PERSIAN ARCHITECTURE: CONFORMITY WITH NATURE IN HOT-DRY REGIONS

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ABSTRACT

The climatic characteristics in different regions of Iran have created architectural design problems. It is advantageous to look at various architectural solutions to such problems. In the hot-dry climate of the indigenous settlements of Iran, particularly interesting design solutions are found. Most solutions, such as high thermal capacity construction materials, compact structure of cities, narrow winding passageways, thick walls, courtyards, internal vegetation, arched roofed chambers, highly elevated wind towers and big water reservoirs, are in conformity with nature and environment. The role of architectural elements is to make use of natural forces such as light, heat, wind and water in design. In this paper, the effects of climatic factors on urban and architectural forms in the hot-dry regions of Iran, climatic design problems and architectural solutions are explained.
Keywords: hot-dry regions, passive system, Persian architecture, traditional house, wind tower.

1 INTRODUCTION

There are several interrelated factors that have influenced architectural styles in Iran, among which climatic factors are of particular importance. A relative knowledge of these influential factors is necessary for understanding various values of Persian architecture.

Particular climatic factors that affect architectural styles in hot-dry areas are high radiation and temperatures in the summer, diurnal fluctuations of temperature, seasonal fluctuations from hot-dry summer to cold-dry winter, low humidity, limited water supplies and dusty, sandy winds [1].

Various examples of dwellings responsive to climatic constraints are found in vernacular architecture throughout Iran. Compact cellular layouts with minimum external surface exposure to the sun, whitewashed surfaces to reduce absorptivity, blind external facades, courtyards, vegetation to provide humidity and shade, and heavy buildings with materials of high thermal capacity are common passive features. Wind towers for cooling ventilation are well known in Persian architecture, which, along with cooling of air by the evaporation of water, keep the building comfortable in hot periods.

2 NATURE AND PERSIAN CITIES

Nature plays an important role in shaping the fabric of cities in Iran. The fabric of traditional Persian cities exposes their adaptability to climate, geography and cultural factors. Generally, traditional Persian cities are classifiable into two main groups. In one group are the cities that are located in hot-dry areas in the centre, and in cold areas in the mountainous regions of the country, with attached and connected texture. In another group are the cities that are located in the moderate and humid climate of the north, and in the hot-humid climate of the south, with separated and disconnected urban fabric.

Although the basic criteria of both kinds of urban fabric are similar, the structure of each city has its own special characteristics. In a hot-humid climate, wind plays an important role in reducing the heat in summer days. To use wind in providing a microclimate, the separation of buildings from each other is an important urban planning strategy. In a hot-dry climate, the cities with continuous texture are located on the edge of or in the desert. The physical structure of these cities provides a surrounded and covered space to neutralise the effect of the desert on the life of the city. For this reason, houses

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Figure 1: A city in hot-dry climate – continuous texture, attached houses, narrow streets and passageways (Yazd, Central Iran).

Figure 2: Courtyard with gardens and a pool in order to absorb and moderate the heat and to create a suitable microclimate inside the house.

are completely attached to each other and roads and alleys are narrow. The access has been designed mainly for pedestrians and primitive vehicles (Fig. 1).

The design concept of private spaces in both kinds of urban fabric is a continuation of the design concept of public areas. The houses and the public spaces have been designed in such a way as to provide the best climatic condition for inhabitants. In areas where the climate is moderate and the land is green, there is no need to provide a microclimate inside the buildings. But in a hot-dry climate, the inner design of the building is completely under the effect of the climate. In such a climate, open spaces play an important role in air circulation. For this reason, houses are built around an open space as a central courtyard designed with two main elements – gardens and small pools. The existence of greenery and water provides a suitable microclimate inside the buildings (Fig. 2).

3 GEOGRAPHIC FACTORS

Geographic factors have a high effect on the shaping and physical development of cities. Two phenomena have affected the development of Persian cities. First, access to existing construction materials on the site, and, second, methods of construction in particular in the desert and mountain cities.

In exposing the close relationship between the life of the city and nature, the role of construction materials is important. In one way, it limits the quantity of structural space of the city and, in another way, when used for roofs and facades of buildings, due to special physico-chemical combinations, it produces a colour that exposes the relation of the city with the surrounding environment.

4 ECOLOGICAL FACTORS

Ecological and natural factors have influenced both the fabric and the form of the cities. The existence of Persian cities has been secured by the existence of drinking and agricultural water. In desert cities, water has influenced the quality of urban infrastructure and the location and quality of its agricultural land, and it has contributed to the form that guided the way of physical development of settlements. In some Persian cities, the method of water distribution into houses and public buildings, such as public baths and mosques, has affected the design of the city, density of buildings and physical development of the city.

5 NATURE AND PRINCIPLES OF BUILDING DESIGN

In the hot-dry regions of Iran, comfortable buildings made of mud and fired brick have been created by builders. Comfort within these buildings is primarily controlled by factors such as air temperature, humidity and airflow. Each can have a dominating effect. Their effects are not necessarily additive and practically never linear. These passive cooling systems are environmentally responsive and use nature's elements in providing comfort to people in a manner that is minimally destructive to the environment. They are non-depleting of natural resources and use the building itself in the comfort creating process. They are 'sustainable', i.e. a nature incorporating, comfort generating, security providing environment in which the building composition itself is the 'machinery' that creates protection, health and comfort.

These passive cooling buildings rely on natural sources of cooling: night ventilation, which lowers the temperature of building's thermal mass; evaporative cooling, in which sensible heat is absorbed as latent heat to evaporate water; and ground cooling, in which air is cooled by the ground via a matrix of piping or groundwater cooling. Desert buildings use proper orientation, thick walls, natural cross ventilation, indoor and outdoor living spaces, natural and man-made shade for summer cooling; south facing courts and windows with tile floors, which, when coupled with the thick walls, provide for capture and storage of warmth during winter conditions.

The existence of deep basements, courtyards with gardens, ponds and fountains in traditional houses makes summer afternoons cool for the inhabitants. Summer rooms are open vaulted spaces facing north across the courtyard, away from the sun, while the winter rooms, with glass doors, face south towards the low winter sun. At night in summer, the cool night winds circulate through the wind towers and open doors drawing the heat of the day from the great mud walls of the house. The courtyard level and winter living rooms, with timber and glass doors, are used during the winter. The heat of the sun, caught by these doors, is stored in the thick mud or brick walls and it keeps the inside warm at night.

High-rise wind towers above the roof catch the passing winds and channel them down to the ground and basement spaces in order to cool the internal spaces on summer mornings and evenings when the air is cooler than room air, and to provide ventilation to refresh the air. At night, when the air is cool, it passes over the walls, floors and ceiling, draws the stored heat of the day from them and makes them cool for use the following day.

The whole form of the house is designed to maximise its passive cooling potential in summer and its power to warm in winter, when sun angles have to be designed well to ensure the maximum penetration of the sun into the winter room. For this reason, roof design is important, i.e. slopes and orientations according to the sun's path. Orientation is a fundamental concept of solar use for passive systems. Proper orientation is critical for optimising the solar resource. A properly oriented building can optimise solar gain for human comfort heating and, with proper shape and overhangs, can minimise summertime overheating. Using natural winter heating and minimising summer heat impacts reduces the size of heating and air conditioning equipment as well as the energy needed for these buildings.

Construction materials used in the buildings, such as mud or fired brick, white lime plastered walls and baked floor tiles, not only absorb and store the heat and cool but also act as insulators to retain the heat or cool the inside. The massive form of the building, with partially filled cavities, and shaded walls and roofs reduce the effect of sunlight. The curve of domes and vaults minimises solar gain into the rooms and spaces below and speeds up heat loss from the rooms through ventilated cupolas (Fig. 3).

The design principles of traditional houses in the hot-dry regions of Iran in conformity with the environment in order to make use of natural forces such as light, heat, wind and water are as follows:

- The orientation of a house is such that it minimises the heat of the sun in summer afternoons. The best orientation is 25° south-east in order to minimise the area of the wall surfaces exposed to sunlight.
- The houses are low-rise. The cellar is underground and the main hall is two storeys.
- An effective architectural element, the Ivan, a semi-open space, is included in the building for use in the summer. The Ivan leads to a small closed space that is cool in the summer.
- Homogenous and local construction materials are used in the buildings in conformity with the environment.
- Overhangs are used around the roof edge in order to reduce sunlight entering the house.
- Gardens are used in the courtyard near the rooms in order to absorb and moderate the heat (Fig. 2).

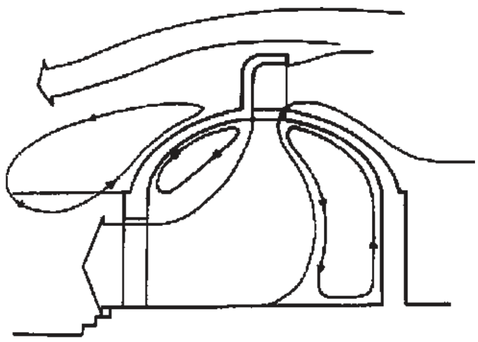

Figure 3: Use of ventilated cupolas and vaults to minimise solar gain by creating shadow and to speed up heat loss from the rooms below.

- The area of the roof surface exposed to sunlight is reduced by using vaulted and domed roofs, which make some parts of the roof shaded (Fig. 3).
- High-rise parapets are used around the roofs in order to make some parts of the roof and the nearby passageways shaded.

6 CONSTRUCTION MATERIALS

The use of construction materials plays an important role in heat-insulation of houses [2]. All passive heating and cooling systems are based on the ability to gather and store solar energy within a material for a period of time. This is accomplished by using a material which will hold heat until it is needed for heating, or capturing heat that will be dispelled at a later time. Dense materials like earthen materials, i.e. adobe, stone and brick, are good holders of heat. This attribute is called thermal mass. Thermal mass is used to store heat from the sun during the day and re-release it when it is required, to offset heat loss to colder night-time temperatures. Thermal mass can significantly increase comfort and reduce energy consumption. The heating application of thermal mass is to select materials that will absorb heat from solar exposure during the day, hold that heat for a time during non-solar periods and then give it up as conditions warrant. The same action can be incorporated for building cooling. As an area heats up, heat can be absorbed into the thermal mass material in the walls, floor or ceiling and then held until evening time when effective cooling takes place using cross ventilation and night sky radiation. This action is based upon fundamental principles of thermal transfer. Thermal lag is a term that is used to describe the amount of time taken for a material to absorb and then re-release heat, or for heat to be conducted through the material. For an adobe wall of 250 mm thickness, the time lag is about 9 hours.

The houses are traditionally built of mud, so they have a low rate of heat absorption and because of their light colour they also reflect the sunlight. In hot seasons, heat is preserved in thick walls for a few hours before it is gradually transferred to the inner compartments. In cold seasons, the temperature absorbed by the wall and the building during daytime serves as an isolation barrier, which protects the air inside from being affected by the cold air outside; thus, the inside of the house remains warm. The practicality, availability and relatively low cost, as well as the skilfulness and experience of the craftsman in working quickly and efficiently with the material, have made mud the primary building material (Figs 4 and 5).

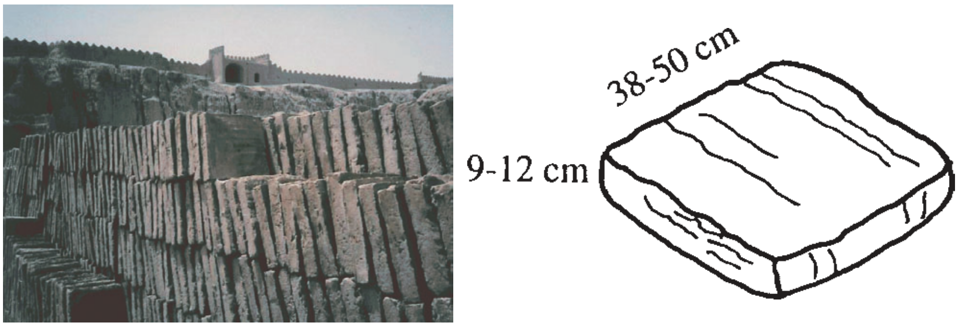

Figure 4: Adobe with a low rate of heat absorption and a high rate of reflection of sunlight as the main construction material (Bam Citadel, South-east Iran).

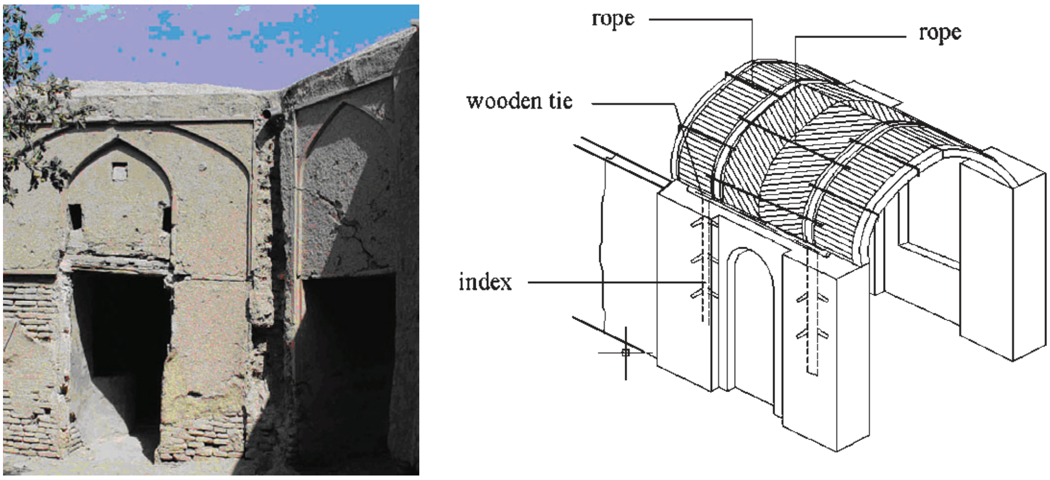

Figure 5: Method of construction of adobe structures – quick and efficient.

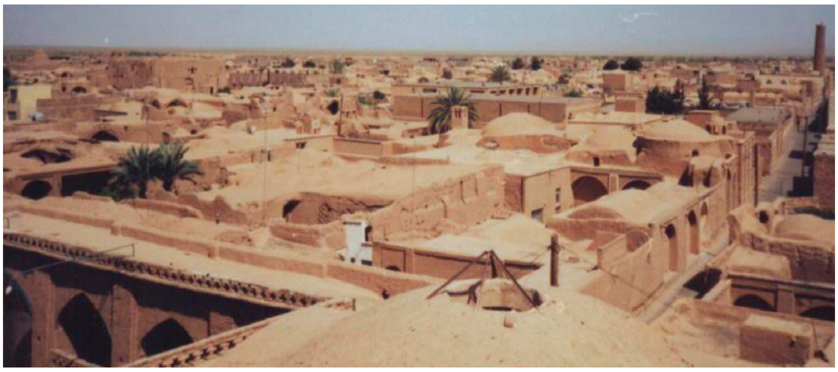

Figure 6: Attached houses, deep shaded courtyards in summer areas with their back to the afternoon sun (Ardestan, Central Iran).

7 THE SET OF BUILDINGS

In hot-arid regions, the overall structure of the town is compressed and compact in order to minimise the penetration of hot radiation and sunlight. Buildings are built in tight or adjoining sites. Houses are very close together, so that sometimes walls are shared and boundaries between houses become unrecognisable. Walls and roofs are usually thick so that they protect the interiors from external heat (Figs 5 and 6).

8 PASSAGEWAYS

In hot-dry regions, the city fabric is composed of narrow winding streets or passageways with high walls of adobe and brick, often roofed at various intervals. This form of urban design, which used to be commonplace in Iran, is an optimal form of desert architecture that minimises desert expansion and the effects of dust storms. It also maximises daytime shade and insulates the fabric from severe winter temperatures (Fig. 7).

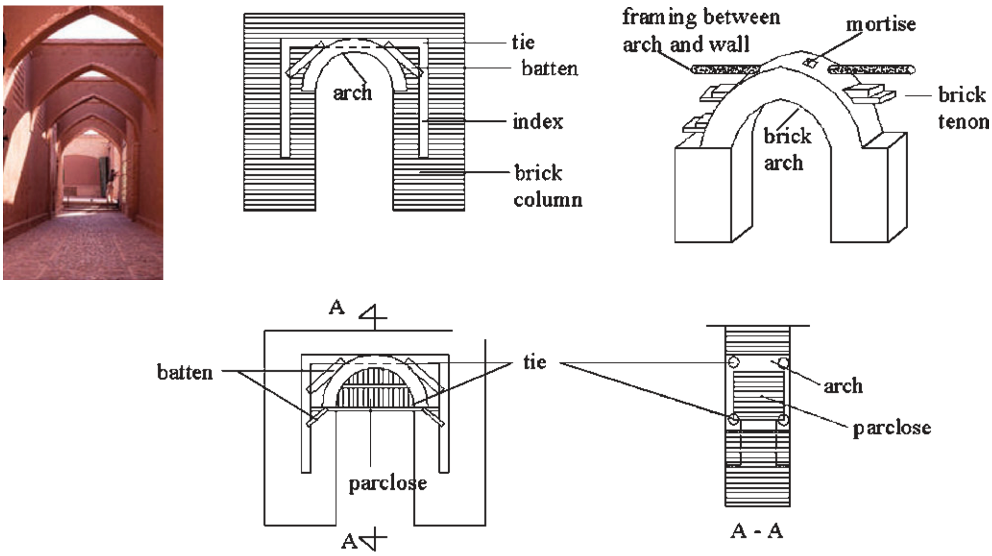

Figure 7: Narrow passageway with high walls and roofed at intervals to reduce the effects of dust storms and increase daytime shade – construction details.

9 THE COURTYARD AND THE IVAN

Courtyards – private open spaces surrounded by walls or buildings – have been in use in residential architecture for almost as long as Iranians have lived in constructed dwellings. Courtyards have historically been used for many purposes including cooking, sleeping, working, playing, gardening and even as a place to keep animals. Courtyard homes are perhaps more prevalent in temperate climates, as an open central court can be an important aid for cooling the house in warm weather. However, courtyard houses have been found in harsher climates as well. The comforts offered by a courtyard – air, light, privacy, security and tranquillity – are properties nearly universally desired in human housing.

A typical traditional Persian courtyard house consists of a central square courtyard enclosed by buildings on four or two opposite sides. During the night, cool air settles on the courtyard floor and keeps the sun's heat out for a few hours during the day. The part of the house on the southern side, which is shaded in the day, is used during the summer to avoid the heat of the afternoon sun because it is mostly in shadow and therefore cool. The existence of a garden and a small pool in the courtyard, using favourable wind, raises the humidity in the house by evaporation and makes it comfortable (Fig. 2). The Ivan on the southern side is a semi-open space whose floor is a few steps higher than the courtyard floor and makes use of the comfortable temperature created by the garden and the pool.

10 DOMED AND VAULTED ROOFS

Space cooling can also be achieved by improving the performance of roofs. This is because the roofs are the most exposed surfaces to direct solar radiation and can cause excessive heat gain in hot periods. Mud or brick masonry domes are the most common means of covering spaces. The form of the dome allows winds to cool its surface easily, and it also ensures minimal frequency of intense radiation at any one point (Figs 3 and 8). The double-shell dome is an excellent solution to

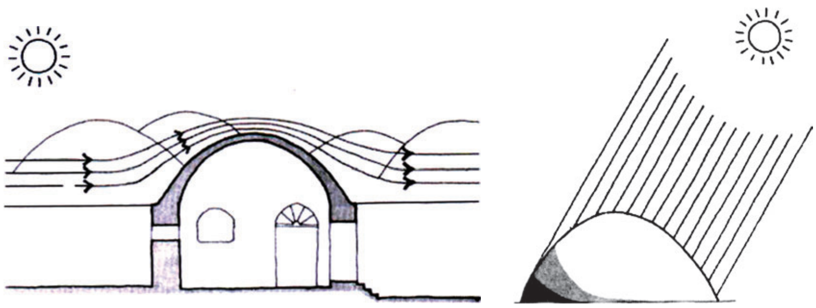

Figure 8: Cooling the dome surface by winds, and reducing the roof surface exposed to sunlight by the curve of domes and vaults.

the problem of intense radiation. The space between the inner and the outer shells acts as an insulation layer. Therefore, when there is intense summer solar radiation, the outer shell becomes extremely hot, while the inner shell remains cool. Circulation of air between the two shells from openings reduces the radiation problem.

The barrel vaults of rooms in houses are built with hollow shells. The space between the shells is used for heat insulation and structural reasons. The rooms are used as living space in the summer.

11 WIND

The structure of the city is open to the favourable winds and closed to unfavourable ones, particularly when the directions of the cool-pleasant or dusty-unpleasant winds are quite distinct. The cool-pleasant winds are drawn into the heart of the city by means of wind towers. Cool night air is retained in deep basements and courtyards.

Another way of using the strong prevailing winds of hot-dry regions involves the windmills, which are mostly found in Eastern Iran. The large wall that faces the prevailing winds not only funnels the wind through the mill, but also acts as a windbreak for the villages.

12 WIND TOWERS

The wind tower is a particular characteristic of Persian architecture in hot-dry areas, in particular in Yazd and Kashan, Central Iran [2]. Iranian houses in hot-dry regions are designed to make use of an ingenious system of wind towers that creates unusually cool temperatures in the lower levels of the building [3]. Thick massive walls are designed to keep the sun's heat out in the summer time while retaining the internal heat in the winter. Wind towers are used for ventilation and cooling of inside spaces and are constructed on the southern side of houses, which is in shadow and used during the summer.

In the cooling system of a wind tower, convection or both convection and evaporation may be used. In the convection method, cool air is conducted inside the house through the wind tower inlet. The cool air is circulated throughout the inner space. In the convection and evaporation method, there is a small pool of water inside the closed space. The air passes over the water surface and makes the space more pleasant by evaporating water. In some cases, the wind tower is built away from the main building and it is connected to the building by an underground canal. A garden is located on the top of the canal. After watering the garden, the roof and walls of the canal get wet and, therefore, the air passing through the canal becomes cool and makes it comfortable inside the house (Fig. 9).

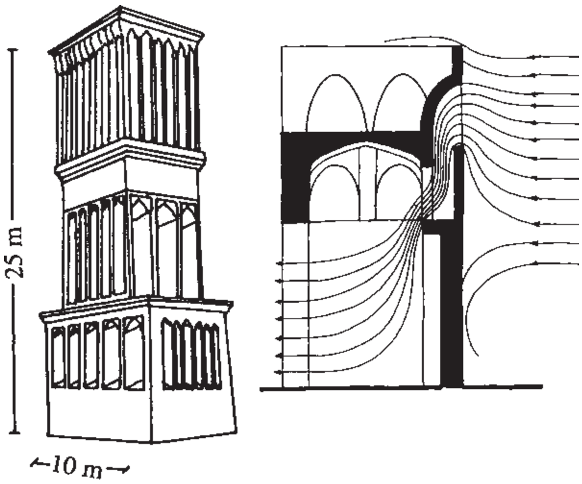

Figure 9: System of ventilation using wind towers.

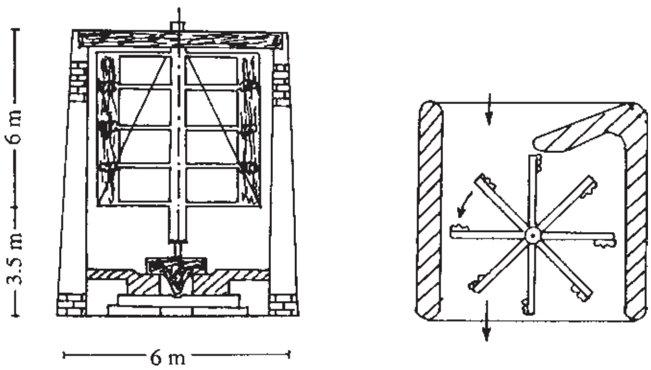

Figure 10: Windmill – utilisation of wind energy and windbreak for villages (Sistan, Eastern Iran).

13 WINDMILLS

The utilisation of wind energy for turning windmills is common to save a large amount of energy (Fig. 10). A number of windmills are closely built to act as an obstacle against strong winds and storms and to use the wind energy.

14 WATER

In hot-dry regions, the level of underground water resources is low, and access to water is difficult. This affects not only the general form of the urban structure but also its details. In these regions, the access to water is possible by the qanat system, the system of subterranean aqueducts, which brings water from the mountainous regions through underground canals into towns and transfers it to gardens, dwellings and public services. Water is stored separately for each neighbourhood.

The scarcity and availability of water and the methods of storing it along with the climatic characteristics of hot-dry regions have led to special allocation of dwelling and services.

15 CISTERNS

Traditional cisterns of Iran have certain architectural, structural and thermodynamic characteristics that reveal the knowledge of the builders. In the hot-dry parts of the country, due to the dry and long summer, a shortage of permanent surface water and a lack of drinking underground water, the natives stored rainwater in subterranean water tanks, traditional cisterns, which date back to the second millennium BC. Cisterns play a vital role in providing drinking water in these parts of the country.

Cisterns are generally built on slightly sloping land in order to conduct rainwater to the reservoir after passing through the settling basins. The shape of the reservoir of a cistern is generally cylindrical with a thickness of 1 m or more and a diameter of more than 20 m. The conical roof is set on the reservoir with a height proportional to the diameter of the cylinder. Wind towers are sometimes used as a part of a cistern to cool the water and for ventilation (Fig. 11). Materials used in the cylindrical reservoir consist of limestone rubble and traditional cement as mortar and a water-impervious lining.

16 THE ICEHOUSE

Icehouses are used for storing ice during the summer in hot-dry regions. An icehouse system consists of shallow basins, tall mud walls running from east to west on the southern side of the basins to prevent the sun from radiating on the basins during the day and an ice reservoir (Fig. 12). The system mostly depends on the transfer of temperature in the form of radiation from the water surface to the clean and chilly sky during cold winter nights. In the winter, the basins are filled with water at night, when the water is frozen. The next day, the ice is broken and stored in the ice reservoir. The stored ice is consumed during the summer.

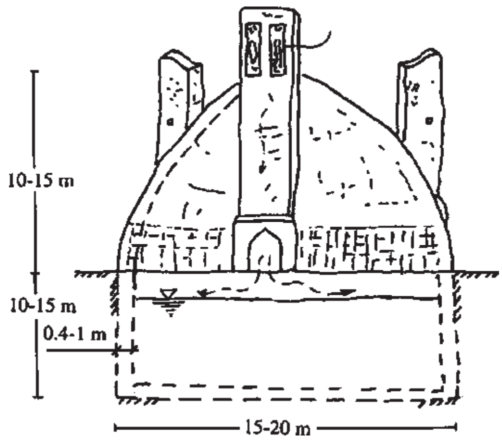

Figure 11: A cistern with wind towers to store cool water in hot-dry regions (Yazd, Central Iran).

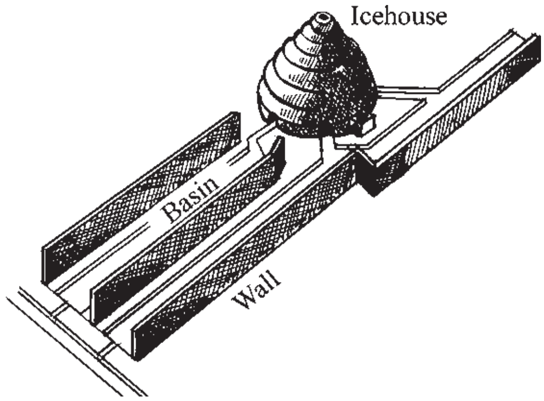

Figure 12: Icehouse for storing ice during the summer in hot-dry regions.

17 CONCLUSION

This paper discusses the ways in which traditional Persian cities have been developed, based on natural and ecological characteristics of their environment. In hot-dry regions, particular architectural styles have been used for adaptability to climatic factors. Certain architectural elements have been adopted for utilisation of natural factors such as light, heat, wind and water. By this means, unfavourable climatic factors have been changed into favourable ones.

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