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Experimental investigation on air heating and natural ventilation of a solar air collector

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Abstract

Solar air collectors are important components for solar energy utilization in green houses. In this paper, experimental studies were carried out regarding to a solar air collector (SAC), for which the length of air channel is 1500 mm, the width is 500 mm, and a variable air channel gap ranges from 100 to 500 mm. In the experiment, the uniform heat flux along the air channel is effected by three electric heating plates, which play a role as solar radiation. It is found that the temperature distribution of air and the induced natural air-flow rate are highly dependent on heat input, inclination angle, channel gap, etc. Experimental results indicate that the optimum inclination angle for the SAC is 45°, under which a maximum natural ventilation rate can be created. Also found is that there exists an appropriate channel length, about 1 m in this study, beyond which the obtained heat and the natural ventilation rate cannot be increased drastically. Higher the volume of air-flow rate through the SAC, lower the temperature difference between inlet and outlet, consequently, it should be balanced between the air temperature rise and a suitable mechanical air-flow rate in order to obtain maximum heat. Additionally, theoretical analysis based on heat balance equations is testified to agree well with experimental results.

Keywords: Solar air collector; Heating; Natural ventilation

1. Introduction

It is important to exploit natural energy, as well as to choose reasonable architecture structures for saving energy, which will meet the sustainable development of architectures, energy and the environment. A solar house promotes a comfortable indoor environment utilizing solar radiation, one of the most important sources of heat gain in a building and through its surroundings. It is also considered as an appropriate architecture for developing countries to provide heating, cooling and ventilation and improve indoor air quality depending on seasons [1]. The traditional Chinese house, mainly in rural areas, with a gable roof, can be well designed to integrate a solar air collector (SAC) to form a structure available for solar thermal utilization. In summer, it is feasible to use the roof structure to induce natural ventilation. In winter, it can be employed for space heating by mechanical ventilation with a payment of small electricity consumption.

In the past decades, building roof structures based on solar air collector utilization have attracted attention in various investigations. Most of them were concerned with natural ventilation. Khedari et al. [2] conducted an experimental study of a roof solar collector (RSC) made by using CPAC Monier concrete tiles on the outer side and gypsum board on the inner side, and concluded optimum dimensions of the studied unit as follows: short length about 100 cm; tilt at 30°; and the space between upper and bottom plates equal to 14 cm. Khedari et al. [3] carried out another field measurements of the same kind RSC, and the experimental results showed that large air gap and large and equal size of openings would induce the highest rate of air-flow rate. Hirunlabh et al. [4] proposed four different configurations of the RSC to maximize natural ventilation through numerical modeling. Another kind of building roof structure comprising solar thermal utilization is solar chimney, which is similar to those mentioned above except

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Nomenclature

A	cross-section area of SAC channel (m^2)
A_i	cross-section area of SAC inlet (m^2)
A_o	cross-section area of SAC outlet (m^2)
C_p	specific heat of air (J kg^{-1} °C^{-1})
D_h	hydraulic diameter of the air channel (m)
f	friction factor of the channel wall
h_b	convective heat transfer coefficient between insulation and indoor air (W m^{-2} °C^{-1})
h_c	convective heat transfer coefficient (W m^{-2} °C^{-1})
h_o	overall heat transfer coefficient between top plate and indoor air (W m^{-2} °C^{-1})
h_r	radiative heat transfer coefficient (W m^{-2} °C^{-1})
H	channel gap (m)
I	heat input (W m^{-2})
L	length of SAC (m)
q	obtained heat (W)
Q	air-flow rate across SAC channel (m^3 s^{-1})
T	temperature (°C)
T_{fp}	mean air temperature inside air channel (°C)
$T_{fp}(x)$	sectional mean air temperature (°C)
V	mean air velocity of SAC channel (m s^{-1})
W	Width of SAC (m)

Greek symbols

β	inclination angle of SAC (degree)
β'	coefficient of expansion of air
δ	thickness (m)
ε	emissivity
λ	thermal conductivity (W m^{-1} °C^{-1})
ξ	local loss coefficient
ρ	density of air (kg m^{-3})
ΔT_{fp}	air temperature difference between inlet and outlet of the channel (°C)

Subscript

1	asbestos board
2	bottom plate
3	glass wool blanket
4	top cover
f	air inside channel
o	outlet of SAC
r	indoor air

Dimensionless terms

Nu	Nusselts number
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number

that the outer side is replaced by glazing. Bouchair [5] have done some experiments to testify the applicability of solar chimneys in improvement of indoor thermal environment by promoting natural ventilation in summer. Afonso and Oliveira [6] compared the behavior of a solar chimney with a conventional one. Their results showed that there was a significant increase in ventilation rate with the solar chimney. Theoretical and experimental studies on the natural ventilation induced by solar irradiation were also done by Awbi and Gan [7], Chen et al. [8], Ong [9], and Bansal [10], etc.

The aforementioned investigations were almost based on natural ventilation of building roof structure. However, heating in winter is the same necessary as ventilation in summer for most regions of China. Hence, the practical roof structure with the integration of SAC developed in China should be made to implement function of heating by mechanical ventilation, besides passive cooling by natural ventilation. In this paper, natural ventilation effected by SAC with an uniform heat flux on a single wall was experimentally investigated for different channel gaps, heat inputs and different SAC inclination angles. In addition, its air heating performance was studied at different air-flow rate across the SAC channel with the channel gap of 200 mm. The obtained heat and the natural ventilation air-flow rate of the SAC were theoretically analyzed according to heat balance equations, and were compared with the experimental results.

2. Experimental set-up

Fig. 1 shows the schematic diagram of the experimental set-up and sectional view of air channel. The dimensional sizes for tested SAC was (length × width × channel gap) 1500 mm × 500 mm × 100–500 mm. The SAC was supported by a bracket and could be tilted with different angles. The bottom and two sidewalls were all made of wood plank with thickness of 15 mm. The top cover, which was used to adjust the channel gaps by inserting it into five different slots on the two side walls, was also a wood plank with dimensional sizes 1500 mm × 500 mm × 3 mm. To create an uniform heat flux at the bottom of the air channel, three stainless steel electric heating plates were arranged in series, acting as the heated surface. Moreover, a voltage regulator was used to change the input power.

In order to supply heat for a given space in winter, mechanical ventilation mode was adopted by adding an upper cap over the air channel and connecting it with a fan through air ducts. The cap was, however, unnecessary for natural ventilation mode, it was removed when natural ventilation was needed.

Temperatures at different points were monitored using T-type thermocouples with the certainty of measurement of ±0.5 °C, as shown in Fig. 2. There were six T-type thermocouples that were fixed on the heating plates to