

Identification and Analysis of Architectural Features of Windcatcher in Yazd

Hojjatollah Rashid kolvir and Nushinpishkar

Hojjatollah Rashid Kolvir School of Mohaghegh Ardabili University, Iran

Abstract: Present research, in the analytical and experimental conducted studies and reviews, is about the temperature changes during the whole day, season and changes of thermal comfort between the internal and external spaces of constructions in the central regions of Iran; since long time ago, this subject has caused that the Iranian architects to invent the local-oriented mechanisms in the constructions. The main purpose of present article is to study various types of common (traditional) windcatcher as well as considering its architecture as one of the most efficient components and elements of domestic constructions in cities with warm and dry and warm and humid climate in Iran (environmental-friendly constructional element) and considers it as one of the most significant natural ventilation system and a proper alternative to the modern cooler system. Limited fossil energy sources, necessity to recycle the wind energy in warm season, reducing the dependence on the energy carriers and achieving the sustainable energy are the other objectives of this paper.

Key words: Windcatcher • Warm and dry climate • Wind • Comfort • Ventilation

INTRODUCTION

Type of climate is a phenomenon about which people always have thought about the special measures to cope with its conditions; meanwhile "The wind is one of the natural factors which its effect on human life including his settlements is studied in the context of geographical factors and in this regard, the rural people has made great efforts to identify and control the wind, [1].

Natural ventilation and air cooling without using the electrical energy is the most important architectural feature in both warm and dry and warm and humid climate. Using the architectural knowledge for overcoming the natural factors such as the wind, Iranian architects have considered the windcatcher as an important factor in the natural cooling of constructions in these regions (architecture consistent with the atmospheric conditions).

With emphasis on "the main function of windcatcher and entering the outside air into the construction, relative cooling and establishing the normal flow of air in people's work place and house", [2] this study has evaluated the

historical city, Yazd, as a case model because it has the highest number of windcatcher compared with other central cities of Iran.

Climate is one of the important factors affecting the energy consumption and waste in constructions [3] since Yazd is located in warm and dry climate (the most important factors of this land are: the little rain combined with its high evaporation, low relative humidity coupled with high heat and extreme temperature fluctuations), the main features of this type of climate are studied.

Four Climate Divisions of Iran: Iran is a high plateau which is located at latitude 25-40 degrees in the northern hemisphere and in a warm region. Its quad climate divisions are as follows:

- Warm and dry climate (central plateau of Iran)
- Cold mountain climate (mountain regions in the west of Iran)
- Temperate and humid climate (southern coast of Caspian Sea)
- Warm and humid climate (northern coast of Persian Gulf and Oman Sea) [4].

Warm and dry climate (central plateau of Iran):

- It includes most of the subtropical regions and the weather is very dry because of the immigrant winds blowing from the southwest and northwest to the equator.
- Sky is without a cloud most of the time, the radiation reflected from the arid lands of ground is so high and there are fog, storm and dust in the afternoon.
- Rainfall is very low, humidity is very low and air is so dry.
- Central plateau consists of two distinct regions including the desert and semi- desert regions; the cities such as Tehran, Mashhad, Isfahan and Shiraz are as the semi-desert areas and cities such as Yazd, Zahedan can be considered as the desert areas.
- Other features of this climate are the hot days and very cold nights and harsh and cold winters and hot and dry summers.
- Vegetation in this climate is very low [5].

Terminology of Windcatcher in the Architectural Glossary of Iran and Neighboring Countries:

Windcatcher, as one of the natural and indirect way of draught, "is a channel which is built with the construction materials, its interior walls is flat and has several blades which are deliberately predicted to add the volume of materials and increase the heat capacity" [6]. In Dehkhoda Dictionary, the natural cooling system in the traditional and stable architecture of Iran (windcatcher) is known as the words like Badras, Badghar, Badghad, Badkhan, Badkhan, Badghan, Badghas, Badhanj, Badahanj and Badahang [7]. Also "the windcatcher in some poets' poems in Iran is mentioned as the certain names like the Badghard, Badghar, Badkhaneh and Badkhan" [8] In the book "An Introduction to the Islamic architecture" Professor Mohammad Karim Pirnia has noted that: "Windcatcher is derived from the ancient and various names such as Vatghar and Badhanj and Batkhan and Khishvad and Khishkhan [1]. Except the windcatcher, another cooling tool called Khish or Khishan, which was used in ancient times in Iran and even was sent to the neighboring countries and far climates, can be mentioned" [9].

The windcatchers built in the architecture of countries such as Egypt, India and "also other Middle East countries such as Afghanistan, Pakistan, The United Arab Emirates, Jordan, Bahrain, Qatar, Iraq, Oman, Kuwait and Egypt can be noted as the successful samples of windcatcher", [10] also "few windcatchers, which are

used as the traditional architectural elements for natural ventilation in the construction buildings, have been seen over the constructions of Mediterranean regions such as Syria, Lebanon, Palestine or Israel, or in Turkey and Mesopotamia island" [11]. These countries have chosen the names, which were derived from the Iranian name or its translated word, for the windcatcher. This architectural element is known as Badkhor in Pakistan and in New Egypt the word windcatcher is usually known as the word "Malqaf", meant the windcatcher, or Malkaf" [12]. "This word is known as "Bajeer or Barjeel" in Iraq; it seems that the transmission and spread of constructing the windcatchers to Syria and Egypt has been started from this land after Islam" [13]. "The significant application of the Persian word "Badhanj" and "Badanj" (Badahang) in the Arabic literature and massive construction of this structure in the architecture of Arab countries, especially in Egypt, indicates that the windcatcher has also spread in the far lands like many other Iranian architecture elements" [14].

Evaluation and Effect of Wind in Creating the Consistent with the Climate-Architecture:

Wind is one of the natural factors, which has a significant effect on the human life and his built structures, "sometimes the human being runs away from it or struggles with it (Harmful wind) and sometimes seeks it willingly in order to take advantage of its qualities properly" (Useful wind) [15]. It should be noted that the "Useful wind" is introduced in Iran as a factor for absorbing the thermal comfort inside the structure.

Winds have certain features which the city and villages residents are well aware of its properties. Some of the features of winds are: "being permanent or seasonal, wind direction (North, south, etc.), duration of wind blowing (120-day winds of Sistan), quality of wind (Wet, dry, cold, etc.), Winds Properties (harmful or helpful), wind with rain named "Kaj Baran (Crooked Rain)" in the northern Iran" [16]. In optimal use of useful wind in the biological environments and creation of structure in the climate, the following cases should be noted:

- Materials of walls body
- Surfaces and Views
- Roof covering
- Central courtyard
- Ventilation
- Crossings and streets
- Number and area of openings
- Plans and maps

- Urban context [17]
- Creating the natural draught
- Creating the adobe rooms without a window and putting the small holes in large numbers in a wall in front of the wind
- Building the openings in the wind direction
- And finally creating the windcatcher" [18]

Windcatcher History: In an article entitled "the Iranian identity of windcatcher and finding its history in the architecture quoted by Mahyari And Roaf, Mahnaz Mahmoudi and Seyyed Majid Mofidi noted that: "The simplest example of windcatcher can be found among the Mochica Indians in Peru. They ventilated their houses using the windcatchers. The reason for this case is a clay jar, which shows an image of three ranches with multiple windcatchers. This sample is documentary evidence for the presence of windcatcher, but lack of its continuity in the building industry of Peru throughout the history has led to the doubts on this evidence" [19].

In Egyptian drawings, which were drawn on papyrus and belonged to 1500 BC, another sample of windcatcher is drawn. In these drawings two triangular windcatchers are seen on top of the luxurious home owned by the new kingdom. Elsewhere, Roaf refers to two wind recipients behind the royal Babylon hall (600 BC) [20].

"The basic concept similar to the windcatcher can be considered as the simple holes on the "Primitive tents in Sri Lanka"; in the structure of these tents the weight of tent is put on a piece of wood which goes out of the tent when the tent is pitched and its toward the wind-side is covered; on its top, there is a small opening which is able to provide air flow to the center of the tent (Figure 1)" [21].

A kind of windcatcher is found in the painting on the tomb walls of Nebamun, a Middle Egyptian king and as Roaf said these elements were probably the stairways

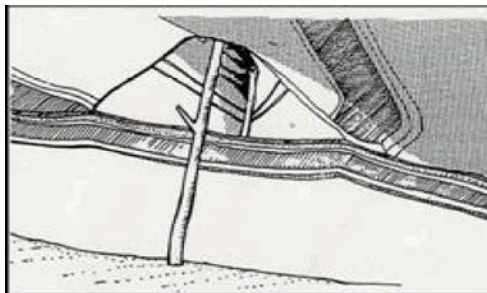


Fig 1: The initial idea for using the tent and wood in order to trap the wind and ventilate the tents (Roaf, 1988, 5)

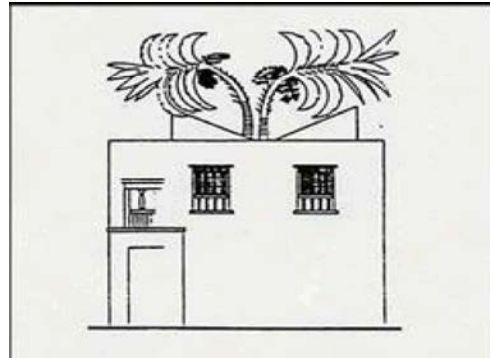


Fig 2: Figure found on the papyrus in Egypt New Kingdom tomb for 1580-3222 BC. (Roaf, 1988, 3)ss

leading to the roofs, but she said that definitely the samples, in which the height of angled roof met the external wall, they were most likely the windcatchers (Figure two).

Windcatcher: "The high heat of Yazd has forced the various buildings manufacturers to think about the measures for air ventilation and building the dry places. Building the high places back to the sunshine in the structures such as the mosques and schools are some of these solutions" [22].

Another main method of acquiring the behavioral knowledge of heat exchange is the use of windcatcher in various forms; windcatchers are built in different forms and openings ??in the central and southern climate of Iran, "the way of building the windcatcher and its form follow the desirable height and wind direction"[23]. Windcatcher chills the inside air by directing a proper wind to the space under it and an air flow into the yard and other spaces.

Windcatcher Based on Iranian Architects' Views: Windcatcher has covered the body of structures in Yazd like the costly and golden clothing; the Iranian architects have provided the architectural and noteworthy definitions some which are referred in this essay. Sasan Moradi has written about the windcatcher: "Windcatcher is an inseparable element in houses in the hot and dry desert climate; windcatchers have been built in different forms and openings in the central and southern climate of Iran. Windcatchers are built with openings facing the favorable winds in order to direct the cool wind to the interior spaces in order to ventilate and adjust the air" [24]. Windcatchers have different types and are built in different forms based on the weather conditions and wind direction across Iran [25].

Based on Akbar Zargar's view the windcatcher is in fact: "A channel built with construction materials with flat interior walls and several blades which are deliberately predicted to enhance the volume and thermal capacity of materials. Windcatchers are the typical architectural volumes which are built on the top of houses with different heights" [26].

Windcatcher is one of the architectural elements which is constructed with the climate approach in the local architecture of warm and dry and warm and humid regions of Iran and shows off as a vertical channel in the view of some cities [27].

Mahnaz Mahmoudi notes that: "Windcatcher, as a cooling system, provides a desirable air conditioning by using the renewable wind energy. This architectural element can be seen in the domestic architecture of warm climates of Iran" [28].

"As the name suggests, the windcatcher is considered as a part of structures body in warm and dry or warm and humid regions of Iran and has had an effective role in directing the wind flow and utilizing the clean energy in moderating the temperature and changing the temperature of living space into the temperature for human comfort" [29].

Author of the article "Effect of climate on the body of windcatchers in Yazd and Bandar Lengeh" wrote about the windcatcher: Windcatcher can be seen as a vertical element in the view of living space in the old cities; it directs the favorable wind to the interior spaces of structures by the vents in its own head and benefits from the sustainable energy of environment by an architectural link to the surrounding environments and entering a dynamic wind flow of environment"; the main function of windcatchers has been to direct the outside air into the structure, relative cooling and establishing the natural flow of air in people's work places and houses in the cities and different regions" [30].

Windcatcher in the Travel Literatures of Iran: Passengers who came to Iran have told about the types and function of windcatchers in cities of this land; some of them are mentioned in this article.

Marco Polo stated in his travel literature: [31] "There are very good small and large cities in it and Hormuz with Arabic-speaking people is one of them. The heat is terrible there and for this reason there are ventilation tools for catching the wind in their houses. These ventilation tools have been located in a direction which flow the wind from outside to inside the house in order to make it cool".

Garcia de Silva Figueroa wrote in his travel to Iran literature about the windcatcher that: The houses of city are high, but the windcatchers, which are like the small towers on the roof, are much higher than them. In fact, the human needs always has been forced him to eliminate the defects in the nature.

In the book "Windcatcher, the Iranian engineering masterpiece" has been written about the history of windcatcher: Erneste Orsolle stated in his travel literature about the windcatcher: "Windcatcher Mansion" had got its own name from the small towers which were built for using the mild winds and desirable air flow".

Identifying the Indicators and Main Features of Windcatcher Architecture: The windcatcher can be classified and evaluated based on several factors:

Based on Appearance: Form of column section.

- "The number and types of windcatcher openings
- Total floor of windcatcher
- Building inside the column

Based on Performance:

- Functional windcatchers
- Symbolic windcatchers
- Symbolic functional windcatchers" [32]

The main features of windcatcher architecture can be divided into the following cases:

- Peaceful coexistence with the nature
- Benefit from the wind energy in the cooling
- Benefit from the daily fluctuation of wind
- Linkage of windcatcher in the body of structure
- Emphasis on the height-orientation and height and greatness of structure
- Being raised as a decorative element in the structure
- Development of plasterwork decorations; especially plaster molded openings
- Development of Brickwork decorations
- Adding the beauty to the building especially the whole volume of structure
- Using the disturbing normal force (wind) in order to adjust the indoor air
- Energy conservation
- Coordinating with the climate
- Reducing the use of new resources
- Meeting the residents' needs

- Identity and meaningful structure of windcatcher
- Converting the patterns and geometric shapes into the plans and facade (administrative work)
- Selecting the suitable building or structure
- Selecting a geometric pattern.

Physical Components of Windcatcher: Physical components of windcatcher are linked to the elements such as the shelf, main blades and stems and branches and closed and open openings.

Shelf: shelf is the top of windcatcher and includes the channel for passing the air.

Stem: It is a part of the windcatcher body located between the shelf and the roof.

Blade: Blades are the elements composed of clay and brick and they divide the windcatcher channel to few small channels.

Main Blade: They are the walls which continue to the center of tower and divide the wind channel into smaller channels.

Sub-blade: They are the walls which do not continue to the center of tower and only come the width of exterior walls. The sub-blades appear like the blades of cooler channel in the view of windcatcher.

Open and Closed Openings: in the view of windcatcher, any space between two blades (either the main blade or the sub-blade) is called the opening and if it is open and the air passes through it, it is called the open opening otherwise the closed one [33].

Channel: "Channel or body of windcatchers is the vertical duct which is usually made as a cube and sometimes a prism in order to move the air flow in a vertical direction from top to bottom or vice versa".

Structure and Function (Performance) of Windcatcher
Traditional buildings expression the real architecture and provide the comfortable life conditions in all types of climate because of what is called the environmental sustainability. There are a number of architecture elements which help to supply the cooling in interior spaces; some of them are the windcatchers Khishkhan, Shodan, central courtyard, Sabat (sunshade), pool etc.

Wind Tower is another structural element, which is important in the traditional typology is used now and the wind hits it from one or more side and is directed into it. Therefore, due to being light, the warm air exits from around and the cool air, which is heavier, enters down and into the room and because of the continuation of this act, there is always a fairly favorable draught blowing and the relative comfort is provided [34].

In fact, the windcatcher receives the useful wind and directs the wind to the internal spaces of structure for cooling and pleasant ventilation. "The opening facing the windcatcher is under the positive pressure (+) and the one behind the wind is located in the suction region [negative pressure (-)]" [35]. The blade in the middle of windcatcher separates the pressure region from the suction one. Wind comes from the opening facing the wind hits the vertical blade in the middle of windcatcher and is directed through the channel facing the wind to the interior spaces.

In some types of windcatcher, a pool or pan is located at the end of windcatcher channel; the wind entered the channel, increases the cooling air when passes on the water of pan or pool through evaporating the water in the pool.

Air, used in the internal spaces, exits fast through the channel behind the wind due to the light weight (Absorbs the heat of indoor) and also the created suction so the fresh air is replaced with the consumed air is in the internal space.

In some cases, the windcatcher is covered with the chaff, mat and thorn bushes and... and it helps to increase the cold air by spraying the water on the materials.

Other kinds of windcatcher cool inside the building only through the convection and others do also this action through moving the convection and by evaporation [36].

Secret of Windcatcher Immortality and Significance:
Because of what we know about the identity in the urban context, evaluating the factors affecting the continuity and immortality of windcatchers seems essential. The immortalized work, like the windcatcher, can be evaluated and analyzed based on three attitudes including the elite friendly, general friendly and comprehensive view. What makes the effect of windcatcher immortal is the simultaneous attention to all human aspects proposed in the architecture area. Significant building and creating the windcatchers with its own specific local architecture reminds the principles such as being the same as people, avoiding the futility,

static and self-sufficient which Professor Pirnia considered it as a keyword for the work immortality. Undoubtedly, it can be written that the secret of durability and immortality of windcatchers in Iran is the rational response to the special and general needs (Collective wisdom) and the human thoughts beyond the time and place.

Windcatcher architecture is mixed with the identity and meaning and it benefits from the language of code and mystery according to the traditional (Native) architecture in order to emphasize on its own durability.

Factors Affecting the Windcatcher Shaping:

- "Wind blowing direction
- Factors such as hot and dry, warm and dry, or warm and humid weather and severe seasonal winds have had a significant effect on constructing and using the windcatchers" [37].
- "Climatic conditions of warm and dry regions have their own features and special architecture structure and the scorching sun of day, night chill weather, little precipitation with very rapid evaporation, dry air with low humidity and severe winds are some of the features in shaping a windcatcher" [38].
- Another factor is reducing the heat transfer inside the building
- Natural ventilation and cooling the air without using the electrical energy is the most important feature of windcatchers.
- "Since that the blowing of constant seasonal and daily winds is considered as one of the main climatic features of desert regions in Iran, the windcatchers in these regions have been built in the direction of pleasant and high speed winds" [39].
- Natural ventilation and cooling the air without using the electrical energy is the most important feature of windcatchers.

Feature of Yazd Windcatchers:

- Is larger than other built windcatchers in Iran;
- Since some of the windcatchers have four sides, they are able to receive and direct the wind from four sides into the building;
- Increased number of sides from four to six and eight is one of the evolutionary stages in building the windcatchers. (Dowlat Abad Garden windcatcher) (Figure 4-4)

- They have higher height than the other types of windcatchers.
- They have their own beauty and complexity based on the architecture structure.
- In some cases, the windcatchers of Yazd have two floors (two-ranch) and it can be named as the evolutionary windcatchers of Yazd.

Shortcomings and Disadvantages of Traditional Windcatchers:

"Ancient and efficient structure of windcatcher has also had the shortcomings despite the outstanding features and creating the favorable conditions in the people's life in desert" [40], the following cases are some of the disadvantages of windcatchers:

- Openings or inlet vents of windcatchers have been the place for entering the dust, insects and sometimes the small birds into the building.
- A part of air, entered from each opening of windcatcher, is sent out by the other opening and does not achieve the opportunity to enter the building. However, this problem persists in the windcatchers which use only an opening for wind entering.
- The amount of cooling energy stored in the mass of windcatcher structure is limited due to the low mass of building and this energy cannot meet the cooling needs of a hot summer day. Moreover, there is a possibility of inadequate contact with the air in the high temperature.
- In the buildings, which use the basement, despite passing the air from the moist surfaces, the potential evaporative cooling air is not fully utilized. The evaporative cooling in warm and dry areas has an effective process in providing the thermal comfort.
- The windcatcher is not useful for the regions in which the wind speed is not significant.

In order to overcome these shortcomings, the new plans should be provided in order to upgrade the Performance of traditional windcatchers. Applying the windcatcher with "the wettable columns" and "wetable surfaces" can help us to achieve this goal [40-42].

- Due to the limited cooling energy, which can be stored in the structure of windcatcher, the windcatcher cannot meet the cooling need of a hot summer day.
- Potential evaporative air cooling is not fully utilized.

- The air flow and the amount of humidity and coldness cannot be fully controlled.
- The windcatchers increase the wind power due to their tendency to grab the wind.

Compared with traditional windcatchers, the new ones have been changed; these changes include:

- Head of windcatcher
- Increasing the heat transfer surface
- Evaporative air cooling [43].

Constructional-executive Features: In the book "The book of desert architecture (Review of Yazd cisterns) quoted by Ms. Roaf, Gholam-Hossein Memarian divided the windcatchers based on the number of directions receiving the wind by the windcatcher; his classification is as follows:

1-Uni-directional windcatcher, 2-Bi-directional windcatcher 3-Windcatcher with diameter blades, 4-Quad-directional windcatcher and 5-Hex or oct-directional Windcatchers.

CONCLUSION

Since years ago, the efficient use of climate conditions has been one of the most important designing and implementing factors of buildings. Nowadays, the importance of energy savings in buildings and providing the comfort conditions have been declared more than before for the professionals, managers of communities and people, so that many experts have raised this subject as the determinant factor of sustainable development in future of construction industry.

Considering the climate conditions is one of the most fundamental principles of Iranian architecture. Yazdi windcatcher architects have had the knowledge of natural environment (Peaceful coexistence with the nature) and followed the architectural objectives with the insight into the climatic conditions. Windcatcher is the most ingenious contrivance which utilizes the natural energy of wind and provides the cooling comfort in the warm areas.

Developments, which have been achieved in the fields of science and technology, the emphasis on the design, analysis and scientific construction of windcatchers seem quite essential. Building designers can use the windcatchers for providing the buildings residents' cooling comfort properly by applying the

scientific achievements and guidelines [44-45]. In fact, having the knowledge about the role of traditional architecture element (windcatcher) in the biological environments is a potential possibility for the future buildings.

Climate design and keeping constant or minimizing the cost necessary for maintaining the desirable conditions and comfort inside the building is one of the results of this study. Maintaining the thermal comfort, which results from the temperature equilibrium between the body and surroundings, is another result of this paper for achieving the highest efficiency in order to making the architecture close to the nature and avoiding any matters against the environment.

Changes without any intellectual, analytical and scientific support in some of the human-built areas has led to many forgotten innovative local techniques, despite the fact that using the new technology and materials is considered normal, they will lead to the consequences such as reducing the energy, environmental pollution, etc. Combining the traditional architecture with new facilities in order to reduce the shortcomings of old architecture seems the best solution in today architecture and is another result of this study.

It is hoped that the importance, which there is in the sustainable energy sources and the physical-functional cognition of architectural element (windcatcher) will be the guides for the architects and designers in order to participate in optimizing the fuel consumption with the climate measures in designing the buildings.

REFERENCE

1. Haji Ebrahim Zargar and Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 89.
2. Bahadorinejad and Mehdi, 1387. Windcatcher, Iranian engineering masterpiece Yazda Publication, first edition, Tehran, pp: 5.
3. Effect of climate on energy consumption in the residential buildings in Tehran, Mohammad Ali Abdoli, Ofelia Fasihi.
4. Moradi and Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, pp: 37.
5. Moradi and Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, pp: 38.

6. Haji Ebrahim Zargar, Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 98.
7. Dehkhoda, Ali Akbar, 1336. Dictionary, Sirous publication, Tehran, pp: 9.
8. Bahadorinejad, Mehdi, 1387. Windcatcher, Iranian engineering masterpiece Yazda Publication, first edition, Tehran, pp: 7.
9. Pirnia, Mohammad Karim, 1390. An introduction to the Islamic Architecture, edited by Gholam Hossein Memarian, Soroush Danesh publication, Sixteenth Edition, pp: 333.
10. Bahadorinejad, Mehdi, 1387. Windcatcher, Iranian engineering masterpiece Yazda Publication, first edition, Tehran, pp: 22.
11. Roaf, S., 1988. The Windcatcher of Yazd, Ph.D thesis, Department of Architecture; oxford polytechnic.
12. WWW., Vi.
13. Varjavand, Parviz, 1372. Shia Encyclopedia, Shia Encyclopedia institution, second edition, Tehran, pp: 3-162.
14. Rosenthal, F., 1977. Poetry and Architecture: the Badhanj, Journal of Arabic Literature, 8(1): 1-19.
15. Haji Ebrahim Zargar, Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 89.
16. Haji Ebrahim Zargar, Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 90.
17. Moradi, Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, pp: 40-46.
18. Haji Ebrahim Zargar, Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 92-96.
19. Mahyari, A., 1996. The Windcatcher, Ph.D thesis; Sydney University; Australia, pp: 44.
20. Roaf, S., 1988. The Windcatcher of Yazd, Ph.D thesis; Department of Architecture, oxford polytechnic, pp: 4.
21. Roaf, S., 1988. The Windcatcher of Yazd, Ph.D thesis; Department of Architecture; oxford polytechnic, pp: 4.
22. Memarian, Gholam Hossein, 1372. Review of Yazd cisterns architecture, the book of desert architecture, Soroush Danesh publication, Tehran.
23. Moradi, Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, compiler : Saeed Ghabadi, pp: 143.
24. Moradi, Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, pp: 47.
25. Pirnia, Mohammad Karim, 1390. An introduction to the Islamic Architecture, edited by Gholam Hossein Memarian, Soroush Danesh publication, Sixteenth Edition, pp: 331.
26. Haji Ebrahim Zargar, Akbar, 1388. The book of an introduction to the identification of Iranian Rural Architecture, Shahid Beheshti University Press, Fifth Edition, Tehran, pp: 98.
27. Mahmoudi, Mahnaz and Mofidi, Majid, 1387. Iranian identity of wind catcher and seeking its history in the Iranian architecture, Hoviat-e Shahr Journal, pp: 2.
28. Mahmoudi, Mahnaz and Mofidi, Majid, 1387. An analysis of architecture typology of Yazd windcatchers and finding a functional efficient type, Honarhaye Ziba publication, pp: 36.
29. Mahmoudi, Mahnaz and Mofidi, Majid, 1387. An analysis of architecture typology of Yazd windcatchers and finding a functional efficient type, Honarhaye Ziba publication, pp: 36.
30. Bahadori, M.N., 1978. Passive Cooling System in Iranian Architecture, Scientific American, 283(2): 144-145.
31. Bahadori, M.N., 1977. Natural Cooling in Hot Arid Regions, in Solar Energy Application in Buildings, edited by A.A.M Sayigh, Academic Press Inc., New York, pp: 195-225.
32. Yule, H., 1871. The Book of Sir Marco Polo the Venetian, London, pp: 383-384.
33. Bahadorinejad, Mehdi and Dehghani, Alireza, 1387. Windcatcher, Iranian engineering masterpiece Yazda Publication, first edition, Tehran.
34. Mahmoudi, Mahnaz and Mofidi, Majid, 1382. Climate effect on the body of windcatcher in Yazd and Bandar Lengeh, Proceedings of Third International Conference on Fuel Optimization, Tehran, pp: 1.
35. Negro A. and L. Stafferi, 1984. Tecnologia Dei, Materiali, Da Costruzione, Eeizionni Liberia Cortina Torino;
36. Moradi, Sasan, 1389. Adjusting the environmental conditions, Shahidi publication, fifth edition, new edition, pp: 147.

37. Nasri, Masoud and Hekmat-panah, Raheleh, 1388. Role of windcatchers and necessity to consider the environmental tensions in urban designs of desert areas, Proceedings of the National Conference on Sustainable Architecture, Educational and cultural center of Sama hamedan, Hamadan.
38. Zamrashidi and Hossein, 1373. Iranian architecture-components of traditional building, Zomorod publication, Tehran.
39. Dehghani, Alireza, 1385. Evaluating the history and evolution of windcatchers, these beautiful phenomena and factors of pleasant traditional ventilation, ventilation and refrigeration, 19: 4-13.
40. Bahadorinejad, Mehdi, 1387. Windcatcher, Iranian engineering masterpiece, Yazda Publication, first edition, Tehran, pp: 4.
41. Bahadori, M.N., 1985. An Improved Design of Wind Towers for Natural Ventilation and Passive Cooling, Solar Energy, 36(2): 119-129.
42. Pakzad, Amir Reza, 1378. Analysis of two new windcatchers for the climate of Iran and comparing them with the current windcatchers, M.S Thesis, Faculty of Mechanical Engineering, Sharif University of Technology, Tehran.
43. Bahadori, M.N. and A.R. Pakzad, 2002. Performance Evaluation of New Designs of Wind Towers, Paper No. FEDSM 2002-31247, Proceedings of ASME FEDSM02, ASME 2002 Fluids Engineering Division Summer Meeting, Montreal, Quebec, Canada, Jurnal, pp: 14-18.
44. Bahadorinejad, Mehdi and Dehghani, Alireza, 1387. Windcatcher, Iranian engineering masterpiece" Yazda Publication, first edition, Tehran, pp: 301.
44. Bahadorinejad, Mehdi and Yaghoubi, Mahmoud, 1385. Natural ventilation and cooling in the traditional buildings of Iran, Iran University Press Center, Tehran;
45. Khishkhan was a cottage or Darafarin around which was covered by a mat, pottery or Alhagi Persarum (Manna) bushes and was sprayed by water in order to absorb the cool air due to the blowing air.