Numerical Modeling and Experimental Study of Air Flow in theYazdi Wind-Towers

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Abstract

This paper is an attempt to Numerical Modeling and Experimental Study of Air Flow in the Yazdi Wind-Towers. Wind Towers has been known as one of the most effective climatic elements in Iranian traditional architecture. This paper is an attempt to evaluating Yazdi wind-tower to discussion the two main questions: 1. What is the role of Orientation of wind-towers span, regarding to climate and height of it, in Yazdi wind-tower? 2. How isthe performance of Yazdi wind tower in natural ventilation and air flow in the different seasons of the year? Computer Modeling and Simulation methods and Logical reasoning have been applied in this article, and study of Library Resources was another part of research.Thus, first, the wind-tower has been modeled in computer environment, then after Appling the climatic characterize, final simulation figures and diagrams have been extracted. Results indicate that increasing of the cooling power and optimized efficiency are one of the most important principles of wind-tower design process, and Yazdi wind-towers has mentioned this fact through 4 seasons of the year. By validate computer modeling and simulation, this paper clarify that Iranian traditional ventilation systems has many undiscovered secrets and facts, which need further investigations. This article indicates that natural tactics, which have been applied in the traditional architecture of Iran, can be mentioned as methods to using this valuable heritage in contemporary architecture.

Keywords: Yazdi wind-tower, simulated wind tunnel, wind velocity

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Introduction

In the beginning of new century, consumption of energy in parallel with economic and technological development has been increased, and will be upraised so on. With this situation, Islamic republic of 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 Irangrows 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]. With this background, using clean resources and passive systems like wind, solar radiation and etc., seems necessary. Especially, wind presents an attractive source of renewable energy employment in many countries in the world, andthe positive impacts of wind energy on the mitigation of climate change as well as opportunity to diminish energy dependency are indisputable.
Wind towers or wind catchers constituted a system of natural ventilation that could also be used in evaporative cooling (Fig1). As stated *wind towers* are designed to catch the wind at higher elevations and to direct it into the living space by using thermal and pressure gradients [3]. The wind tower consists of a vertical shaft with several openings which connect the tower to the rooms to be ventilated[4].This technique was used for many centuries in parts of the Middle East, notably Iran, Egypt, and Jordan. It represents a significant wealth of traditional technologies based on climate responsive buildings and natural environment such as wind, water, and vegetation[5]. This article by computer modeling and simulation is an attempt to analysis the wind velocity and air pressure in *Yazdi wind towers*. First, after description research literature and research method, the computer modeling will be analyzed. Then, results of analysis discussed and conclusion has presented. This paper is a try to indicate the quality of climatic design of Iranian traditional architecture.

Fig1: Wind towers in Iran[Authors]

Literature review

1.1 Wind towers

Wind catcher 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 [6].The wind catcher 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 catcher with respect to the structure it cools greatly affect performance of wind catchers. [7]. Wind towers consists of different parts such as cabinet, 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 (Table 1).

Wind tower parts	Definition
Cabinet	Head part of wind tower which consist of air flow transmission duct
Shaft	Part of shaft which located between cabinet and roof of the wind tower
Partition	Brick and adobe elements which divide wind tower opening in to smaller openings
main partition	Parapets which continued to central part of shaft and divide wind tower in to small openings.
subsidiary partition	Parapets which do not continued to central part of shaft and are the wind tower's wings
Open and closed pore	Any space which located between of two partitions. Open one allows airflow and closed one inverse.

Table 1: Definitions main parts of wind towers [Authors]

Totally, performances of wind towers are air conditioning and air vacuum, cooling nutrition and preventing of putrefaction of water in water storages[8]. In wind towers in one direction the funnel of air occurs and in behind direction because of negative pressure and air vacuum, proper air will be flew into tower and internal hot air comes out[1]. Also in some niche or closet of wind towers, a wooden door that had existed up to control the operation of the wind, which is similar to compartment of contemporary refrigerators.

2.2 Thermal performance of wind towers

Two methods can be considered as performance of wind towers, one with and another without wind flowing. In the first method, when wind flow directed to wind tower and attached building, wind pressure occurs at all opening and different levels of building. This pressure obtained from equation 1:

$$(1)\ P=C_p \tfrac{1}{2}\rho V^2$$

In this equation, P is pressure, ρ is specific gravity, $V$is velocity of wind, and$C_p$is the wind pressure coefficient [9]. Also the pressure difference between the openings toward to theeach funnel of wind tower obtained from equation 2. This pressure difference causes a certain amount of air flow in wind tower, which obtained from equation 3.

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

$$(3)\ V_{i,j}=\Delta P/R_i$$

In equation 2, 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[10].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 3 is established, which means from wind tower funnel directed to wind (i) air flows in, and from opening (j) will pop out of building. Thus, 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 2 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 Fig2. The case study of the paper is located in wind tower place and the five side of building has a 1.5*1.5 meters opening which cause a difference pressure between one, two, three and four wind tower opening and building opening.

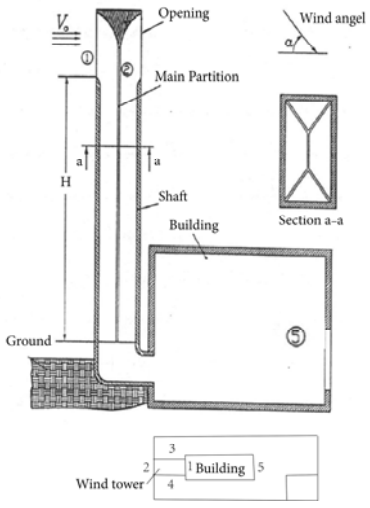

Fig2: A: the assumed plan for research, B: behavior of a multi openings wind tower and its parts

2.3 Wind towers typology

Iranian Wind towers can be divided in to 3 main categories, Ardikani, Kermani and Yazdi[11]. Ardikani wind towers are located in Ardikan town in Yazd province and have a single opening directed to Isfahan wind. Ardikani wind towers with simple architecture and structure were economically affordable. A kind of Ardikani Wind towers with a short height and directed to the sea beach are located in southern cities of Iran like Bandar-Abas, Bandar Boushehr and etc, to capture cool breeze into buildings [12]. Kermani wind towers are two-sided and have simple architecture either. The performance of this wind tower is more accurate because the wind pressure on the one hand, causes the rapid evacuation of hot and infected air on another hand. Also the wind towers of Cistern[2]are mostly Kermani type [12].Yazdi wind towers which are usually larger than other types are made in four openings or multi openings types and its height is high. This kind of wind tower is more complex and more beautiful than other types [13]. Classification listed consists of various types of conventional wind tower is divided with regard to this topic which in different regions of Iran we can find these types.

4. The problem and research process

Performance of wind towers as one of the most significant climatic effect in Iranian traditional architecture has been repeatedly studied. In these researches the thermodynamic issues and air temperature in the different part of wind tower's shaft are mentioned mostly and for this reason this article evaluate the performance of Yazdi wind tower with assessment the air flow by wind velocity and air temperature parameters. However the main purpose of this research is appraising the performance of Yazdi wind towers through modeling the effect of wind velocity.

4.1 Research questions

1. What is the impact of wind tower opening orientation regarding to climate and wind tower height?
2. How is the quality of natural ventilation and air circulation inthe Yazdi wind tower?

4.2 Research method

This paper analysis the performance of the wind and wind velocity in the Yazdi wind towers. The research method of the paper is modeling and simulations and conclusion stated through logical reasoning [14] and also method of theoretical data collection is library studying (Figure 3). The purpose of this study is introducing and analyzing the performance of Yazdi wind tower with numerical calculation Mechanic science to determine value and velocity of wind in it. Modeling process performed by Autodesk Vasari 2.0, at the first step, wind tower had been modeled and then by applying climatic and numerical data obtained through calculations, the wind tunnel simulated and Yazdi wind tower model had been analyzed. Finally the results presented in the diagrams and simulated computer figures.

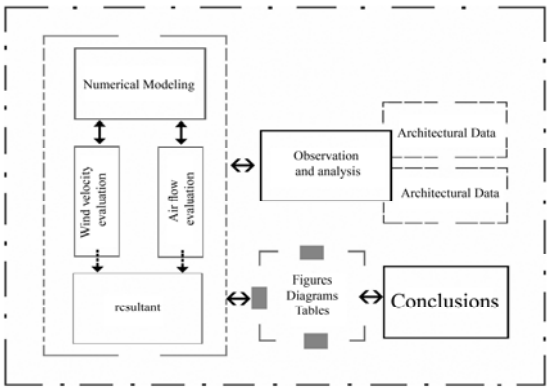

Diagram1: Process of research method [Authors]

4.3 Research literature

In the line with scientific study of behavior and thermal performance of wind towers, numerous studies have been done.Bahadori [3], by computer modeling and numerical assessment of a wind tower, calculatesair temperature in different parts of the wind tower's shaft.

[2]Ab-Anbar in Persian

Dehghani[15], 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[16], 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[17], 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[18], compared one sided and two sided wind towers and concluded that two sided wind towers are more efficient in thermal behavior. Kalantar[19] by comparing wind towers with wet surfaces and dry surfaces indicated that the first one is more efficient. . Also Montazeri[20], 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. Bouchahm[5], by numerical modeling indicated that wind towers with more height and smaller partition width are more efficient in natural ventilation and air flow.

5. Wind tower modeling

Equations (1), (2) and (3), have been used to perform numerical modeling of wind tower. 5 Year period average of synoptic climatic data was used for getting more accurate simulations and also wind velocity and wind direction have been determine for Yazd city (Table 2).
Also performance of wind tower ventilation in 12 month of year and separately on 5 Year period average have been calculated. Because of comparing approach of this paper, the air flow resistance, considered as a constant value. With these assumptions, following relationships are dominated:

α=90°research assumption Equation (4)
R_{ij}= constant

Also test of wind tower in simulated wind tunnel and using the result of Bahadori (2: 447) C_p coefficient determined for each opening in each month (Table 3).Regarding to equations (1), (2), (3) and (4) and the data from table (1) and (2), wind pressure of wind tower in twelve month of year and difference of pressure between openings of wind tower and window of the building and wind velocity of this pressure difference have been determine. Regarding to assumed 45 degrees wind angle, C_p coefficient of west opening (=-0.35), east (+o.67), north (+0.29) and south opening (+0.41) determined. Table (4), shows the numerical pressure between each opening with the window of the assumed building (opening number five), and calculated wind velocity of each opening through the twelve month of the year.

Table2: 5 Year period average of synoptic climatic data of Yazd city [21]

5 Year average	Dec	Nov	Oct	Sep	Aug	Jun	Jul	May	Apr	Mar	Feb	Jan	Station	Parameters
89	40	73	70	19	75	163	179	114	93	75	110	37	**Yazd**	**Wind direction**
7.7	5.7	5.2	6.7	8	8.7	9.6	8.8	10	9.7	9.1	5.9	5.9	**Yazd**	**Wind velocity**

Table 3: C_p coefficient determined for each opening in each month of Yazdi wind tower [21]

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

Table4: Numerical pressure between each opening with the window of the assumed building

5 Year average	*Dec*	*Nov*	*Oct*	*Sep*	*Aug*	*Jun*	*July*	*May*	*Apr*	*Mar*	*Feb*	*Jan*	
19.56	*-11.79*	*-7.28*	*-18.27*	*-22.88*	*-16.23*	*-21.28*	*-20.87*	*49.5*	*-23.28*	*-21.86*	*7.65*	*-14.1*	***P1***
-11.73	*-6.43*	*-5.32*	*-8.64*	*-14.78*	*-25.39*	*-27.87*	*-15.33*	*-23.65*	*-17.03*	*-15.94*	*-6.50*	*-6.70*	***P2***
-9.13	*-8.93*	*-7.28*	*-17.28*	*3.87*	*34.55*	*42.07*	*-20.87*	*-15.95*	*-23.28*	*-21.86*	*-5.74*	*-13.40*	***P3***
-16.30	*15.90*	*12.78*	*21.72*	*29.92*	*-26.64*	*-28.89*	*-34.07*	*-18.7*	*43.98*	*38.71*	*12.44*	*12.44*	***P4***
-2.93	*-6.07*	*-4.46*	*-8.64*	*-10.91*	*-5.41*	*-6.08*	*-12.77*	*-1.65*	*-14.48*	*-13.20*	*-2.48*	*-6.70*	***P5***
22.49	*-5.72*	*-2.82*	*-9.69*	*-11.97*	*-10.82*	*-15.2*	*-8.1*	*51.16*	*-9*	*-8.66*	*4.13*	*-7.40*	***ΔP15***
-8.8	*-0.36*	*0.86*	*0*	*-3.87*	*-19.98*	*-21.79*	*-2.56*	*-21.91*	*-2.55*	*-2.74*	*-4.08*	*0*	***ΔP25***
-6.20	*-2.86*	*-2.82*	*-8.64*	*14.78*	*39.96*	*48.15*	*-8.1*	*-14.3*	*-8.8*	*-8.66*	*-3.09*	*-6.70*	***ΔP35***
-13.37	*21.97*	*17.24*	*30.36*	*40.83*	*21.23*	*-22.81*	*21.3*	*-17.05*	*58.46*	*51.91*	*14.92*	*19.14*	***ΔP45***
20.86	*13.03*	*12.46*	*12.03*	*39.77*	*30.39*	*-11.65*	*2.54*	*-2.1*	*38.11*	*31.85*	*11.88*	*5.04*	***V***

[Authors]

For approaching the accurate modeling, the data of a four sided Yazdi wind tower is selected (Montazeri, 2010: 1427), which presented in Fig3. Then computer modeling of this model and wind tunnel simulation, with Autodesk Vasari 2.0 analysis software was done (Fig4, 5, 6).

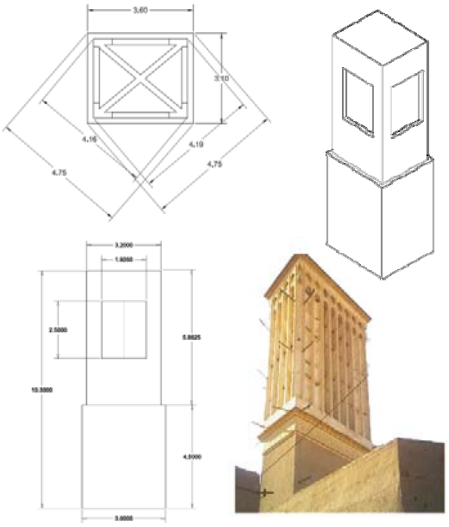

Fig3: Numerical data of a four sided Yazdi wind tower

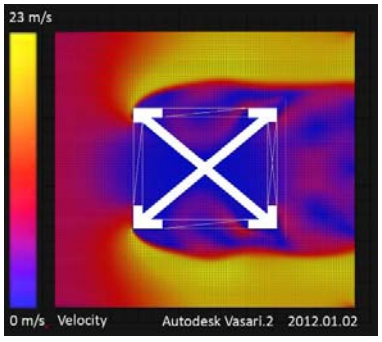

Fig4: wind tower modeling and wind tunnel simulation, with Autodesk Vasari 2.0 analysis software, Plan analysis [Authors]

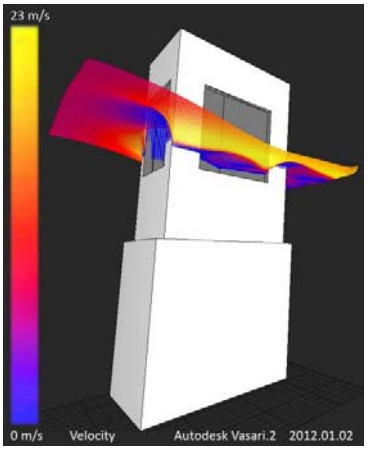

Fig5: wind tower modeling and wind tunnel simulation, with Autodesk Vasari 2.0 analysis software, 3d analysis [Authors]

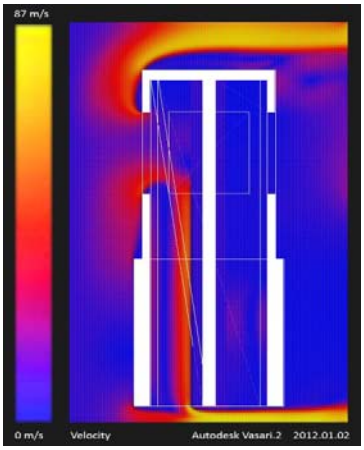

Fig6: wind tower modeling and wind tunnel simulation, with Autodesk Vasari 2.0 analysis software, Section analysis [Authors]

6. Discussion and Results

Analyzes results of simulated wind tunnel and diagrams of wind velocity, can be classified in to three aspects consist of plan, section and numerical diagrams.

Plan: regarding to figure 5, in addition of the opening which oriented to the predominant wind direction, the number two and four also getting wind air flow in to the building. Also in the rear opening of Yazdi wind tower we can see air turbulence, which preventing air flow on this opening. This may cause because of non-formic design in this specific wind tower. Totally, designers of Yazdi wind towers efficiently used the around air masses of openings but couldn't use the air flow in the rear wind direction opening (Fig4).

Section: regarding to figure 6, we can find that air turbulence in the opening oriented to the predominant wind direction is too small, which is a positive point in the formic design. This point causes a direct air flow in the main opening of the Yazdi wind tower. Also in the rear opening of wind tower, despite of huge air turbulence, we can clearly see the maximum wind velocity is located in the bottom of the shaft which means we have air flow in this opening too (Fig5, 6). These two points indicates the creative aspects of designing in the traditional architecture of Iran.

Numerical diagram: regarding to diagram (2), we can find that the velocity of air flow of the Yazdi wind tower in July are maximum and in January is minimum, which both are positive points. Totally in winter and autumn the air flow velocity is to low, which is advantage for *Yazdiwind tower*. Also by analysis of air flow velocity in the summer and spring seasons, we find out that in July, August and October the factor is efficient. But in June, September is to low regarding 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 huge disadvantage for design of Yazdi wind tower. Of course we must mention the climatic data of the local city, which in specific month has a specific value, and all of the data above are related to the wind velocity of local region. Totally the performance of this specific Yazdi wind tower except in June, May and September in hot season is positive, but the average of cold seasons is higher than hot seasons.

Diagram 2: Air flow velocity in the openings Yazdi wind towers [Authors]

Table 4: Positive and negative points of Yazdi wind tower analysis [Authors]

Negative points	Positive points
Non efficient use of maximum wind velocity in the rear opening to the predominant wind	Efficient use of maximum wind velocity in the almost all openings
Maximum of turbulence in the rear opening which cause low air flow in this opening	Maximum of ventilation regarding to the minimum turbulence in the shafts of the wind tower
High air flow velocity in autumn and winter season	High air flow velocity in July, August, April

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.

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