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WIND CATCHER: PASSIVE AND LOW ENERGY COOLING SYSTEM IN IRANIAN VERNACULAR ARCHITECTURE

B. Ahmadkhani Maleki

Seraj Higher Education Institute, Tabriz, Iran, bahram_ahmadkhani@yahoo.com

Abstract - Environmental and natural phenomena play a very significant role in laying the region's interrelated cultural, economic and social infrastructures. The buildings in the Iranian desert regions are constructed according to the specific climatic conditions and differ with those built in other climates. Due to lack of access to modern heating and cooling equipment in ancient times the architects were obliged to rely on natural energies to render the inside condition of the buildings pleasant. In the past, without modern facilities, it was only the intelligent architecture of the buildings that enabled people to tolerate the hot summer. The ventilation structures called Badgirs were the most important means by which the interior was cooled. The wind-catcher operates according to the condition of the wind and sun radiation in the region. In ancient times and in traditional buildings in arid and dry regions the air trap functioned like the present modern air conditioning system. Wind-catcher is like a chimney whose end is in the underground and the top is set over a specific height on the roof and were built at the entrance of the house over underground water reservoirs or ponds built inside the house. The dry and warm wind will pass over a pond with a fountain gets cool and wet through evaporation. The Badgir's material again plays another role. Due to high fluctuation of temperature differences between day and night in this climate and night time coldness, Badgir which is made with mud-brick, gets cool by radiation and convection.
The system works, when there is no wind, but when wind is blowing this system does not have problems. Because during the day, if there is wind, then cool air flows faster and at night, with wind, it may absorb the heat of the walls, because the night wind is cool enough.

Keywords: Sustainable Architecture, Wind-Catcher, Cooling System, Vernacular Architecture, Energy.

I. INTRODUCTION

Wind tower is a key element in traditional architecture of Iran. It is seen in settlements in hot, hot-dry and hot-humid climates. They look like big chimneys in the sky line of ancient cities of Iran. They are vertical shafts with vents on top to lead desired wind to the interior spaces and provide thermal comfort. This architectural element shows the compatibility of architectural design with natural environment. It conserves energy and functions on the basis of sustainability principles [5].

The result of this research shows that traditional architecture can give ideas to enrich modern architecture. In traditional architecture of Iran, climate, local materials and renewable energy resources have been used. Wind tower shows the harmony of human built environment with nature. Traditional building techniques were normally well adapted to the climate.

However, the modern way of life and imported western technologies have often replaced the established traditions in the design of the buildings.
There examples which reflect the way people organize their environment in various forms. This paper shows different forms of wind towers adopted by people in different situations. Wind towers are described in terms of their function, structure, details, components, ornaments and form.

II. HISTORY AND DEFINITION OF WIND TOWER

Wind is one of the important elements for studying the climate. One of its important users is the provision of comfort in hot region. This is because the wind current creates a difference in pressure on the exterior walls that has an effect on the natural ventilation and interior air temperature of a building. For architects, the wind is an important factor in the design of a building [3].

They consider the wind's effect on the thermal comfort through convection or ventilation and the penetration of air in interior spaces. Wind has been given much attention in urban design, and in particular in cities with hot weather such as Yazd, it is to be seen clearly from the images of the city. The effect of the wind on building forms is recognized through the use of formal features such as wind tower which provides for the best use of the wind for the comfort of the occupant. Thus, along the northern shores of the Persian Gulf and the sea of Oman, architects have known how to make effective use of the sea breeze. They have achieved this by designing the wind tower with an opening towards the breeze for the maximum use of natural ventilation.

Wind towers as their name implies, are ventilation tools used for obtaining natural cooling. They have been used for centuries in countries with hot-arid climates, particularly in Iran. Wind towers in the central cities of Iran are known as "Badgir" which literary means wind catcher. Wind towers not only appear on top of ordinary houses but also can be seen on top of water cisterns, mosques. The first historical evidence of wind towers dates back to the fourth millennium BC. An example of a simple wind tower was found in Iran by a Japanese expedition in a house from the site of Tappeh Chackmaq some eight kilometers north of Shahrood and the southern slopes of Alborz Mountains in north eastern Iran. Wind tower comprises a tower with one end in summer living quarter of the house and the other end rising from the roof [2].

Wind tower is divided into several vertical air passages by internal partitions or shafts. The shafts on top terminate in to opening on the sides of the tower head. The flow inside the wind tower is in two directions, up and down. Namely, when the wind blows from one direction the windward opening will be the inlets and the leeward opening will be the outlet and vice versa.

III. ORIENTATION AND FUNCTION OF WIND TOWER

The orientation of wind tower generally means the positions of the wind tower flank based on the four main geographical directions. It is determined in view of function, use of wind power and the desired direction in which the wind blows. There are one-directional wind towers in Meibod, they are facing to the desired wind and in some cases one directional wind towers act as air suctioning and the air flow turned its back to the wind to locate itself in a negative pressure region to cause warm air in interior to blow out of the house. The desired wind currents in Yazd blow from the north-west. The long sides of wind towers are, therefore, oriented towards the north-west for maximum usage of the wind to provide cooling for buildings. In coastal regions like Bandar Lengeh, buildings have an east-west orientation. Sea breeze that blows during both days and nights but the most desirable wind blows from the east to the west.

Wind towers are therefore, built with a four directional orientation in order to use all of the desirable winds from north to south and from east to west (Figures 1 and 2). Orientations of wind towers are different according to the blow of main desired wind [1]. A Wind tower is a formal structural element in Iranian architecture that is used to convey the wind current to the interior spaces of buildings in order to provide living comfort for occupants.

In Iranian architecture a wind tower is a combination of inlet and outlet openings. The tunnel provides cool air for the building while serving as a conduit through which the stuffiness within the building is conveyed through its shaft. There were wind towers in Bam which were destroyed by earthquakes; they weren't directly connected to the living hall. They were built away from the house. An additional underground tunnel links the base of the wind tower to the basement. In most wind towers, especially the four sided types, the tower is divided by partitions.

One of the shafts operates all the time to receive the breeze and the other three shafts work as outlet air passages. They convey the stuffiness out of the living space through the "flue" (chimney) effect. The chimney effect is based on the principle that the air density increases with the increase in temperature. The difference in temperature between the interior and exterior parts of a building and between different regions creates different pressures and result in air currents [6].

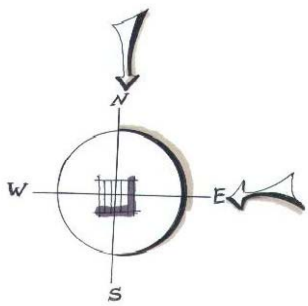


Figure 1. Orientation of wind towers in Bandar Lengeh

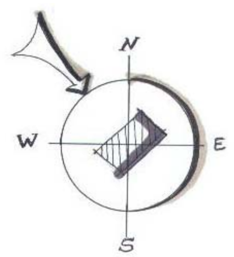


Figure 2. Orientation of wind towers in Yazd

The average relative humidity in moisture in hot and dry regions is low and it is necessary more humidity there for wind towers are used to provide living comfort through the use of the air current and evaporation. Through the wind tower, the air current first passes over a stone pond and fountain after entering a building, thereby bringing humidity to the other spaces in the building (Figure 3). In some places, mats or thorns are placed within the wind tower, and users pour water on them in order to increase the humidity and the coolness of the air flow. The hot weather in Yazd has the potential effect of causing water to evaporate easily to develop cooling in the living spaces and relative humidity in the air, thereby reducing the heat and dryness [1].

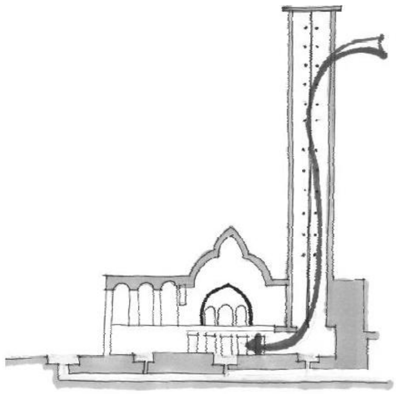


Figure 3. Function of tower in Yazd

It is clear that there is usually high humidity in hot and humid regions because of their being in vicinity of the sea. In these regions, wind towers reduce the temperature of the weather only through the movement of the air they facilitate, not through increased humidity (Figure 4). The level of humidity in this region is already high and an increase in the humidity would make living conditions troublesome.

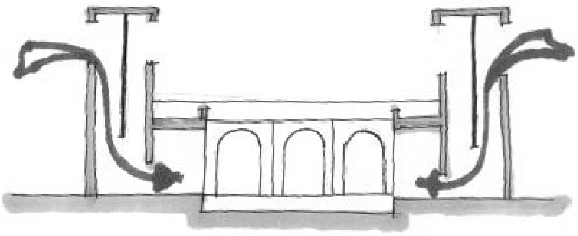


Figure 4. Function of tower in hot and humid

A wind tower in a hot and dry region brings about comfort by evaporation and air motion but a wind tower in a hot humid region only moves the air and conveys the wind into spaces [6].

IV. CATEGORIES BASED ON FUNCTIONS

The tower head may have vents on one, two or four sides that face the predominant wind direction to accommodate wind in suitable directions. Wind towers are often described by the number of directions in which they face; such as one directional (yek-tarafe), two directional (do-tarafe), four directional (chahar-tarafe), and eight directional (hash-tarafe).

A. The One Directional Towers (Yek-Tarafeh)

These towers generally face north-west or north. They have a sloping roof and one or two vents only. Otherwise they are commonly described by the direction in which they face such as "shomali" or north facing. The survey of wind towers Roaf (1988) reveals that 3% of the wind towers were unidirectional in Yazd.

Figure 5. Typical plan of one directional wind towers

B. The Two Directional Towers (Do-Tarafe)

The tower, in a simple example, is divided in to two shafts by a vertical brick partition. It has only two vents. They are often called by direction, such as north-south towers. Roaf's survey indicates that 17% of towers are in this kind and all are made on the ordinary houses [4].

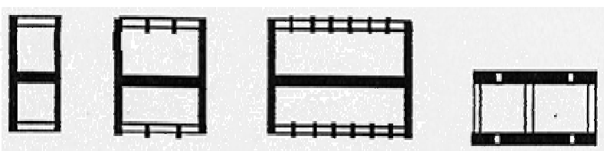


Figure 6. Typical plan of two directional wind towers

C. The Four Directional Towers (Chahar-Tarafe)

Studies indicate that this is the most popular wind tower. They have four main vertical shafts divided by partitions. More than half of the wind towers in hot and dry region have been of this kind, as reported. They are so common locally called Yazdi. All of wind tower in hot humid region are four sided type.

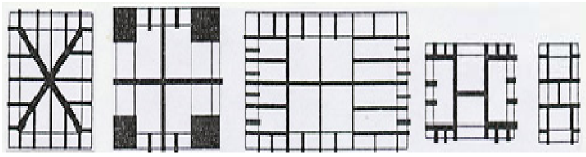


Figure 7. Typical plan of four directional wind towers

D. The Eight Directional Towers (Hasht-Tarafe)

According to the Roaf survey (1988) only 2% of the wind towers of Yazd are in this kind. They are most common on water cistern. The greatest wind tower on top of bagh-e-dolatabad has an octagonal plan.

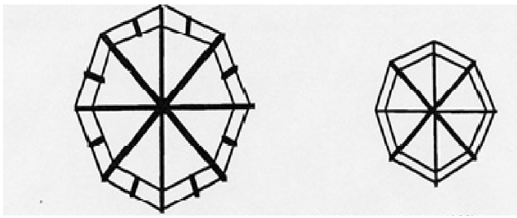


Figure 8. Typical plan of eight directional wind towers

Figure 9. Baghe-e-dolatabad wind-catcher section

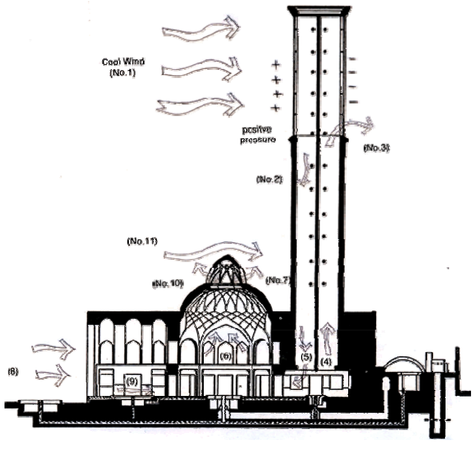


Figure 10. Baghe-e-dolatabad wind-catcher section

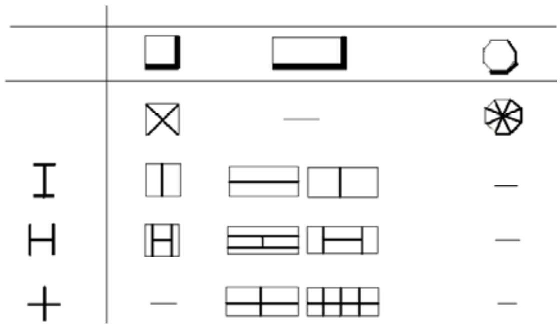
V. CATEGORIES BASED ON FORMS OF PLANS

Forms of the plan were reported square, rectangular and octagonal. The square form is the type used in the four directional wind towers in Yazd. The rectangular forms consist of one, two, four directional wind towers. Eight directional wind towers are those with an octagonal plan. There are enormous range of size and dimension from 0.40x0.80 m to 5x5 m. In plan and the ratio between widths to length is 1:2 of which, is reported [2].

Partitions are component in wind towers to divide it in to several shafts. They are built of mud brick. These partitions form a plane grid of vents ending to a heavy masonry roof on top of the tower. Partitions can be classified in to group: main partition and secondary partitions. Main partitions continue to the center of the tower, forming a separate shaft behind the vents.

These partitions often start between 1.5-2.5 m above the ground floor level. The patterns of the partitions vary from tower to tower, but the most commons are in forms of I, H and diagonal. Secondary partitions remain as wide as the external wall, about 20-25 cm. A shaft can be subdivided by a number additional partitions performing either structural or thermal role. These can separate the tower, respectively in two or four shafts. Wind towers could be categorized according to forms of the plan and patterns of the partitions (Table 1).

Table 1. Categories of wind towers based on plan



Partitions divide tower to small shafts to increase air motion according to "Bernoly effect". It express that air rate will be increased when air pass from narrow section. Such an arrangement provides more surfaces in contact with the flowing air, so that the air can interact thermally with the heat stored in the mass of these partitions. They act climatically in spite of aesthetic aspects. They work as fins of cooler window or fins of radiator because mud brick partitions give back stored heat during night and they are prepare to absorb heat. Warm wind contact with mud brick partitions there for its heat transfer to partitions after that wind with less heat enter to space [3].

VI. TYPOLOGY OF WIND CATCHERS WITH OBLONG PLAN

This is the most commonly applied type of wind catcher and the only one out of 53 types of wind catchers under consideration that has an oblong plan. The varied main blades that make up a wind catcher provide a plan with an oblong shape in different types.

A. Wind-Catcher with X-Form Blades

This type of wind catcher exists rarely or in a small number in Yazd. The length of wind catcher of this species is fairly 1/5 times as many as its width. There were only two out of 53 houses under study in Yazd had wind catchers with oblong blade and blade X (Figure 11).

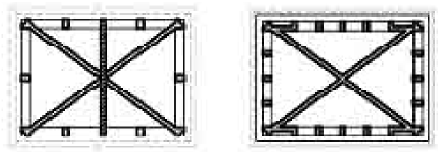


Figure 11. Wind catchers with (X) form blades

B. Wind-Catchers with + Shaped Blades

Wind catchers with blades perpendicular to each other and with a + shape is the most dominant shape of a wind catcher in Yazd. The different types of them with their varied symmetries have been seen there. The depth of its canal in linear front is 1/2 of its latitudinal depth. In this latitudinal front the depth of its canal depends largely on its length and number as well as forms of its separating blades. This specie of wind catcher can be separated in to two more subsets (Figure 12).

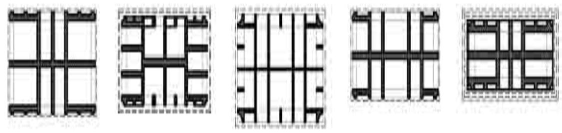


Figure 12. Wind catchers with + form blades

In these types of wind catchers, the blades are equally spaced and as a result of it some tiny canals are created with equal sizes and spaces. This type of wind catcher is the most prevalent one in Yazd in view of plan. Plan symmetries (length-width) vary from 1-1.4 to 1-2.25 (Figure 13).

Figure 13. 3D model of a wind-catcher with equal canals

Plan extension is more oriented in these species of wind catcher and the symmetries of plan vary from 1-1.58 to 1-2.92 according to field study. In species where the canals on the latitudinal form are larger, the width of oblong plan faces the dominant winds. In these patterns, the architect could not lay the wind catcher exposed to northern dominant wind from longitudinal form because of the plan form the house had and as a consequence, having changed the plan form, the architect was able to provide more wind to flow from the latitudinal to that of longitudinal (Figure 14).

Figure 14. 3D model of a Wind catcher with different canals

C. Wind-Catcher with H-Form Blades

For these types of wind catchers, the plan is designed that the main blade of a wind catcher that isolates the duct of it is inserted in to the centre of canal and does not extend to the latitudinal walls of wind catcher. The symmetries of plan approach the square (quadrant) and plan is not extended with an oblong. The symmetries of a plan is 1-1.3 or less.

This type of a wind catcher is seldom seen in Yazd. Four of them under study are adapted to this plan configuration. This specie reveals that the cross- section of canal in the latitudinal front is larger than canals that receive wind from the longitudinal from.

D. Wind-Catcher with a K-Shaped Blade

This species of plan design is, indeed, combination of a plan and X blade and + shape. This had been rarely seen in living houses architecture (Figure 15).

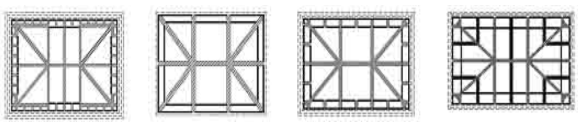


Figure 15. Wind catcher with K form blades

E. Wind-Catcher with I-Shape Blades

The main blade is hidden in the latitudinal front of the wind catcher. One closed opening exists on the opposite side of an opened hole to let wind escape, for the wind would have escaped through a hole or gap on the opposite direction. This is the most extended oblong. Shape plan in Yazd the proportional plan of which is 1-3.75. Only one model out of 53 has been configured and drawn as below (Figure 16).

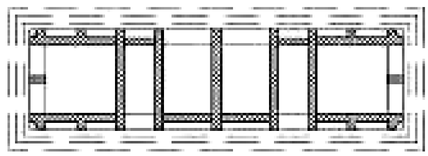


Figure 16. Wind catcher with I form blades

VII. MATERIAL, COLOUR, TEXTURE AND HEIGHT

The construction materials used for wind towers depend on climate. The choice of materials is made to ensure that the wind tower operates effectively as a passive cooling system. Wind towers in hot dry are built either of mud brick or more commonly of baked brick covered with mud plaster. Mud brick (adobe) passes heat at long time, because soil has got uncompressed volume and mud makes from water and soil.

After evaporating, there is made empty pit. It causes that heat and cool cannot arrive in molecules of soil and mud brick or adobe. Mud plaster (kah_gel) is mixture of wet earth with fine or chopped coarse straw. These construction materials give the wind tower a coarse texture. The mud plaster covering the facade of a wind tower has a light colour and there for reflects rays well [4].

Wind towers in hot humid are covered with (gach) plaster and (sarooj) this type of covering resists moisture. Vapor in the air in this region sits on the surface with temperature less that dew point in the environment. If there are high penetration on walls and surfaces of building, these drops penetrate in wall for the osmosis pressure or absorption of materials. It causes demolition of surfaces. It pushes salts of materials out of surfaces.

The texture of wind towers is polished with a white colour, which also ensures that the wind towers do not absorb rays. It provides more operation in climatic function. Wind towers trap the desired wind currents and transport these to interior spaces. To fulfill this purpose, a wind tower is designed to raise above roof the building. To enable its serve its function effectively through the appropriate utilization of wind currents, the ratio of its length and its width to height is important. Height of Wind tower in hot dry and hot humid is different. Height of wind towers in hot dry regions is more than hot humid regions. When the air current is closer to the land surface, it is warm because of the effect of the sunshine on the ground. Thus in a hot and dry region, because of the low temperature and a higher wind velocity at greater heights, wind towers are built higher to enable them to trap such currents.

The residential regions in hot humid are built near to the beach. In the hot and humid regions, the temperature on the land surface is low and desired wind and breeze or current is at a lower level thus wind towers in such areas do not rise very high at their highest, they rise only one level above the roof. Since building levels in central plateau of Iran are also below the ground level, wind towers are designed to service two interior spaces in different levels: the basement space and the reception hall on the ground floor used in summer. Water surface in Bandar Lengeh is higher because of the proximity of the sea. Thus there are no basements in the buildings in this region [8].

Here the transportation of wind currents at their minimum temperature is an important design objective for wind towers. Survey shows that over 60% of all wind towers are less than 3 meters high above the roof parapet level and only 15% rise above 5 meters high. The higher towers carry the potential for structural failure, particularly in the head of the towers, which are weakened by a number of vents.

Shafts of wind tower in hot dry regions are longer than shafts in hot and humid regions. Firstly, because wind towers in hot dry areas serve to basement floor, and this service is not needed in hot humid regions. Secondly, the height of wind from the earth has also a role in determining the height of wind towers. If desired wind current is in low levels, wind towers must receive it in low height. Longer shaft also increases wind speed during the shaft [6].

VIII. WIND-CATCHER ELEMENTS

Each elements of a wind-catcher form is affective in its final formation. A wind-catcher in order from down to upward is formed of following parts: chimney, stalk, catgut and chain, shelf.

A. Chimney

The chimney part of the wind-catcher is usually an incomplete pyramid form. The different proportions of upper part of the wind-catcher are arranged with this part. In some samples, its height is as high as a person's height and in some other it is some meters high.

B. Stalk

That part of the wind-catcher which is located between shelf and the room is called the "stalk"; the higher is the wind-catcher the higher is its stalk too. The higher of the stalk in Yazd wind-catchers according to the climatic reasons and the height of the wind-catcher is for taking suitable wind which blows in heights, the beauty of this part is mostly dependent on the brick working decoration.

C. Catgut and Chain

The catgut and chain is located between the stalk and the shelf. This element would be made and the shelf, this element would be made in different shapes.

D. Shelf

The head of the wind-catcher is the shelf which includes the blades, the channel of air passing. The common types of geometric figure of the shelf include: a lengthened, vertical rectangle, horizontal and a square. Shelves are usually front open or front closed. And this feature would be changed according to the wind blast, on the other hand two shelves would be usually considered for each ways of air channel towards the room [7].

IX. STRUCTURE AND ORNAMENT

Body of wind towers soar to receive winds in the height. Open vents reduce resistance in front of horizontal forces there for it is clear importance of structural elements. Mud brick and timbers are used in the construction of wind towers (Figure 17). Since a wind tower rises above a building, it needs elements to support it. The wind towers are built of mud brick or more commonly of baked brick and timbers. The main structure of a typical wind tower consists of a tower, several vents and partitions (Figure 18).

Timber beams are used to support partitions at various levels and to fasten the structure together in order to increase the shear resistance of the tower. The beams are left to project out of the structure to provide a ladder and scaffolding for building the tower and for use during subsequent maintenance. Main and subordinate partitions are accounted as an element to support wind towers more [5].

There are two kinds of ornamental features in wind towers, which may be considered notable among Iranian ornamental architecture. The first comprises ornamental elements that are added to the body of the wind tower for aesthetic reasons. The second consists of ornamental elements that serve as functional elements. Features of the wind towers of Yazd that may be referred to as ornamental elements include the gach feature placed at the end of the fins in different shapes in a variety of arches. Each architect used a different type of arch according to his personal preference; it can thus be said that this type of ornamentation was his signature (Figure 21). Such features are just for decoration and serve no other function. For example, brick rows are sometimes placed on the top and bottom part of the head of a wind tower, thereby probably creating a shadow effect on the body of the wind tower. These differences in ornamental elements are in no way connected with the climatic conditions and functional problems existing in these areas, but are rather a reflection of cultural features and effects [5].

Figure 17. Wind tower in Yazd

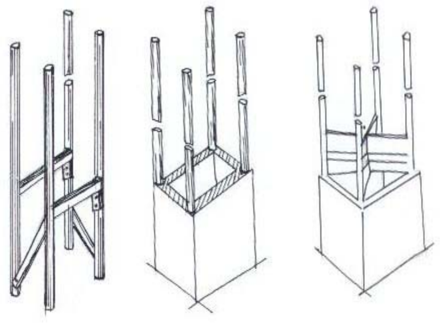


Figure 18. Structures of wind towers

X. FUNCTIONS

A Wind tower is used to convey the wind current to interior spaces of buildings in order to provide living comfort for occupiers. In Iranian architecture a wind tower is a combination of inlet and outlet openings (Figure 19). The purpose of using wind catcher is reaching reasonable temperature and relative humidity. Therefore, considering below parameters will improve wind catchers operation:

1. Wet decks; which is used as water basin or jug that is placed below wind catcher canal. Hence, leaving air temperature from wind catcher is reduced as the air flows over this humid system.
2. Geometry; cross section and wind catcher height [5]. Evaporation efficiency is proportional to air volume in constant speed. Namely, the more cross section of wind catcher, the more air will flow through building with suitable speed and evaporation efficiency will improve. The most important item to achieve this goal is wind catcher geometry. The more wind catcher height (distance from air entrance to discharge point), the more pressure difference will be and efficiency will improve. On the other hand, according to Bernoly effect, as the air flows through smaller cross section, the airflow speed will increase. Therefore, increasing height proportional to total area of canal will cause the wind flow speed increase (Figure 20).

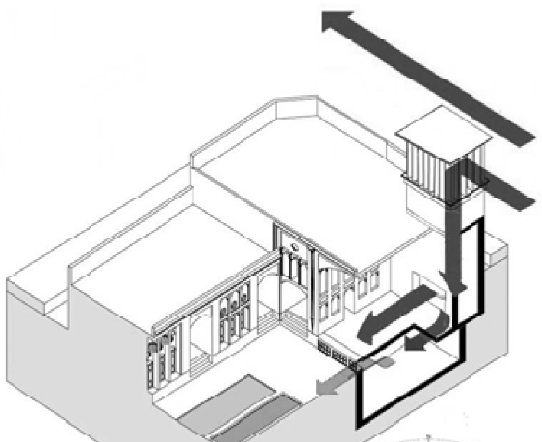


Figure 19. Function of wind tower with high wind speed

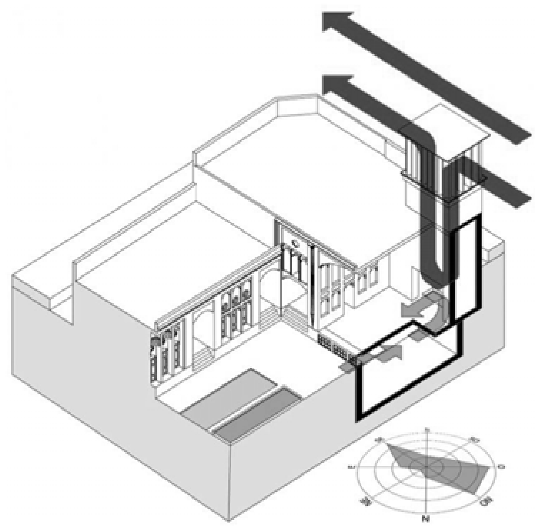


Figure 20. Function of tower with low wind speed

The tunnel therefore provides cool air for the building while serving as a conduit through which the stuffiness within the building is conveyed through its shaft. Wind tower is divided by partitions to make disparate shafts. One of the shafts operates all the time to receive the breeze and the other three shafts work as outlet air passages. They convey the stuffiness out of the living space based on the chimney effect. The chimney effect is based on the principle that air density increases with temperature increase. The difference in temperature between the interior and exterior parts of a building and between different regions creates different pressures and result in air currents [8].

XI. BASES TO SELECT SAMPLES OF WIND CATCHERS FOR AN ANALYSIS OF HEAT TREATMENT

This section indicates conclusion of inside and outside temperature of building that has equipped wind tower in one of summer hot day. This specimen ventilation has been made about 135 years ago in south of Semnan its height is 20 meters. It is highest wind tower of Semnan (Figures 21 and 22).

Figure 21. Rajabi wind tower in Semnan

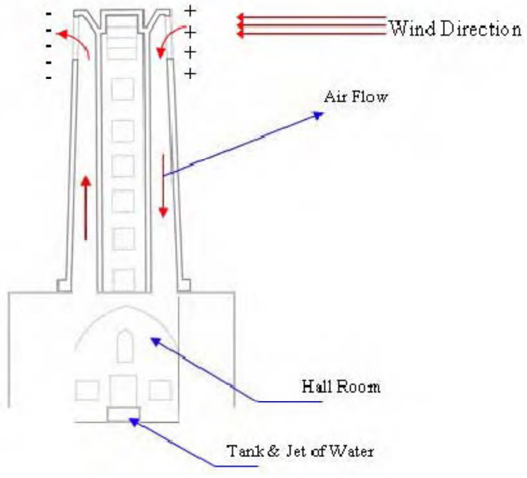


Figure 22. Direction of wind path in Rajabi wind tower

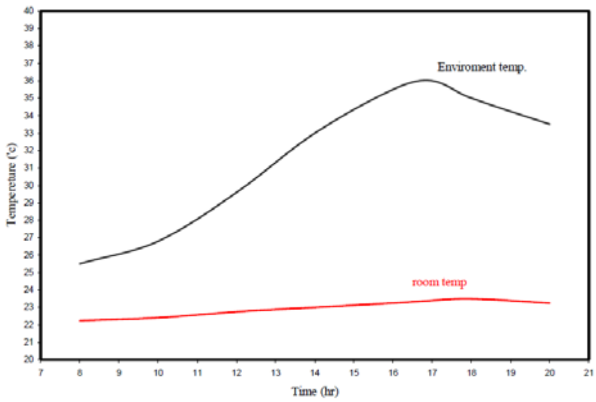


Figure 23. Room temperature comparison

As shown in above graph (Figure 23) wind tower can moderate weather of room. Other important point is fixing temperature of room and keeps it in suitable situation. Above graph shown average degree of environment in the outside is 32 centigrade and average temperature of room is 23 °C . It is desirable weather in the warm area.

XII. CONCLUSIONS

Iran's traditional architecture is caused by the climate and conditions in which it has been grown and developed, so climate as the most effective factor has been affecting in architectural element structure, specially the wind-catcher, which has climatic function. The wind-catcher is the most intelligent arrangement that proceeds of exploitation from. This will lead up the art of architecture to sustainability while increasing the profitability of clean energies. In respect to the growing need for environmentally responsive architecture from one side, and from another side, the shortcoming in provision of electricity in many small cities and villages in Iran, the use of traditional wind towers are recommended. In large cities, in low and medium rise buildings, with new mechanism and some skills, the natural cooling systems can be renewed.

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BIOGRAPHY

Bahram Ahmadkhani Maleki was born in Tabriz, Iran, 1980. He received the B.Sc. and the M.Sc. degrees from University of Shahid Beheshti (Tehran, Iran). Currently, he is a full time Academic Staff of Seraj Higher Education Institute. His research interests are in the area of Sustainable Energy in Architecture, Green Energy and Green Architecture.