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Performance of single and multiple pressure wind catchers in terms of air flow changes

M. R. Abouseba[1], J. Khodakarami[2]

[1] Sepehr Institute of Isfahan, Isfahan, Iran.
[2] Engineering Department, Ilam University, Ilam, Iran.

Abstract
Although air current is the major cause of flow inside the wind catcher networks, the effect of wind direction changes on the performance of different types of wind catchers is unknown yet. Therefore, present paper aims at creating desirable conditions for comparing single-pressure and multiple-pressure types of wind catchers in order to discover the effect of wind direction changes on the performance of each type of wind catchers. To this end, The CFD model is devised for both types exposed to wind blowing at the speed of 3 m/s and at the angles of 0, 45, 90, 135, and 180 degrees. The obtained results indicated that the type of high-pressure area against the cage inflow determined the direction of wind inside their networks. Despite of this fact, during every blow towards the single-pressure type only one flow was generated whereas in multi-pressure type both downward and upward flows were generated. Moreover, while in the single-pressure types only the high-pressure area in front of the inflow was been used, in the multiple-pressure-type the entire high-pressure area around the cage was been practically in used.

Keywords: Wind catcher; Natural ventilation; Thermal simulation; CFD.

1. Introduction

Wind catchers are building elements which have been used in traditional buildings for many years in the Middle East [1-3]. These elements have been providing natural ventilation and passive cooling in hot and arid as well as hot and humid areas [4]. Moreover, they are ornamental elements which have greatly influenced the urban architecture and helped present impressive views of the urban areas where they have been employed.
Different classifications for wind catchers based on local names [5], function [6], typology [7], and wind-receiving surfaces [8] have been proposed by several authors. In view of the subject under the study and wind catchers function analysis, the classification based on the pressure inside the wind catcher network was used in this paper [9].

1.1 Single pressure wind catchers

Single-pressure is used to refer to a type of wind catcher which constantly has positive or negative pressure inside its columns. Therefore, depending on wind direction towards the wind catcher's inflow, the wind catcher may operate a Badkhor (wind scope) or Badkhan (wind tower) at any moment. This type of wind catcher doesn't have any shared blade inside its column and the external frame determines the wind catcher's network connections (Figure 1). The inflow is located only on one cage front and the outflow often leads to a space. According to some classifications this type of wind catcher is called one way or Ardakani wind catcher.

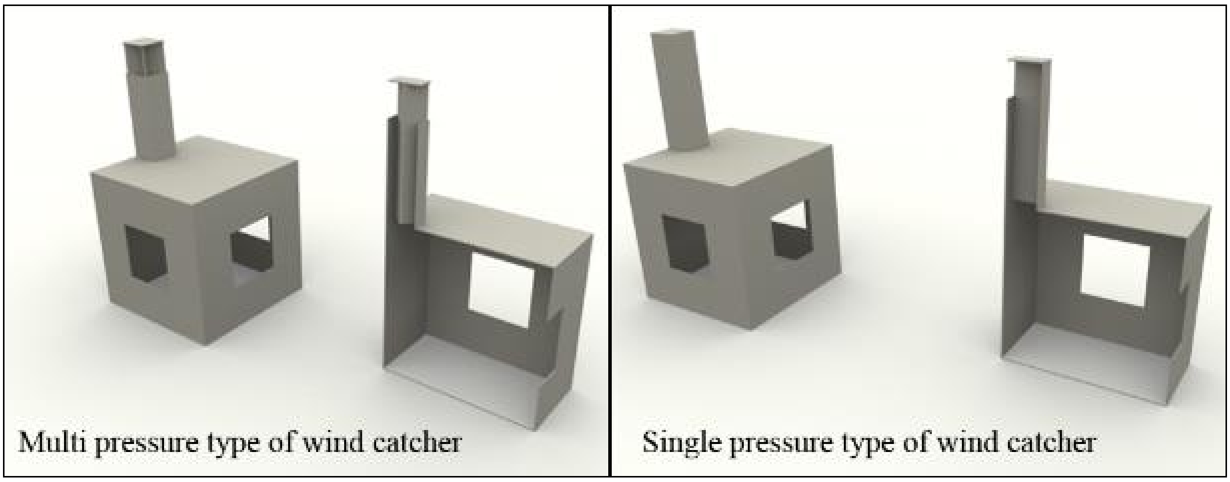

Figure 1. Traditional wind catcher' types

This type of wind catcher is used in some countries such as: Egypt, Iraq, Iran, Pakistan, and Afghanistan [10] (Figure 2). The direction of single-pressure wind catchers' inflow is determined by the quality of the prevailing wind. Therefore, when the prevailing wind is free of pollution, and dust, or carries lower temperature, and more desirable humidity, the inflow of the wind catcher will have the same direction as the prevailing wind. Otherwise, the direction of the wind catcher will take a direction opposite to that of the prevailing wind. The height of the wind catcher is determined by the kind of technology employed for their construction and the height of the prevailing wind [11].

1.2 Multiple-pressure wind catchers
In wind catchers which have internal dividing walls inside their column, different gusts of air generate diverse pressures around the wind catcher cage which directly affect the internal pressure of the internal networks of the wind catcher [2]. Therefore, several positive and negative pressures are simultaneously generated [12]. Inside the wind catcher, dividing walls are of various types and the external form no longer determines the relationship of the wind catcher's internal networks (Figures 1, 2). The inflow of the wind catcher is located on all fronts of the cage and the outflow leads to one or two floor (first floor and basement) [13] (Figure 2). In some classifications they are called two, four, six, and eight sided as well as Yazdi and Kermani in some other classifications [14]. These types of wind catchers are used in Iran and some other countries [15] (Figure 2).
Due to consuming clean and complimentary energies, the wind catcher is considered as one of the most sustainable and economical energy production systems, but because of some functional difficulties their use has been restricted, and therefore a lot of efforts have gone into optimizing the performance of traditional wind catchers. A handful of such efforts are mentioned below.
Later, Karakatsanis et al [16] defined the coefficients of wind pressure at different angles in proportion to each other. Within the same year, Cunningham and Thompson [17] offered a model as a combination of single pressure wind catcher and solar chimney (Figure 3). Givoni [18] used their data during a semi-empirical investigation and stated that the performance of these wind catchers is subject to temperature difference between humid and dry climate, specifications of wind catcher, and thermal behavior of the lateral space of wind catcher.
Formerly, in EXPO92 exhibition, a model of single-pressure wind catcher for rural areas was displayed within which full evaporation was carried out by means of suitable sprays and a pleasant environment for walking was created under the wind catcher [19].
In 2002, Bahadori Nejad & Pakzad [20] analyzed the performance of traditional multi-pressure wind catchers and investigated the mass flow and outgoing pressure of these types of wind catchers in different directions and rates . Also Badran [4] studied the efficiency of single-pressure wind catchers in different climates of Jordan and concluded that in all these climates the height of these kinds of wind

catcher's column should be about 9 meters. In 2008, Azizian & Montazeri [21] particularly conducted an empirical study on the hydraulic efficiency of traditional single-pressure wind catchers which a blow at 0^o angle provided the best efficiency. Within the same year, taking into account the wide variety of multi-pressure wind catchers in plan as well as sculpting and insertion style, Mahmudi & Mofidi [14] conducted a typology of wind catchers of Yazd.

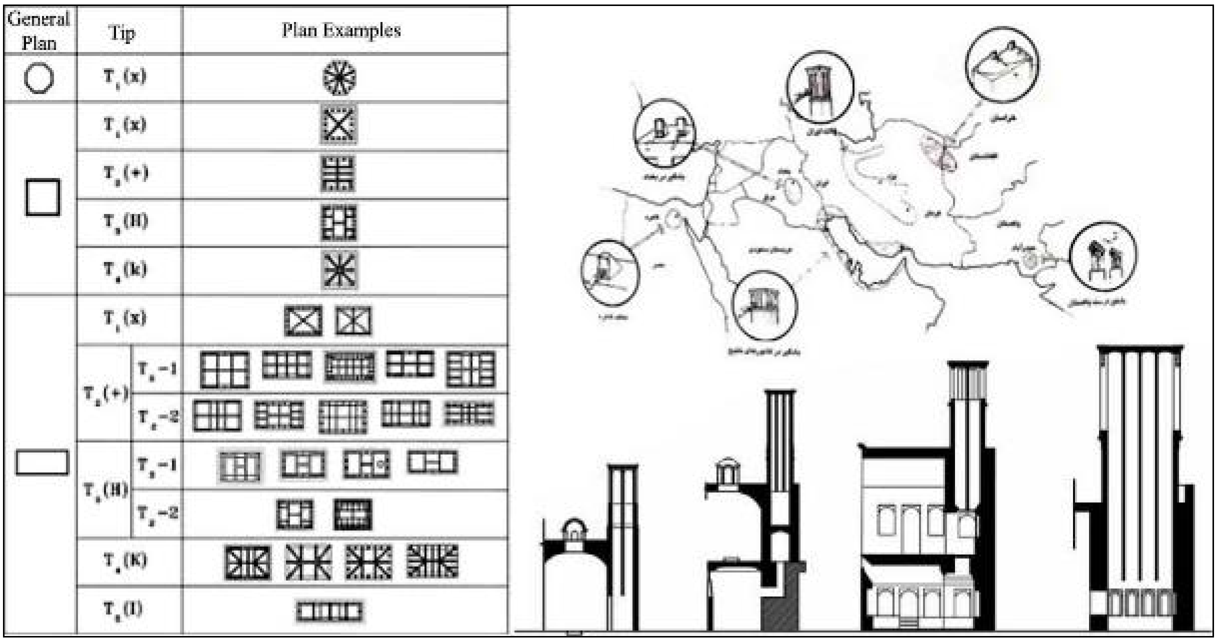

Figure 2. wind catchers' dispersal [10] and cross-section and plan typology of Multi pressure type [20]

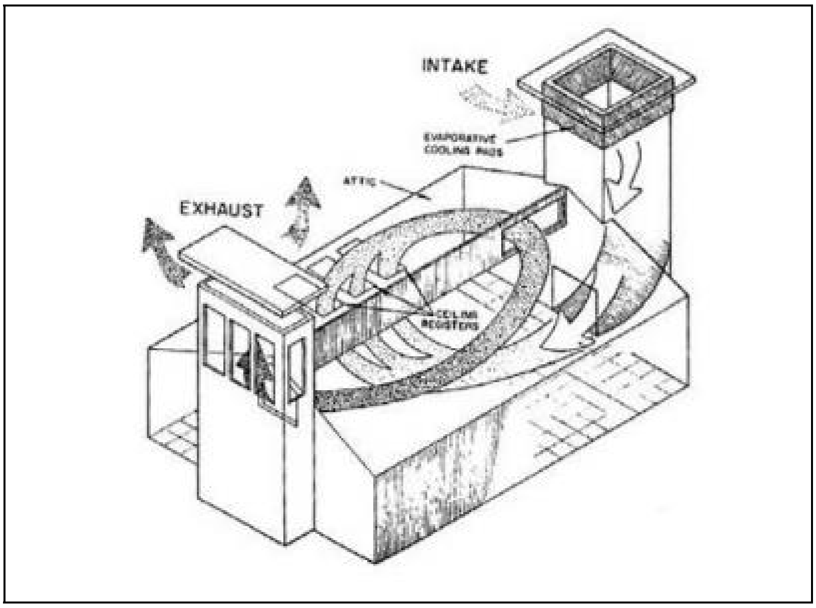

Figure 3. Experimental model of Cunningham and Thompson

Huges et al [22] introduced the background of conducted studies on complementary trend of wind catcher's commercial type. Within the same year, Abousaba [23] conducted studies on recognizing the behavior of the performance of traditional wind catchers and determined the preferred type by using simulation method. in these studies, the performance of traditional multiple – pressure wind catchers' were investigated in multi – floor buildings and, ultimately, pressure separating two – floor cage was used as a strategy to establish pressure stability in wind catcher networks.

Taking into account the above studies, it is certain that no study has so far been conducted on the effect of wind direction on the single-pressure and multiple-pressure wind catchers. Therefore, we aim to study the performance of single-pressure and multiple-pressure wind catchers exposed to different wind directions during which the external air current with a rate of 3m/s hits the both types of wind catchers at 0^o, 45^o, 90^o, 135^o, 180^o angles. The air current angle in proportion to the wind catcher's cage is shown in Figure 4.

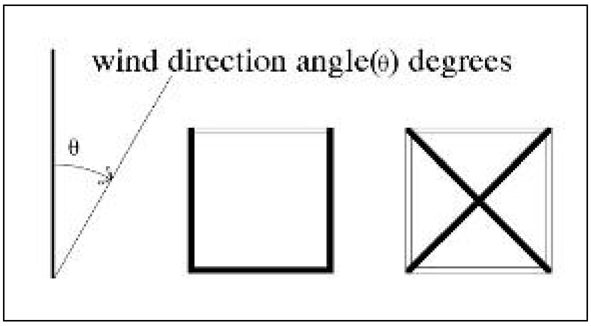

Figure 4. Air current angle in proportion to the wind catcher's cage

2. CFD models properties

The dynamic performance of wind catchers can be simulated by means of CFD model. Before using the commercial package of CFD offered in the Fluent Software, a model of the intended volume has to be designed and networked in other software, and for this purpose we used Gambit software. Therefore, in the first stage two volumes with the same conditions were constructed in the Gambit Software which is shown in Figure 5 in detail.

According to this figure the dimensions, the height of the channel, and the height of the cage are respectively 0/5 * 0/5, 1/5, and 0/5.The right image shows a single-pressure wind catcher whose channel doesn't contain any internal blade and the left image shows a multiple-pressure wind catcher which has the internal space of its column divided by two crossing blades into four parts. It should be mentioned here that there are many different plans for traditional multiple-pressure wind catchers, but in order to obtain the kind of results which allow comparison between the two types of wind catcher, a simple model with crossing blades has been used. Moreover, the height of the wind catcher's column is determined in proportion with the dimensions of the plan; however, basically the height of the wind catcher's column is determined by the level of favorable winds and as at this stage of the study the fluid is single-phase and no moisture is injected into it, the temperature fall resulting from momentum transfer between water and air phases doesn't occur. Therefore, the height of the channel is not increased excessively. In most spaces leading to the wind catcher, the internal blades of the wind catcher stretch down to a height equal to the height of an average man to foster surface evaporation by increasing pressure in the outlet as well as to cause a pleasant flow in a lower level. Therefore, since more complex performance is created in the bottom side of the wind catcher the internal blades of the wind catcher are stretched down up to the height of the ceiling. On the other hand, in most of similar studies the same technique is employed. Another important point which should be mentioned here is the construction of three openings in the eastern, southern, and western fronts of the model. Mainly in traditional buildings will be opening in along the yard and the wind catcher but in order to generalize to different spaces and determine wind catcher’s disadvantages in different situations, we used two additional openings in the eastern and western fronts.

After devising the model volume in a range close to 320,000 faces, Volumes were meshed by using Tet / Hybrid networks and over 150,000 cells were created and to increase model accuracy, the number of cells was increased by approaching the important areas. Meanwhile, according to the simple geometry of the wind catcher channel and lower channel space and also having highly important the flow treatment in this area; Therefore, in order to regulate the flow treatment and the reduction cell model, this area was meshed by using Hex / Wedge networks. After building and meshing the model, boundary conditions were determined according to Figure 6.

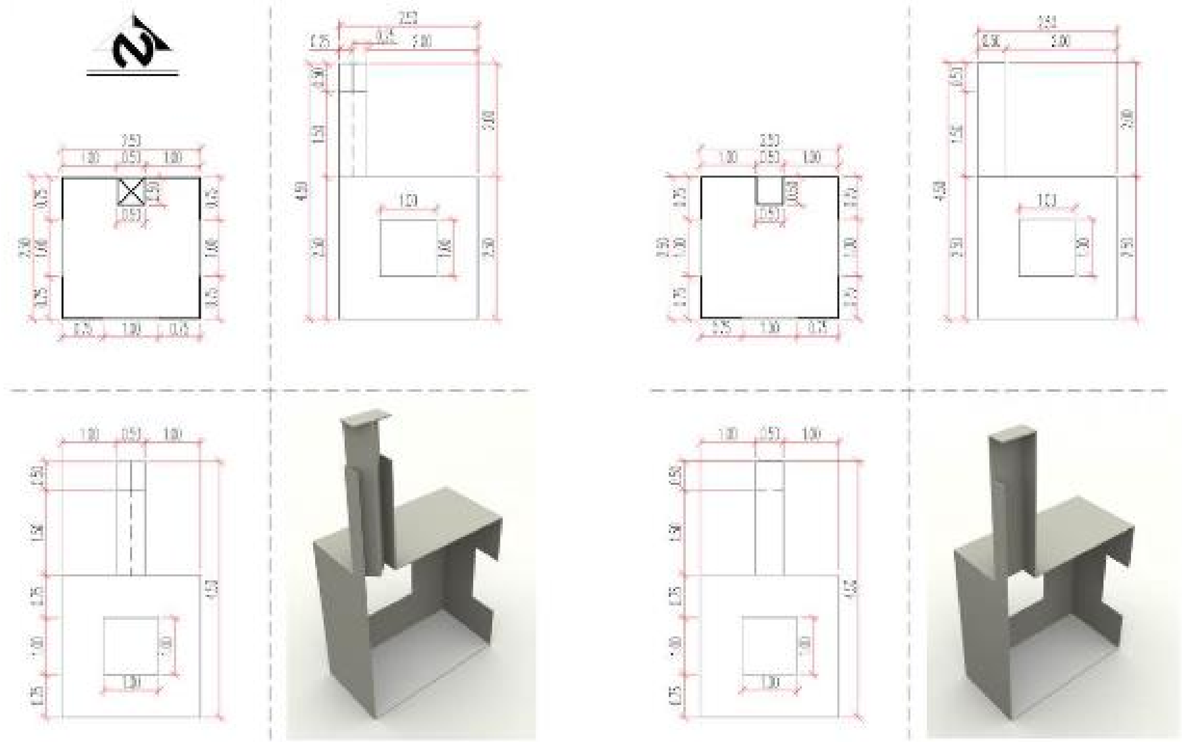

Figure 5. Details of CFD model traditional wind catchers

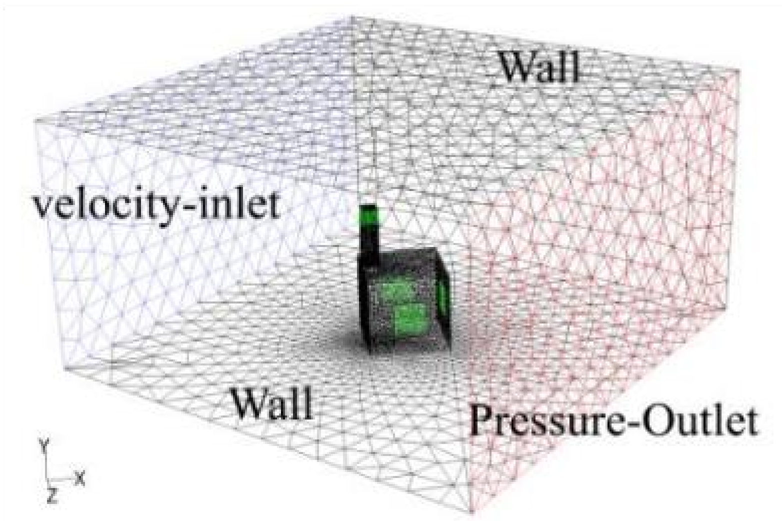

Figure 6. CFD model boundary conditions

Secondly, devised model was read in FLUENT software (Fluent 6.3) and solution conditions were defined as follows:

1- Solver: Pressure Based
2- Space: 3D
3- Formulation: Implicit
4- Time: Steady
5- Operating Pressure: 101325 Pa
6- Pressure-Velocity Coupling: SIMPLE

Because at this stage of investigation, flow velocity and pressures will be enough to compare species of wind catcher and air is the fluid used (and not the ideal gas), so energy equation was considered inactive. Considering that the 10-year average wind speed in the warm months in the Yazd (origin of wind catcher in Iran) was 3.17 m/s; Velocity inlet was considered 3.00 m/s (Table 1).

Table 1. 10-year average wind speed in the warm months in Yazd (m/s)

Year/Month	JUNE	JULY	AUG	SEP	Annual
1996	2.47	2.72	2.52	2.72	2.61
1997	3.80	3.55	3.39	2.98	3.43
1998	3.34	3.96	3.55	3.24	3.52
1999	3.14	3.86	3.03	2.67	3.17
2000	3.39	3.75	3.03	2.52	3.17
2001	3.34	3.86	3.39	2.78	3.34
2002	3.50	3.65	2.98	2.83	3.24
2003	3.34	3.39	3.34	2.83	3.23
2004	3.29	3.44	3.03	2.67	3.11
2005	2.93	3.03	3.08	2.52	2.89
Annual	3.25	3.52	3.14	2.78	**3.17**

According to previous studies and simulations of natural flow, Viscose Model was used as the standard k-epsilon model. Continuity, Momentum, k and epsilon equations were governing on the flow. Following two criteria were measured to determine the validity of data.

Wall Y plus: Because turbulent flows are strongly affected by the wall, therefore it is necessary to evaluate the sensitivity of mesh near the wall through measurements criteria y+. Usually when the k-epsilon model is used, the mesh near the wall must be arranged so that it should be provided y +> 30 or y + <5.

In Figure 7, red line shows the rate of Y^+ in the center of the inner blade of wind catcher, which shows the range $45<Y^+<251$ in height 2.5-4.5 m. Due to the lack of wall at a height less than 2.5 m, the rate of Y^+ is considered as zero. The black line shows Y^+ rate on the vertical wall along the north and wind catcher, which is zero due to absence of cage wall in the range 4.0-4.5 m. At other altitudes, the observed range is $33<Y^+<216$.

Flux Reports: In this model the mass flow rate is reported as follows:

Mass Flow Rate (kg / s)

Flow Outlet -440.99994

Flow Inlet 441.00001

Difference 0.00007

Given the above report, the balance difference the flow rate is very low. Thus the model seems to be necessary conditions for the flow simulation.

2.1 Analyzing the behavior of a single pressure type at different degrees wind blowing

Figure 8-a-S shows the flow behavior at zero-degree angle to the cage of wind catcher. According to this picture, it will be determined that the air flow is moving toward the model with speed of three meters per second(3m/s) that due to collisions with the walls of the wind catcher, the speed of flow has increased in the cage of wind catcher. After the collision outflow with the cage, part of it entered into against the wind channel and the remaining passed from the cage which caused the creation of a negative pressure zone behind it. Afterwards, the outflow crosses the volume and created a weaker negative pressure zone behind the south opening.

Analysis of the flow behavior inside model shows that entering the flow into channel and collision with the walls has increased air velocity in the wall facing the wind, but it has decreased in the wall behind the wind. Then, the flow out of the end of the channel is about two meters per second (2m/s) wind speed and has created a vortex flow within the model. More analysis is needed to examine velocity vectors shown in the Figure 8-a-P for vertical view. This picture indicates that speed of airflow is intensified after hitting the northern wall and through it which has caused a negative pressure zone at the back of all openings. At the same time, the negative pressure in the outer west and east openings and outflow of the wind catcher has led internal flow drawn out. In order to balance the volume of incoming and outgoing flow, outflow is drawn through the southern opening. It was already predicted that the flow enters through the western and eastern openings and flow out of the wind catcher should be exited from the southern opening while suction flow out of the east and west openings are much larger than suction in south opening.

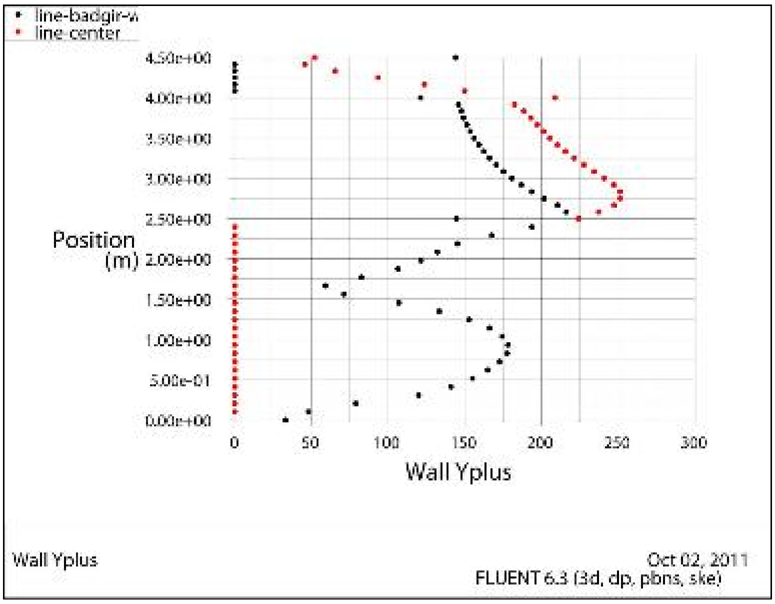

Figure 7. Y^+ chart near the outer wind catcher wall and the inner blade center

Figure 8-b-S was obtained when the wind tunnel was rotated 45 degrees. In the 45 degrees blowing, same situation with the zero degree has occurred because the airflow through the channel of wind catcher into the model. But here the entrance to the channel flow rate has decreased. Figure 8-b-P also makes clear that due to flow entry from the East opening and exit from the South and West openings, only one vortex flow is established within the South West model.

When airflow dealing with the model at 90 degrees (Figure 8-c-S), the flow path inside the channel is contrary and moves slowly upward. The reason of such trend can be seen in creating negative pressure area around the cage and moving the flow from east to west opening. It is clear that airflow is denser after colliding with the east wall and crossing from it. Next, this event is repeated around the wind catcher. For this reason, there have been rapider and denser vectors. Horizontal velocity vectors in 90 degree angle blowing are shown in Figure 8-c-P. This picture shows off the air flow after the collision with the east wall; Considerable portion of it is moved through the opening and the rest of it has passed around the model.

As is shown in Figures 8-d-S&P, air flow deals the model with angle of 135 degrees and passes on the southern and eastern walls. Simultaneously, the air flow has created a negative pressure zone in the north and west which has increased the air velocity inside the channel of wind catcher. In other words, at this angle to 90 degrees, not only the negative pressure is increased around the cage, but the eastern and southern openings increased air velocity upward within the channel.

Figure 8-e-S shows the details of the wind angle of 180 degrees. According to this picture, it will be clear that the main cause of airflow movement is the entrance of external airflow into the model through the southern opening. Also, like the blowing 135 degrees, upward flow within the channel is increased. It is necessary to mention that the two-vortex flow is in the upper and lower of internal space of model which is obtained from a combination of inflow of southern openings and outflow of wind catcher and other openings. The most important thing which should be noted is that as shown in Figure 8-e-P, the airflow enters from an opening and exits from two other openings. Unlike blowing 135 degrees, the airflow enters from two openings and exits from an opening.

Now, it can be stated that the performance of single pressure type of wind catcher strongly depends on the wind flow direction as well as the number and location of openings of model (Figure 9).

In order to conduct a quantitative study on passing volume flow rate in openings and cage, Table 2 is presented which confirms the above results and also shows that a more accurate comparison is possible.

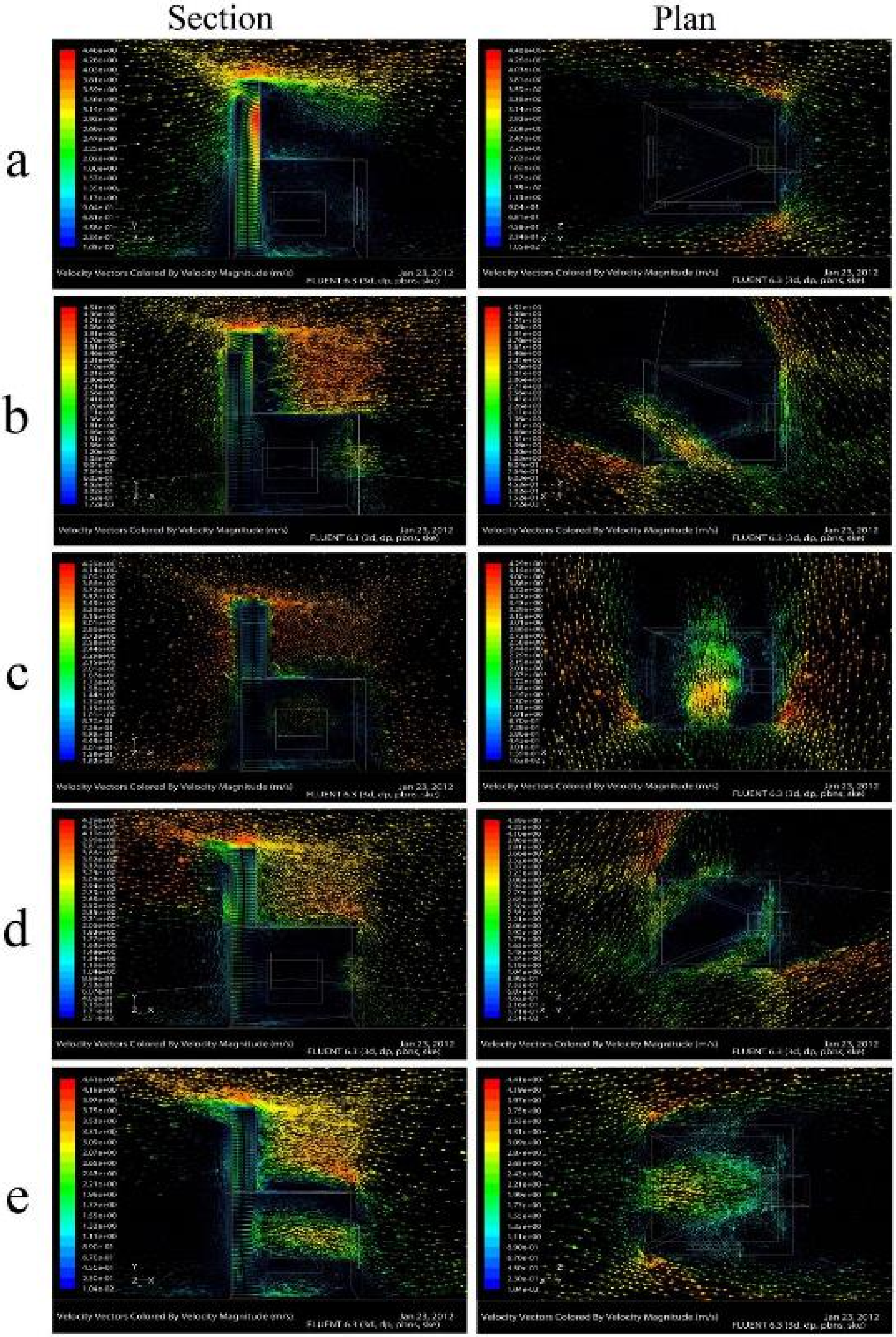

Figure 8. Sections and plans of vectors of velocity magnitude of single pressure wind catchers in different directions blowing

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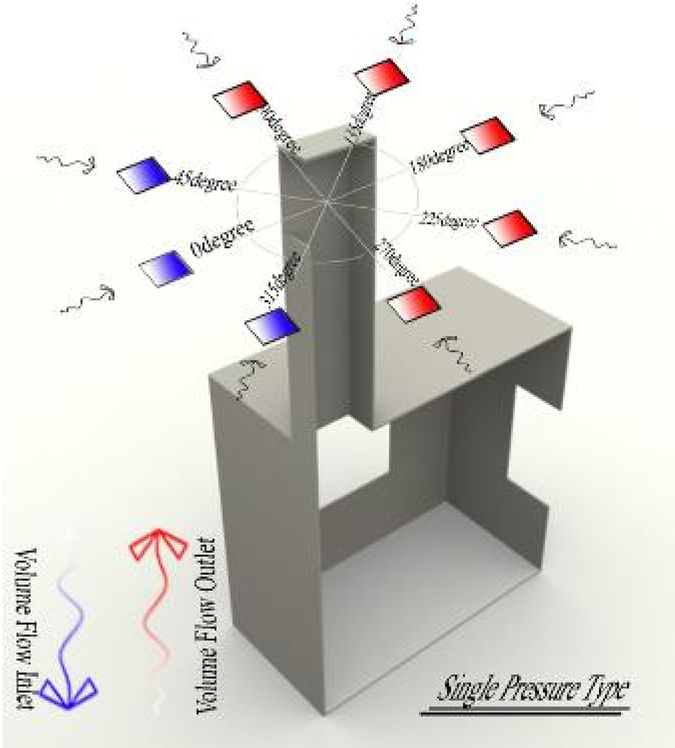

Figure 9. Direction of the airflow inside the single pressure type of wind catchers in different angles blowing

Table 2. Volumetric flow rate in openings and cage

		Volumetric Flow Rate (m3/s)				
Single pressure type	East Opening	-0.4456	1.7306	2.3984	1.1173	-0.9102
	West Opening	-0.4335	-0.4486	-1.6027	-1.7604	-0.9498
	South Opening	0.3591	-1.6274	-0.5939	1.0275	2.1732
	Cage	0.5201	0.3454	-0.2018	-0.3844	-0.3132

2.2 Analyzing the behavior of a multi pressure type at different degrees wind blowing

Figure 10-a-S shows the flow behavior at zero-degree angle to the cage of this type of wind catcher. As in this figure shown, the flow direction and velocity in terms of its magnitude, is shown. This picture indicates that the airflow is denser near the model and its speed is reduced in places where escape is not found. Also, the edges that were created under pressure are released so that its velocity is increased. This is well visible in the roof of the wind catcher. In contrast, the southern opening, the low negative pressure area is created so that it cannot stop being drawn into the external flow. After the airflow passes through the cage of wind catcher, a set of regions of positive and negative pressure is created that has led in the direction of airflow above and below the wind catcher move through the channel. Flow downward into the cage is affected by the positive pressure and then compressed with a speed close to four meters per second (4m/s) is downward. In other channel, under the influence of negative pressure around the cage area, about one meter per second (1m/s) flow velocity rises. That can be one of the causes of relatively high difference between upward and downward flow velocity of the suction openings of the flow from the east and west along said. Within the model, the vortex flow is created has occurred under the influence of the end of the outflow channel and outflow of both Eastern and Western openings and inflow of Southern opening. This theory is obtained by studying the Figures 10-a-S&P.

2.3 Analyzing the behavior of a multi pressure type at 45 degree blowing

According to Figure 10-b-S which shows this type of wind catchers at 45 degree blowing wind, can be express that airflow is dense in the eastern and northern walls and then passed on model of nearly four meters per second (4m/s) speed. There is a range of high speed airflow created under the influence of airflow entering from the East opening and exit from the south opening. Comparing Figures 10-b-S&10-

a-S shows that in the 45 degrees blowing, the flow velocity downward is reduced and upward flow velocity is increased. Another point is that at the end of the wind catcher, withdrawal is occurred easier than zero blowing conditions so it, may operate by vortex flow inside the model.

As shown in Figure 10-b-P is how the airflow has passed around the model and the negative pressure area is being created behind it. The interestingly point is how to create the vortex flow within the interior space occurred by the movement of the air flow from east opening to south opening.

Figure 10-c-S shows the displacement quality of airflow around the model under 90° blowing. Due to its wind catcher, flow velocity has decreased in border wall that seems to be caused by the collision with the wall of the east wind catcher. Noteworthy, same direction of flow in both North and South channels which may be due to the suction flow is derived from the cage. Given the experience that we gained in zero-degree blowing, we forecast that the flow moves down through the Eastern Channel, but this picture is not clear. In the area south of the volume; flow is drawn through the opening which may be due to the entry from eastern opening and exit from western opening (Figure 10-c-P).

It is depicted in Figure 10-c-P that the air has continued to move in three directions after hitting the model. It goes in both directions around the model that has been associated with increased speed and the other that passes through the model; its speed has been increased slightly. We are witnessing a four-vortex flow inside the model which seems that movement mainstream of the building is the most important factor. Likewise, the southern opening, the flow of air to take out and also due to wind catcher down and lift flow same time, leading to a compressive force in the vertical direction is on flow inside.

According to Figure 10-d-S which shows the wind catcher at 135 degree blowing, it can be stated that the airflow movement is due to the positive pressure created in the southern wall of wind catcher and negative pressures occurred in the northern wall. The interesting thing that we have not to deal with it is that wind catcher output flow is rapider than input flow thrust because one can see the flow entering from the two opening and flow out of an opening (Figure 10-d-P). So we are inside flow congestion control that leads to increased negative pressure in outlet channels.

According to Figure 10-d-P, flow path is changed to the north and west after dealing with the model and then is entered into the wall openings. Flow into the model is dense behind the western wall and out of the opening. The vortex created in this situation is happened behind the northern wall model which affected the movement of the northeast region and ceiling model is occurred.

Based on Figure 10-e-S in which flow blows with a 180° angle relative to the model, it is obvious that the collision with the southern wall, condenses it and moves it on the roof. Then get to the wind catcher channels, speed has been increased along the vertical and has reached the cage. Part of the airflow around the cage is entered into the South Channel. The rest of airflow passes the cage and causes a negative pressure area behind it so the flow is moves upward.

In comparison with the wind blowing at zero degree, it is indicated that flow velocity downward is reduced but upward flow velocity is increased. It can be seen as the most important factor in air flow getting into and out of the openings. The important thing in the Figure 10-e-P is a strong vortex that is the northern side and the air flow entering through the southern opening which causes the current compression and wake vortex formation in the interior space.

2.4 Brief analysis of the behavior of multi pressure type of wind catcher at different angles blowing

At the end of this discussion, it can be concluded that in all angles of the wind blowing, multi pressure type of wind catcher, simultaneously provides entry and exit of airflow due to the use of multiple internal channels. In general, we can say where the wind blowing was perpendicular to the wind catcher (zero, 90 and 180 degrees) only the channel against the wind is directed to flow downward and other channels are directed to flow upward. But in other wind blowing (45 and 135 degrees), to flow downward through the two channels (Channels against the wind) and upwards is drawn through two other channels (Figure 11). Finally, the location and number of openings are considered as the most important factors in the wind catcher flow velocity inside the channels.

Finally, Table 3 is represented which confirms above results and makes it possible to compare them more precisely.

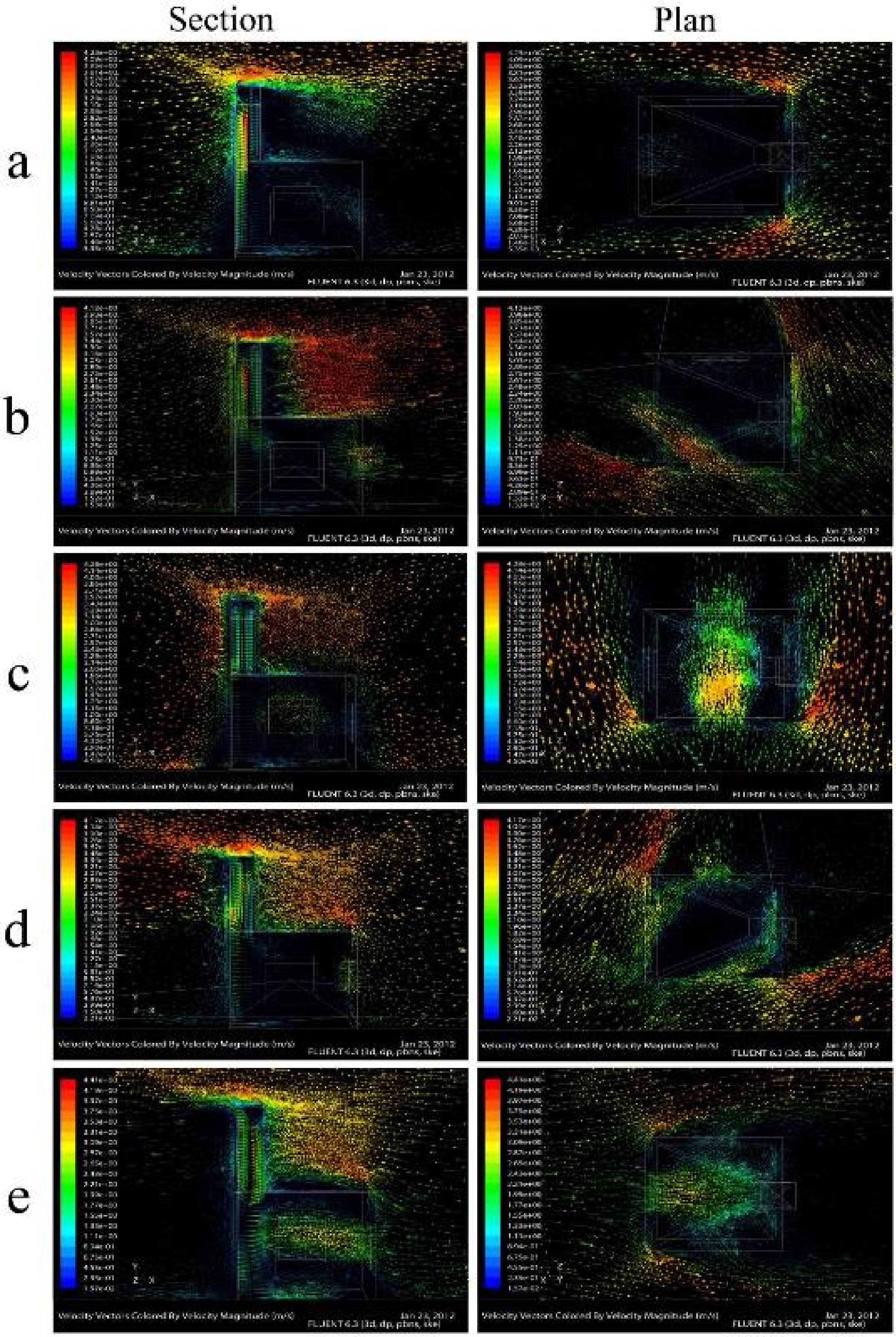

Figure 10. Sections and plans of vectors of velocity magnitude of multi pressure wind catchers in different directions blowing

Table 3. Volumetric flow rate in openings and channels

			Volumetric Flow Rate (m3/s)				
Multi pressure type	Openings	East	-0.2930	1.7577	2.3882	1.0065	-0.9498
		West	-0.2888	-0.1883	-1.6339	-1.7815	-0.9803
		South	0.6368	-1.6275	-0.6604	0.8815	2.1543
	The canal of wind catcher	East	-0.0697	0.1160	-0.1280	0.0625	-0.1069
		West	-0.0507	-0.0867	0.0758	0.0736	0.1208
		South	-0.0703	-0.0870	0.0565	-0.1211	-0.1072
		North	0.1358	0.1159	0.0897	-0.1214	-0.1308

3. Conclusion -Comparing the behavior of Single and Multi pressure types of traditional wind catcher under the influence of changing the angle blowing

At the end of this paper and due to the same conditions for Multi pressure type and Single pressure type of wind catcher, we can compare them together. The results show that in Single pressure type, the entire space inside the channel is used for motion flow in one direction. But in Multi pressure type the entire space inside the channel is used as part of the internal space channel for motion flow downward and the remaining space to create an upward flow. That is how to move the internal flow channel in a function of wind direction (Figures 9, 11 and 12). The wind flow is caused by a series of low compression and congested areas around the cage of both species that Single pressure type uses pressure area in front of the inlet of cage (only one side) but Multi pressure type uses all areas around the cage (Figure 13).

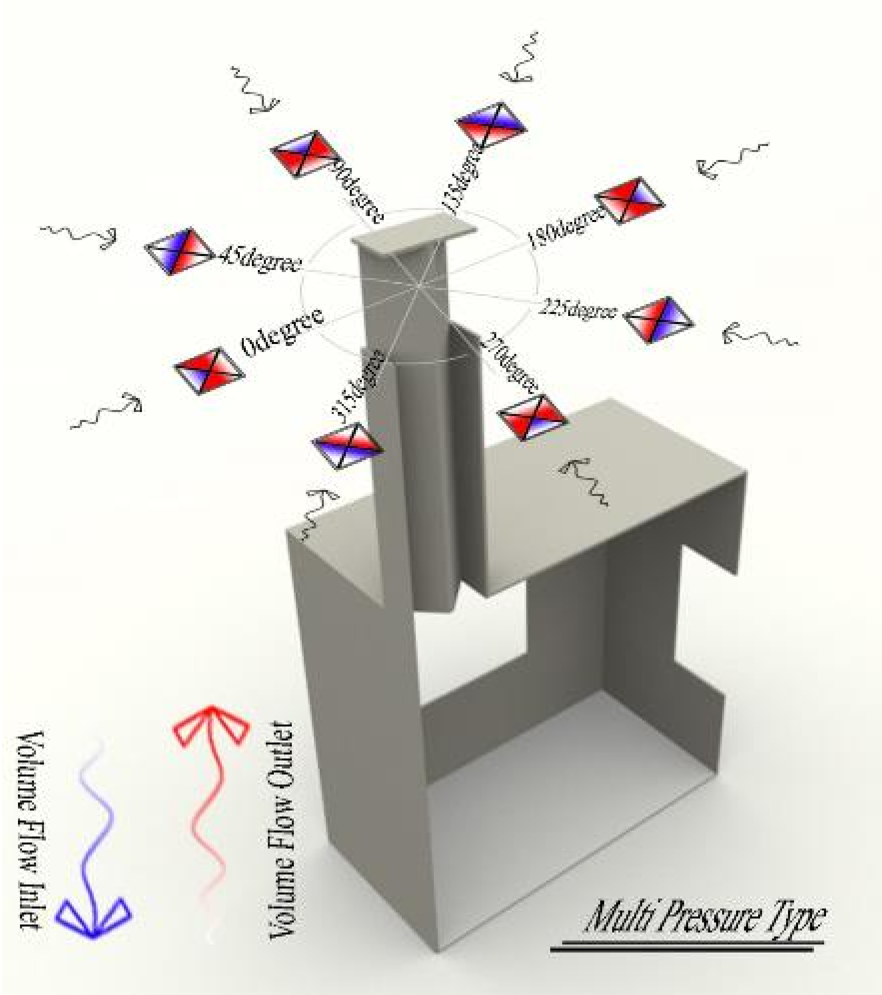

Figure 11. Direction of the airflow inside the multi pressure type of wind catcher in different angles blowing

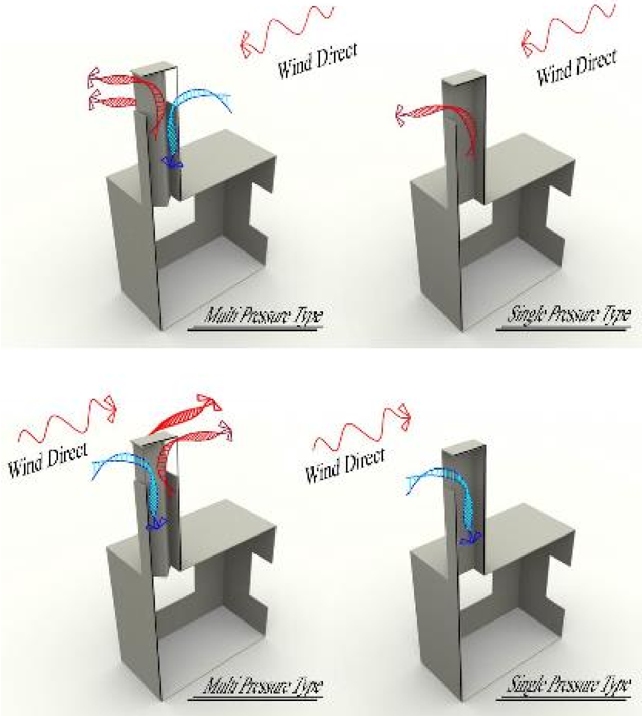

Figure 12. Behaviors of Multi pressure type and Single pressure type of traditional wind catcher in different angles blowing

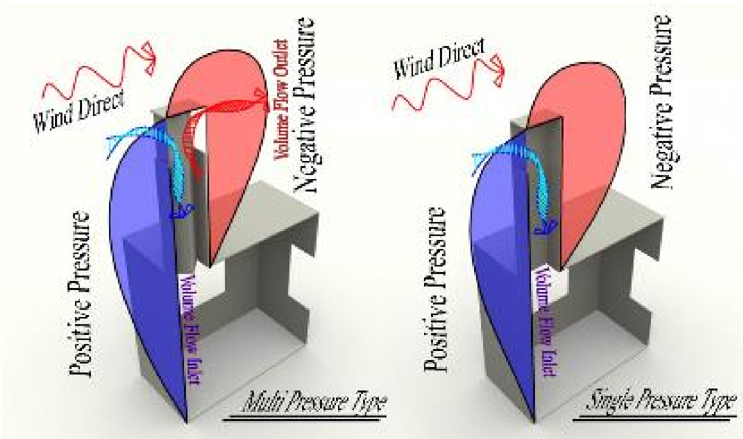

Figure 13. The utilization of Multi pressure type and Single pressure type of traditional wind catcher of high pressure areas around cage

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M. R. Abouseba is a lecturer at Faculty of Engineering, Sepehr Institute of Isfahan, Isfahan, Iran. His MSc degree is in Energy Efficiency in Buildings from Ilam University, Iran, and he completed his study in 2012. His main research interests are in Natural Ventilation and Energy Efficiency. He is currently an architectural member of Iran Construction Engineering Organization (IRCEO).
E-mail address: mabousaba@yahoo.com

J. Khodakarami is an Associate Professor at Department of Architectural Engineering, Faculty of Engineering, Ilam University, Ilam, Iran. His PhD degree is in Energy Efficiency in Buildings from Cardiff University, UK, and he completed his study in 2008. His main research interests are in Thermal Comfort, Natural Ventilation, and Energy Efficiency. He is currently a senior architectural member of Iran Construction Engineering Organization (IRCEO).
E-mail address: j.khodakarami@ilam.ac.ir