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Performance assessment of ancient wind catchers - an experimental and analytical study

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Abstract

Wind catchers – " Baud-Geers" in Persian– are the main component of the traditional buildings in the hot regions of Iran. A Baud-Geer is a tower linked to a building that uses wind to provide natural ventilation and passive cooling. This passive renewable strategy offers the opportunity to improve the ambient comfort conditions in buildings whilst reducing the energy consumption of air-conditioning systems. In this research the natural ventilation performance of a typical wind tower in a hot dry central region of Iran -Yazd city- is studied. The tower is equipped with wind, temperature, air-velocity and solar sensors to acquire a climatic database. Using the measured data, the theoretical values of the ventilation rates are estimated and analysed to assess the performance of the wind tower. Additionally the data collected from the on-site measurements will assist in the validation of a CFD computer model. Finally the findings from this field study will lead to a discussion on the potential of Baud-Geers in achieving thermal comfort. This can contribute to energy savings for cooling and to the reuse and reappraisal of wind towers in Iran.

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*Keywords:*Passive systems ; Heat-induced natural ventilation ; Wind catcher component ; Experimental measurements

1. Intruduction

Building components that improve natural ventilation, like wind catchers, have been used in Iran and its neighbouring countries for centuries .These ancient wind towers stimulate passive ventilation through natural air flow due to a combination of heat- and wind-induced effects. [3,6,8] .In this paper the thermal behaviour of a wind tower of the

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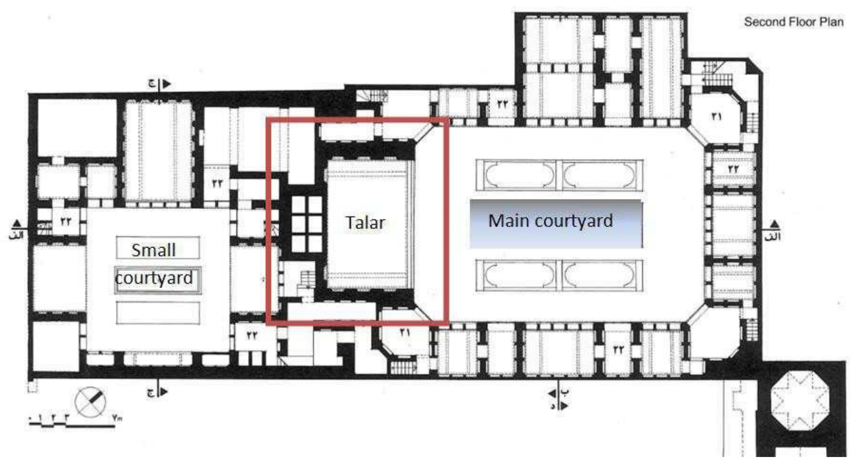
'Mortaz House' in the city centre of Yazd is studied. The city of Yazd is well known as the city of the wind catchers. It is located at latitude 31°53'50"N, near the central desert of Iran. It has a hot and dry climate during the summer and it has cold winters. The average annual temperature difference in Yazd is about 61 degrees Celsius (a maximum of 45°C and 12% relative humidity in the summer and a minimum of -14°C and 73% R.H in the winter) [13].This paper aims to assess thermal performance of a full-scale wind catcher in Yazd to understand its operation and to reappraise its natural ventilation potential. In order to assess and explain the thermal behaviour of wind catchers, good climatic data is required. However, due to the time consumption and the high costs of in situ measurements it is hard to find any useful data that is based on an empirical study of a full-scale tower. Therefore a low-cost experimental setup for full-scale onsite measurement and analysis was built during this research. Using the measured climate data the heat transfer between the outside and inside air flow and the heat transfer between the outside flow and the wind tower itself were analysed.

2. Research methodology

There are numerous research methods to study the performance of natural ventilation systems: numerical simulation with computational fluid dynamics software (CFD), wind tunnel analysis on reduced-scale models and full-scale in situ measurements. [6]. Van Hoof [14] reports that the full-scale measurement method is very valuable in giving insight to natural ventilation. In this study a representative four-sided wind catcher in the historic city centre of Yazd was selected to equip with temperature, wind, air velocity and solar sensors. The monitoring was performed over a three month period during the winter. The studied tower has a rectangular cross section of 6.05 m × 3.45 m and has six internal shafts with an area of 1.5 m^2 per shaft (Fig.2) .The ambient air enters the tower at the top and flows to the lower building spaces through shafts. Which shafts are used is defined by the tower geometry and depends on the wind direction. To monitor the flow pattern in and around the wind tower, four shafts of the tower were equipped with temperature, air-velocity and solar sensors. As shown in Fig.6 a central measuring equipment box (Fig.4) containing a data-logger, a Raspberry pi and a UPS (uninterruptible power supply) was installed in one of the shafts. All sensor data was continuously logged and stored at 1 minute intervals since September 2014.



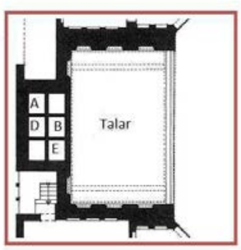


Fig. 1. Plan of the "Mortaz" House with the position of the central -courtyards, Talar and wind tower

Fig. 2. Position of the six shafts in wind tower

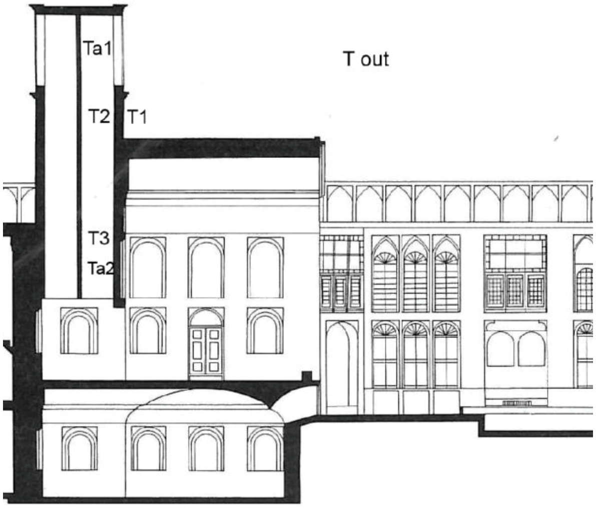


Fig.3.Section of A-A Position of the temperature sensors in the Wind tower shafts
T1: Temperature sensor on external surface at a height of 10 m (H=10 m)
T2: Temperature sensor on an internal wall of the tower (H=10 m)
T3: Temperature sensor on an internal wall of tower (H=4 m)
Ta1: Air temperature sensor (H=10 m)
Ta2: Air temperature sensor (H= 4 m)
T out : Outdoor temperature sensor

3. Building instrumentation

As can be seen in Fig.1, the Mortaz House is composed of two courtyards with interconnected rooms on all sides. The wind tower is located in the middle. The main courtyard, as well as the nearest semi-open room (Talar) and its basement, receive circulating air from the tower. During the measurements the tower was equipped with wind, temperature, air-velocity- and solar sensors to acquire climatic data. The parameters identified for the data acquisition and monitoring were the indoor air velocity (m/s), the tower surface temperature and the air temperature in the shafts (◦C), as well as the wind- and ambient temperature (◦C), the wind speed (m/s) and the wind direction. These last parameters were taken from an onsite weather station on the roof of the Mortaz House. All the sensors - 26 sensors - were calibrated before installation and commissioning. In this research the data obtained from the temperature sensors were analysis and presented. The DS18B20 digital thermometer has an operating temperature range of -55°C to +125°C and is accurate to ±0.5°C over the range of -10°C to +85°C.The opening of the basement was closed during the measurement period, so that there was no link between the tower and the basement. This enabled the air to flow freely from the windward side of the tower through the shafts to the Talar. Fig.5 shows the weather station that was installed on the roof of the Mortaz House. The weather station recorded the wind speed (m/s), wind temperature (◦C), wind direction and ambient temperature (◦C). The wind sensor from the weather station was located at around 10 m above the ground level.

Shaft code	Sensor name	Sensor position
Shaft A	Surface temperature	Outside inside Down inside Top
Shaft B	Surface temperature	Outside inside Down inside Top inside Down inside Top
	Air temperature	Inside Down inside Top
Shaft D	Surface temperature	Outside inside Down inside Top Outside
Shaft E	Surface temperature	inside Down inside Top

Fig4. Setup of the datataker and the Rpi inside the measurement

Fig5. Weather station on the roof of the Mortaz house

Table 1.list of temperature sensors of four shafts , Mortaz house

4. Experimental results – Temperature data analysis

The ambient air temperature data, collected from the onsite weather station, is used for the generation of the site temperature profile. During the three month measurement period from 03 Nov.2014 to 03 Feb.2015 the maximum ambient air temperature was recorded on 03 November at 15:44 hr (T=26.02 °C). The minimum temperature was recorded on 26 December at 06:13 hr (T=-01.01 °C). As can be seen in Fig. 6 there is a daily temperature difference of ± 17 °C - 18.5 °C, both during warm days (03 Nov) and cold days (26 Dec) of the measurement period.

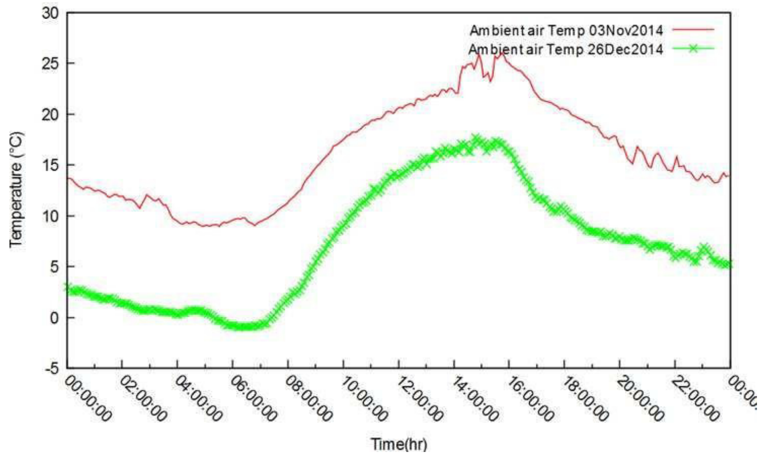


Fig. 6. Ambient air temperature profile - warm and cold day of the measurement period

4.1 Temperature profiles in four equipped shafts

The measured temperatures on the four sides of the tower show that the south wall - external surface of shaft D - absorbs higher solar radiation compared to the other surfaces. When the ambient air reaches around 25 °C at 03.00 PM on 03 November, the external surface of shaft D heats up to 50 °C. This stimulates the stack effect, inducing an upward airflow due to the temperature gradient [8, 3] on the south side of the wind tower.Fig .7 b shows the potential of heat-induced natural air flow during a cold day (26 Dec).

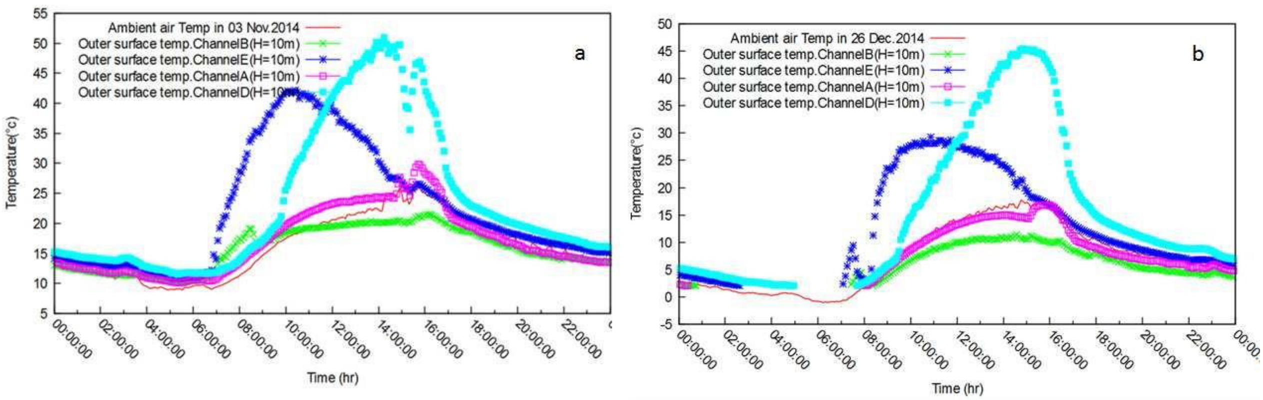
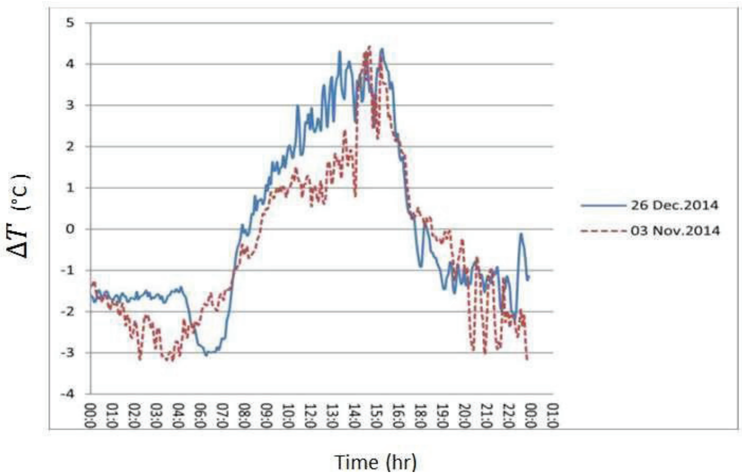


Fig . 7. Tower wall temperature variations in four shafts (a) in 03 Nov.2014 ;(b) in 26 Dec.2014

Fig .8 shows the temperature difference (ΔT) between the exhaust air from the tower and the ambient temperature during the warm day and cold day of the measuring period. This graph shows the ability of the wind tower to lower the air temperature (in range of 0.5 - 4.5 °C) during the warmest hours of the day (between 08.00 AM and 16.00 PM) and to increase the air temperature (in a range of 0.5 - 3 °C) during the night and early morning on 03 November and 26 December . On both days a maximum temperature difference of 4.5 °C was observed around 15.00 PM . The equation to estimate the temperature difference between outlet air temperature (T_{a2}) and ambient temperature (T_{out}) can be expressed as

$$\Delta T = T_{out} - T_{a2} \qquad (1)$$



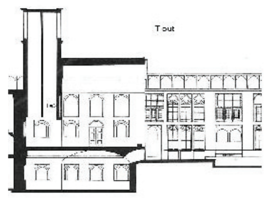


Fig 8. Temperature difference between outlet air temperature (T_{a2}) and ambient temperature (T_{out}) in shaftB- in 03 Nov.2014 and 26 Dec.2014

The flow rate due to thermal force is calculated from the Eq. (2) as follows

$$Q = C A \sqrt{\left(h \left[\frac{(T_i - T_o)}{T_i} \right] \right)} \qquad (2)$$

Where Q is the flow rate (m^3/s), C is the discharge coefficient , A is the flow area(m^2) , h is the height from inlet to outlet (m), T_i is the indoor air temperature (K) and T_o is the outdoor air temperature (K)

This means that the maximum natural heat transfer due to the indoor and outdoor temperature difference occurs between 13.00 PM and 16 .00 PM.

4.2 Temperature profiles in Shaft B

In Fig.9 the temperature difference between the outer surface (T_1) and inner surface (T_2) of the tower at height of 10 m above the Talar is plotted during a day in 03 Nov.2014 and 26 Dec.2014 .The performance of the wind tower wall in north side during the day and night is presented in Fig.9 .The maximum temperature difference of five degree were recorded during the day and night on 03 Nov . As observed in Fig.10 the temperature of the outlet air (Ta_2) and the inlet air (Ta_1) are almost the same during the day and night .The maximum temperature differences were recorded during the warmest hours of the day between 9.00 AM and 15.00 PM, both on warm days and cold days of the measuring period.

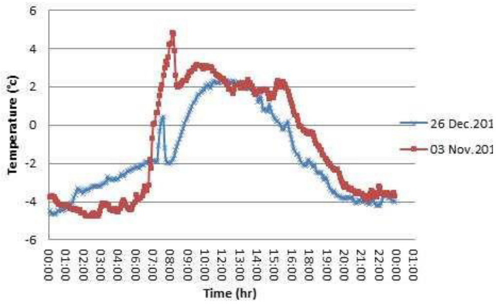


Fig .9 .Temperature profile in shaft B – Temperature difference between the outer surface (T_1) and inner surface (T_2) of the tower at height of 10 m above the Talar

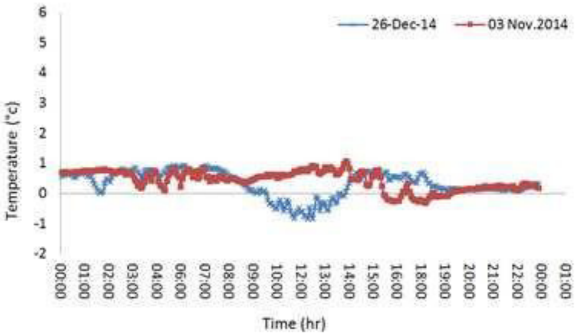


Fig .10 .Temperature profile in shaft B — Temperature difference between the inlet air temperature (Ta_1) and outlet air temperature (Ta_2) at height of 10m and 4 m above the Talar

5.Conclusions

This research revealed that the ancient wind catchers under hot and arid climate conditions, as in the case of the Mortaz house in Yazd , perform by changing the temperature of air in and around the tower.The results obtained from the temperature difference between the outlet air temperature from the tower (T_{a2}) and the ambient air temperature (T_{out}) show that the maximum efficiency of the wind catcher of Mortaz house is estimated around 22% on 03 November and 70% on 26 December during the coldest hours of the day. The wind catcher can be 17 % and 26% effective in lowering the air temperature during the warmest hours of the day on 03 November and 26 December respectively. It can be explained by the high thermal inertia of the tower walls during the warmest hours of the day .However the cooled night air can be also stored in the tower mass during the night and early morning. This energy storage plays an important role in providing thermal comfort during the following day.

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