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Review article

Use of sustainable wind energy in traditional architecture of windmills in Iran

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ABSTRACT

One of the main principles of sustainable architecture is the use of renewable energy. Aerodynamic force wind and its energy were effective in ventilation, heating, cooling and milling the grain in hot-dry areas of Iran. According to studies on the local, windmills known as Asbads. Windmills (asbads) are located in the eastern part of Iran (the southern part of Khorasan and Sistan).people in this part of Iran due to lack of water used 120-day winds for milling wheat and producing flour. The major purpose of this paper was to explore how windmills in Iran work via using the sustainable wind energy and analyze the indexes of sustainable architecture in such traditional buildings. History, origin and performance manner of windmills in using the sustainable wind energy are proposed by means of descriptive-analytical methods and collecting data through historical study and field study methods. Then principles and indexes of sustainable architecture in vernacular architecture of Windmills (asbads) are mentioned. Finally, it is concluded that recognition, introduction, and conservation of such buildings through documentation, proposing comprehensive plans for restoration and registering them in the World Heritage List can be effective on building an appropriate environment, improving the energy consumption pattern, attracting tourists and cultural, artistic and economic development. Moreover, creativity of the Iranian desert

dwellers in building these monument and how they have adapted to the nature are displayed.

1. Introduction

In the past, Iranians employed the existing natural possibilities to make life favorable and deal with hard climatic conditions. Iranian architect achieved solutions in the construction of traditional buildings in the area which were completely consistent with the nature and climate. A large part of Iran Is formed warm and less water areas so in traditional architecture were developed several strategies to cope with the harsh conditions of climate. Desert Wind energy is one of the most important sources of renewable natural that in Iran was used for ventilation, cooling and grinding grain.

Windmills are the oldest examples for exploitation of natural force.In Sistan land and Khaf Planes, located in Zouzan plane, a type of wind blows which called 120-day winds and certainly, the main motivation was the invention of windmills in East and North-East of Iran.

Iranian long time for milling wheat was used mill types. Areas where water was abundant types of water mills were used, where was dominant wind blowing, the windmills were used. Before applying the power of wind and water, the primary source was man-power which are used for milling wheat and they said mill manually (or Dastas).It consists of two words" dast " meaning hand, and "As" means a mill , Then water mills, windmills and mills Satori (or Kharas) was used to turn the mill stones, "kharas consists of two words" khar "means donkey and" As "means the mill which is moved these mills usually horses and camels and cattle, and sometimes the donkey and mule. (Khosravi, 1994). In Moeen Dictionary, "As" is defined as: two rounded and flat stones on each other through which a metal shaft passes. The above stone turns around by the power of men's hands, water, wind, or water steam and as a result, the grains are ground. It is not known when the first wind power was used as an energy source.

According to the documents, investigators believe that first the people of East Iran's have used wind power in windmills to grind wheat and to raise water and the industry have been moved from Iran to Europe, China, India and Egypt. (Farshad, 2009) Therefore, European countries like Holland have used Iranian students in the construction of windmills.

Today, windmills seen in parts of Afghanistan, Sistan, Khorasan and despite the importance of this industrial heritage, the studies conducted in this field, is very low. Follow the development of the industry, relationship between architecture and the environment were severed So that Structure and function of more windmills has been damaged while valuable features of architectural, technical, engineering can be found in them and where in the world goes to utilization of natural energy and reduce pollution, The bases for these structures can be used in industry and architecture, and the building introduced as part of sustainable architecture to be protected.

2. History and origin of windmills

Most historians believe that the technology of windmills been invented in eastern Persia, Khorasan and Sistan (Forbes, 1972, 195).In these areas due to winds-120 days that blowing from Ghezelghom in Turkestan, windmills wheel turns.tourists in the past traveled from Mashhad to Herat and bordering India, they have observed mill unusual with the rod vertically. The first written reference to windmills was an ancient Indian book which called Arthasastra of Kantilya that have been written about 1400 BC. The writings of the early Islamic period is available, explicitly talk about windmills that were used for flour, grain and high water. (Farshad, 2009).

The author of "Date Masoudi" wrote: Sagestan (Sistan) is the land of wind and gravel, where the wind rotates the mills and Wind takes up water from the river, the land is irrigated with water. Nowhere in the world benefits from the wind as this city does. (Masoudi, 1962) Estakhri, in his Masalek va Mamalek [religions and regions] book, states:" Sistan is a tropical city. Strong winds blowing, the mills are built for the winds" (Estakhri, 1969). In Asar al-Belad va Akhbar al- Eelad [Ages and news of the lands] book written by Ghazvini, About Sistan writes: Wind is

never quiet in Sistan and the reliance of these wind are built mills, They can grind all the wheat with them.There is a warm land. (Ghazvini, 1943)

Apparently the wind mill and sails had gone to China in the 13th century, when Mughal rule in Persia and China. “Johan Nieuwhof” has written: windmills in China, like windmills Iran but without the walls that Is located surround the Persian windmills. In the late nineteenth century, yet some of these mills was used for irrigation and drainage the brine in China. (Farshad, 2009). The vertical axis windmill was spreading rapidly in the Muslim world and windmills became an important source of power for the same cane in Egypt. (Forbes, 1972). In the eleventh century, windmills were used in the Aegean Islands, Spain, Portugal, but not the vertical axis rather than horizontal lines have a slope of 30 degrees. (Farshad, 2009). So the probability this invention has gone to Europe by Muslim rule in Andalusiaand the Crusades. (Hedin 1977). The Village "neh" in Sistan have 75 Windmills and has milled amount of one ton grain during 24hours, which is a Chapter 120 tons (AfsharSistani, 1989).a historian and geographer who has recently visited the windmills, stated:"In the downstream of Khaf and Zouzan, windmills have eminent value, above the doors and walls, in the design of the building. They demonstrate appraised and fruitful gains of the past" (Khosravi, 1994, 83).

So in fact, nobody knows that the primary basis for this type of windmill is left at what time.

According to local people: parents, grandparents and those before them, do not have remembered time to build windmills and they believe that they were used of centuries ago and whitout changes in them structure and they have not been used to Method of them and the people of this region have inherited the windmill from their fathers. Based on studies present structure dating are included to the Safavid and Qajar period

The origin of the Windmills from North East to South-East of Iran, between Zabol and KHAF.Wind power is a major factor in rotating windmills, In this area, wind has able to turn the mills.120-day winds for 3 months into the windy crossing covers Sistan and Baluchestan South Khorasan, South Khorasan Razavi, on the basis of these are the main centers for creating windmills in iran.

Today, examples of these windmills in the southwest of zabol, khaf, khansharaf, nashtifan, khonik, nehbandan ,……..are visible.

Aldameshghi, the Syrian scholar (1256-1326) has explained about the structure of windmills in Sistan. We have found his explanation accompanied by a picture (Figure 1).

Fig. 1. traditional model of the windmills.
Source: Farshad, (2009).

3. Mechanics, elements, and parts of windmills

The windmills design is very simple and they are connected without any complex techniques. The windmill is composed of two main space: Askhaneh and Parkhaneh.

The ground floor is located mill rooms (or Askhneh) and upstairs is located Parkhaneh (where the blades are located). (Figure2).

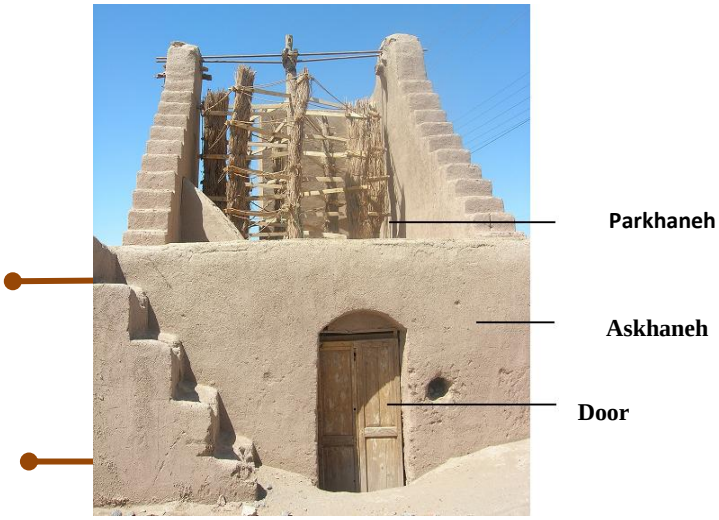

Fig. 2. A windmill in Nashtifan.

4. Parkhaneh

This section has an important role in the structure of the windmill because the wind wheel is located in it. The mud brick walls are located surrounding Askhaneh and only about 1 meter space is open in the northeastern and it say "Dargabad" or Darbad, which is located the downwind 120 day winds. Mud brick walls around the wind wheel play an important role to direction and intensity of wind flow and a height of approximately 6 meters. The side view walls are oblique and staircase.

Parts of the highest of the Parkhaneh are in order: Kharpol, Tirpol, Bazou (arms), Par and Darbad. (Figure 3).

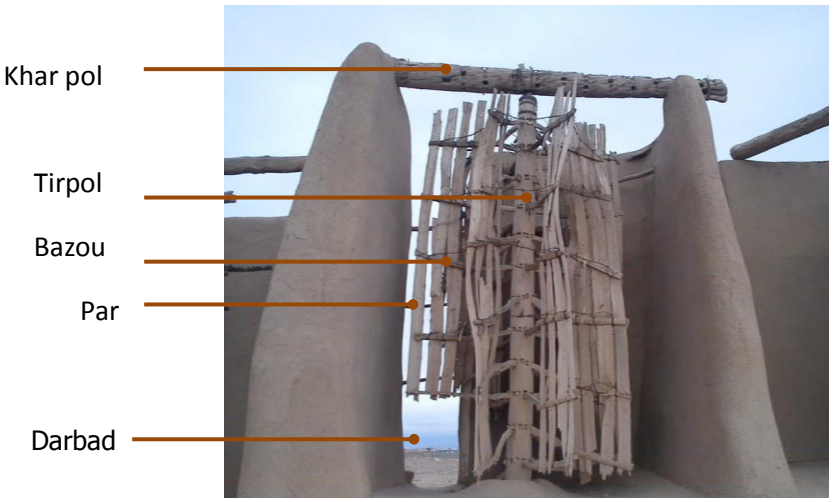

Fig. 3. different parts of Parkhaneh at Windmill of Nashtyfan.

Tirpol: Timber made of pine or sycamore tree with a length of approximately 8 meters and a diameter of 20 cm. Its diameter at the top and bottom are Not too much, and the trees are not find this proportions, Tirpol is composed of three parts that form; tongue and groove are connected to a the wedge fitting and then pass them in the middle to prevent lateral movement resulting in the loss of pressure due to the wind.

Arm [also called Bazu (or Bahou by native people): it is s composed of lumbers with 175 cm length, 7 cm diameter. arms are attached blade to a Tirpol.

Sail (or Par): Each Arm is formed 5 to 7 wooden board whith 14 cm wide and 1 cm thick. Wind wheel to move better when the Arms are thinner because there is less wind wheel weights.

Darbad -Dargabad: Reeds that are woven together like a mat and placing them against Darbad, it stop moving windm wheel.

Sargazak (wood plug): Horizontal wood on the walls is Askhaneh and made of willow tree. The reason being is that the two branches of the motion of a rotating windmill can be prevented.

5. Askhaneh

Rectangular space in which it is enlarged twice in the input space is usually low height wooden door. (Figure 6). The most important part of Askhaneh: Porkhogandom [or porkhoard] (battalion wheat), stone Asia, Toure (Srtkht), Studs (Shrrvnh), rocker (stain spots), folding beds, Thtyr (Mvshth) (Figure4).

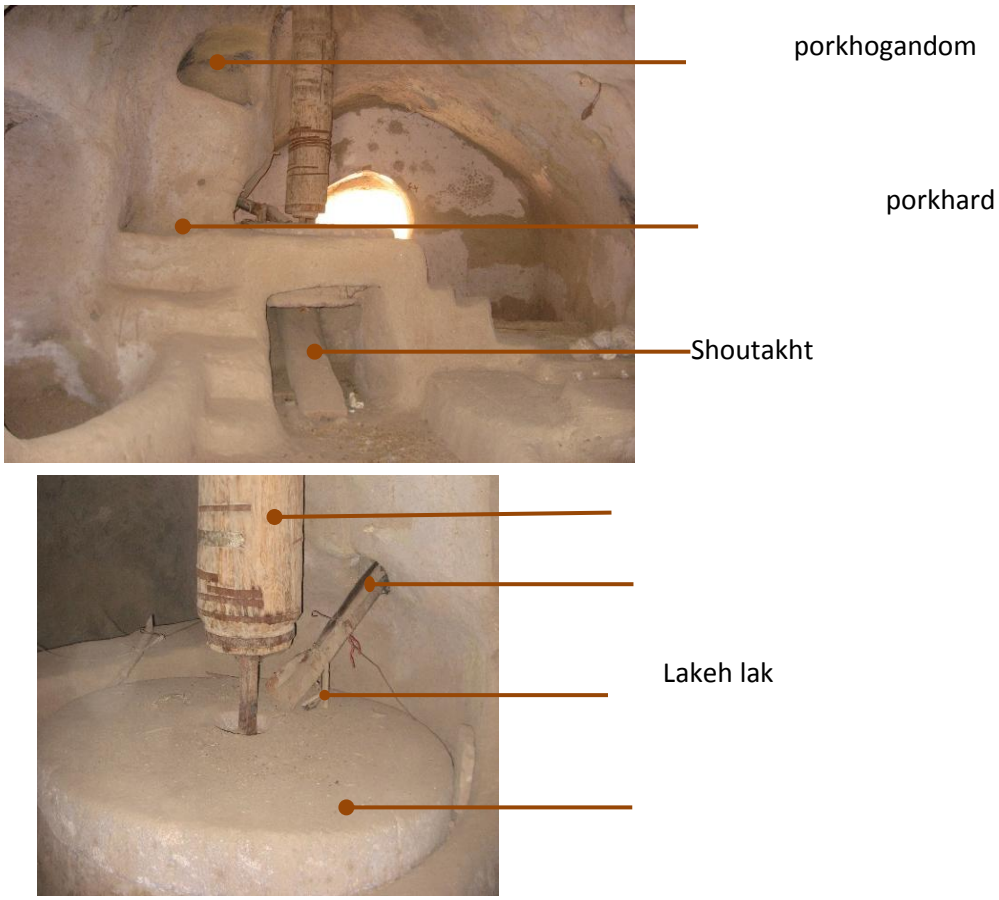

Fig. 4. Different parts of Askhaneh at Windmill of Nashtyfan.

- Porkhogandom [or porkhoard]: There are two parts near the Stone Mill. Porkhogandom is located in the upper and is attached to the center hole the mill stones. The below part is Porkhoard and the duct is attached the underside of the stone the mill.
- *Stones Mill*: they are composed of two parts: Lower stone the mill is fixed in place with 1/5 to 2 meters in diameter and 20 cm in thickness, Top stones windmill is sometimes too much stones bottom and sometimes it can be built with smaller radius.

- *Toureis*: a piece of metal, like swallow tail or bow tie with 36 to 50 centimeters length. Toure in its narrowest part, which is itsmiddle part, is 10 to 12 centimeters wide. It is also 2centimeters thick in its thinnest part and 12 centimeters thick in its thickestpart. A thick metal slat is amounted on one end of the tirpol whose end is two-folded and is located in the middle of toure. With the rotation of tirpol and its end slat, the toure and then the runner stone rotate (Saeidian, 2012, 9300).
- *Chute (or Shoroneh-Duct is a lumber,):* The Wood with a width of 12-15 cm and a length of 70-60 cm were hollow inside it. One of the chute inside the Porkhogandam, the other end is steep and wheat leads to pierce the stone. Later gutters made from galvanized or tin sheets were made. (Figure 4).
- *Esbak (Or Lake lak):* The Wood length 40-50 cm, diameter5-6cm, one end is attached to the chute and the other end is free on a stone mill. By rotating the stone mill, Esbak can tumbles over a milling the stone, causing it to shake chute.
- *Shoutakht:* It is a wooden support with 2 m length and 30 cm width and its diameter is equal to 4 cm. Tip of Shoutakht is placed inside the depression under the lower stone of the mill and its end is placed on the wooden or metal lever known as Varkesh (Figure 4).

6. The Operation of Windmill

After the wheat was harvested, and 120 days wind was blowing (From 15 May to 15 October duration of 120 days),farmers turn to grind their wheat ,If the wheat was not yet out of the skin,in front of the local wind flap with "Kajrhkob" would beat to separated wheat from the shell.

Then the grain was poured into a large sieve and Drbad was open and the air flow of guided the destination shaking sieve, the wheat is separated from the shell by wind and Wheat is clean and ready to be milled, Then stick the gap was removed Darbad (Dargabad), the wind was directed Parkhaneh, the wind wheels was turned. The wind blows the Sails, they are move in the opposite clockwise then Tirpol was rotates also. At this stage, Toureis was moved,the wheat was in porkhogandom through chute was poured into the Hole stone mill. With the move stone mill, wheat were the flour.

When winds- 120 days, windmills working day and night, but in the early fall day when 120-days wind was finished, windmills were shut down and winter, the Sails were open.

7. Typology of windmills

Based on comparative studies, the Iran windmills are divided into two categories:

1 - Single windmills

2 -linear windmills

8. Single windmills

The main characteristic of the windmill, the individual is organized. Their architectural spaces consists of: entrance Hashti (space division), Askhaneh and barn. A vault and a dome is used in this type of windmills, these coatings are highly resistant to 120-day winds. Such as: Moji windmill in Sistan. The windmill is built on two floors, the ground floor had three rooms, one of them was milling house. On the first floor, only wind wheel existed. In this floor: upper Tirpol is attached to the walls of the windmill and the third slot on the wall, when the wind hits the sails, grinding turns (Figures 5 and 6)

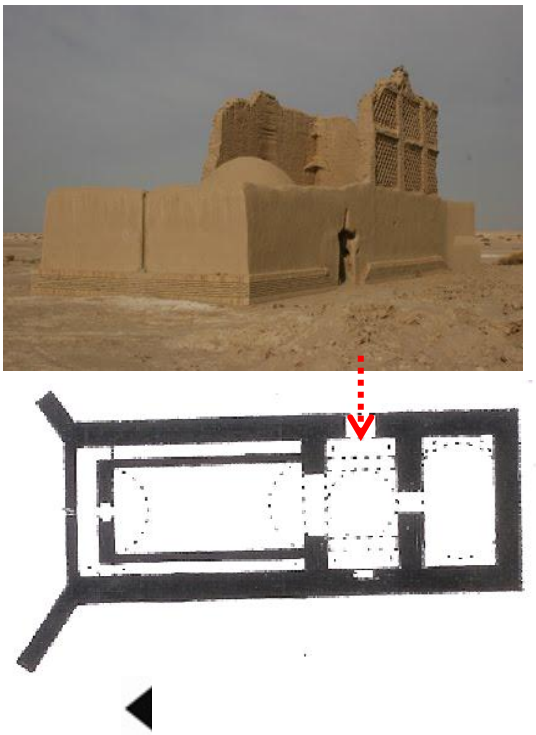

Fig. 5. The Single windmill of Moji and the plans of watermill's ground.

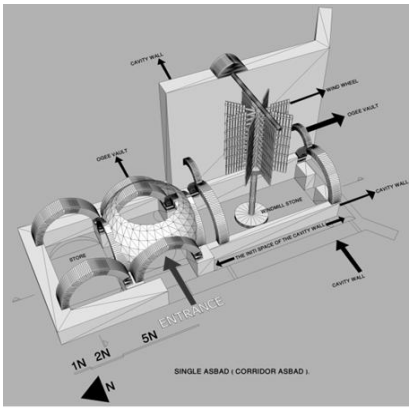

Fig. 6. The elements of single windmills. Source: Saeidian, (2012.)

9. Linear windmills

This type of windmill is smaller than the single windmills and most of the time some of these mills are arranged near each other on the high hills. They are grouped together so that their resistance against 120 day winds and the imposed load from the wind wheel is increased (Saeidian, 2012, 9303)

These windmills are 2 floors: Askhaneh the first floor, the second floor is Parkhaneh. (Figures 7)

Each one was considered as a support for another and resistance of the windmill against wind was increased. Another reason is their centrality, since windmills were indeed built where farmers gathered together after the harvest and created a small society for selling and buying wheat and flour. Also such lengthy linear wall was a good protection for cities against strong winds. Windmills in cities in Khorasan are of this kind. They have two floors that the first floor is Askhaneh and the second floor is Parkhaneh.

Fig. 7. The linear windmill of Nashtyfan and the plan of ground floors.

10. Materials of windmills

The windmills were used native material. These material is compatible with a warm and dry climate in this area. Main materials of windmill is mud brick. Mortar used in windmill mixture of soil and sand, this creates has an interesting link with mud brick.

Inside and outside the windmills are lined with thatch. Small parts such as parkhogandom is lined with plaster.

Mortar, plaster, stone for mills, timber and planks to Wind Wheel of other materials that are used.

Wooden panels made up of pine and ash trees were used in vane of windmills. The vanes of windmills in Nehbandan and Sistan were built of tamarisk and reed, because wood is very scarce in this region. Metal sheets, wire, and belts were also used to create connections among wooden parts. Millstone was made up of stone which was extracted from a rocky area located 18 kilometers south of Khaf.

11. Principles of sustainable architecture in Iran windmills

The part of Vernacular architecture in Iran are Windmills, many of sustainable design principles were existed in their architecture, which is given below:

Architecture as a living organism: The use of Vernacular materials that are produced in local. These materials do not harm the environment. They are returned to nature, and it can be digested, because the interests of these structures is derived from the nature like mud brick

Use of renewable energy: Use of wind's renewable energy to turn windmills, would eliminate the need for fossil fuels.Also energy consumption is saved and it prevents to contaminate the environment.

Creativity in architecture: In the windmills is used the wind as an energy source for milling grain because water is low in this region and have been created advanced engineering structures , which show the creativity of the previous generation.

Construction of windmills, traditional expertise in design and construction which are transferred from generation to generation, and responsive to the functional, environmental.

Materials, structures and manufacturing techniques: Mud brick, the main material is the windmill, due to a combination of mud brick and thick mud brick walls, their resistance is very high. These buildings are somewhat resistant to mild earthquakes. Mud brick walls of Windmills are thick, the arches and domes are being used in them that have high heat capacity. Technology of windmills have been passed on trial and error from generation to generation and have made use of sustainable energy, wind (TCP, ،2006).

Windmills to the structure, the material is consistent with the surrounding environment and climate requirements.

11. Conclusion

Sistan and khorasan, which are in the path of 120-day winds, have a lot of windmills. The main reasons for the use of windmills in this area:

1 -aerodynamic force of 120-days winds that could turn windmills.

2 -The water shortage in these areas forced people to use of wind power to mill wheat.

This industrial heritage have features such as local materials, climate adaptation, utilization of renewable energy, creativity in architecture so windmills have a sustainable design that can be used in contemporary architecture.

For the conservation and better utilization of the windmill and introduce them as a sustainable architecture should:

- Given to high speed of 120-day winds and the energy provided in this way, sustainable wind energy can be utilized more efficiently in the industry, power generation and manufacturing sectors if the windmills system is modified. This is especially important as the modern world proceeds to use clean energies. Such models can create an appropriate environment and save the energy consumption. Therefore, it is essential to protect such valuable heritages and recognize them.
- These valuable buildings should be introduced in regional, national and international scale to convert the region into a place to attract tourists and be a model for the current and future generations in

using the proper techniques in industry and architecture with full protection of nature, because if they are introduced properly, it will be effective on increasing of public awareness about historical, cultural, indigenous and technical values of the buildings and protecting their integrity and authenticity.

- Comprehensive plans should be prepared for conservation and restoration to prevent their structural and functional damages.
- They should be documented accurately and registered in the World Heritage List to be a sign of cultural, artistic and historical development of the people in the region and an evidence of creativity and manner of their compatibility with natural limitations, because they have many features of the UNESCO for being registered in the World Heritage List.

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