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Original Paper

Comparison between Some Wind-catchers and Its Effect in Natural Ventilation: Case Study

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Abstract

Nowadays, non-renewable energy sources are declining rapidly which they require a lot of energy and a lot of time and resources. They also require costly maintenance; the manufactured artifacts have a lot of rubbish and contaminants that are difficult to recycle. Using renewable energy sources and low cost with the least pollution can help to reduce the consumption of non-renewable energy sources and reduce environmental pollution. In this work, research and study has been done on the advantages of using clean energy such as wind energy, wind-catchers construction method, advantages of using wind-catchers and finely comparison of parameters created when using wind-catchers and comparing them with the optimal standard parameters. Six buildings with different conditions wind-catchers in Yazd city, which is a desert city in center of Iran, were selected for research. All specifications of these wind-catchers such as model, length, width and etc., are shown. Then important parameters such wind speed, outside temperature, indoor temperature and humidity of each case is measured in two stages during the day and night in intervals of 1 to 4 months. Investigation of indoor and outdoor pollution, when the wind-catchers valves are open or close, and the effect of wind-catchers on the entry of noise, dust and air pollution such as carbon dioxide into the building, and compare it to the acceptable standard limit provided by the health organization, as well as the effect of size of opening and height of the wind catchers on amount of increase or decrease in the entry of pollutants into the building. Recognizing the benefits of using clean energy, and recognition of types of wind-catchers, their construction methods and other parameters expressed, in general, all the information collected and *comparisons and evaluations can be used to select best type of wind catcher and best use of resources and knowledge.*

Keywords

natural ventilation, wind energy, wind-catchers, outdoor and indoor temperature, humidity, noise, air pollution

1. Introduction

It is now more popular as a result of the harmful effects of air conditioners on the environment that use environmentally friendly features. They use renewable energies to run the system, such as wind and solar power. The wind-catcher is one of those environmentally friendly devices which mentioned in the introduction. Wind-catchers have been used in the Middle East for ventilation and cooling purposes and they are environmentally friendly and sustainable energy systems. They only provide thermal comfort and fresh air rely on natural forces (A'zami, 2005). For centuries has been used the wind-catcher for cooling the room and create natural ventilation in buildings. Different types of wind-catchers have been seen in many different places in the world but it's not quite clear who invented the very first wind-catcher.

Firstly wind-catchers were built in areas with hot-arid climates where there is a prevailing wind, and the air is free of moisture. In these areas usually wind-catcher mounted at the top of the building in order to catch and cool air induction into the building, facing the prevailing wind. Using ordinary windows in hot and dry areas does not help for ventilation, so using the wind-catcher as a separate ventilation system provides air movement and use windows just for natural day lighting.

A wind-catcher is a fixed flue shaped device that can act as both an air inlet and outlet. Using the benefit of wind and stack effect at the same time is another advantage of wind-catchers (Battle McCarthy Consulting Engineers, 1999). Wind-catchers catch the breeze from any direction, for do this; they have vertical shafts with openings on two, four, six and sometimes eight sides at the top of the shaft. Those vertical shafts are divided into several separate shafts based on partitions that run along each other along the entire shaft to allow air to enter from one side or two and exit from the other (Soflaee & Shokouhian, 2005; Fathi, 1986).

Wind-catchers are useful both when the wind is high and when the wind velocity is insufficient to run the system. In first they collect air from the wind ward side and extracts hot and polluted air from the leeward side and in low wind velocity they act as a chimney and exhausts indoor air to outside. In wind-catcher both the inlet and outlet are situated in the same device, this advantage of wind-catcher that makes the wind-catcher different from other types of natural ventilation devices.

2. Wind-catcher Theory and Basic Information

As we know the wind creates a pressure difference around the barrier. When wind hits the wind-catcher as an obstacle, in the windward area the air density increases in comparison to leeward area. Because of positive and negative pressure forms on the both side of the wind-catcher, wind enters from the area with the positive pressure and tends to move to the lower pressure zone. The bottom of the wind-catcher's shaft is lower pressure zone, so fresh air enters to the building. Higher negative pressure exhausts indoor hot and polluted air to the opposite side of the inlet (Bahadori, 1994; Pyrnia, 1981).

Because of a density differences between indoor and outdoor air the stack effect occurs in wind-catchers. The pressure gradient forms between top and bottom of the column which helps to exhaust warmer, lighter air to the building and introduce cooler denser air from wind-catcher's structure. Furthermore, where denser heavier cool air is located, there are usually some openings in lower level of the building, fresh air enters the building from the openings and hotter lighter air exhausts from the top of the room (Yaghoubi et al., 1991; Battle McCarthy Consulting Engineers, 1999).

Denser cooler air enters to the wind-catcher's structure when the temperature of outdoor area reduces during the night. That air is mixed with the hot air that have been absorbed by the wind-catcher's structure and building during the day, then mixed hotter air goes up from structure or other opening in the building, cooler air is introduced to the indoor area. Till the temperature of the wind-catcher's structure and outdoor temperature become equal this cycle continues (Soflaee & Shokouhian, 2005). For this reason, the windcatcher can benefit from this overnight performance in an area that has a cumulative effect over a 24-hour period (Elmualim, 2006).

The wind-catchers act as solar chimneys during the day when there is no or less wind. The wind-catcher increases the air exhaust same as a solar chimney. Moreover, wind-catchers by creating air movement inside the area and that helps with the evaporation of sweat from body surfaces, so wind-catcher creates more pleasant indoor place in a very hot time of the year (Roaf, 1988).

Although the type of wind-catcher is affected by the environmental and climatic conditions (Konya, 1980). Two main types of wind-catcher are as follow:

1). Wind-catcher in hot and humid areas

2). Wind-catcher in hot and arid areas

The parameters can be counted as the effective parameters on wind-catcher's performances are fallow:

• Height
• Cross sectional plan
• The orientation of the tower
• The location of outlets and inlets

3. Indoor Environmental Quality (IEQ) and Natural Ventilation (NV)

Most of the people spend their lives in a building; however there is a strong belief that the internal environment may be greater risk to human health to make out (Bako-Biro, 2004). Many stimuli, such as air quality, thermal conditions, noise and light that has a different impact on occupants. By addressing key environmental factors Indoor Environmental Quality (IEQ), notably by increasing the ventilation rate, we can reduce the amount and frequency of symptoms (Seppanen et al., 1999). The relationship between ventilation and positive aspects of IEQ has been established by many studies in the literature as a means of conditioning for occupants comfort settings thermal and atmospheric pollutants that overall indoor air quality (IAQ) is determined.

One benefit of a building with natural ventilation (NV) is that domestic conditions are a function of external conditions. So, occupants can visually and thermally communicate with their indoor environment by wearing seasonal clothing and using environmental settings such as opening or closing windows.

The thermal comfort is a value that can be very subjective, taking into account personal factors, technological or environmental, cultural, and not just internal temperature is reached. Air strategy as an important factor in the delivery of thermal comfort is known for building occupants control over their environment NV When tolerance, greater tolerance to heat conditions are different. In addition, by properly capturing indoor thermal conditions, direct benefits to occupants protect their right to health; while indirect benefits are significant in terms of financial cost (Fisk, 2000). Thermal comfort is usually measured with surveys, but, do surveys can be fraught with difficulties and depends on the prevailing conditions of a building. For example, a survey conducted under severe psychological and/or environmental conditions may elicit the same extreme reactions from the occupants of the building in question (Nicol & Roaf, 2005).

Indoor air quality must be defined by its impact on humans, so one way to determine IAQ is by determining occupants' perception of IAQ based on bioeffluent odour (Fanger, 2006). But, sensory responses to an internal pollutant are not always commensurate with their toxicity, and therefore understanding the IAQ is not always a universal measure of the overall IAQ (Seppanen & Fisk, 2004).

In addition, occupants of NV buildings are more tolerant of changes in the level and amount of carbon dioxide than MV buildings (Hummelgaard et al., 2007). Indoors, measuring CO2 over time is a very useful indicator of IAQ and ventilation in a building because it is produced as a two-person product or human respiration or combustion (Persily, 1997). If CO2 inside just happen through human breathing, the production number, size (age, sex, weight) and physical activity occupants are concerned (BSI, 1991; Roulet & Foradini, 2002).

The association between SBS symptoms and CO2 concentrations above 1500 ppm, while lower ventilation levels is associated with increased CO2 concentrations as they are associated with decreased work performance (Myhrvold et al., 1996; Mendell & Heath, 2005). CO2 concentration and SBS symptoms measured in non-residential buildings showed an increase in SBS symptoms with higher

CO_2 concentration, there is also a similar relationship between CO_2 concentration and health (Seppanen et al., 1999; Apte et al., 2000).

Relative Humidity (RH) and air vapor pressure vapor pressure of the air at the same temperature a sample that can be expressed as a percentage (McMullan, 2002). Such as CO_2, as specified in the levels required for thermal comfort and IAQ good is difficult, although it is thought to be acceptable levels of between 30-70% (CEC, 1992). But unlike CO_2, RH is a direct cause of IAQ weakness through formaldehyde release and can be directly related to the number of occupants because in a sedentary environment, up to 25% of excess body heat is lost through transpiration, evaporation of moisture through sweating and respiration (Liddament, 1996). In addition, if the activity increases and the temperature increases, it can increase between 50 and 80%. Human transpiration is reduced by high RH, which leads to discomfort, and increased by low RH, which leads to dehydration. Perceived IAQ decreases with increasing air temperature and RH, also with a constant level of pollution, temperature and RH have a strong and significant impact on the perception of IAQ (Fang et al., 1998). Finally, with the increase in air temperature and humidity, IAQ understand the level of contamination is reduced.

In a building, broadband noise is a combination of direct sound from a source and its reflection. Noise has three sources: (Ling, 2001)

1). External noise

2). Internal noise

3). Path effects

Noise inside a building is generally less than 85-90dBA and does not because hearing damage to the ear, however non-auditory effects are far more dangerous to health (Stansfeld & Matheson, 2003). Noise created by mechanical ventilation systems of aerodynamic turbulence caused by the expansion and contraction fans and duct work that may be branched elements, diffusers, grills and Van rotating form (Ling, 2001). Natural ventilation systems have relatively large openings that are less resistant to external noise. The need to provide low-resistance ducts for free airflow and noise reduction is a paradox (Simons & Maloney, 2003). The average traffic noise bandwidths that can be found in urban areas are roughly 70dBA and therefore have weakened the building and its ventilation element is 35 to 30 dBA (Shield & Dockrell, 2003).

Heat dissipation and maintaining positive internal thermal conditions are just two of the many components of a building’s Indoor Environment Quality (IEQ). Other factors include noise; indoor pollutants, odour and light have a direct or indirect effect on occupants (Mendell & Heath, 2005).

Understanding the occupants of Indoor Air Quality (IAQ) is also important because the effects of poor IAQ can be as one or more types of negative symptoms that are traditionally or as disease-related buildings grouped (Seppanen et al., 2002).

In many modern non-residential buildings, Heating, Ventilation and Air Conditioning (HVAC) systems are seen as the solution because they provide complete control over ventilation, temperature and humidity, while providing air purification systems. HVAC systems that are centrally air to wherever you need to have, but a lot of space and infrastructure need. Standalone systems do not require a central input and may be installed quickly and easily to meet local needs. A typical building with air conditioning, double energy costs and CO2 emissions associated with a building with natural ventilation. It is also likely to increase capital and maintenance costs are also higher (Carbon Trust, 2007).

Natural ventilation is earned using three main principles: a one-way manager uses one or more openings in a façade and relies on the wind or a float to move the airflow. The net amount of these forces is often small and therefore the flow velocity is low.

Cross-ventilation uses inlet air that is constructed through a façade on one side of the building and exits from the other. The flow velocity is more reliable than one-way ventilation and it is easier to achieve good penetration, although this is independent of a clear flow path free of internal obstructions.

Finally, the stack ventilation uses the current created due to the difference between the indoor and outdoor temperatures and is so called because of the analogy of the currents inside the chimney stack (Etheridge & Sandberg, 1996). Low levels of air through openings into the building and before entering the room from the room are drawn into the duct. In winter, more current is obtained, while the direction of flow can be reversed in summer when the outside temperature is higher than the indoor temperature.

The wind-catcher, which consists of a split tower consisting of several shafts, each vertically connected. Wind-catchers are known in Iran as Badgir, the use of which has been traced back to the 14th century, although the hypothesis of pre-Christian construction to this day is uncontrollable (Roaf, 1982). Wind-catcher brick structure in Iran is heated during the day and so acts like a chimney and pulls hot air out of the building (Roaf, 1982). A positive pressure difference is created in the air shafts when the wind blows, and directs the air into the building. Reciprocally, a negative pressure difference in the lever branches pulls the air out of the building. The result of this element is that wind and buoyancy forces can act against each other and reduce its efficiency.

The function of all natural ventilation methods is based on equal pressure in space through the movement of air (Eley Associates, 2004). Natural ventilation gives fresh air into the building or pollutes the indoor air. The difference in wind and temperature creates a difference in natural pressure around the building, and consequently natural ventilation systems take advantage of this phenomenon (Battle McCarthy Consulting Engineers, 1999). In short, the performance of natural ventilation depends on wind pressure and temperature difference (Battle McCarthy Consulting Engineers, 1999).

Natural ventilation is usually created by combining wind and temperature differences as the forces acting on a building. This difference in wind and temperature difference between inside and outside and between different levels of a building depends. The following equation (1) can be used to calculate the velocity of air flow during wind and ridge impact (Awbi, 1991).

$$Q_T = (Q_W^2 + Q_S^2)^{1/2} \quad (1)$$

This equation is total air flow rate (m^3/s), QW is total air flow rate due to wind (m^3/s) and QS is total air flow rate due to stack effect (m^3/s).

4. Case Studies

Six cases have been selected from Yazd city located in the center of Iran, Yazd city has a hot and dry climate or in other words desert.

When selecting subjects, an attempt has been made to select from different regions in different geographical directions to show more changes and to include the result of the analysis of the whole city. Also, the selected wind-catchers have been tried to be different in terms of appearance and construction. Due to the good performance of the 4-way rectangular wind catchers and the relatively easy and cost-effective construction, most of the wind-catchers are rectangular.

In Table 1, parameters such as the approximate age of the building, their geographical location in Yazd city, the type of wind-catcher, the height, size and surface of the wind-catcher and the number of rooms related to the wind-catcher room, etc. are listed for 6 cases.

Table 1. Case No. 1-6 Parameters

Case No.	Age	Building Height (m)	Floors	Wind-catcher Type	Wind-catcher height (m)	Wind-catcher size (cm)	Wind-catcher size (m²)	Adjoining ground floor room area (m²)	Adjoining basement room area (m²)
1	300-400	5.7	2	3*8 M	5.4	180*360	6.48	44	16
2	400-450	5.6	2	4*12	5.6	200*380	7.6	36	30
3	350-450	5.7	2	4*10	5.4	190*350	6.65	41	27
4	400-450	8.8	3	4*5 S 3*3 B	7.1	150*180 200*220	2.7 4.4	40	42
5	500-550	5.9	2	4*6 B	5.3	240*280	6.72	21	21
6	350-450	5.8	2	6*9 K	5.5	240*310	7.44	49	27

The first case to be studied is an old building located in the northeast of Yazd, 300-400 years old, which is built on two floors, including the ground floor and the basement, which has a summer and winter part. The height of the building is 5.2 meters. In the summery part, a room with an area of 20 square meters has a wind catcher of 8 * 3 medium types with dimensions of 180 x 360 with an area of 6.48 square meters and a height of 5.4 meters.

Two rooms are located next to the main wind catcher room, which are connected by doors measuring 2.10 x 140 which is the total area of the two doors with 2.94 square meters and has two windows, each of which has an area of 2.94 meters. In total, the openings are 5.88 square meters, so that fresh air can flow to the adjoining rooms and reduce the temperature and normalize the air in the adjoining rooms.

Figure 1 (a) is an aerial image of case number 1, Figure 1 (b) shows a view of the wind catcher of building number 1 and Figure 1 (c) is plan of the building.

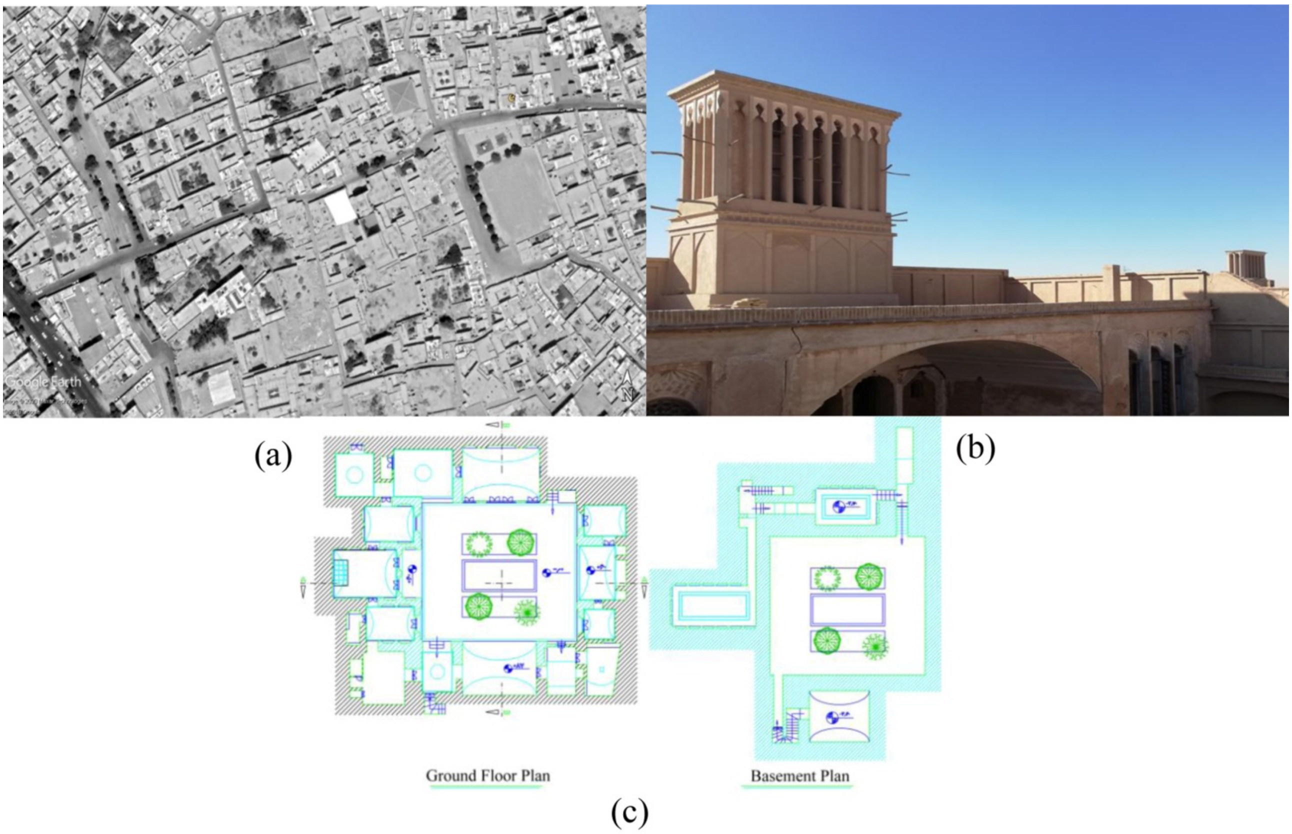


Figure 1. Case 1, (a) Aerial View, (b) Building Façade and (c) Plan

The second case, study of a building with a date of 400-450 in the northwest of Yazd city includes two floors, one floor on the ground floor with a height of 5 meters and an underground floor with a height of 2.9 meters. It has two parts, summer and winter, and the wind-catcher with a height of 5.6 meters, type 12 * 4, with dimensions of 200 * 380 square centimeters, with an area of 7.6 square meters, is located in a room the size of 36 square meters. Dimensions 180 * 140 are related and one side of the room has 5 windows with dimensions of 100 * 240 cm for sufficient light, which is a total of 12 square meters of windows, which is about 5.5 square meters, which can be opened to better rotate the air flow.

Also, in the lower part of this room, there is a basement room with an area of 30 square meters, in which the wind catcher continues, and it was mostly used as a storage place for food. In the basement room, there are 4 windows with dimensions of 110 * 70 cm, the total of which is 3.08 square meters. In Figure 2 (a), you can see an aerial photo, in Figure 2 (b); shows a picture of the wind catcher of the building and Figure 2 (c) is plan of building.

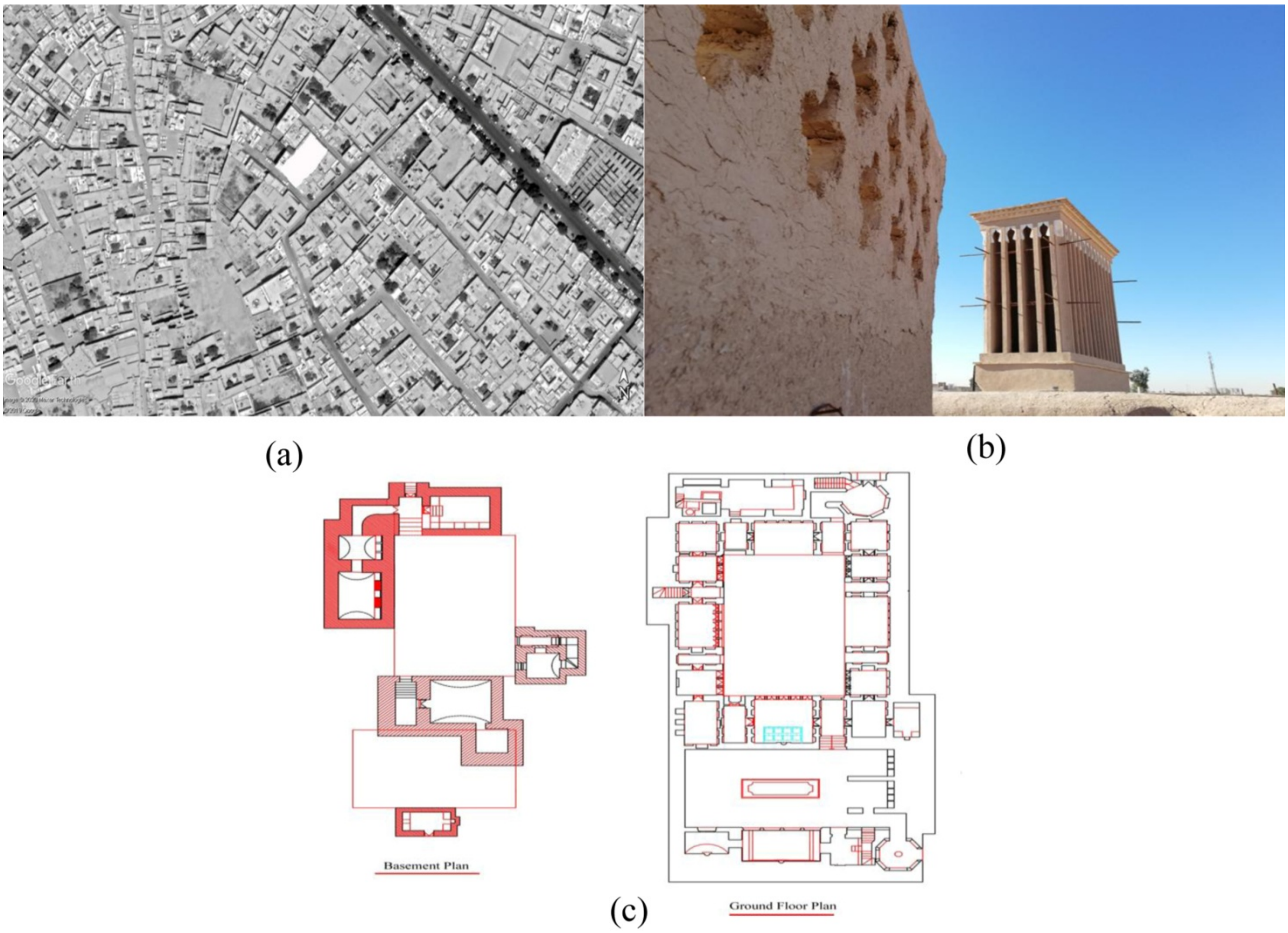


Figure 2. Case 2, (a) Aerial View (b) Building Façade and (c) Plan

The third case studied is a mansion that consists of a floor plus a basement. The ground floor has a height of 4.9 meters and a basement height of 3 meters, which is 350-450 years old and is located in the north of Yazd. It has two summer and winter parts. The wind catcher room on the ground floor is 41 square meters. It has 2 large window openings with dimensions of 140 * 280 cm, which has a total opening of 7.84 square meters. Also, the wind catcher is of the 4 * 10 type with an area of 6.65 square meters with dimensions of 190 * 350 and the height of the wind catcher is 5.4 meters. The basement room area is 27 meters, which includes a space for storing materials that need low temperature and a part for resting in the hot hours of the hot days of the year, and the entrance door of the basement is 185 * 155. Figure 3 (a) is an aerial photo of the building, in Figure 3 (b); you can see a picture of the wind-catcher for building and Figure 3 (c) shows the building plan.

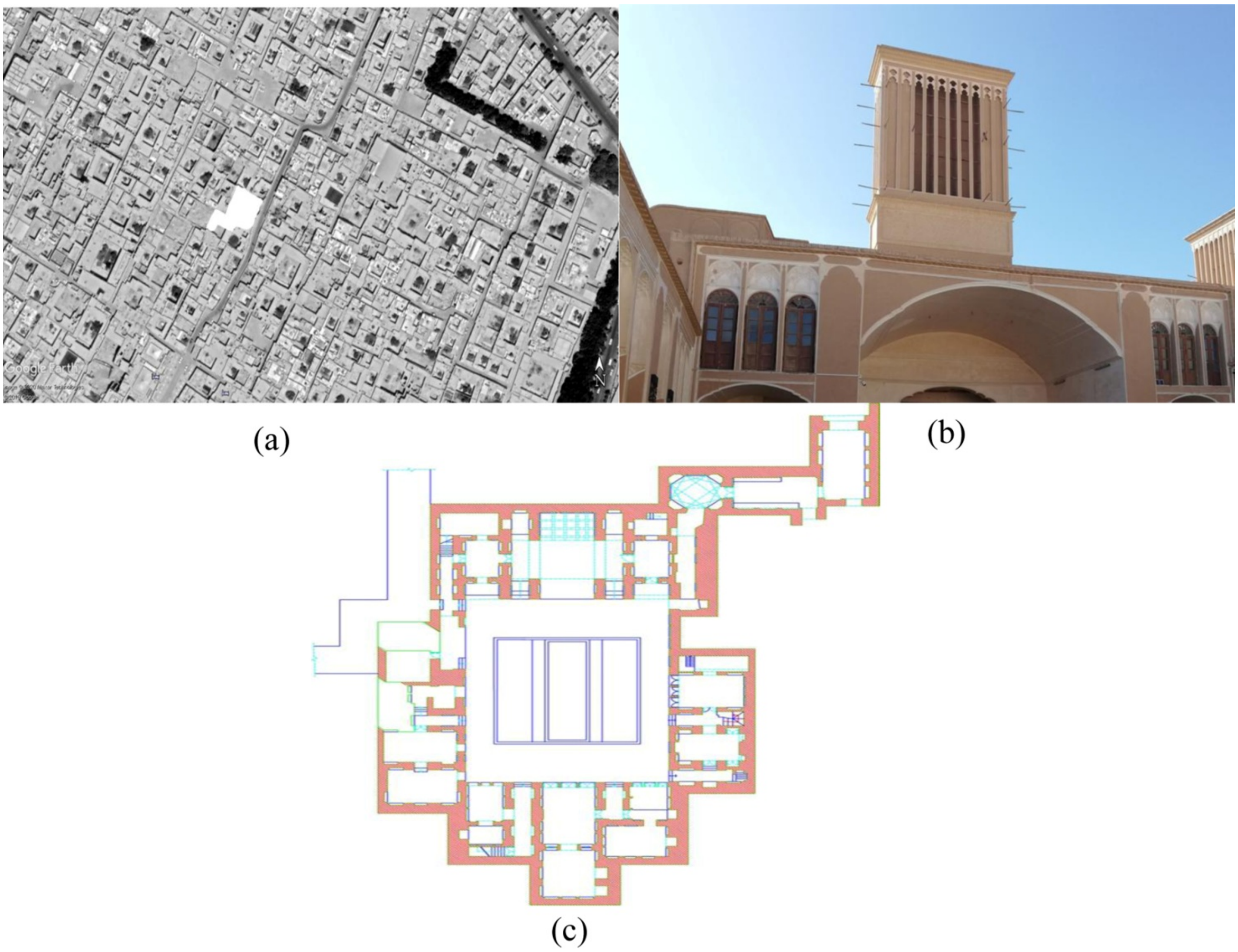


Figure 3. Case 3, (a) Aerial view (b) Building façade and (c) Plan

The fourth case in question is a large mansion with many rooms on either side or a courtyard in the middle of the mansion, which consists of 3 floors, including the same floor and basement, and 3 rooms on the roof, which are built side by side. They are connected by opening. Basement in the eastern part of the building under the wind catcher room with a height of 2.9 meters and an area of 42 square meters in two parts. The end part is due to the lower temperature, it is used to protect food and materials that need low temperatures and is the initial part for the rest and relaxation of the residents. It also has an entrance with dimensions of 190 * 150 cm and 4 windows with dimensions of 100 * 60 cm, which has a total opening of 2.4 meters.

The ground floor is 5.1 meters high and has an area of 40 square meters, at the end of which there is a room with an area of 16 meters, which are connected to each other by opening it with the dimensions of 170 * 110. Also, the wind catcher of this two-story mansion with an area of 7.1 square meters. One of its floors is 2.7 square meters and the other is 4.4 square meters. The lower floor has a long channel and a total of two floors with a total height of 7.1 meters. The aerial image of building number 4 is shown in Figure 4 (a), in Figures 4 (b) you can see an image of building wind-catchers and Figure 4 (c) is plan of building case No. 4.

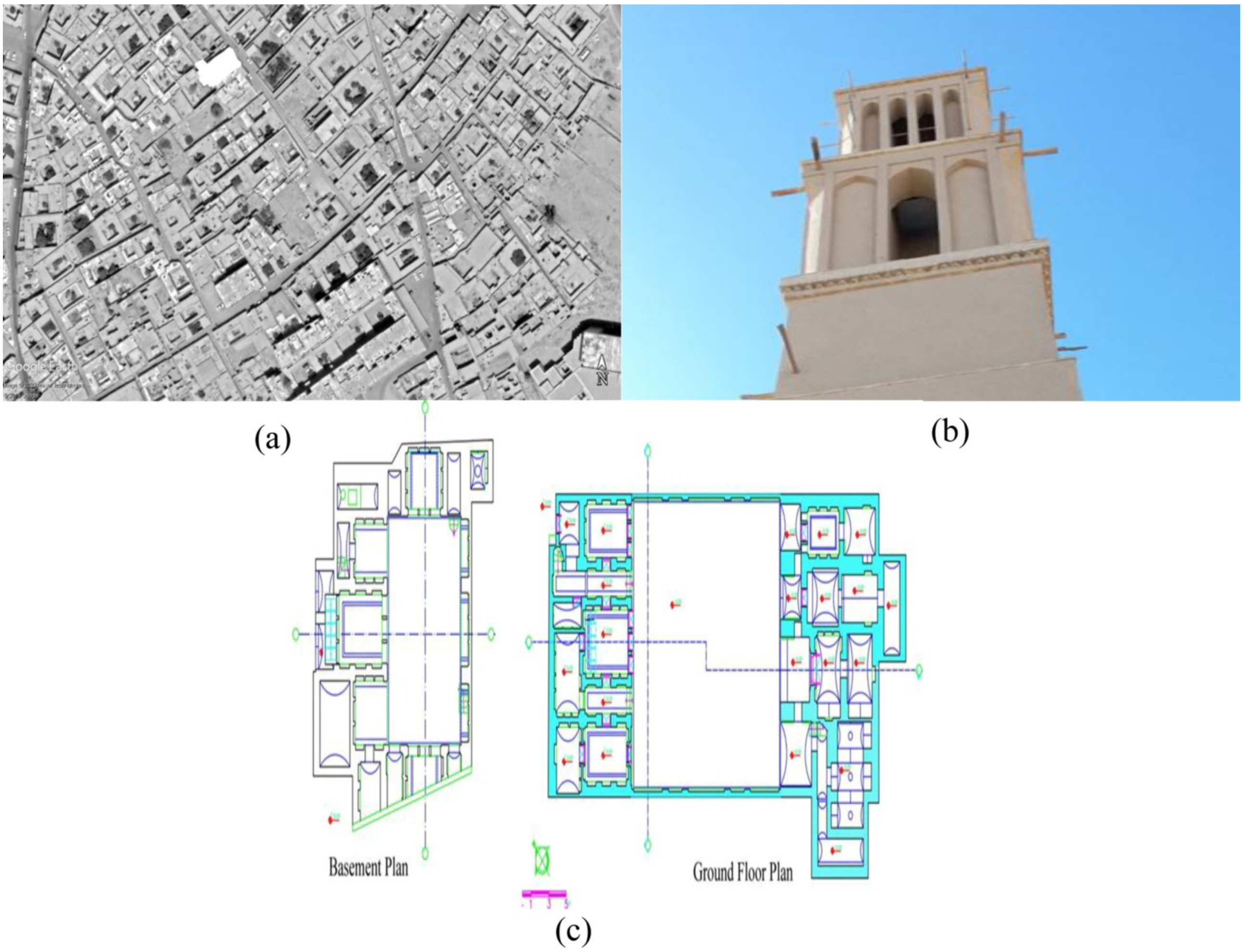


Figure 4. Case 4, (a) Aerial View (b) Wind-catcher View and (c) Plan

The fifth case studied is a relatively small old mansion dating back 500-550 years, located northwest of Yazd. It consists of two floors, a ground floor and a basement, and the rooms are on three sides of the courtyard, with a large Pond in the middle of the courtyard. On the south side of the courtyard is a very large room that was used as a hall, and the wind catcher room is located on the east side according to the old architectural principles. The wind catcher room area is 21 square meters and the wind catcher entrance area is 6.72 square meters, which is a 4*6 B model (BIG). The basement wind-catcher also has an area of 21 square meters that with a small wall with an opening, the space under the wind catcher is separated from the basement. Height of the building is 5.2 meters and the height of the basement is 3 meters. In Figure 5 (a), you can see the aerial image of building case No. 5, in Figure 5 (b), you can see a view of the building and the wind-catcher and Figure 5 (c) shows the plan of building.

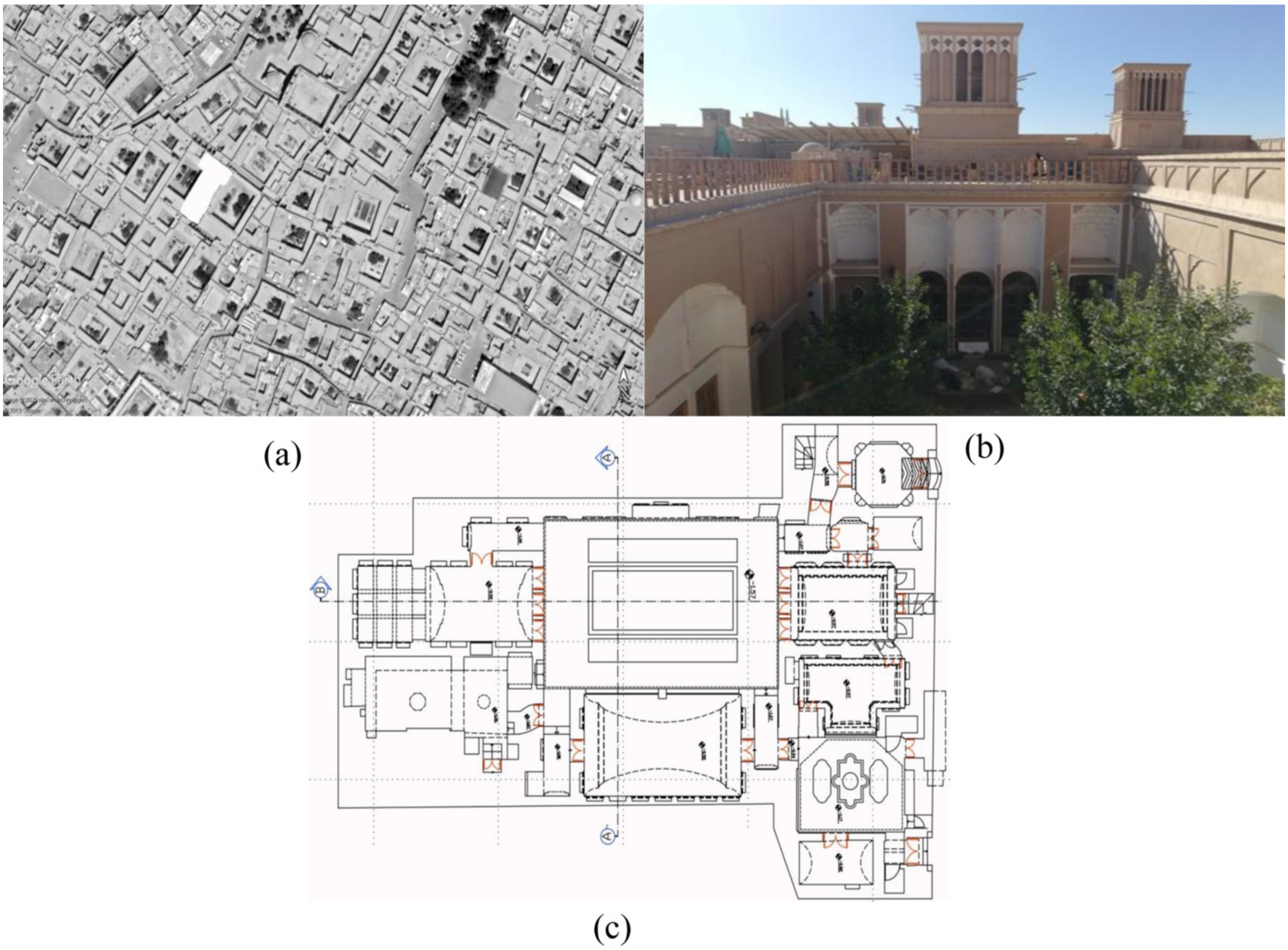
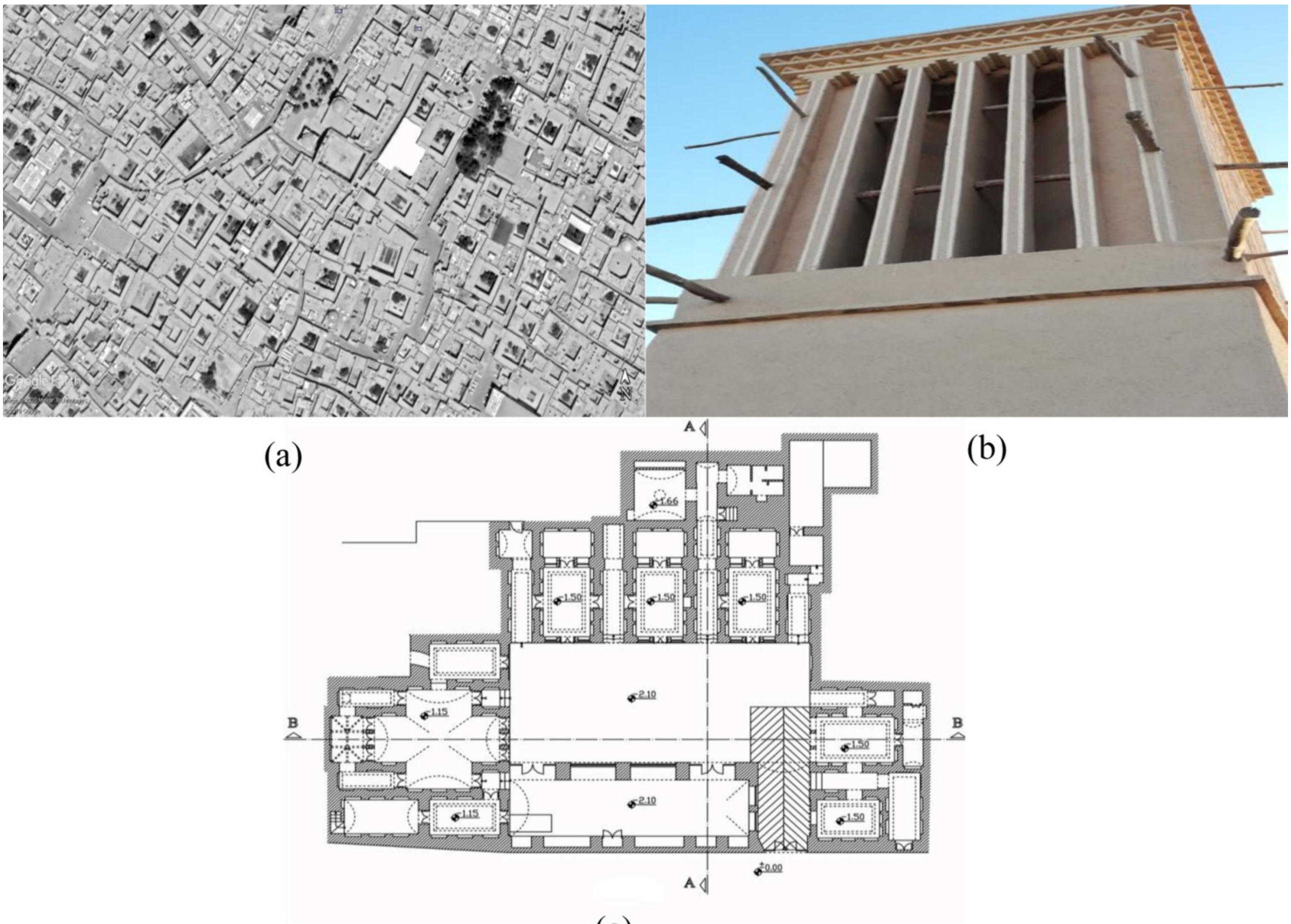


Figure 5. Case 5, (a) Aerial View (b) Building Façade and (c) Plan

The sixth case is a 350-450year old building located in the north of Yazd that like most buildings built 3 to 5 centuries ago and according to the architecture of that time, it has a ground floor that includes a courtyard and rooms around the courtyard and a wind catcher on the east side of the building and a basement. There is a courtyard in the center of the building and there are several rooms in the northern part that there is a corridor between them. In each room, in addition to the door into the courtyard, one or two doors open to the corridors. To the east of the courtyard, there is a wind catcher room with an area of 49 square meters and a height of 5.2 meters. Figure 6 (a) shows the aerial photo of building case No. 6, Figure 6 (b) shows the wind-catcher view of the building and in Figure 6 (c) you can see the plan of case No 6.



(a) (b) (c)

Figure 6. Case 6, (a) Aerial View (b) Wind-Catcher View and (c) Plan

5. Results and Discussion

5.1 Wind Speed and Wind Direction

Wind speed is one of the most important factors in lowering the temperature of houses with wind-catchers, and moving moisture from outside to inside and from inside to outside. In Yazd city, the wind direction is mostly from northwest to southeast and from southwest to northeast and in some cases from north to south and south to north. So, most of Yazd's wind-catchers were built on four sides, but the two sides with longer length and more valves were built in the direction of the prevailing wind to direct the maximum amount of wind into the building. The wind speed in Yazd city and the existence of mountains around the city have caused the wind to carry a small amount of sand and dust with it and bring it into the wind catchers, as a result of which the amount of pollution entered into the wind catchers and houses is not too much, is normal. The maximum wind speed was 23 km/h in March and the minimum wind speed in Yazd was 2 km / h, which was in August and April.

5.2 Humidity

In desert cities such as Yazd, which have a hot and dry climate and the amount of rain and snow in it is very low, and especially in hot seasons, the ambient humidity is very low. In collecting moisture information, information was collected for greater accuracy in two stages per day because the humidity was significantly different between day and night. One step at 3 am, which usually had the most moisture per day, and one at 12 hours later, at 3pm, which had the least daily humidity due to sunlight. Then the average daily humidity and average humidity in the rooms with wind catchers were measured, and the data collected in 122 days from July 1 to the end of September are shown in Figure 7 According to the Health Organization of Iran, the amount of moisture acceptable for buildings in hot seasons at least between 20 and 30 percent, which is observed according to the diagram of this index and using traditional methods has reached the required normal humidity in buildings.

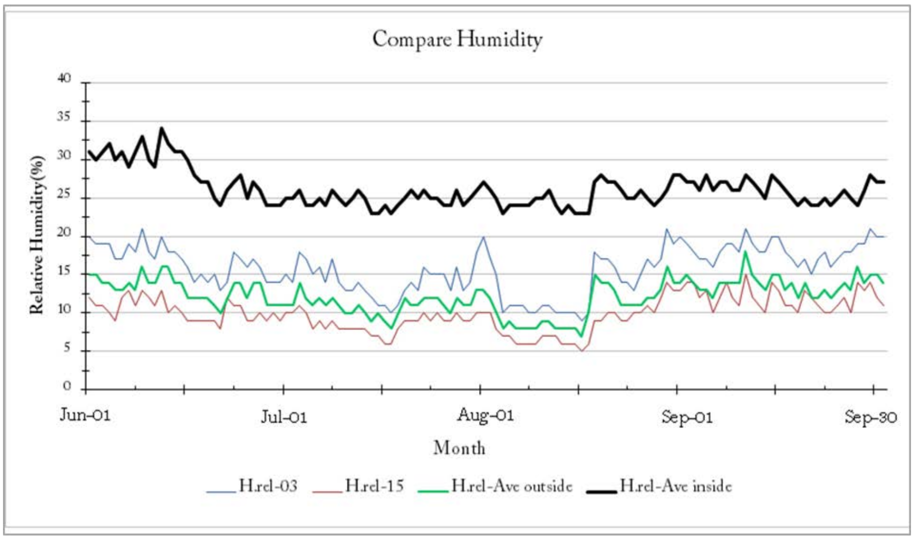


Figure 7. Relative Humidity, Yazd City, Jun01-Sep30 2019

In Figure 8, the red numbers are the minimum amount of moisture, and the blue numbers are the maximum humidity of each case, and the green numbers are the amount of moisture that is most frequently repeated; as you can see, the lowest humidity in case number 6 is 17% and the highest humidity is 35% in case number 5, and the highest fluctuation and maximum humidity is the highest repeated humidity in case 5 with 32.5%. According to the Yazd City Climate Health Organization, minimum standard humidity for residential houses in Yazd city, considering the hot and dry climatic conditions and the presence of sandstorms and the presence of suspended dust in the ambient air, is 15% for the old texture with wind catchers.

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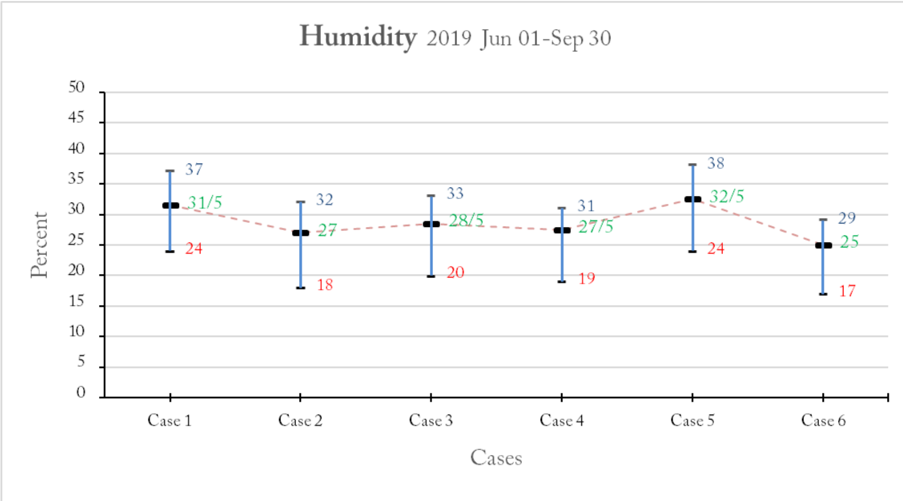


Figure 8. Cases Humidity, Yazd city, Jun01-Sep30 2019

5.3 Temperature

The most important indicator studied is temperature, which is examined monthly for a period of 122 days. Yazd city, due to the small size of the city and very low temperature changes in different parts of the city; the whole city is considered integrated. After collecting the temperature information outside of buildings, we collected the temperature information inside each case and measured the maximum temperature and average temperature for the inside of the buildings.

Indoor temperature information is shown as the maximum temperature and average temperature. It should be noted that the average internal temperature is the average temperature of all 6 cases studied and the maximum internal temperature is the average of 6 maximum internal temperatures. Figure 9 shows the information collected about temperature over a 122-day period. which includes the maximum outdoor temperature marked in blue and the minimum temperature outside the building is marked in red and the average outside temperature marked in faint green compared to the average indoor temperature, that is thick line dark green.

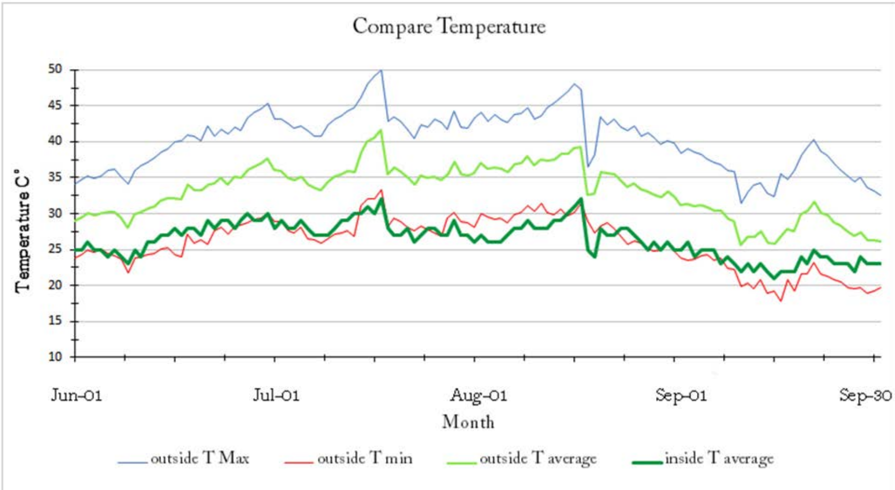
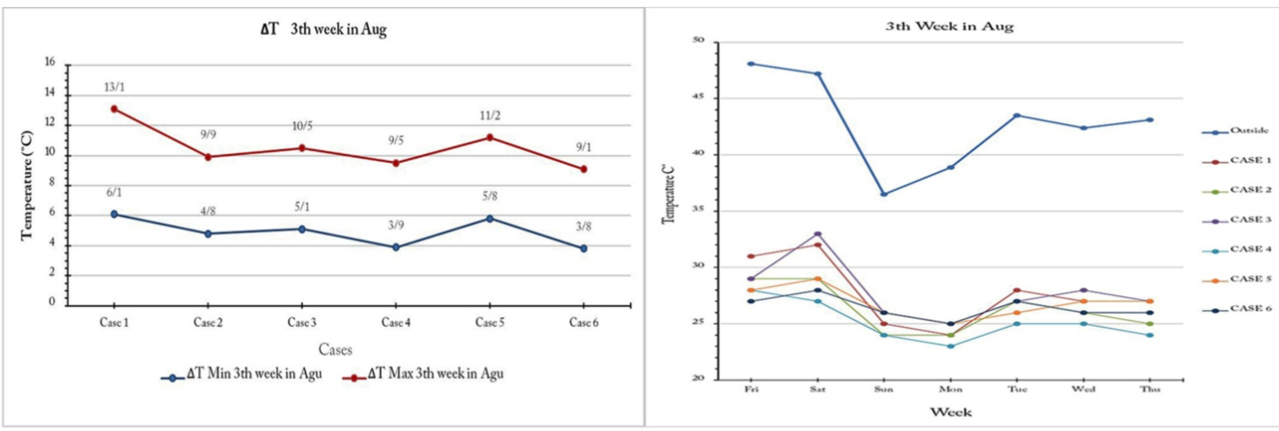


Figure 9. Compare Temperature, Yazd City, 2019, Jun01-sep30

The temperature inside the buildings is not the same and in some it is lower and in others it is higher according to Figure 9, the lowest minimum temperature changes belong to case 6, which is equivalent to 3.8 degrees Centigrade, and the highest maximum temperature changes belong to case 1, which is equivalent to 13.1 degrees Centigrade. With the constant outside temperature and wind speed, other factors affect the internal temperature, which are: type of wind-catchers, the size of the wind-catchers, the amount of space that the wind-catchers should cool the number and size of the wind catchers.



(a) **(b)**

Figure 10. (a) ΔT Max and Min, 3th Week in Aug (b) Compare Cases Temperature, 3th Week in Aug 2019

Figure 10 (a) shows the temperature changes in the third week of August for each case. The third week of August has been chosen because of the greater temperature fluctuation and the apparent changes. The red line is the maximum difference between the outside temperature and the maximum inside temperature, and the blue line is the minimum difference between the outside temperature and the inside of each case.

To check the temperature of each case in the third week of August and compare them with the outside temperature, the information obtained for the temperature of each case and the outside temperature is given in Figure 10 (b). In Figure 10 (b), the blue line at the top of the chart shows the average outside temperature in the third week of August, and the bottom six lines each show the average temperature of one of the cases studied which in the chart guide; each one is marked with a specific color.

Another factor that affects the temperature of rooms with wind catchers is the size of the space that should be reduced, or in other words, the size of the room with the wind catcher, in Figure 11 (a), we show the size of the room where the wind catcher is located, as in the diagram it is clear that the largest room has a wind catcher case number 6 and the smallest room with a wind catcher belongs to case number 1. To better understand the effects of the size of the room with the wind catcher, we divide the amount of wind catcher inlet opening area by the area of the wind catcher and display it in Figure 11 (b) to the percentage.

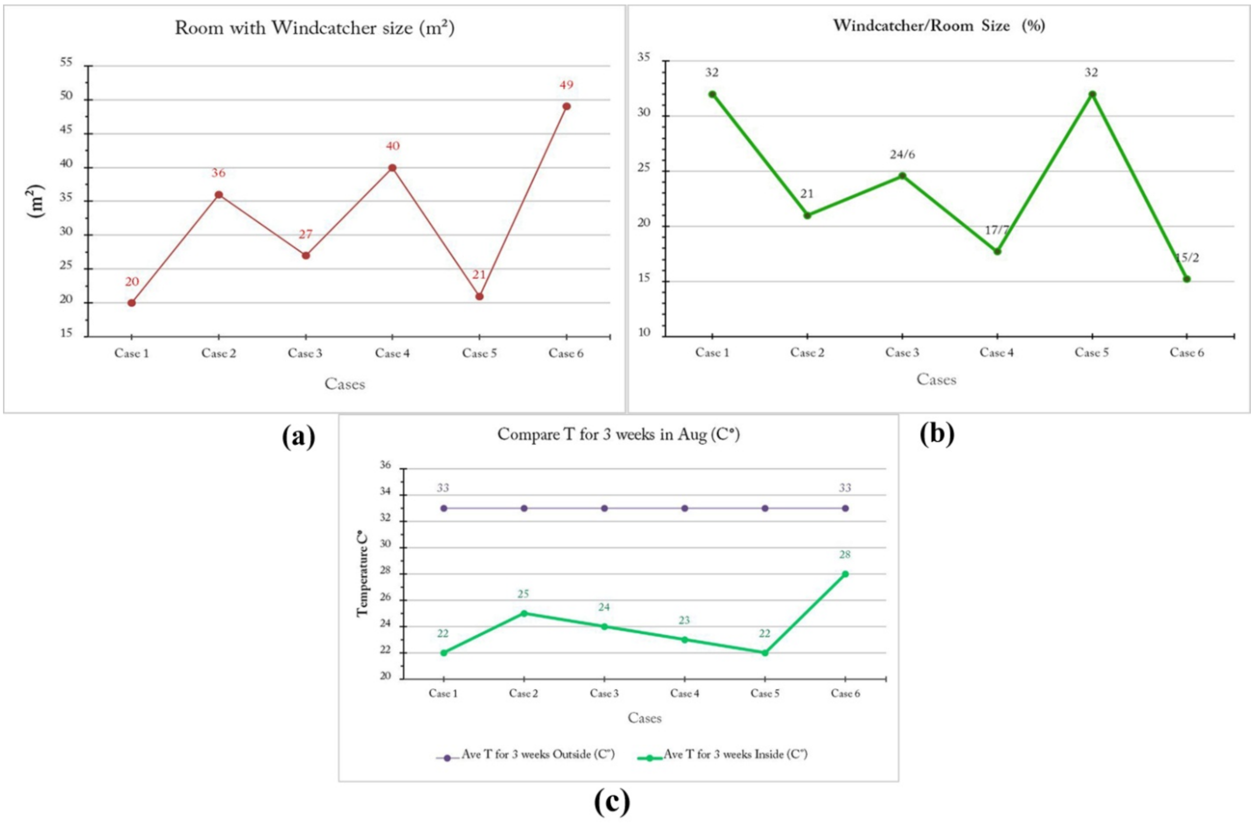


Figure 11. (a) Room with Wind Catcher Size (m2), (b) Wind Catcher/Room Size (Present), (c) Compare Temperature, Outside and Inside, 3 Weeks in Aug 2019

Now, to check the performance of each case, we have obtained average outside temperature for 3 weeks in August, which has highest temperature and highest temperature fluctuation, which is equal to 33 degrees Centigrade and in Figure 11 (c) we put each of the studied bags next to average internal temperature. The outside temperature is displayed in a smooth line with purple, but air temperature of the different cases is different, which we will discuss below.

A simple comparison show, for example, case number 1 when outside air averaged 33 degrees, interior has an average temperature of 22 degrees, Case number 1, although wind catchers area multiplied by its height is 35 cubic meters. However, due to the small area of the room, which is 20 meters, it has a lower temperature than case number 6. Because case number 6, although the result of multiplying the area of the wind catcher by its wind catcher height is 41 cubic meters. But because it has an area of 49 square meters, the average indoor temperature is 28 degrees. Also, case number 4, whose room area is 40 square meters, is close to case number 6. But the average temperature inside is 23 and close to case number 1. This is due to the blue line and its high height and construction model.

In Figure 12, the blue column shows the average temperature changes and the red column the size of the wind-catcher inlet and the green column the size of the room, which is divided by 5. As shown in the diagram, the smaller the green column or the size of the room, the larger the red column or wind catcher. It increases the temperature changes and the blue column becomes taller, which means that the size of the room is inversely proportional to the temperature changes. And the size of the wind catcher valve is directly related to temperature changes, so the smaller the room and the larger the wind catcher, lower room temperature and the better air.

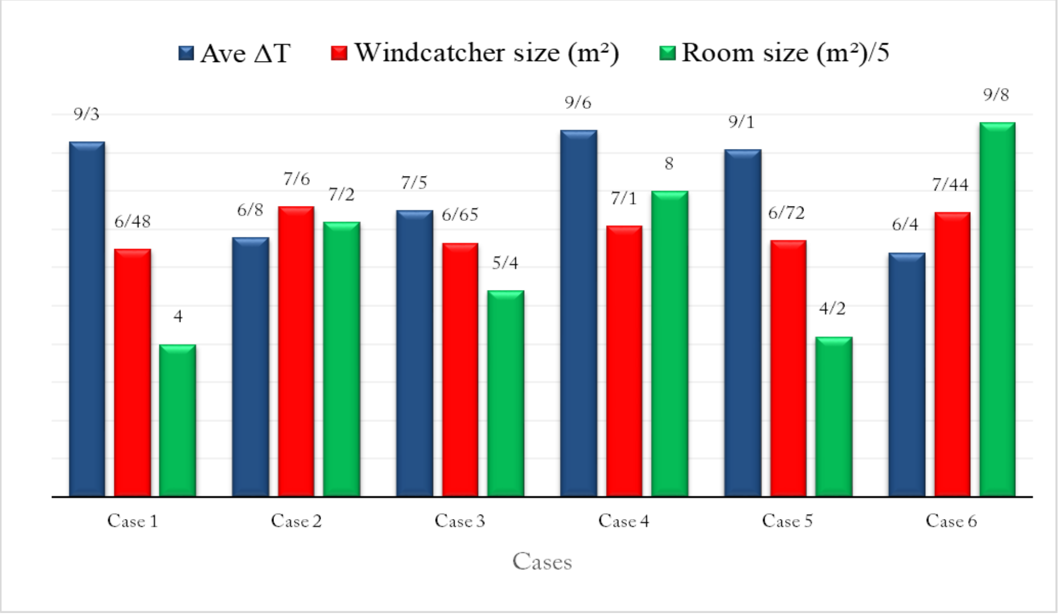
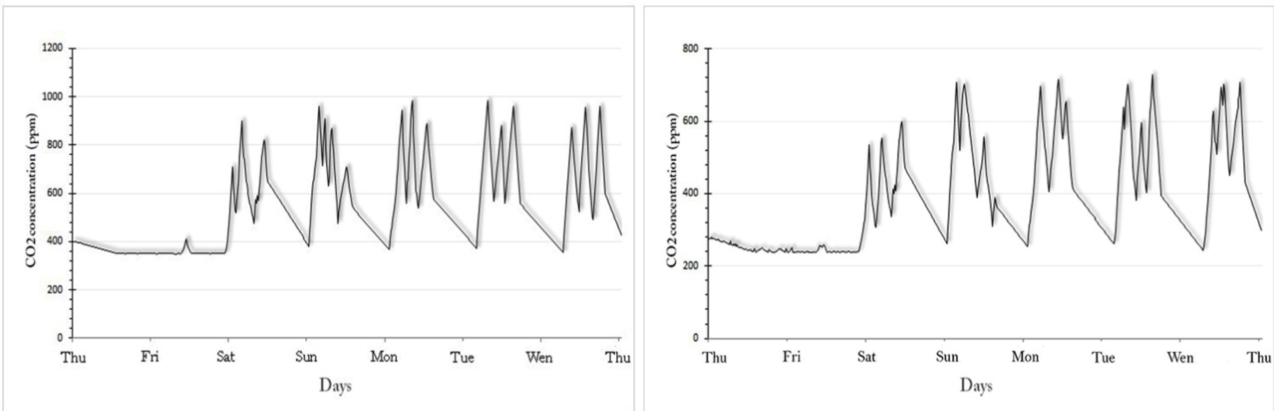


Figure 12. Combined Diagrams, Ave ΔT, Wind Catcher Size (m²), Room Size (m²)/5

5.4 Carbon Dioxide

Due to the fact that wind-catcher creates a communication space between inside and outside building, it can also cause entry and exit of a series of unwanted things that may be harmful to the physical or mental health of residents. In Yazd, most of the pollution, according to the General Statistics Office of Iran, is less than the quorum and can be ignored. But we chose carbon dioxide as the most polluting indicator in the city, for study.

According to a test conducted in August 2019 in Yazd, amount of carbon dioxide in a week tested is according to Figure 13 (a), in which highest pollution of carbon dioxide is related to mid-Monday and Tuesday, which is the peak of factory work and car traffic.



(a) **(b)**

Figure 13. (a) Co2 Concentration (ppm), Yazd City, Week in Aug 2019 (b) Co2 Concentration (ppm), Inside AVE for Cases 2, 5 and 6, Week in Aug 2019

In Figure 13 (b) shown average amount of carbon dioxide in wind catcher room for 3 cases studied, which had relatively large and more general inlet valves, namely bags 2, 5, and 6. As can be seen, internal carbon dioxide chart is about 30 percent lower than outside, and its maximum is about 700 ppm, which is lower than the standard.

5.5 Noise Pollution

One of parameters of mental health and human body is to have enough rest and relaxation, but in today's societies, a lot of noise and noise pollution is produced, which affects human health. To detect the effect of sound entering buildings through wind-catchers, we measure amount of sound outside building and also check sound entering building when the wind-catcher is closed and open. Audio measurement test was performed in the fourth week of August 2019, in Figure 14 of blue line of noise outside building and the purple line of noise inside the building when the wind catcher valves are closed and green line of noise inside building when wind catchers are open.

As we can see in Figure 14, the highest amount of noise entering building is 42 dB, which is less than the standard amount for residential buildings that are 50 dB, and interior space for rest and relaxation, despite open air vents, is completely without problems and it is ideal. Therefore, effect of the wind catchers studied on increasing noise entering the building is not to the extent that it causes restlessness and affects rest, peace and mental security of residents.

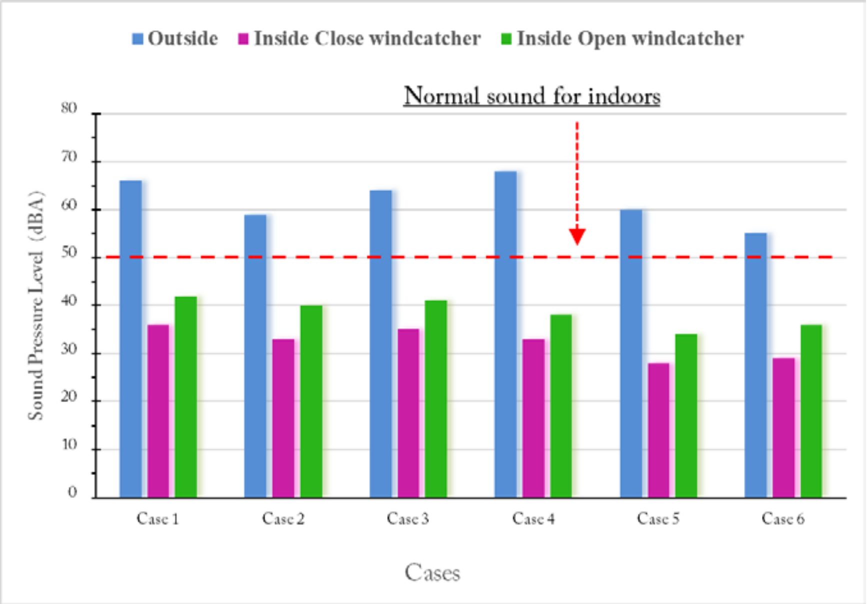


Figure 14. Sound Pressure Level (dBA), Outside, Inside, Close and Open Wind-Catcher

6. Conclusion

As mentioned in previous chapters, main purpose of wind-catchers is to create an air cycle by collecting moving air at higher altitudes than buildings and directing them into the building through the wind catcher channel, as well as creating a hot and exhaust air outlet inside the building. This is done to reduce temperature of building and to cool and optimize air inside rooms with wind catchers.

One of the effective factors is wind speed and wind direction, so that wind speed is directly effective in reducing the internal temperature, the wind direction is also effective because if the wind speed is sufficient, but to the side of wind-catcher inlet valve and not entering the wind catcher path channel into building will be practically useless. Another effective factor is the height of the wind-catcher. Usually, higher height of the wind catcher, more air can be directed to the building and will be cooler. Another factor influencing the wind-catcher is the size of wind catcher inlet, widening of the wind catcher opening is directly related to increase in cool air entering house and decrease in room temperature. Next factor influencing decrease in air temperature by the wind-catcher is size of the openings in room with wind catcher. Size of the openings is directly related to decrease in air temperature. Higher the number of openings, such as windows and doors result to the lower the temperature.

Construction and appearance and models of wind-catchers, use of basic materials and old texture, traditional and beautiful space that creates in addition to all the benefits, including air conditioning and cooling, low cost of materials and construction and non-dependence and use of sources such as electricity and fossil fuels, etc., it has another advantage which attracts tourists and visitors.

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