the spread of intensity of solar radiation over a larger area, thereby decreasing the average heat of the roof and its transmission to the interior. A domed roof, in addition to being partially shaded from the sun for most of the day, allows winds to cool its surface easily and thereby minimizes the intensity of radiation [19].

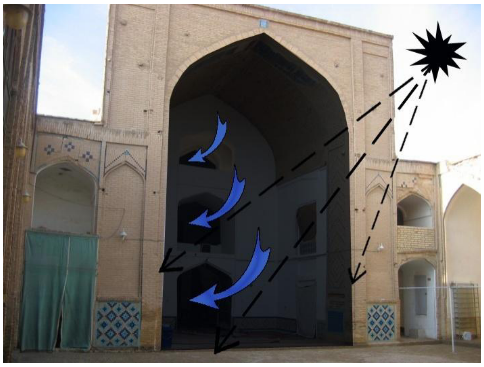
South Iwan, which connects the prayer chamber to the yard, is located in the intermediate position of light, heat, ventilation and view. This Iwan creates the motion hierarchy from the open space of a yard to the semi-open space of Iwan to the closed space of the main prayer chamber. This Iwan which is covered by white plaster, minimizes heat absorption and provides a very cool and shady place for a summer afternoon. This Iwan directs cool air from the yard to the prayer chamber. The main concept for ventilation of the prayer chamber is the use of natural forces Fig. 4(a). Also, the south Iwan, which has huge gate, is the outlet of warm air that moves upward in the prayer chamber.

4.3. The eastern and western colonials' porches

Colonial's porches in-between space, where you are neither outside nor inside, where you are both "in the court" and in the "bed-chamber" at the same time.

Various additional strategies are found in the design of hot and arid climate buildings for providing transition spaces between the building and the climate. This involves adding semi-outdoor areas such as colonial's porches to the basic building form. These spaces are important forms of buffer zoning providing privacy and varying degrees of shading to the building and glare control. The airflow around this open type of space is important so as to maintain the climate control function. Thus these external spaces provide useful microclimate that moderates the climatic extreme of hot and arid climate [20]. In the summer, as the sun gets higher the colonial's porches cut off the direct light and the bedchambers are cool and offer a comfortable place to enjoy cool breezes during the hot summer months.

(a)



(b)

Fig.4. (a) South Iwan of Varzeneh Mosque, And (b) Western column's porches (Author).

The eastern and western colonial's porches are considered semi-open space surrounding the courtyard of the mosque and direct desirable air and indirect light to bedchambers. These porches are pleasant places for prayers in the summer because of the air flow. Also, the great height of the colonial's porches and use of curved roof are climatic solutions to provide comfort Fig. 4(b).

The colonial's porches, a shaded balcony in summer and a sun space in winter, protects the interior from summer overheating yet allows the lower sun of winter to penetrate for solar advantage. [21]. Colonial's porches offered the visitor the opportunity to sit outside in hot summer and enjoy the view and interact with other worshipers. [22].

4.4. The use of ecological material

The organization of the building plan and form and its pattern of use may take advantage or create shape and seek particular relationship with the sun. However the use of materials which compose the site and the building itself can change, enhance or negate advantage. Furthermore, our sensual perception of an interior space is largely determined by materials. Or reflected by the texture and colour of internal surface, its quality, delight and utility are established [23].

Another important factor in the architecture of this mosque that makes it climatic-responsive is the material used in construction of the mosque. The most common materials are sun-dried brick. The raw material for construction brick is soil which is plentiful and readily available and makes it a very practical and economical material to use. Construction skill for this material is well developed because it has been used for more than 6000 years [24]. Another reason for using brick in these regions is a shortage of wood and stone. Brick is a durable material and it strongly resists the incessant sunrays in hot seasons, but it acts poorly in rainfall and high moisture. So architect covered the bottom level of the wall with stone that is more resistant.

Brick, because of its high thermal capacity, performs better than any other material in hot and arid regions. It takes a long time to absorb most of the heat received during the day before passing it into the inside surface of the mosque [25]. The energy that brick absorbs from the sun during the day is retained in the wall for about 8 hours. It gradually transfers from one side of the wall to another side and it transfers to inner space when the sun goes down. So the architect keeps away the heat during the hot day and retains the warmth during cold nights in the desert Fig. 5(a).

Mosque walls are very thick, so they are strong enough to bear the weight of arches and ceilings. Also, in cold seasons, the huge volume of material used in the wall protects the inside air from being affected by the winter desert climate, especially at night [26].

4.5. Using an arched roof instead of a flat roof

The roof provides the imagery, which is articulated in many cultures, and this is hardly surprising as it is a highly defensive mechanism in the climatic control system of the building. The types of the roof are discussed in relation to climate types and the section of the building. The importance of the building section in conjunction with the roof demonstrates the climatic control features in the building, in particular ventilation, solar access and lighting [27].

Flat roofs are not appropriate for hot and arid regions because they receive the most heat from the sun. The entire surface of a flat roof is always exposed to the sun throughout each day. So, architects constructed arched and domed roofs which were inclined to the sun’s radiations. When a dome is exposed to solar radiation, only a small part of its surface area receives it directly at normal incidence. The rest of its surface is either self-shaded or receives the radiation at much greater incidence angles. More importantly, the areas exposed to the radiation change throughout the day as the sun moves through the sky. Thus, a much smaller area of the roof is exposed to the full intensity of the sun and, even then, for a much shorter amount of time. There is not the same slow build-up of sol-air temperature over the whole day as with a flat roof, so the peak heat flows are much less and occur from different parts of the inside surface of the dome at different times during the evening and night [28]. So the heat received by the arched roofs is a lot less than flat roofs Fig. 5(b).

Also, arched roofs are exposed to the flow of air caused by winds. It helps the roof to cool faster as well. The outer sides of the arched roof that becomes cooler because of its shape, transfer less heat to the inside space and make it cool during the hot day [29].

(a) (b)

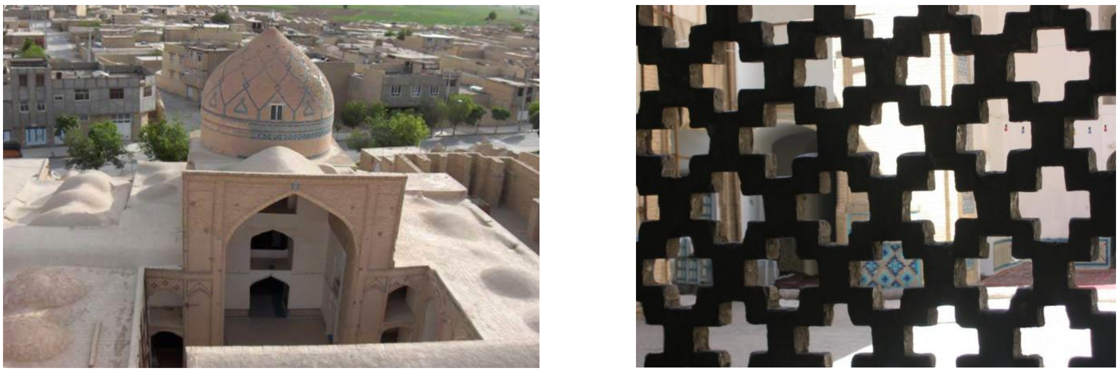


Fig.5. (a) The use of domed and arched roof (municipality of Varzaneh), And (b) The use of material (Author).

4.6. The colour in the mosque

The colour of the walls and the roof has tremendous effect on the solar impact on the building and its indoor climate, particularly in the desert regions where solar intensity is higher than that in other regions [30]. The dominant colour of the mosque is brick-colour. But a wide section of the prayer chamber, north and south Iwans and bedchambers are covered with white plaster which reduces the interior temperature. While light colour reduces direct absorption, it helps reflect light onto a greater surface of the distributed mass. In addition, light colours are also much better for natural lighting reducing the glare that comes with dark interiors contrasting too greatly with large bright openings [31].

(a)

(b)

Fig.6. (a) Eastern column's porches (Author), and (b) Interior of the eastern column's porches (Author).

5. The pathology of the mosque

The Varzaneh Jame mosque has been changed in foolish ways. For example, the pool which was placed in the middle of the yard was removed. Pool had the ability to cool the dry and arid air by water evaporation. This desirable microclimate has been removed now.

Also, the eastern portico is now covered by metal windows. This change destroys the harmony in the yard and connects it to the eastern bed-chamber Fig. 6(a). In the past, this place was used in summer to provide pleasant air, but it is used in winter at present. The heater is being used to warm up this place. Hot air produced by heater moves upward to the upper level and the lower part needs a lot of energy to become warm Fig. 6(b).

6. Conclusion

Designing with climate, and not against it, is nothing new. It is the way in which buildings were constructed for thousands of years. However, in the recent past, architects have been led to ignore the climatic context of buildings, relying on abundant fuel and sophisticated technology when designing for human comfort. Now that the demands on architects are changing the most pressing challenge is to create and adopt an architecture which shelters people in sustainable manner. Central to sustainable architecture is a climatic strategy [32].

Varzaneh as desert city has its specific architecture due to its climatic conditions. Traditional building in this city regarding identity and cultural and religious issues are specific and is in accordance with nature. Varzaneh Jame mosque, which is one of the oldest buildings in the city, has no pollution and produces a healthy and comfortable place for prayers and improves the environment quality. Although the construction principles which are used in Varzaneh Jame mosque cannot be imitated as an exact model for present day, knowing these principles help us a lot for designing. It seems that advantages taken from past architecture improve the quality of architecture and would pave the way to achieve permanent design.

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