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Evaluating the efficiency of YAZDI wind tower, an experimental study

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Abstract

This paper is an attempt to evaluate ventilation performance in YAZDI wind tower with aid of an experimental study. Wind Towers has been known as one of the most effective climatic elements in Iranian traditional architecture and performance of wind tower is air conditioning and air suction, cooling nutrition and preventing of putrefaction of water in water storages. Iranian Wind towers have been categorized in three main types, ARDAKANI, KERMANI and YAZDI, and this paper deals with YAZDI wind tower. First, an analytical model defined and then case studies modeled in Vasari software environment, furthermore theoretical modeling presented to assess the accuracy of measurement procedures and the uncertainty of experimental modeling. Modeling and Simulation methods and Logical reasoning have been applied to the article, and study of Library Resources was another part of research. Results indicated that YAZDI wind tower with four openings has a positive air flow rate in hot seasons (air flow rate=+0.018) also air flow rate in cold seasons is positive too (air flow rate=+0.012). Therefore YAZDI wind tower regarding to its performance in the whole year can be categorized as an efficient device in its climate, Also with the aids of some simple devices, natural ventilation performance can be increased.

Keywords: *YAZDI wind tower, Simulation, Wind velocity, Air flow, Efficiency.*

1. Introduction

In the beginning of new century, energy consumption in parallel with economic and technological development has been increased, and will be upraised so on. *Iran* with one percent of world's population has a nine percent part of energy consumption, also in the last decade the capitation of energy consumption in Iran grows to 5 times more than universal average [1]. According to *Mostafaiepour*, it is well known that fossil fuels have limited resources and at current rates of exploitation they are expected to deplete within the next centuries. This is one of the reasons why clean, sustainable and environmentally friendly alternative energy resources are currently sought [2]. Thus, usage of clean resources and passive systems like wind, solar radiation and etc., seems necessary. Particularly, wind energy is an attractive source of renewable energy employment in many countries in the world, and the positive impacts of wind energy on climate change mitigation, as well as opportunity to diminish energy dependency is indisputable.

Wind tower or what is called Baud-Geer in Persian language has been employed in arid central regions of Iran and the neighboring countries to provide natural ventilation and passive cooling. In these regions due to the hot summer time, the buildings used to have special architectural features and components in order to protect the occupants from the harsh outdoor environment [3]. The wind tower systems come in various configurations to suit various building type and requirements such as the incorporation of solar panel (solar chimney) and light pipes to boost stack effect. By using of fluid mechanics principles it can be estimated that height, cross section of the air passages, placement and the number of openings as well as placement of the wind tower with respect to the structure it cools greatly affects performance of wind towers. [4]. Wind towers consists of different parts such as openings, shaft, partition: main partition and subsidiary partition and etc., which some of them are just for reaching elegance and some are functional and some are both. Wind towers constituted a system of natural ventilation that could also be used in evaporative cooling (Figure1). As stated wind towers are designed to catch the wind at higher levels and to induce it into the living space by using thermal and pressure gradients [5].

Numerous studies have been performed around wind tower subject. Bahadori [5], by computer modeling and numerical assessment of a wind tower, calculates air temperature in different parts of the wind tower's shaft.

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Dehghani [6], by experimental calculating of three parameters of wind which are temperature, moisture and mass flow of a wind tower in Tehran, concluded that this traditional method with some changes can be useful nowadays. Mazidi [7], by numerical assessing of Dolet-Abad garden wind tower concluded that air temperature of pip out wind in this wind tower with wet or dry surfaces are the same and their changes are negligible. Mohmoodi [8], by modeling YAZDI wind towers in Yazd city, evaluated the thermal behavior of YAZDI wind towers and presented an accurate typology of wind towers in Yazd city. Montazeri [9], compared one sided and two sided wind towers and concluded that two sided wind towers are more efficient in thermal behavior. Kalantar [10] by comparing wind towers with wet surfaces and dry surfaces indicated that the first one is more efficient. . Also Montazeri [11], by modeling a two sided wind tower in 1/40 scale maquette and analyzing in a mechanical wind tunnel, concluded that these wind towers have positive performance.

Fig. 1. Wind towers in Iran [Authors]

Bouchahm [12], by numerical modeling indicated that wind towers with more height and smaller partition width are more efficient in natural ventilation and air flow. Authors in another research [13] have studied air velocity and pressure influences in YAZDI and Kermani wind towers in order to choosing efficient one. The present paper is a continued research regarded to Mahdavinejad and Javanroodi (2012) and assesses YAZDI wind tower natural ventilation performance with a sample room and calculates induced air velocity in to the room, thus this study is an innovative research to completing previous researches.

2. Materials and Methods

2.1. Research methods

The paper has applied modeling and simulation methods along with analytical methods [14]. Modeling process is performed by Autodesk Vasari Beta 2.5 version (Figure 2). [15] At the first step, analytical modeling through several complicate equations performed and demanded data obtained. Then, wind tower had been modeled and then by applying [16] climatic and numerical data obtained through calculations, the wind tunnel simulated and models had been analyzed. All in all, results presented in the diagrams and simulated figures. [17] Thus, first analytical method is described first then modeling process defined in detailed explanation. In this study it was assumed that no short-circuiting and airflow through window can be obtained using algebraic sum of these two values.

2.2. Ventilation performance of wind towers

Two methods can be considered as performance of wind towers, one with air flow and another without air flow. In the first method, when air flow directed to wind tower and attached building, wind pressure differences occurs at all opening and different levels of building. This pressure calculates from equation [a]:

[a] $P=C_p \tfrac{1}{2}\rho V^2$

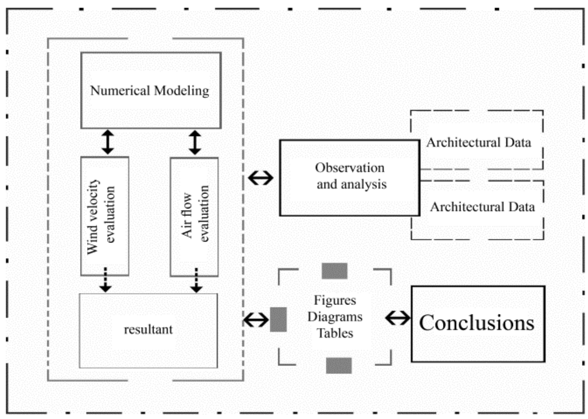

Fig. 2. Process of research method [Authors]

In this equation, P is pressure, ρ is specific gravity, V is velocity of wind, and C_p is the wind pressure coefficient [15]. Also the pressure difference between the openings toward to the each funnel of wind tower calculated from equation b. This pressure difference causes a certain amount of air flow in wind tower, which calculated from equation c.

[b] $\Delta P= P_i-P_j= (C_{pi}-C_{pj})\ \tfrac{1}{2}\ \rho V^2$

[c] $V_{i,j}=\Delta P / R_i$

In equation b, V is volume of air flow, ΔP as pressure difference, R represents air flow resistance, i and j represent the funnel, and ij represent the air path [16]. With air pressure difference ΔP_{ij}, between i and j funnel in terms of air flow resistance in the way it is, the air flow according to equation c is established, which means from wind tower funnel directed to wind (i) air flows in, and from opening (j) will pop out from building. Thus, by using air flow network, we can determine the amount of air flow in any direction or duct. The air duct passes through a heat exchange with the surrounding surfaces and its temperature will change [1]. Figure 3 is showing the behavior of a multi openings wind tower and introduces its parts, and also showing the plan of a house which is assumed for this research. The building which assumed in this paper is shown in Figure2. The case study of the paper is located on wind tower mark and the fifth side of building has a 1.5*1.5 meters opening which cause a difference pressure between number one, two, three and four opening in wind tower.

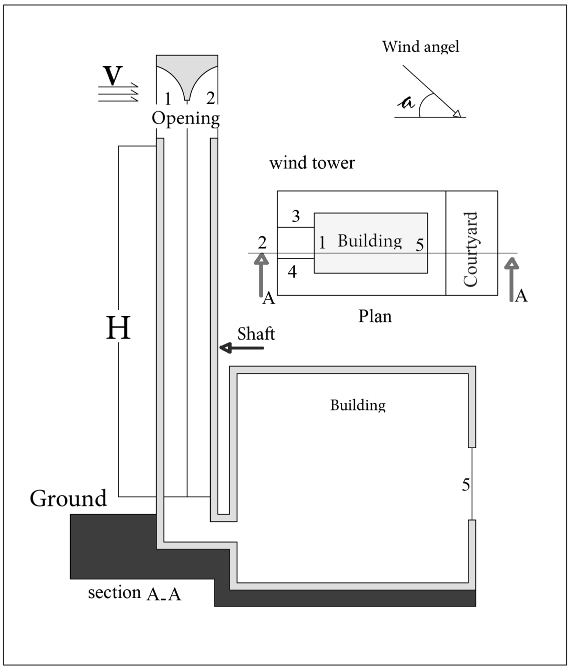

Fig. 3. A: the assumed plan for research, B: behavior of a multi openings wind tower and its parts

3. Results and Discussion

YAZDI wind tower has been modeled in Vasari project beta 2.5 Software. The wind tower is connected to a sample room. The sample room is a square with 600 centimeter length and 300 centimeter height, which the wind tower was erected beneath the wind tunnel (Figure 5). Regarding to the study assumption all dimensions and conditions in the sample room and shaft are equal. *YAZDI* wind tower with four openings and opening number two is directed to prevailing wind, likewise (Figure 3). Simulated contours are presented in two main part, plans and sections and are showing air pressure and wind velocity. Also Table 1 and 2 and 3 are showing climatic data for Yazd city, calculated C_p for openings and also pressure difference for each opening and the opening of sample room.

Table 1 5 Year period average of synoptic climatic data of Yazd city

Station	Parameters	Jan	Feb	Mar	Apr	May	Jul	Jun	Aug	Sep	Oct	Nov	Dec	5 Year average
Yazd city	Wind velocity	5.9	5.9	9.1	9.7	10	8.8	9.6	8.7	8	6.7	5.2	5.7	7.7
	Wind direction	37	110	75	92	114	179	162	75	19	70	72	40	89

[22].

Table 2 C_p coefficient determined for each opening in each month of *YAZDI* wind tower

	Jan	Feb	Mar	Apr	May	Jul	Jun	Aug	Sep	Oct	Nov	Dec	Annual
C_p	-0.74	0.4	-0.48	-0.45	0.9	-0.49	-0.42	-0.39	-0.65	-0.74	-0.49	-0.66	0.6
	-0.35	-0.34	-0.35	-0.33	-0.43	-0.36	-0.55	-0.61	-0.42	-0.35	-0.36	-0.36	-0.36
	-0.7	-0.3	-0.48	-0.45	-0.29	-0.49	0.83	0.83	0.11	-0.7	-0.49	-0.5	-0.28
	0.88	0.65	0.86	0.85	-0.34	-0.86	-0.57	-0.64	0.85	0.88	0.86	0.89	-0.5
	-0.35	-0.13	-0.29	-0.28	-0.03	-0.3	-0.12	-0.13	-0.31	-0.35	-0.3	-0.34	-0.09

[Authors]

Table 3 Pressure difference between openings and window in Yazdi wind tower

Parameters	Dec	Nov	Oct	Sep	Aug	Jun	July	May	Apr	Mar	Feb	Jan	Annual
P1	-11.79	-7.28	-18.27	-22.88	-16.23	-21.28	-20.87	49.5	-23.28	-21.86	7.65	-14.1	19.56
P2	-6.43	-5.32	-8.64	-14.78	-25.39	-27.87	-15.33	-23.65	-17.03	-15.94	-6.50	-6.70	-11.73
P3	-8.93	-7.28	-17.28	3.87	34.55	42.07	-20.87	-15.95	-23.28	-21.86	-5.74	-13.40	-9.13
P4	15.90	12.78	21.72	29.92	-26.64	-28.89	-34.07	-18.7	43.98	38.71	12.44	12.44	-16.30
P5	-6.07	-4.46	-8.64	-10.91	-5.41	-6.08	-12.77	-1.65	-14.48	-13.20	-2.48	-6.70	-2.93
P15Δ	-5.72	-2.82	-9.69	-11.97	-10.82	-15.2	-8.1	51.16	-9	-8.66	4.13	-7.40	22.49
P25Δ	-0.36	0.86	0	-3.87	-19.98	-21.79	-2.56	-21.91	-2.55	-2.74	-4.08	0	-8.8
P35Δ	-2.86	-2.82	-8.64	14.78	39.96	48.15	-8.1	-14.3	-8.8	-8.66	-3.09	-6.70	-6.20
P45Δ	21.97	17.24	30.36	40.83	21.23	-22.81	21.3	-17.05	58.46	51.91	14.92	19.14	-13.37
ΣV	13.03	12.46	12.03	39.77	30.39	-11.65	2.54	-2.1	38.11	31.85	11.88	5.04	20.86

[Authors]

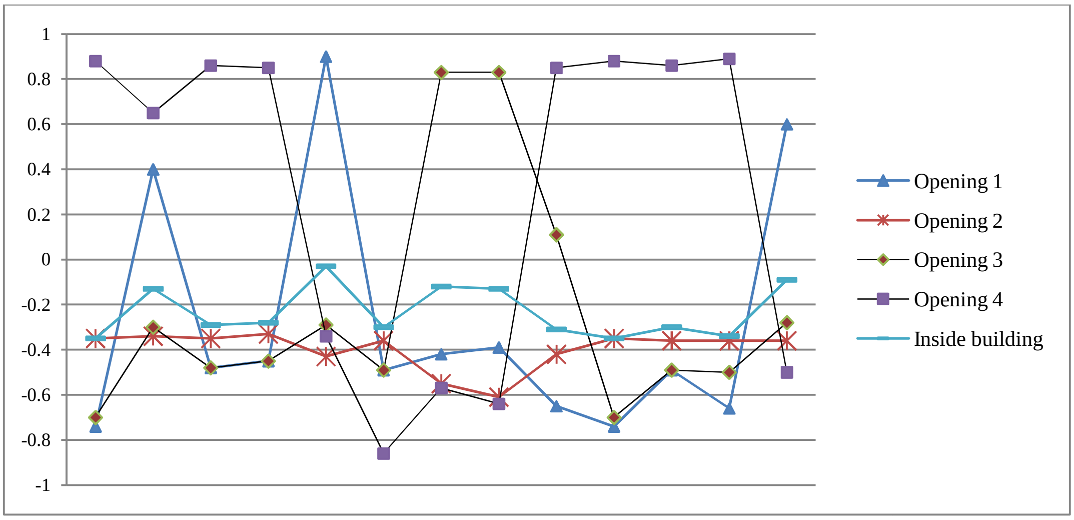

Fig. 4. Average pressure coefficients at the opening and pressure coefficient inside the building. Yazdi wind catcher [Authors]

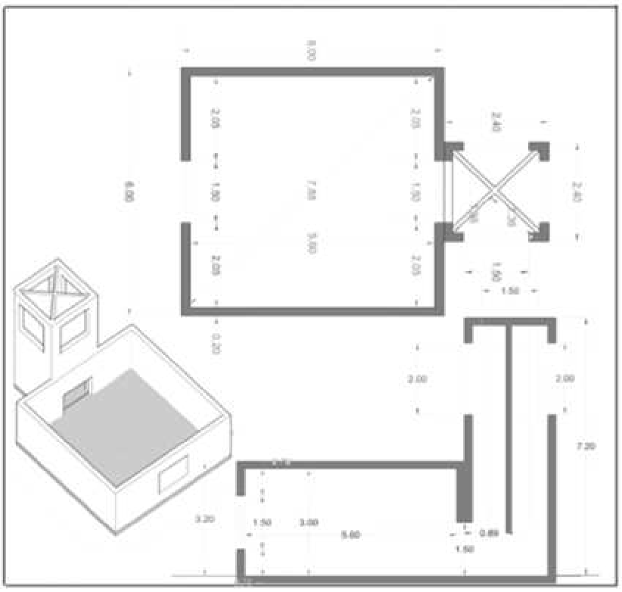

Fig. 5. Yazdi wind tower modeling data [Authors]

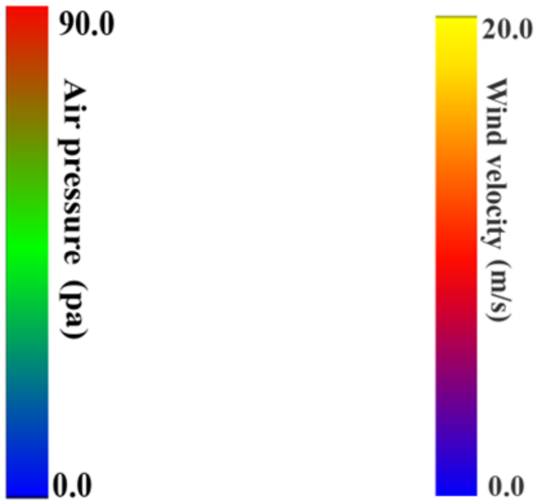

Fig. 6. Simulation spectrum zones

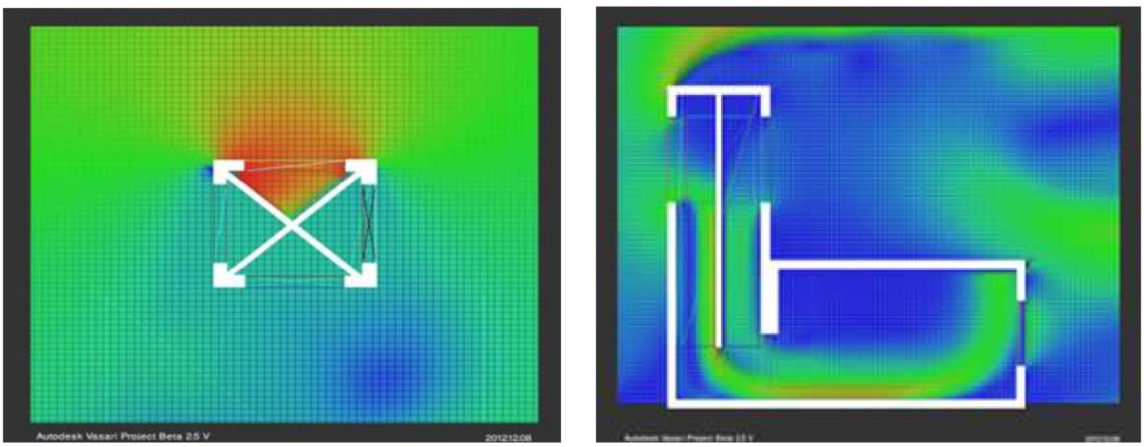

Fig. 7. Wind pressure simulation contour at plan and section, Autodesk Vasari Beta 2.5

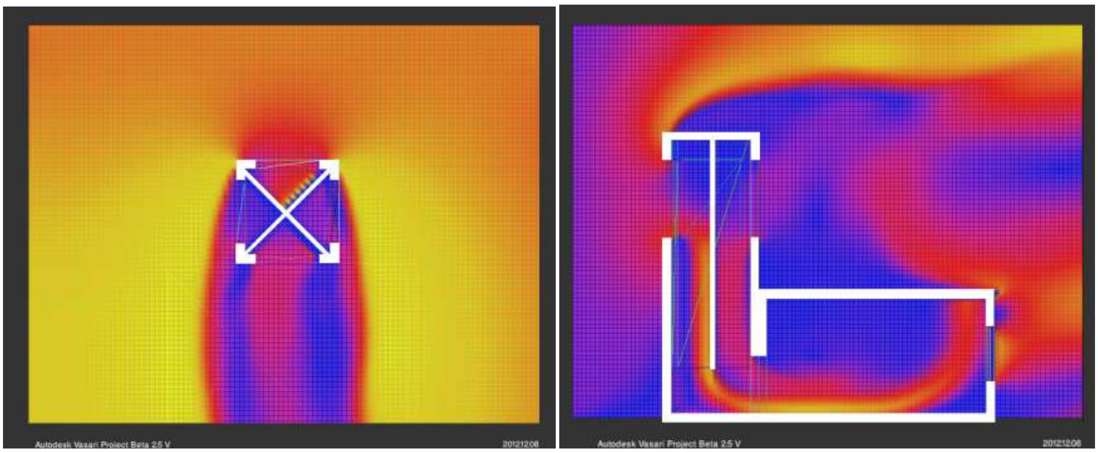

Fig. 8. Wind velocity simulation contour at plan and section, Autodesk Vasari Beta 2.5

Figure 7 and 8 shows the top view of the passes flow through the four-sided wind tower and air pressure at outside and inside of it. Visualization tests shows air pressure at the four openings, as it is clear pressure value at windward opening is larger than other three openings. Also pressure coefficient at windward opening is consequently the highest value among the others. This means that windward opening drives fresh air in to wind vent and openings number 3 and 4 acts as an exhaust vent. Figure 7 shows air pressure distribution at wind tower and the sample room. Air pressure value at the window and leeward opening is high enough to prevent induced air to leave. Figure 8 shows wind velocity at the top view of wind tower, as it is obvious windward opening and leeward opening drives fresh air at a high value in to wind vent and opening number 3 won't induce air in to the shaft, and opening number 4 only drives a little amount of air in to the shaft. Therefore, this wind tower performance has some advantages and disadvantages. Firstly, windward and leeward openings induce large deal of air and wind in to the wind tower vent. Secondly, pressure value at the window and inside of sample room is high enough to prevent air exhaustion through them. But *YAZDI* wind tower has an important disadvantage, opening number 3 and 4 because of low value of pressure coefficient acts as exhaustion vent. These openings decrease induced air from windward and leeward openings. All in all, *YAZDI* wind tower has a positive average performance through the year and is a useful device for natural wind tower.

The velocity of air flow at the shaft and sample room in July is at highest level and in January is the less, which both are positive points (Figure 9). Totally in winter and autumn the air flow velocity is too low, which is an advantage for *YAZDI* wind tower. Analysis indicated that in the summer and spring seasons (July, August and October) air flow velocity and enteral air flow is efficient. But in June and September is too low due to its value in the winter and autumn seasons. Also the average air flow velocity in spring is lower than this value in winter, which is a great disadvantage for *YAZDI* wind tower (Table 9). However climatic characteristic in the Yazd city is different from Kerman and *Ardakan*, in which wind velocity is lower than those cities. All in all the performance of this specific *YAZDI* wind tower except in June, May and September in hot season is positive, but the average enteral air and air flow velocity of cold seasons is higher than hot seasons, which is totally insufficient (Table 4).

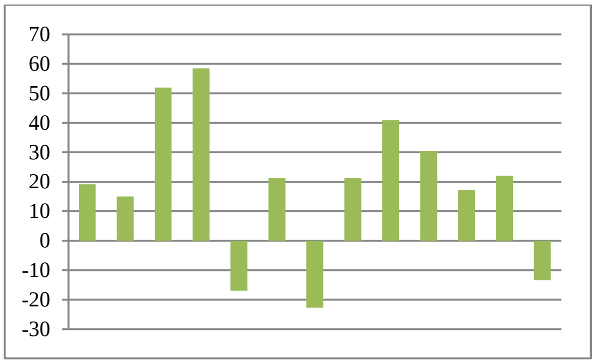

Fig. 9. Wind velocity at the entrance opening of wind tower in to the sample room.

7. Conclusions

Simulated figures and diagrams extracted from the software in this paper indicates that the architecture and designing of wind towers are so genius and even nowadays by more investigating on the principles of its structure and researching on its performance can be used for production of ventilation channels and natural ventilation systems. Also results shows that cooling capacity and optimized efficiency was one of the most important principles in designing of wind towers. Increasing the number of openings regard to two sided or one sided wind towers in the sample *YAZDI* wind tower has many positive and negative points so that a specific wind tower cannot be an absolute advantage over another one, and each wind tower according to the climate in its area and region can perform better. The height of wind tower did not impact directly on the analysis but also indirectly by making air turbulence and wind pressure was influential. With accurate simulation and modeling can be found clearly that traditional ventilation systems have many untapped secrets and notes that to find these points we will require further investigations in this area.

Table 4. Advantages and disadvantages of *YAZDI* wind tower

		Winter	Spring	Summer	Autumn
Disadvantages	**Analytical simulation**	Large amount of air suction in April	Air flow in the in June is too low comparing to the predominant wind direction especially in April	-	-
	Computer simulation	Constant air pressure in the non-directed openings toward predominant wind direction which causes air flow reduction and even air suction around them			
		Not efficient use of maximum wind velocity in the rear opening to the predominant wind direction			
		Winter	**Spring**	**Summer**	**Autumn**
Advantages	**Analytical Simulation**	Efficient performance in air flow and wind velocity	Good performance in air flow and wind velocity in April	Positive performance in air flow and wind velocity	Efficient performance in air flow and wind velocity
	Computer Simulation	High air flow velocity in three opening and only one opening (left) act like a suction vent			
		Sufficient air ventilation from three openings and good air flow and wind velocity inside			

[Authors]

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