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Effects of different internal designs of traditional wind towers on their thermal behavior

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ABSTRACT

The purpose of this study is to investigate the effects of different internal designs of traditional wind towers on their thermal behavior numerically. Among the enormous variety of designs of internal partitions in traditional wind towers, which are used in hot and dry areas of Iran, five main important types were chosen. Calculations were done using evaporative cooling – wet partitions – and without it – dry partitions. In the modeling evaporative cooling, the partitions were considered as the wet surfaces which inject water droplets in the air in a very low speed. The CFD open source package – Open FOAM – was used to produce the current three-dimensional CFD simulation by adopting both the Eulerian approach for the air phase and the Lagrangian approach for the water droplets were adopted. The three dimensional plan of a building and its wind tower were simulated in an analytical space like a tunnel. In addition, to simulate the turbulence flow the k–ε standard model was used. The results were compared with some experimental data indicating that whenever the evaporative cooling is used in the best design condition, the air temperature decreases 6.5 K and reaches to 311.5 K while the temperature of the surrounding is 318 K.

1. Introduction:

Wind towers are one the most famous Iranian local architectural elements of buildings with climatic function. Wind towers, as a cooling system, provide ventilation and passive cooling in the hot, arid regions of Iran and neighboring countries for centuries. As wind towers work with the renewable energy of the wind, they do not use electricity and therefore they do not produce any greenhouse gases. Some of the defining characteristics of wind towers are related to their esthetic values while others have important roles in their thermal behavior. In order to explain the thermal behavior of wind towers, understanding their functional elements is required. Fig. 1 shows different parts of a typical traditional wind tower including its roof, the canal, the partitions, the material, and the color. Canals can have a square, rectangular, or even multi-gonal cross section; however, rectangular cross sections are the most common ones in Iran.

One of the most important elements of traditional wind tower that has large effects on its thermal behavior is called partitions. Fig. 2 shows a general view of a typical traditional wind tower and the way it works. This wind tower has a rectangular cross section and four openings on its top. As it can be seen in Fig. 2, wind enters the wind tower at point 1 and then it is guided by the partitions to the hallway that is located under the wind tower. A portion of the inlet air exits the tower because of the negative pressure coefficient at point 4 that is one of the disadvantages of traditional wind towers.

The functional behavior of wind towers has been studied by several researchers. Bahadori [1–4], for instance, performed full analysis of the design of wind towers in several locations such as Yazd city in the center of Iran's desert and presented two new designs of wind towers.

Elmualim and Awbi [5] carried out an experimental study and CFD simulation to evaluate the performance of square and circular section wind catchers. The achieved results showed that the efficiency of four-sided wind catcher is much higher than that of the circular one for the same wind speed.

Li and Mak [6] performed a CFD study of a wind tower with cross-shape partitions. Their numerical results demonstrate that the wind tower performance is greatly influenced by the external wind speed and in relation to the wind tower quadrants. In all cases studied, the maximum velocity of the air entering the room is close to the external wind speed and the wind tower system is found to be an efficient way to channel fresh air into the room. The study also shows that the airflow rate of the air entering the room increases with the wind speed.

Montazeri et al. [7,8] studied wind towers with one opening and two openings in a wind tunnel. The results of their analyses-carried out in experimental wind tunnel and smoke visualization testing-demonstrate that the maximum airflow will be obtained when the

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Nomenclature

A	area (m^2)
c_P	specific heat (J/kg K)
C_p	wind pressure coefficient
D_P	water droplets diameter (m)
f	friction factor for the rough duct
f_s	friction factor for the smooth duct
g	gravitational acceleration (m/s^2)
h	convective heat transfer coefficient (W/m^2 K)
h_s	average convective heat transfer coefficient (W/m^2 K)
h_m	mass transfer coefficient
H	height of wet columns
k	turbulent kinetic energy (m^2/s^2)
m_W	water mass flow rate per unit of surface area ($kg/s.m^2$)
P	pressure (N/m^2)
Q	absorbed heat (W)
T	temperature (K)
V_P	the droplet velocity that is perpendicular to the surface (m/s)
U, V, W	velocity components in x-, y-, and z-direction respectively (m/s)
w	humidity ratio of inlet air
w'	humidity ratio of saturated air
x, y, z	the Cartesian co-ordinates

Greek letters

ε	turbulent kinetic energy dissipation rate (m^2/s^3)
ϕ	variable quantity (1, U, V, W, T,. . .)
Γ_ϕ	diffusion coefficient of the variable quantity ϕ
ρ	air density (kg/m^3)

Subscripts

a	air
adb	air dry bulb
aew	air exit from wet columns
ma	moist air
p	particle (water droplet)
sat	saturated
w	water

Abbreviation

CFD	computational fluid dynamics

air direction is normal to the opening of the wind tower. Montazeri and Azizian [9] also investigated the effects of the numbers of openings by modeling a circular cross section wind tower that has several openings at equal angels. The results show that the number of openings is a main factor in the performance of wind tower systems. It also shows that the sensitivity of the performance of different wind towers to the wind angle decreases by increasing the number of openings. Moreover, when it is compared with a circular wind tower, a rectangular system provides a higher efficiency.

Hosseinnia and Saffari [10–12] studied a numerical simulation of evaporative cooling in a wind tower. They used the partitions as surfaces that inject water droplet in very low speed normal to the surface for simulating evaporative cooling. The interaction between the airflow – as continues phase – and water droplets – as discrete phase – was described. Several parameters such as the diameter of the droplet, the injection rate per square meter of the surface, and the speed of the injection were separately studied. The results were compared with some analytic data and showed a good agreement

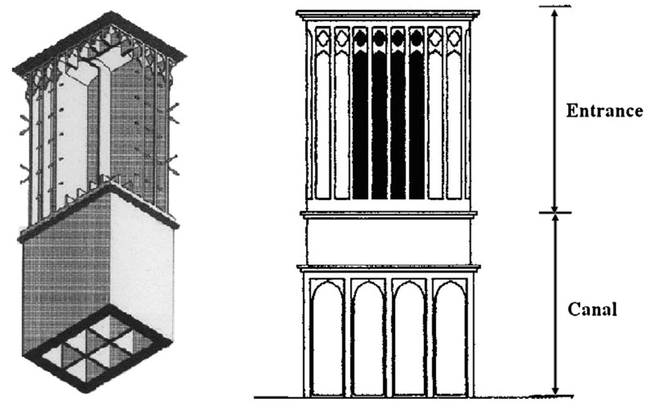

Fig. 1. Physical characteristic of traditional wind tower.

with them. In addition was it suggested that using evaporative cooling has a grate increase in wind towers performance.

However, there are not any studies on the effects of different internal designs of traditional wind towers on their thermal behavior. Therefore, finding the effects of various internal partition designs in the traditional wind towers with respect to the wind tower performance is the main goal of this study. Among lots of traditional wind towers which are located in the hot and arid region of Iran [13], five common and important internal designs have been chosen (Fig. 3). All of them have rectangular cross sections and four openings. In other words, they can catch wind from all four main directions and guide it to the hallway. For simulation evaporative cooling, the internal partitions are considered as the wet surfaces.

2. Modeled case

2.1. Geometry

A typical example of a building that has a courtyard and is located in a hot and arid region of Iran is modeled in the full scale

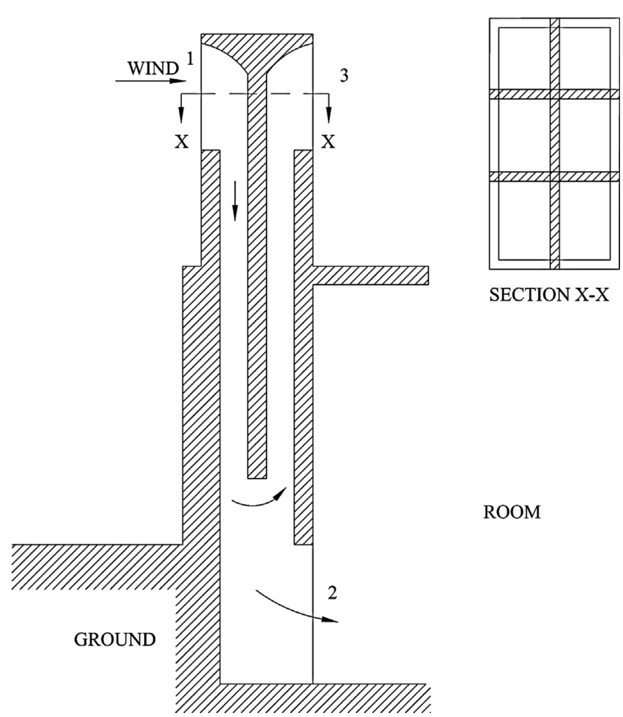

Fig. 2. The overall view of operation of wind tower.