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Performance analysis of a passive cooling system using underground channel (Naghb)

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ABSTRACT

The present study, aims at introducing and studying the effect of an old and specific type of house cooling system in Bam city. Primary of the system is similar to Baud-Geers (wind tower) but in the mentioned system, there is an additional channel connected to Baud-Geer which is called Naghb. Naghb in fact is an underneath channel that uses the ground humidity to cool the air. Baud-Geer input wind passes through the Naghb and evaporation cooling makes it cooler in the Naghb. Therefore, the cooling effect of Baud-Geer enhances. Unfortunately, all of Baud-Geers and Naghbs in Bam destroyed in the earthquake happened on December 26, 2003 and only ruins of them are left, hence in order to study Naghb performance in the present study, a one-dimensional model is presented and the conservation equations of energy, mass and momentum have been solved simultaneously. In order to evaluate the model, a simple experimental setup is made on the basis of real dimensions of Naghb. The model results reveal the ability of Naghb in cooling the air during hot and dry months in Bam.

1. Introduction

Before the invention of cooling systems, human employed ingenious ways of using available sources of cooling to provide thermal comfort in hot weather, for instance in hot and dry regions of Iran like Bam, Kerman and Yazd, buildings have been traditionally cooled by wind tower called Baud-Geer in Persian language. A Baud-Geer operates in different fashions according to the presence or absence of wind and time of day. Briefly the function of the Baud-Geer is to capture the wind from external air stream and direct it into the building to cool the occupant [1,2]. Yaghoubi et al. discussed the effect mechanism of Baud-Geer in detail [3]. They concluded when the tower is high and exposed to continuous strong solar radiation, like the case of Lary House and Dowlat Abad in Yazd, the circulating air is heated up by hot surfaces of Baud-Geer and the air output temperature from the tower is not lower than ambient temperature. Consequently the tower is not efficient in reducing the room air temperature. In this case, one possible solution is to pass the output air through humid regions before entering the room, thus having evaporative cooling [3]. Wind towers acting as evaporative coolers are found in Persian architectures, like ancient houses in Bam. Baud-Geers of old houses in Bam have been designed and constructed traditionally in a way that the input wind passes through an underground channel before entering the house. The underground channel called ''Naghb'' in local accent enhances the tower efficiency in cooling the input air as a result of increasing evaporation. Obviously, each factor raising the evaporation from Naghb walls into the air, enhances the air cooling and system efficiency. Therefore in the most cases in old houses in Bam, like Ameri House, Naghb is constructed near the garden at a depth of around 5–7 m below ground level to increase the humidity of the channel. Thus the used water to irrigate the garden is applied to cool the house as well. Since the gardens were irrigated once or twice a week in Bam traditionally, Naghb wall surface was almost always damp that caused more air cooling. In fact Naghb is a kind of Earth to air heat exchanger (EAHE) in which the underground air duct is made of brick; hence the air is cooled not only by means of temperature gradient between outdoor air and the earth but also by humidification process. The effect of EAHE in a house integrated with vault is studied in detail by Chel and Tiwari [4].

The air path from Baud-Geer input to the house basement in Ameri House and the construction detail of the Naghb are illustrated in Fig. 1(a) and (b) respectively.

During hot months, warm ambient air enters Baud-Geer through the opening in the sides of it and goes through Naghb, evaporation takes place on the wall of Naghb and makes the air cooler. Accordingly moisture content or humidity ratio of air increases while its temperature drops off as it moves from the channel beginning, i.e. point A in Fig. 1(a), toward the channel end, i.e. point B. Since the cooler air is heavier than the warmer air and

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Nomenclature

A_a	cross sectional area [m^2]
A_c	side section area [m^2]
c_s	specific heat [J/kg]
H	humidity [kg/kg]
h_c	heat transfer coefficient [w/m^2 °C]
$\dot{m}$	air flow rate [kg/s]
$\dot{m}_{evp}$	rate of evaporation [kg/s]
$\dot{m}_{dry,air}$	rate of evaporation [kg/s]
Q_c	overall cooling load
RH	relative humidity [kPa/kPa]
$T_{in,exp}$	experimental setup input air temperature [°C]
$T_{in,N}$	Naghb input air temperature [°C]
T_{max}	maximum temperature [°C]
$T_{out,cal}$	calculated outlet air temperature [°C]
$T_{out,exp}$	experimental setup output air temperature [°C]
$T_{out,N}$	Naghb outout air temperature [°C]
T_{wall}	Naghb wall temperature [° C]
$\bar{V}$	average air velocity [m/s]

Greek letter

Δh_{evap}	specific evaporation enthalpy [J/kg]
τ_w	shear stress [N/m^2]

Subscripts

cal	calculated
evp	evaporation
exp	experimental
in	input
max	maximum
N	Naghb
out	output

Naghb is constructed slantingly, air moves down through Naghb and enters the basement. When there is no wind, the house warm air is replaced with the Naghb's output cold air resulting in a natural ventilation, While the wind is blowing, the air is pushed through Naghb, building and outside of the windows and doors. Therefore Naghb cools house whether the ambient air is stagnant or not, but when it is windy the air flows faster and Naghb is more effective.

Unfortunately, because of the earthquake happened on December 26 in 2003, all of the traditional Baud-Geers and Naghbs have been ruined and collecting the practical data from Baud-Geers and Naghbs in Bam is not possible at present; therefore, to study the effect of Naghb, a one-dimensional mathematical model of Naghb is proposed. The model predicts the variation of the air temperature, pressure and humidity from Naghb input to output (points A and B in Fig. 1).

2. Theoretical analysis

Since the surface of channel is drenched due to diffusion of water and due to the fact that brick thermal conductivity is not so high, the cooling process of air inside the channel can be assumed as an adiabatic humidification process.

As illustrated in Fig. 2 the channel is divided into identical control volumes to obtain the variations of air temperature, pressure and humidity along the channel. The following assumptions are made to simplify the model:

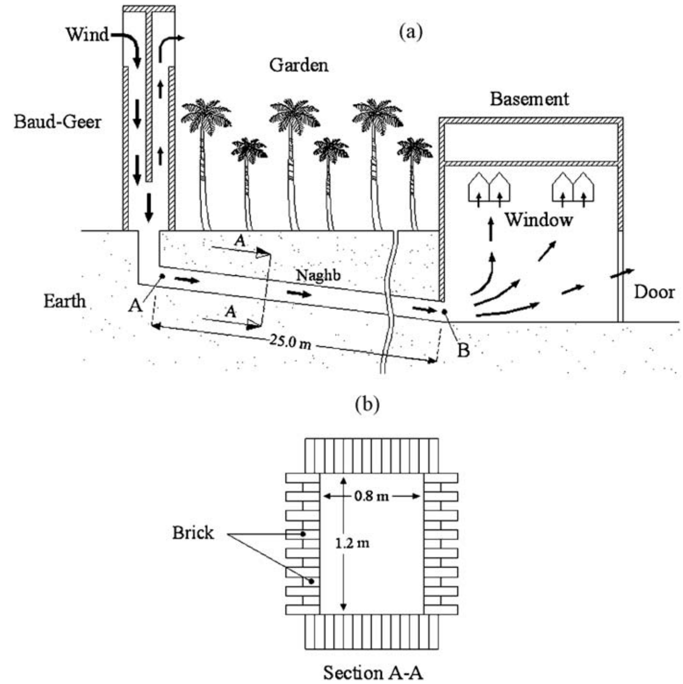

Fig. 1. (a) Schematic view of the air way through the Baud-Geer and Naghb at Ameri House. (b) A cross section of the Naghb.

a. The system is at steady-state condition.
b. Naghb wall temperature is considered to be between ground water temperature and the ambient air wet-bulb temperature.
c. Uniform temperature, humidity, velocity and pressure are considered in the x and y directions.
d. The air is considered as an ideal gas.

The model presented here consists of mass, energy and momentum conservation equations which are discussed in the following section.

3. Thermal, mass and momentum transfer model

Inside the control volume shown in Fig. 2 the input gas is contacted with water on the channel surfaces, so the input gas with an initial humidity of H_{in} and temperature of T_{in} is cooled and humidified to T_{out} and H_{out}. The process is adiabatic inasmuch as no

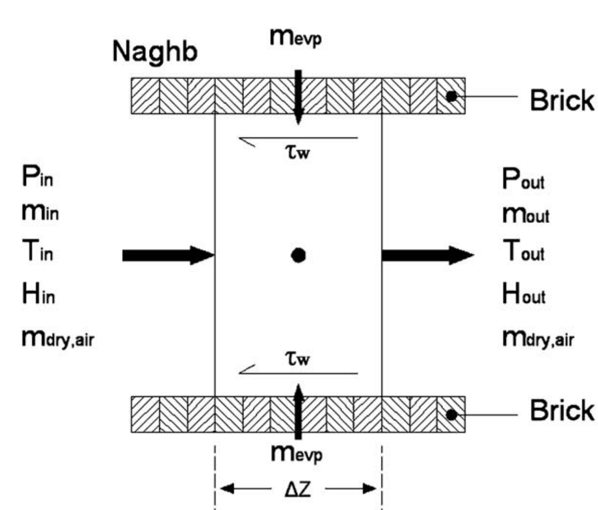

Fig. 2. The chosen control volume.