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Wind catchers: remarkable example of Iranian sustainable architecture

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ABSTRACT

As scientists we tend to view technology as a scientific system but in fact the success of a particular technology at a particular time may rest less on its efficient performance and more on its 'social' relevance and impact. We now need to identify sustainable design investments for a very uncertain future of expanding populations, scarcer resources and climate change. Buildings in the Iranian desert regions are constructed according to the specific climatic conditions and differ with those built in other climates. Desert buildings are equipped with air traps, arched roofed, water reservoirs with arched domes and ice stores for the preservation of ice. The operation of modern coolers is similar to the old Iranian air traps which were built at the entrance of the house over underground water reservoirs or ponds built inside the house. Lofty walls, narrow and dry streets, highly elevated air traps, big water reservoirs and arched roofed chambers, are the outstanding features of desert towns in Iran. The ever shining scorching sun of the desert has rendered life very difficult for its hardy and warm-blooded inhabitants and has compelled them to resort to facilities that can moderate the unbearable heat. In the following paper, subjects relating to the building materials of desert towns and the method of operation of the traditional cooling systems in the cities with warm and arid climates are described. Herein the great wind catchers of Iran are a zero carbon cooling technology, but because the high towers of the region grew too large during a period of economic boom and soaring social hubris these structures may survive less well than if they had been more modest in their design.

Introduction

Environmentally Sustainable Architecture, also known as "Green Architecture" or "Green Building," is an approach to architectural design that emphasizes the place of buildings within both local ecosystems and the global environment. Sustainable architecture, framed by the larger discussion of sustainability having to do with the pressing economic and political issues of our world, seeks to minimize the negative environmental impact of buildings by enhancing efficiency and moderation in the use of materials, energy, and development space.[Nicol, 2007] It has been said that civilization may be defined by its buildings, because they, more than anything else, reflect the spirit and truth of society at the time they were built. Not only is it the communal aspect which distinguishes architecture from painting, sculpture and literature, but by definition, it is the art and science of building and therefore, it has to employ the current language of science, engineering and technology albeit set within a cultural, social and aesthetic context. [Markham, 1944] In a vast country such as Iran, with different climatic zones, traditional builders have presented a series of logical solutions for human comfort. In this paper we will focus on hot and arid regions. 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 modem 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.[Roaf,1982] By this way, without any mechanical methods and just by utilizing environmental energies such as wind, solar energies and architecture elements such as shape of roofs (Using dome & arched roofs instead of flat roofs),walls(using huge and thicken walls), materials (includes mud, mud brick ,stone, brick, mortar, lime and wood) Godal Baghcheh in house yard (Increase of contact surface of building with Earth), window, wind-tower (badgir), comfort condition have been provided for occupants. Furthermore, the urban morphology in hot-arid regions is the cause of condensed and concentrated urban texture in which the main arteries are facing the desired wind and opposing undesired one. As Iranian sustainable architecture suggests various solutions which are adapted with environments potentials, Natural ventilation, as a certain parameter for cooling and sense of comfort, plays key role in architecture formal design, which is called wind-tower.[Bahadori,1985] the early 1990s that a shift towards the high tech, air-conditioned buildings for instance, would significantly increase the greenhouse gas emissions from the built environment further driving climate change and reducing the quality of the building fabric in the process. This has proved to be true. Since then research has demonstrated that populations in different regions, climates and cultures do occupy a unique range of comfortable temperatures in their homes and work places based on the daily thermal experiences that shape , and are shaped in turn by, their own choices. The concern with climate change is that as the world warms then traditional thermal thresholds that guide the safe thermal experiences of the individual's diurnal thermal experience in the traditional homes of 95% of the world's population will be breached. Homes will become too hot to occupy. The dream of the 20th century was that air-conditioning would solve this problem and bring high levels to comfort to all, as systems became available to all but

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this dream has been shattered by the soaring costs of fossil fuels and their depletion and delivered energy that makes it increasingly likely that only the very rich will in future be able to afford mechanical cooling, unless renewable energy systems can be made widely available in the very near future. There is a hope that with intelligence people will learn to adapt to the shifting temperature zones of a warming world using minimum carbon strategies sequentially adopting more effective passive cooling systems as temperatures rise. [Mahmoudi, 2007] Research should inform the modification of our local vernacular building types and the necessary upgrading of the passive systems to make the buildings sufficiently resilient to the increasing extreme weather that will be experienced. Such adaptations appears to be sensible and appropriate but any technical evolution may well lead to unintended consequences in the form of economic or social impacts that could have been better anticipated and minimized by policy interventions at an early stage. No technical solution in the real world exists in isolation of its economic and social consequences and at a period when there is a pressing need for forced and effective change to combat rapid climate change and soaring prices of fossil fuels, we had better try to anticipate those consequences, or possibly be damned by them. The wind catchers of Iran provide a historic example of the fundamental inter-connectedness that exists between technical, social, economic and political decisions in reality.[Roaf,1990] The wind catcher systems are, at best, highly complex ventilation engines drawing pressurized air up or down the tower, through underground cool basement rooms, planted courtyard with trees and pools of water and through the high summer 'talar' rooms on the raised ground floor facing west or north west away from the sun.[Nicol, 2007] Therefore, the following paper will highlight the wind-tower function and describe its structure.

Cooling System

Air Trap

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. For example use of arched towers became popular 3000 years before the birth of Christ.Since in arid and dry climates the daytime in summer is very warm and at nights cold, traditional Iranian architects benefitted from this vast difference of temperature to cool the house. One of these skills was using very thick muddy and unbaked brick walls which has been described above. Other systems for cooling consisted of an air trap, duct (ventilator) and water reservoir. Air trap was the specific feature of architecture in the majority of warm regions. Only when the region is placed at the bottom of hills and the town is relatively cool or is attacked by storm and warm winds air trap is not used. Air traps were normally in a suitable location in the house according to the size of the building, the number of air traps that was necessary to cool the summer apartment. In cities where suitable wind is blowing from a specific direction the air trap is open in one direction and closed from the other three directions. [Roaf,1990]

In ancient times and in traditional buildings in arid and dry regions the air trap functioned like the present modern air conditioning system. Air trap is like a chimney whose end is in the underground and the top is set over a specific height on the roof. At the upper outlet many small openings or ducts are set. At the end of the air trap at the bottom of the door often a pool is set whose water was provided by qanats (aqueducts). In the vicinity of this pool or reservoir a place was designed for residents to sit and preserve their easily decaying foodstuff in summers. The height of the surface of the cross sections, the number of openers and the location of the air traps versus the building differed in different buildings. The air trap operates with the change of air temperature and the difference of weight of inside and outside the trap. The difference of weight of the air impels a suction process which causes the air to flow either to the bottom or to the top. Air circulation at various points in the building is adjusted by opening or closing the various openers or ducts at the bottom of the air trap. The air trap operates according to the condition of the wind and sun radiation in the region. The inside and outside walls absorb a lot of temperature during daytime. As a result they cause a balance of temperature at night and bestow the attracted warmth to the cold night air. The thickness of the air trap walls and the dimension of the holes inside it is designed in a manner to allow enough heat. The light warm air inside the air trap ascends and is sucked by upper elevations. As a result cool air flows from windows and doors into the house and continues all through the night. [Meir, 2003]

If wind blows at night, the air will circulate on the opposite direction in the air trap. In other words the cold air is sucked by the air trap into the house. Of course in such a condition the cold air flowing from the air trap duct which has been heated during the day time will warm the inlet air a little. Nevertheless air circulation again refreshes the inside temperature. During daytime the air trap acts contrary to a chimney. In other words the upper parts of the air trap has been cooled the night before and upon contacting the walls of the air trap the warm air cools down and moves towards the bottom and eventually circulates into the house and exits from doors and windows.[Mahmoudi,2005] The flow of air at daytime accelerates the ventilation process. Meanwhile it must be added that against each opener facing the wind, an opener or duct is set opposite the wind. Air trap acts in two ways. Some air traps only change the air temperature and others cause conditions which not only change the air temperature but the air moisture too. For example the water reservoir set at the bottom of the air trap is the coolest place in the building and is normally set in the underground. Not only these pools emit cold around themselves they blow moisture and cold against the inside walls and the inside of the air trap and render the air cool and moist, because part of the air sucked by the trap cools after passing the inside of the air trap and then enters the house. This change of temperature in the air trap impels the moisture to move in the trap and prevents the moisture from remaining static at a single location. Of course part of the wind directly blows into the water reservoir which cools the reservoir and shakes the water and prevents the water from stagnation and pollution. Thus when transferred to the halls and the other sections of the summer quarter the dry desert winds practically pass from cold and moist canals. [Curzon, 1966]

From another angle air traps can be divided into two general groups:

1. Exclusively operated air traps.
2. Symbolic air traps.

Exclusively operated air traps exist in the majority of houses. The symbolic air trap is available at few houses and beside its normal they represent the personality of the house owner and at times the air trap is larger than a room with three doors. In certain desert regions where the elevation of wind differs, we can see air traps which have two outlets at two different elevations.

Sometimes besides using air traps to cool the house the people benefit from the flow of underground waters. When the air flows from the air trap into the underground, due to narrowness of the canal the wind velocity is increased and its pressure is decreased. As a result the air is sucked from the mouth of underground outlet towards the upper elevation and due to coolness of underground waters the ascending air is also cooled and causes a pleasant ventilation process in the building.[Tavassoli,1974] One of the problems with the air traps is that insects, birds and dust penetrate into the house. Of course by covering the trap by net one can prevent the penetration of birds. Another method of preventing the dust is to increase the elevation of the air trap which will involve a lot of cost. Another method to prevent the dust from entering the building is to make the bottom cross section larger compared to the upper cross section which can reduce the speed of air circulation and let dust to settle at certain spots set for that purpose in the canal. [Roaf, 1992] At times architects build arched roof for the air traps. Because of its elevated blocks, the arched roof always generates wind. This reduces the heat which the roof has accumulated due to severe sun radiation. As mentioned earlier at nights too the temperature, repelled by the roof, is quickly emitted. In the construction of public buildings where traffic is tense, two layers of arches are set and the space between the two layers act like an isolation tunnel help the inner layer to remain colder than the outer layer. From geometrical point of view the size of a semi-arched building is nearly three times its base. Therefore the velocity of warm sun radiation over the round roof is reduced and the lower part of the circular dome attracts less temperature and incites a breeze. Thus the arched roofs are less affected by sun radiation. The circular dome is also suitable for air radiation and cooling at night because the heat expelled by the building at nights is better emitted by the arched dome. Occasionally a duct is placed at the top of the circular or cylindrical dome which because of higher velocity and lower pressure helps the warm air to be emitted from the duct on top of the cylinder dome or circular dome. This duct is covered by a protecting cover too. [Bahadori,1985]

Water Reservoir

The water reservoir is dug to a depth of 10 to 20 m on the ground and is covered by a dome-like roof and equipped with several ducts. The water is collected from qanats and is kept cool in the reservoir at the warm summer days. In the design of water reservoirs the architect benefits from change of seasonal temperature in desert regions and the isolated nature of the ground. During the winter the water is accumulated in the reservoir and in summer the dome-like roof of the water reservoir and the upper layer of the water grows warm. Therefore the upper layer of water evaporates and exits from the reservoir with the air flowing in the air trap. Naturally in order to prevent dust and insects from penetrating the reservoirs the reservoirs are not equipped with ventilators. Since the water is stagnant in the reservoir, it is not suitable for drinking purpose.[Roaf,1989] Despite the fact that the main and popular material in desert regions is unbaked brick, due to nearness of the water reservoir to the flowing water (qanats) their walls are coated by bricks to resist the destructive effect of water and this brick is known as water reservoir brick. At various occasions too beside brick and mortar the architect employs stones too for the water reservoir the majority of which are lime combinations. For example lime mortar which is composed of mud and lime, is applied at the back of the reservoir wall and another mortar made of dust, sand and lime is applied to the facing bricks.

The covering of the surface of the water reservoir was the most difficult part of the operation because to cover openings of 15 to 16 m width needed a lot of experience, but this was done by resorting to bends and the elliptical arches which prevent the expelling force.

Meanwhile by digging a well the polluted water was extracted from the reservoir and led into a dry qanat. [Stack,1882]

Sustainability is a stool with three legs: economy, society and environment. But we reduce subjects to one or a few scientific variables to enable us to understand better the complex interactions that, for example, make buildings work as they do. Reductionism can, however, lead us missing the point about why things appear to be as they are in the reality of the complex ecosystems we inhabit. The example of the wind catchers of Iran will, we hope, demonstrate that technical performance plays but a part in their design.

Typologies of Wind Catchers

Varied plans of wind catchers in Iran are nowhere to be seen at least throughout the Middle East area. This indicates how much genius and creativity the architects in Iran have.

Generally speaking, in Iran wind catchers have been recognized in varied forms and plans such as circle, Octagon, polygon, square and oblong. No triangular form of it has been yet recognized or located nowhere in the Middle East area. Wind catcher with a circular plan or form is the very rare.

There is only one sample of it in Yazd suburb. Not in view of their internally- arranged blades form. Such blades as are commonly used in wind catchers are elements that are made up of adobe and brick which decompose a wind catcher's duct in to some smaller ducts. These partitions form a plane grid of vents ending to a heavy masonry roof on top of the tower.

These blades can be divided in to two categories: Main blades and side blades. Main blades take their rise from a floor at ground reaching 1.5m -2.2m high, continue to the ceiling of a wind catcher and contribute to development of smaller ducts. Main blades play operational roles more often and influence operation of wind catcher. In contrast, side blades are inserted within the input gap of a wind catcher and play lesser roles. They resemble exactly the blades of modem cooler.

These blades add more aesthetic feature to wind catchers rather than anything else.

Main blades cannot be in sight on the external view but those of secondary; that is to say side blades substantially affect the outside views of a wind catcher and urban landscape altogether. [Tavassoli,1974]

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.[Mofidi,2008]

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 (fig1).

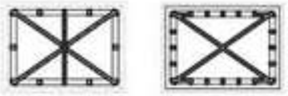

Fig. 1. Wind catchers with X-form blades.[Mofidi,2008]

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 species of wind catcher can be separated in to two more subsets (fig2).

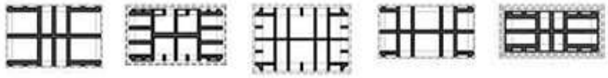

Fig. 2 Wind catchers with +-form blades.[Mofidi,2008]

Wind catchers with equal canals

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 (fig3). 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 (fig4).

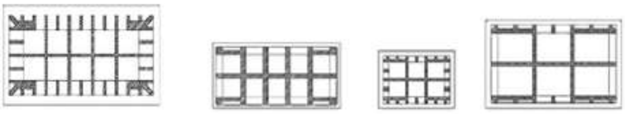

Fig. 3. Wind catchers with +-form blades and equal canals.[Mofidi,2008]

Wind catchers with different 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 (fig 5). In species where the canals on the latitudinal form are larger, the width of oblong plan faces the dominant winds (fig 6).

Fig. 4. 3D model of a Wind catcher with equal canals . [Roaf, 1989]

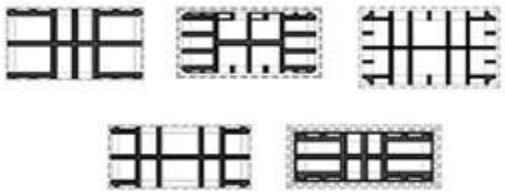

Fig. 5. Wind catchers with +form blades and different canals.[Mofidi,2008]

Fig. 6. 3D model of a Wind catcher with different canals [Roaf, 1989]

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 (fig7)

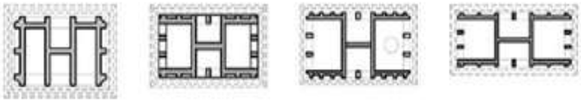

Fig. 7. Wind catchers with H form blades .[Mofidi,2008]

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 (fig8).

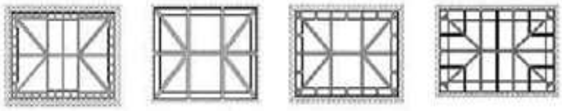

Fig. 8. Wind catcher with K form blades .[Mofidi,2008]

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 (fig9).

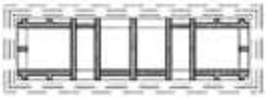

Fig. 9. Wind catcher with I form blades. [Mofidi,2008]

To Restate Traditional Solution

In recent years, a new trend emphasizing the use of hybrid mechanical ventilation systems has characterized the design of buildings. It is probably related to an increasing awareness of the need for an energy-conscious and environmentally -sound approach to architecture. However, offering a substantial contribution to the decrease of the world energy consumption for ventilation and cooling. Nevertheless a reference pattern for the newest generation of architects will need. Furthermore, occupant's hesitations have become low so comfort range to be smaller and that is more emphasizing for making comfort condition. Technical solutions for natural ventilation in traditional architecture can be a guideline for providing a zero-energy building, but the solutions are to be considered with respect to the buildings climatic situation, materials and the occupants` comfort in each region. Furthermore, wind direction is a certain point for building direction design and size of openings and so on, therefore each case will need its specific studies.[Mahmoudi,2005] Some new architecture elements such as double skin facade can associate for natural ventilation which is explained as below.

Double skin facade

Today natural ventilation performance can be distinguished and simultaneously which can be restating of traditional solution. Considering technology improvement can introduce new features and properties for building and which lead the architecture design to integrated design. [Francis,1998] Double skin facade as building envelop behave such as a wind tower but in other way Shaft-facade is one kind of double skin. Which contains a box-window with a vertical shaft (that continues in all floors) causes chimney effect. Outer facade has box-window which has opening for supply air. Chimney effect leads the air to upper and exhausts air from the vents, sometimes mechanical fans can help for acceleration of ventilation speed. Limited number of the openings is its acoustic opportunity. But this method is not suitable for tall buildings.[Givoni,1976]

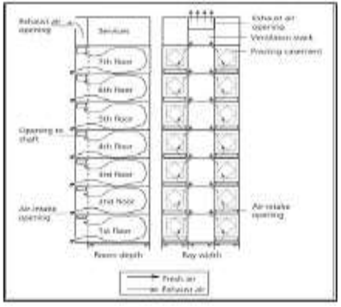

Figure 10. Double skin facade ventilation - stack effect- ARAG 2000 building[Mahmoudi,2007]

Figure 11 Solar chim ey -BRE building

Stack ventilation

Stack effect define structure of wind tower. By designing the individual chimneys air supply enters from lower part or from other openings and air exhaust exit from chimney. Stair shafts can have a same function if roof's vents are designed. In the other hand, we mention to solar chimney. A solar chimney often referred to as thermal chimney is a way of improving the natural ventilation of buildings by using convection of air heated by passive solar energy.[Mahyari,1997] A simple description of a solar chimney is that of a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building. The solar chimney has been in use for centuries, particularly in the Middle east, and today by innovative technique which is one of the most efficient tools for natural ventilation, especially in European countries.

Conclusions

Traditional architecture while energy consumption has not been defined as today, have utilized some passive design methods by attending to the potentials of the region and made them highlight. in hot climate such as Iran, one of the outstanding technical solution for providing ventilation, both for body and structural cooling, were already used in ancient times.[Ghobadian,1998] Furthermore, other techniques had been applied for achieving comfort and controlling it, as main target, at night, day and each season. A fundamental idea of this approach is focusing on providing a zero-energy building. According on the improvement of technology and advanced tools and materials, backward to traditional design hints can offer new technical solution as regard the climate and it can be away for sustainability and sustainable design. In this paper, be mentioned to traditional passive design at hot climate and the methods which have been used especially for natural ventilation. The Iranian passive cooling wind tower system which is called "Badgir", is one of the techniques for ventilation at hot climate.[Fathy,1986] In this way, by introducing it, we can refer the structure of some new methods to it, such as double skin facade which can be used in contemporary architecture design. Buildings technologies fluctuate in their prominence and popularity over time and by region. The zenith of the world history of the wind catcher came in late 20th century Iran where the greatest of all windrowers were built, paid for by the British peddling opium into the Chinese population as a means of subjugating China and expanding the influence and reach of the British Empire. A consequence of the rise of the opium trade in Yazd was the increase in the wealth of Yazdi opium merchants who built the high badgirs. The silk industry re-Located to Balkh in northern Afghanistan, the new silk capital of Central Asia where, in a related flowering of another technology, some of the greatest of the world's ice-houses were built. But that's another story. The badgirs of Iran demonstrate the complex inter-connections between society, economy and technology in a world in which physics dictates that what rises must also fall.[Ghobadian,1998] A technology that is appropriate to one age may soon fall out of favor. Look at the phenomenal rise of other types of high towers in so many cities around the world today, and ask yourself what will become of them in an age when they cost too much to run and the oil based wealth of their owners dries up? The design of any popular technology may be less about optimal performance and more about its 'social' impact. We need now to identify sustainable investments for a very uncertain future of expanding populations, scarcer resources and climate change. The great wind catchers of Iran are a zero carbon cooling technology, but because the high towers of the cities like Yazd grew too large many will introduce too much hot summer air into the homes and basements of Yazd in a warmer world, leading to the need to increase air-conditioning use in them, or abandon them. Small wind towers, such as were used in earlier centuries before the 'Little Ice Age' of the 1st and 18th centuries and are still effective in hotter countries today will be less vulnerable in the warming climate of Iran. The Traditional Technology Trap reminded us not to follow the stereotypical thinking of 'conventional wisdom' but to re-think each design decision clearly for ourselves and reminds us that the sustainability stool has three legs, and if you lose one, the stool falls.

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