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Induced flow for ventilation and cooling by a solar chimney

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ABSTRACT

An experimental and numerical model of a solar chimney was proposed in order to predict its performance under varying geometrical features in Iraqi environmental conditions. Steady, two dimensional, turbulent flow was developed by natural convection inside an inclined solar chimney. This flow was investigated numerically at inclination angles 15° to 60°, solar heat flux 150–750 W/m^2 and chimney thickness (50, 100 and 150) mm. The experimental study was conducted using a single solar chimney installed on the roof of a single room with a volume of 12 m^3. The chimney was 2 m long; 2 m wide has three gap thicknesses namely: 50, 100 and 150 mm. The performance of the solar chimney was evaluated by measuring the temperature of its glass cover, the absorbing wall and the temperature and velocity of induced air. The results of numerical model showed that; the optimum chimney inclination angle was 60° to obtain the maximum rate of ventilation. At this inclination angle, the rate of ventilation was about 20% higher than 45°. Highest rate of ventilation induced with the help of solar energy was found to be 30 air changes per hour in a room of 12 m^3 volumes, at a solar radiation of 750 W/m^2, inclined surface angle of 60°, aspect ratio of 13.3 and chimney length of 2 m. The maximum air velocity was 0.8 m/s for a radiation intensity of 750 W/m^2 at an air gap of 50 mm thickness. No reverse air flow circulation was observed even at the largest gap of 150 mm. The induced air stream by solar chimney can be used for ventilation and cooling in a natural way (passive), without any mechanical assistance.

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1. Introduction

Passive cooling plays an important role in providing a thermally suitable environment for human comfort in under developed countries by providing natural ventilation in dwellings. Solar induced air ventilation could be provided by incorporating solar chimneys in buildings. A solar chimney is a simple channel, glazed on one side, with a collector wall on the other. During the day, solar energy heats the chimney and the air within it creating an up draft of air in the chimney. The induced air created in the chimney can be used for ventilating, cooling and heating buildings. Numerous theoretical and experimental studies have been conducted for the performance of a solar chimney. It has been established that the velocity and temperature magnitudes and profiles in the gap of a solar chimney change considerably with ambient air temperature, wall temperature, gap width and elevation above the inlet of chimney.

Bansal et al. [1] studied solar chimney configuration and performance. A numerical solution showed that for a solar collector area of 2.25 m, the induced air flow ranged from 140 to 330 m^3/h for solar radiation from 200 to 1000 W/m^2. Alfonso and Oliveira [2] developed a thermal model with a computer program that allows the quantification of solar chimney assisted natural ventilation flow rate. Model results were satisfactorily. Khedari et al. [3] investigated experimentally a solar chimney. The study was conducted using a single room school house of approximately 25 m^3 volume. Three different solar chimney configurations of 2 m^2 each were composed on the southern wall, where as the roof southern side included two similar units of 1.5 m^2 each of another solar chimney configuration. They found that there is a little comfort in hot climates when using roof solar collectors alone. In order to increase air speed in a test room, two roof solar collectors together with three different types of solar chimneys were installed and tested by Khedari et al. [4] in the same building. Although the resulting air change rate per hour in the test room was high (8–15), the air movement induced by these solar chimneys was

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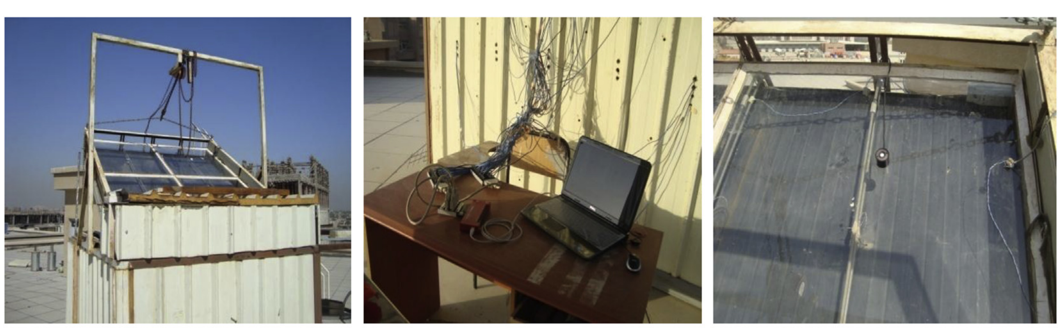
Nomenclature

G_s	kinetic energy generation by shear, J/m^3 s
G_B	kinetic energy generation by buoyancy, J/m^3 s
g	gravitational acceleration, m/s^2
k	turbulent kinetic energy, m^2/s^3
p	pressure, N/m^2
q	solar heat flux, W/m^2
Ra	Rayleigh number, -
S_T	source term for T, N s K/m^4
T	temperature, °C
T_{in}	air temperature at inlet, °C
T_f	mean temperature of air in channel, °C
u	velocity component in the x-direction, m/s
v	velocity component in the y-direction, m/s
x, y	Cartesian coordinate, m
ρ	fluid density, kg/m^3
μ	dynamic viscosity, N s/m^2
μ_t	turbulent viscosity, N s/m^2
μ_{eff}	effective kinematic viscosity, N s/m^2
υ	kinematic viscosity, m^2/s
Γ	diffusion coefficient, N s/m^2
Γ_{eff}	effective diffusion coefficient, N s/m^2
β	volume coefficient of expansion, 1/K
θ	inclination angle, -
δ_t	turbulent Prandtl number, -
δ_{eff}	effective Prandtl number, -
ε	rate of dissipation of kinetic energy m^2/s^3

still too low (average 0.04 m/s) for thermal comfort of occupants with an indoor temperature of about 35–37 °C. This conclusion appears to be in agreement with the observations of Barozzi et al. [5] who investigated a solar chimney based ventilation system for buildings using a 1:12 small scale model in which the roof performs as a solar chimney. Chen et al. [6] carried out an experimental study using an experimental solar chimney model with uniform heat flux on one chimney wall with a variable chimney gap-to-length ratio between 1:15 and 2:5 using different heat fluxes and inclination angles. Their results showed that the maximum air flow rate was achieved at an inclination angle of 45° for a 200 mm gap and 1.5 m high chimney and air flow rate of 45% higher than that for a vertical chimney. Ong and Chow [7] proposed a mathematical model of a solar chimney to predict its performance under varying ambient and geometrical features. The experiments were conducted on a 2 m high × 0.45 m wide physical model with air gaps of 0.1, 0.23 and 0.3 m. Their results showed that the air velocities were between 0.25 m/s and 0.39 m/s for radiation intensities up to 650 W/m^2. Wang and Li [8] have carried out a numerical study to predict mass flow rate, temperature field and velocity field for a vertical roof solar chimney. They found that the optimum ratio of air gap width to chimney height was nearly ½. In Bansal's et al. [9] work, a mathematical model for predicting air flow velocity in a solar chimney with experimental validation of the model has been done. Good agreement between observed and calculated results was seen and the flow velocity up to 0.24 m/s has been experimentally recorded. Mathur et al. [10] studied the effect of absorber inclination on the air flow rate in a solar induced ventilation system. Their results show that optimum absorber inclination varied from 40° to 60°. The maximum rate of ventilation was found at 45° in Indian climate with rate of ventilation 10% higher compared to 60° and 30° inclinations. Gan G. [11] studied solar heated open cavities including solar chimneys and double facades for enhancing natural ventilation of buildings. A numerical CFD package was used to predict buoyant air flow and flow rats in the cavities. Mathur et al. [12] reported an experimental investigation on four different configurations of solar chimneys. The results showed that the rate of ventilation increased linearly with solar radiation. The maximum recorded ventilation rate was 5.6 air changes per hour for 0.3 m air gap and 0.85 m stack height at a solar radiation of 700 W/m^2 for a typical room volume of 27 m^3. Herrero and Celemin [13] proposed a mathematical dynamical model to evaluate the energy performance of a solar chimney. The results showed that for a 2 m high and 14.5 cm wide air channel, a 0.011 kg/s air mass flow rate was induced for 450 W/m^2 solar radiations. Harris and Helwig [14] investigated the performance of a solar chimney. They found that an optimum chimney inclination angle of 67.5° from the horizontal, gave an 11% greater efficiency than a vertical one. Ramadan et al. [15] studied the effect of chimney inclination angle on air change per hour and indoor flow pattern numerically and analytically. Jalil and Zinah [16] investigated numerically a solar chimney at different inclination angles ranging from 30° to 90° and chimney thickness from 0.1 to 0.2 m. They found that the maximum air temperature and maximum volume flow rate were 101.7 °C and 306.3 m^3/h respectively, at a heat flux of 500 W/m^2 and chimney thickness of 0.2 m. Jalil and Rafah [17] numerically studied the effect of induced air flow in the solar chimney to



(a) Room and chimney (b) Data acquisition system (c) Location of solar power meter

Fig. 1. Experimental set-up. (a) Roomand chimney (b) Data acquisition system (c) Location of solar power meter.

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