

Sustainable Traditional Architecture and Urban Planning in Hot-Arid Climate of Iran

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Abstract—The aim of sustainable architecture is to design buildings with the least adverse effects on the environment and provide better conditions for people. What building forms make the best use of land? This question was addressed in the late 1960s at the center of Land Use and Built Form Studies in Cambridge. This led to a number of influential papers which had a great influence on the practice of urban design. This paper concentrates on the results of sustainability caused by climatic conditions in Iranian traditional architecture in hot-arid regions. As people spent a significant amount of their time in houses, it was very important to have such houses to fulfill their needs physically and spiritually as well as satisfying their cultural and religious aspects of their lifestyles. In a vast country such as Iran with different climatic zones, traditional builders have presented series of logical solutions for human comfort. These solutions have been able to response to the environmental problems for a long period of time. As a result, by considering the experience in traditional architecture of hot-arid climate in Iran, it is possible to attain sustainable architecture.

Keywords—Hot-arid climate, Iran, sustainable traditional architecture, urban planning.

I. HOT-ARID CLIMATE OF IRAN

THERE are various climates in Iran and each climate has its special characteristics. Iranian researchers worked on climatic divisions of Iran but the method of Dr. H. Ganjee is the best. He divided Iran based on Koppen's method. Koppen divided the world based on the growing of plants. Microclimates have some effects on urban planning and architecture. In a vast country such as Iran with different climatic zones traditional builders in the past have presented series of logical solutions for human comfort [1].

Based on the Koppen's method the major part of Iran is located in hot – arid climate. Hot – arid climate consists most part of the central plateau (in Persian is called Falat - e-Markazi) which is considered as the outstanding district of Iran [2], [3]. Two deserts in Iran (Dasht – e – Kavir and Kavir – e – Lout) that occupy one seventh of Iran area are located in the center of Iran and are totally barren with very little rain. In this climate summer is very hot and arid and winter is very cold and harsh. The regions with this kind of climate are too dry as they receive almost no rain for at least six months of the year. In these areas sky in most months of the year is without cloud and the weather doesn't have any humidity. High temperature in the days of hot seasons, so much difference

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between day and night temperature, extreme radiation of sun light and relative dryness of atmosphere are considered as climatic specifications of salty desert areas. Shortage of water resources, few herbal cover, and desert (dusty) winds which spread sands in the area are main elements responsible for the harsh situation. The air temperature of different domains of these regions depends on geographical situation, sea level altitude and wind direction. The habitable states of these regions are scattered with different distances from each other and are condensed [1], [4].

In order to create harmony in this climatic condition the vernacular architecture has implemented some strategies and presented a series of logical solutions for human comfort in response to such weather and his design is based on the environmental concerns and the sustainable interaction between the human and the environment. A principle for the existence of building is the need for better environmental conditions. Early men built houses to keep out the elements – rain, wind, sun, and snow. Their purpose was to produce an environment that is necessary for their survival and even favorable for their comfort. This attribute draw a connection between the architecture and climate and demonstrates a physical and architectural characteristic in a particular region [2], [4].

II. COURTYARD AND INTROVERSION

Iranian traditional architecture makes the condition suitable for an introvert and hospitable society that its most important way is having inner spaces which are in the form of courtyards [5]. So by using courtyards the general organization of the spaces in Iranian traditional architecture in hot – arid climate is introvert [6].

Courtyard is a kind of yard that is surrounded by rooms or at least by walls in four sides. It means that at least in one side there are rooms and other sides are closed by walls or in four sides there are rooms [7]. Fig. 1 shows a courtyard that is surrounded by rooms. Sometimes there are two or even more courtyards in residential houses. In big houses with two courtyards the large courtyard is used by family members and their immediate kin and the smaller one is constructed for male guests. Between these two yards there is a large room and because of the connection of this room with two yards it was called a two- sided room [2].

Introversion (in Persian is called Daroungarai) that is one of the principles of Iranian traditional architecture is intensified by using external walls. Introversion shows a tendency to inner feelings and avoids showing them. Facades have been presented in Iranian architecture at very modest level, however

the interior has been decorated in an elegance way. This can be called as introvert architecture. This type of architecture has applied in many residential houses where there is not any direct connection or opening between the interior and exterior spaces. Most of the time when walking in alleys, it is not easy to realize this phenomenon feature on the other side of the walls without getting inside of the building. The only clues of domestic life are the entrances. These houses within their urban environment are like jewel inside an unpolished cover [6], [8].



Fig. 1 A large courtyard that is surrounded by rooms

Courtyard is a social space with an environmental function. It is the heart of the building spatially, socially and environmentally. Courtyards are the main core of social gathering in Iranian culture. It provides outdoor activity and privacy. Family members can gather in the evenings and water the garden and enjoy the small environment and beauty provided inside their houses in a private and comfortable atmosphere. Courtyard makes buildings a comfortable place for living in hot and dry climate. Water in the courtyard not only freshen the air but also creates a good view. Sound of water and the reflection of light on it can add dynamic quality to the space, while water and light are two aesthetical parameters in Islamic architecture. A courtyard can provide security, privacy and a comfortable place in the house [1], [4]. Fig. 2 shows a small courtyard that provides privacy and beauty for family members.



Fig. 2 A small courtyard that makes a private and beautiful place for family members

Almost all of the houses in hot – arid climate have at least one courtyard and the rooms and other spaces of the house are around the courtyard and have openings to it. The courtyard functions as an element to unite different spaces of the house. So the courtyard is surrounded by very high and thick walls that can provide shady area inside the yard. The long and narrow form of the courtyard provides enough and needed shade for this space during the hot days of summer and it is

wide enough to receive solar radiation in winter. Almost in all of the courtyards the ratio of length to width is between 1 and 1.6 [1], [4].

Usually the whole building and specially the courtyard is lower than the ground level. In some cities buildings are even about 1 meter lower than the surface of the alleys and streets. It causes the building to be more resistant against the earthquakes. By placing part of the building under the ground the heat transfer between inside and outside of the building decreases and reduces the fluctuation of day and night temperature. In dry climate access to water resources was an important parameter in design. In desert regions the rate of planting depends on the amount of water and way of accessing to it. In hot and dry region the green space has lots of effects on the small surrounding regions such as decreasing the direct radiation of sunbeams, shading on ceiling, walls, windows and yard spaces, increasing the humidity in dry regions and decreasing the temperature in building. The courtyard where it is usually planted with trees, flowers and shrubs not only provides comfortable condition and beautiful setting but also supplies some shade and increase the relative humidity of the courtyard space. The humidity provided by the water and the plants and in addition the shade provided by high walls can increase the relative humidity of the air and cool the air in order to create a suitable microclimate in the center of the house. The air passes through the courtyard and upon the water in the pond enters the space of the house and make it cool. Even without modern mechanical heating or cooling systems the courtyard provides a comfortable living environment through seasonal usage of different sections of the structures [6], [9].

An appropriate explanation can be provided by considering the thermal properties of the air and the material of the courtyard. As the thermal capacity of air is very low the temperature of the courtyard air follows the temperature of the surrounding surfaces. As the thermal capacity of the courtyard walls and floor is so high, these elements save the sun heat during the day hours and radiate it by long waves during night hours. Because of the low thermal capacity of air surrounded in the courtyard and following of the surrounding surface temperature, the air deposited in the courtyard does not get as much hot as the air out of the building during day hours. In the morning the courtyard air gets warm slowly because the walls and floor of the courtyard serve as a reservoir of coolness. So the air receives the coolness of the floor and walls of the courtyard and the coolness remains until the direct radiation of the sun to the courtyard. Therefore the courtyard air is cooled in contact with the surrounding surfaces and makes a person feel cool during the day hours [2].

According to [10], courtyard is introduced as the best urban built form in hot – arid regions. Four parameters were studied: surface to volume ratio, shadow density, day light and sky view factors. The larger surface to volume ratio of courtyard, in comparison with pavilion, in combination with its thermal mass is a positive advantage in the thermal performance of the building. Shadow density that is the average number of hours of shadow on the ground, for courtyard is higher than the

pavilion and shows that courtyard provides protection to pedestrians. Day light distribution that is the direct day light availability for courtyard is lower than pavilion. Sky view factor is low in courtyard so during day time hours it insures an increase in direct shading and a reduction in reflected radiation. So courtyard form presented characteristics that when considering in an integral way can significantly improve the environmental performance in hot – arid climate [10].

III. WALL

Saving energy is one of the goals of sustainable development. This goal is accessible by using thick walls that don't permit thermal energy to go out of the building and vice versa. In addition thick walls provide better conditions to be able to support heavy domes.

Nowadays buildings have very thin walls that allow thermal energy to go out of the building in cold winters and come to the building in summers. So people have to use a lot of non-renewable energy to heat their homes in winters and cool their homes in summers and provide better conditions to live throughout the year [6]. One of the important elements of Iranian traditional architecture in hot and dry climate is using huge walls that have approximately thickness of about one meter. Constructing these thick walls by materials with high heat capacity provides enough comfort for residents. Constructing thick walls in hot and dry climate was very common in Iran. For example in Arak city that is located in the center of Iran and has hot and dry climate, people make their homes cool in hot summers without using electrical cooling systems, and heat their homes in cold winters just by using a small heater [3], [11].

IV. VERNACULAR MATERIALS

Pirnia, one of the greatest architects in Iran, believed that people should build their buildings, homes, stores, etc. by using vernacular materials so they don't need to import materials from other parts of the country and they can provide their necessities without the need of others. This is one of the main principles out of five in Iranian traditional architecture that in Persian is called Khodbasandegi [5].

The common materials for constructing huge walls in hot and dry regions include mud, mud brick, stone, brick, mortar, lime and wood. Usually the soil that is prepared from excavating the ground is used as the material for constructing the house. There is a lot of economic benefit by using vernacular materials, because people can obtain it at a lower price. Having less reflection of sun ray is another benefit of using these materials that help keep people's eyes healthy [12], [1].

The traditional architect knew every constructional and structural property of the materials.

The thermo physical specifications of these materials are important factors in hot and dry regions. These materials have high heat capacity, so the walls surround the house function like a capacitor that absorb solar heat during the day and transfer the heat to the environment during the night. So that it

can balance the temperature and reduce fluctuation of it during day and night and it makes people to save more energy. The microscopic and many pores of the mentioned materials which are filled with air change them to a material similar to thermal insulator.

The architect used the raw material adorned them with patterns and lines until it progressed to a degree of perfection step by step. In this way the quality of raw materials which were unpleasant and dull were shaped into pleasant and alive features [4], [7].

V. WINDOWS

In hot and dry regions external walls do not have any windows. If there are windows on external walls, they are located on the upper parts of the walls to keep the privacy of the house. Although external walls do not have so many windows there are so many of them on the internal walls facing the courtyard. Passing ventilation is done by these windows. This kind of architecture has applied in many residential houses where there isn't any direct connection or opening between interior and exterior spaces. By creating some openings in interior spaces an access to a private environment is possible [2], [3].

VI. SUMMER SITTING PORTION

Spaces located in the southern part of the courtyard are called summer sitting portion. Since these spaces face the north direction receive less sunray and are shady so can provide cooler places. In Persian they are called Nesar. The height of summer sitting portion is often more than the height of winter sitting portion thus the hot weather goes up and the cooler one replaces it in the lower levels. Wind catchers and air vents are mostly located in the southern part of the building. There is also a very big room, saloon (in Persian it is called Talar), on the main axes of the courtyard and in the southern part. By its ornaments, mirrors, paintings on the wood and paintings on the plaster, this room becomes very beautiful and it is the most noticeable room in comparison with other simple rooms [6], [13].

VII. WINTER SITTING PORTION

Most of the traditional houses are constructed along a specific orientation in such a way that their lengths are from east to the west. This orientation is called the orientation of north to south. This allows the house to be divided into a part in the north and a part in the south. There is a yearly use of space in these houses and for this reason all of the spaces located in the northern part of the courtyard are called winter sitting portions which face the south direction, receive more sunray and heat and become warm so can be used during the cold seasons. The winter sun ray which isn't intense enters into the rooms that are located in the northern part of the courtyard so these rooms become warm during winter. This orientation maximizes the benefit of sunray for cold winter.

Seasonal function: The inhabitants of the house move to the northern part of the courtyard in winter and to the southern

part in summer to adapt themselves to the changes of climate conditions. This seasonal movement to different spaces in the house is one of the human responses to the climate condition [3], [6].

VIII. ROOF

If the flat roofs are used in hot and dry regions and paved with square shaped bricks called paved bricks, since these bricks receive the most radiation of sun, in the early morning temperature increases and in the late afternoon it decreases gradually. This makes the building to be heated during the day and to get cold at night. The domes which were used as covering roof for mosques, water reservoirs (in Persian called Ab Anbars) and shopping centers (in Persian called Bazar) are suitable types of roof in hot and dry regions. The domed roofs of buildings in this region have some thermo physical advantages. Because it has convex surface each part of it always remains in shade during the morning and afternoon [3].

The hot air that gathers under a curved roof is above the living area of the room. In this way the room is kept more comfortable. A curved roof is more effective when it incorporates with an air vent. The operation of an air vent depends on the fact that when air flows over a cylindrical or spherical object, the velocity at the apex decreases. If there is a hole at the apex of a domed or arched roof the difference in pressure makes the hot air under the roof flow out through the vent [1].

According to a research that was done about domed roofs by using ECOTECH software, the temperature changes out of the building doesn't have significant influence on the temperature inside the building if it has domed roof. In addition the amount of radiant energy that is absorbed through flat roofs is twice more than it is absorbed by domed roofs [11]. Therefore domed and arched roofs, high walls and constructing high ceilings are two ways to provide better conditions for people living in hot and dry climate without using nonrenewable energy. Fig. 3 presents a domed roof of a mosque. This element is seen in Iranian Bazars (traditional shopping centers). In hot and dry regions the roofs are domed and arched and there are high ceilings but in cold regions the ceilings are short. What's more arched roofs can be observed in house too. For example in vestibule (in Persian called Hashti) the roofs are domed and sometimes there is a vent on the roof that makes the sunlight to enter into the vestibule and illuminates inside that place [6], [5].

In residential buildings in summer and spring nights, flat roofs were used for sleeping, having dinner and spending free time. For this reason walls were often constructed around the roofs. These walls were made of brick and were grid and were about 1.5 meters height, so the air could ventilate and people could have a private place without the sight of their neighbors. During the day hours these walls could even provide shade on some parts of the roof so they had a secondary climatic role during the day hours [7], [12].

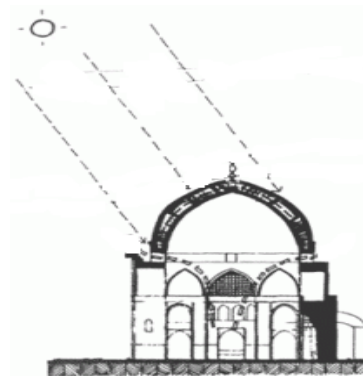


Fig. 3 Domed roof and the radiation of sunlight on it.

IX. VESTIBULE (HASHTI)

In Iranian house the entrance was extremely important and sequence as well. The intention of the entrance was to block direct sight to the interior spaces. Nowadays the interior spaces of buildings are connected directly to the alleys, but in Iranian traditional houses there was a space called Hashti and a corridor between the alley and the interior spaces, so it avoided the direct sight of other people walking in the alley to the interior spaces [4], [9].

Vestibule was a sheltered space out of the main space of the house that was designed in square, rectangular, octagon and other forms. It was a space between the alley and the house's yard, and was the common entrance for different houses. The residents of those houses were kin and use vestibule for speaking and spending time with each other and also vestibule helped them have their private lives.

Vestibule or Hashti was designed as a stopping point and could be used as a temporary reception room for those who didn't want or weren't allowed to enter the guest room. It was as an exterior space for the house. If one wanted to talk to one of the residents of the house or give or get something but didn't want to enter to their home, he waited in vestibule, did his work and talked there without entering the house and without waiting in the alley too. There were usually some platforms in Hashti next to the wall that if they wanted to talk for a long time they could sit on those platforms and even sometimes they would be served something to eat or drink.

Vestibule was connected to the alley by a short or long corridor and this corridor belonged to the domain of Hashti. It means only a person who wanted to talk to the residents of the house was allowed to enter to that corridor; otherwise he was recognized as a stranger or thief.

Some Hashties were simple and some were colorful and beautiful with a lot of ornaments. Some of them had a vent on the roof that direct sunlight to the space of Hashti and made that space very beautiful. These spaces had domed roofs.

The most important usage of Hashti was the division of entrance route into two or more routs and it provided the privacy for some parts of the house [14].

As walking from the entrance toward the interior spaces, there were usually two different corridors. The first one is connected to the exterior part and the second one which was

usually longer and curvy, reached the interior part. This pattern of spatial configuration isn't accidental, it is a carefully considered response to balance needed relation between hospitality and social contacts as well as privacy through the house [4].

X. EXTERIOR AND INTERIOR SPACES

The concepts of privacy and hospitality have had a great impact on the house formation in Iranian Islamic architecture. Iranian family needs to have privacy as well as social contact with neighbors. In order to achieve this aim the hierarchy of spaces starts with a public space, continues with a semipublic space, semi private and at last a private space. Spatial configuration to manage this, divided the whole house into spaces with different characteristics such as the entrance, the exterior part (guest space) and the interior part (private space). The exterior part or guest room or reception area is a part of the house into which male guests can enter. This room is the main space in the house which has been well decorated and it shows the economic condition of the family. This room is situated in the main axis of the yard and has the best view to the courtyard with double height ceiling.

The interior part is the most private part of the house that it has been designed in a way that should not be seen or accessible by guests. All the family members lived in this space and they could have their privacy without the disturbance of strangers [4].

XI. SUNKEN GARDEN

When a building is constructed without any excavation the contact surface of it with earth would be equal to its area but when the excavation is done the contact surface would be increased. In hot and dry regions to decrease the heat exchange of building with the outside air and to provide low expense and natural cooling and heating the buildings are constructed inside a pile of soil as much as possible. When the excavation is done in the center of the courtyard, the space that is made below the alley's surface and the building's surface is called sunken garden (Godal Baghche or Baghchal or Padiav). Sometimes Godal Baghche is one storey below the surface of the courtyard. In some cases Godal Baghche occupies a considerable part of the courtyard so the courtyard was divided into two surfaces. This space was constructed in very hot and dry cities like Kashan, Naeen and Yazd city that are located in the center of Iran and are desert cities [3], [7]. Fig. 4 shows a large sunken garden in Naeen city.

The depth of the yard was more than normal to have access to Ghanat water or subterranean canal of water which was passing under the surface of the yard and was used to water garden and water and broom the courtyard. The floor of the yard was paved with square bricks called paved bricks which water and broom was used to clean them and it caused the yard space to become cool. Having access to flowing water that was passing under the surface of some parts of the house in desert cities was one of the main reasons for constructing Godal Baghche. In some cities like Naeen that had an

advanced network of Ghanats having Padiav was really important. Water that flowed under the sunken garden filled the central pond and then its excess flowed out of the house toward other houses [3], [7]. There were some rooms around the courtyard. In Godal Baghche planting some kind of trees like fig, pistachio and pomegranate was common. By having a cover full of plants and trees and because of evaporation and because Godal Baghche was smaller and lower than the courtyard, it was acting as a cool and fresh air generator for itself and upper yard spaces. This space with more shade and humidity could provide a beautiful and cooler place for the house [4], [13].



Fig. 4 Sunken garden in Naeen city

XII. BASEMENT (SARDAB)

In all Iranian vernacular houses Sardab is considered to be the same as basement or Shabestan or cellar. Since Sardab is an underground part of the house, thermal exchange between inside and outside of it decreases. Sardab is usually located in the southern part of the house or under the summer sitting part of it. In some cases all of it is under the ground and in some other cases it is an underground semi open space which has a ceiling about one meter higher than the surface of the courtyard and the rest was designed to be under the ground. Light and ventilation is provided for basement by this space. The cellar with its small illuminator under veranda takes a dim light. The vent holes conduct cool air blowing from the north into the cellar and produces good ventilation and cooling in hot summers [1], [4].

The underground floors in houses are living places. Inhabitants use the underground in the afternoon and roof at night, which have cooler weather for sleeping. This act of changing daily space is called local – regional correspondence [4]. Sardab was also used for preserving foodstuffs and as a living room for all family members. Sardab provided a cooler place in hot summers. It usually had a pond and sometimes had access to the underground water pathways which are called Ghanat. Sardab was usually cooled by Ghanat and wind catchers [4], [6].

XIII. WATER RESERVOIR (AB ANBAR)

Ab Anbar is a traditional reservoir of water in Persian antiquity. Water reservoir is its equivalent term in English. To withstand the pressure the storage tank that reserves water, was built under the ground. The water reservoir is dug to a depth of 10 to 20 meters under the ground and is covered by a

domed-like roof. One important aspect to consider is its resistance to earthquakes. Many cities in Iran are in danger of earthquakes. However since almost all water reservoirs are subterranean structures and just their heads are barely above the ground level they inherently possess stable structures [3]. The water is collected from Ghanats. So water reservoir is a container for storing water that is dependent on Ghanat. The water is accumulated during the winter, is kept cool in the reservoir and used during the hot summer days [2], [10].

In the design of water reservoir the architects benefit from the changes of seasonal temperature in desert regions and the isolated nature of the ground. In the summer the domed-like roof of the water reservoir and the upper layer of water gets warm. Therefore the upper layer of water evaporates and exits from the reservoir with the air flowing in the air trap. The water reservoir can be divided into two groups:

- 1- Public water reservoirs that are in villages and cities. These are individual buildings in public places.
- 2- Private water reservoirs that are in the houses [6].

The construction material used for Ab Anbars were very tough and extensively used a special mortar called Sarooj made of sand, clay, egg white, lime, goat hair and ash in specific proportions depending on the location and climate of the city. This mixture was thought to be completely water impenetrable. The walls of the storage were often two meters thick and were coated by bricks to resist against the destructive effect of water. These bricks were specially baked for Ab Anbars and were called Ajor Ab Anbar or water reservoir brick. Constructing domed roof of the water reservoir was the most difficult part of the operation because constructing domed roof or an opening that is 15 to 16 meters wide needed a lot of experience but this was done by the elliptical arches which prevent the expelling force [3].

In order to access the water one would go through the entrance (Sardar) which would always be open, traverse the stairway and reach the bottom where there would be faucets to access the water in the storage. Fig. 5 shows the entrance of a water reservoir.



Fig. 5 The entrance of a water reservoir toward the storage tank

Next to the faucet there is a built-in seat or a platform and ventilation shafts. Depending on where the faucets would be, the water would be colder or warmer. Some storage would have multiple faucets located at intervals along the stairway. Thus nobody had access to the body of water itself, hence it minimizes possible contamination. The storage is completely isolated from the outside except for ventilation shaft or wind catchers. To further minimize contamination, the storage tank

interior was scattered with a salty compound that would form a surface on top of the water. The storage tank would then be monitored yearly to ensure that the surface had not been disturbed. Many traditional water reservoirs are built with wind tower that are capable of storing water at low temperature for months in summer [6].

Around water reservoirs there are usually unidirectional or bilateral wind catchers. Wind catchers are located around the water reservoirs and their directions face the appropriate wind. Fig. 6 shows the domed roof of a water reservoir and four wind catchers around it. By putting the wind catcher hatches toward the wind or appropriate winds they are led into the reservoir to prevent the growth of microorganisms, by passing it over the water in an environment which there is not air circulation. After the wind hits the water it goes up from the opposite side of the wind catcher. Fig. 7 shows how prevailing wind enters the storage tank of a water reservoir throughout the wind catchers around it [2].



Fig. 6 A water reservoir and wind catchers around it

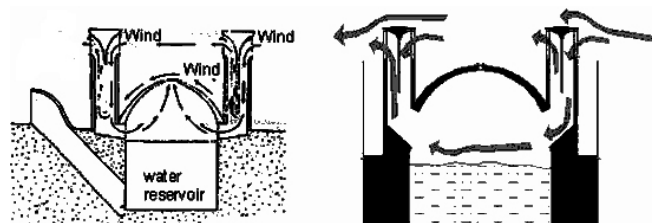


Fig. 7 The flow of air in a water reservoir throughout the wind catchers

XIV. SABAT

One of the important elements of urban planning in cities with hot and dry climate is Sabat. Sabat is the linked arches between two walls of an alley or it can be defined as the roofed lane. Sabat is designed in order to keep human safe in desert from direct radiation of sunlight in shade for some moments and makes the hot temperature of the city more tolerable. In fact these linked arches have been multifunctional structures, particularly over the long days of hot summer these structures with narrow alleys and tall walls of residential buildings create shade and prevent sunlight falling directly on pedestrians and make air to be cooled. It is such a way that any pedestrian under it is positioned in shade and light repeatedly. These structures also protect pedestrians from the cold wind in winter and make the weather warmer. Therefore one of the main intentions behind the construction of Sabats

has been the creation of a bracing system for the linked structures. These structures have also enriched the sense of neighborhood and local correlation among the citizens. Fig. 8 shows Sabat in a hot-arid city in Iran. As it can be seen alley is not wide and Sabat doesn't cover the alley completely.

Iranian architects in some instances built houses up to somewhere lying on the lane and began to build one or more protruded rooms with same eaves above the passage all commuting was made under these rooms called Sabat. In some cases they are as single rooms over the narrow alleys. Sabats improve the stability of the houses and make neighbors more close to each other [1], [3].

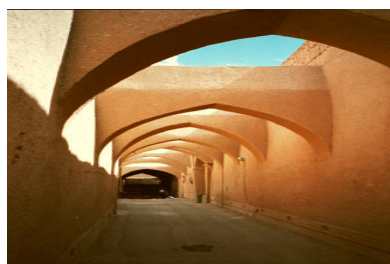


Fig. 8 Sabat in a hot-arid city

XV. GHANAT

The most important problem in hot and dry region is water. Therefore people had to find a way to bring water to the city without any kind of modern technology or pumping system. Ghanat or Kahriz or Kariz is a passive system that was used. Ghanat is a canal that is dug under the ground which connects mother-well to the other wells. Water flows in this canal [15]. A mother-well was dug in a place far from the city where they could reach the water table maybe 100 meters under the ground. Other wells were dug to direct water toward the city with minimum possible gradient. By using the slope of the earth they could bring water to the surface near the city [3]. Fig. 9 shows how Ghanat is constructed and how it works.

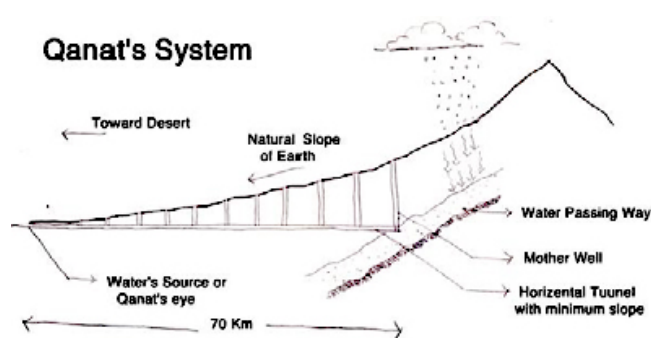


Fig. 9 Elements of Ghanat system

The point where the water comes out to the surface is called Ghanat's eye or water source. This water was used for the irrigation of agricultural land, personal uses such as drinking, cleaning and irrigating small gardens. Other wells were used for carrying excavated soil to the ground surface and as a ventilation route for the underground canal. These wells were

also used as a route for repairing and visiting and cleaning the inside of the Ghanat. The length of Ghanat, which is effective on the amount of its water, depends on the slope of the earth and the depth of the mother-well. The more the water table is deep, the more the mother-well should be long. The most important parameter on the length of the Ghanat is the slope of the earth. The less the slope of the earth is, the more the length of Ghanat should be. Due to the shortage of water in the central provinces of Iran, there are thousands of water wells connected together by Ghanats. At the present time although Ghanats have been replaced by the modern deep wells, the agricultural lands of many Iranian cities in the central part of Iran are still benefited from Ghanats.

By comparing with today's wells, Ghanat is cheaper and it has a longer period of life. But in flat areas or where the area doesn't have enough slope and in the sandy area it isn't possible to dig Ghanat. In addition the flow of Ghanat water is permanent. Even when people don't need water it comes out of the ground and it is not controllable, so Ghanat makes the underground water to be finished and in the seasons that people don't need water it is not possible to avoid water flowing to the surface [1], [3].

XVI. YAKHCHAL (YAKHDAN)

Yakhchal is a traditional natural refrigerator that means storage of ice. It was often used to make and store ice, and sometimes to store food. Each Yakhchal was made of a pond, a tall wall that was called Hesar and a dome. The wall was constructed in such a way that during all hours of the day there was shade on the pond and it prevented the water to be warmed. This structure was a buried big space (up to 5000 m³) which had thick walls of at least 2 meters at the base, made with a special mortar called Sarooj, composed of sand, clay, egg white, lime, hair of goat and ash in specific proportions and which was resistant to the transfer of heat. This mixture was impermeable.

The ice was carried from surrounding mountains during the winter or was made in the Yakhchals pond in the winter and was stored in Yakhchal, which was a specially designed and naturally cooled refrigerator. Then the ice was used during the summer. Yakhchal was often connected to a wind tower which could refresh the temperature during the summer days. These structures were specially built and used in Iran. Among those which have been remained today, many were built hundred years ago [3].

XVII. CONDENSED URBAN TEXTURE

Villages and cities in hot – arid regions are similar to cactus in desert. They have very hard skin and are completely closed. Consequently people run their lives inside this skin. Urban texture is condensed and compressed in these regions.

Cities in this climate have connected buildings and covered shopping centers (in Persian called Bazars). So that these cities can be seen as single roofs with holes (courtyards) and some alleys cut in these roofs. This texture worked as protection against both natural harshness and enemies who

attacked the cities. Houses are compressed to each other and have emerged walls or combined walls and the border between them cannot be identified. This leads the external surface of each building to the least and can minimize the contact of wall surface with air so there would be less thermal exchange between inside and outside of the buildings and houses can conserve the needed energy inside of them for a long time. So to achieve the minimum absorption of solar energy by outdoor walls all buildings are connected to each other. Fig. 10 shows the condensed urban texture in a hot-arid city in Iran. The structure of cities in this climate is planned in a way that arteries are in the direction of desirable winds and are shaped to use cool wind in the summer. Moreover, they aren't in the direction of undesirable winds and sand storms. All spaces of these regions consisted of urban spaces, pathways, yards and buildings are completely protected against dusty winds. Meandrous, serrated and narrow alleys with high walls in both sides which sometimes are roofed by arches can reduce the speed of dusty winds and produce shady area in passages. The urban texture is dense and alleys with tall walls and zigzag and organic form, not straight, in plan don't let the wind blow easily. Furthermore, the wind hits to the curves of the alleys and its speed and the amount of its dust reduces [4], [6].



Fig. 10 Condensed urban texture in a hot-arid city in Iran

Because of the intense sunray during day hours, making maximum enclosure is important. The enclosure of an urban space arises as a consequence of the ratio of wall height to the alley width. By having the less ratio of height to width we have more shade in the alleys so people feel more comfortable walking in the alleys during the day. Some alleys are just wide enough for two people to pass. Like alleys, buildings have enclosure too. They are surrounded by high walls which make it isolated from the outside environment. These walls perform as a shell protecting the building from intense sunray and desert dust winds and in the cold season from cold winds. There are few openings on the shell and in many cases the only opening is the main entrance.

The direction of buildings is toward north to south and has a direct effect on the direction or main axis of courtyards. The aim of this direction is to minimize the amount of sunray, reduce the daily temperature inside the buildings in the summer and maximize the amount of sunlight and reduce the effect of cold winds in the winter [3].

XVIII. KHISHKHAN

One traditional cooling system existed in hot-arid climate is Khish or Khishkhan that was used in Iran since hundreds of years ago. It was look like a hut or Daraferin that was covered with mats, tiles or thistles and splashed with water so cool air was conducted into the room by the wind. Khishkhan was often used outside of the house in hot summers [1], [12].

XIX. CONCLUSION

The experience at the 20th century showed us that nowadays we couldn't have cities with ignoring what was happened in the past. The reaction to modern architecture and modern planning has led to a new appreciation of the traditional city and its urban form.

Residential buildings in Iranian architecture have been designed based on culture, religion and in response to climate and environment of each region. This architecture could create forms which are able to generate a correlation between these parameters.

This paper tried to regain the values of an architecture well suited to its environment. Studying the history of architecture in residential houses in Iran can introduce a new path to architects that how those traditional houses could provide suitable conditions for people's demands at that time and lead them to create a better architecture appropriate to this period of time.

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