

## Solar collector angle optimization for maximum air flow rate in the solar chimney

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**Abstract.** The solar chimney and the solar collector are two important components in solar energy engineering. Solar collector is mainly used to gather solar energy. Correspondingly, the angle at which the solar collector receives the maximum solar radiation is its core parameter. While for the solar chimney, solar radiation is absorbed by the air inside the solar collector to generate air flow into the chimney. Thus, there is a solar collector tilted angle at which the airflow inside the chimney reaches the maximum. There are many reports on the maximum solar radiation (MSR) in the solar collector. However, there are few studies on the maximum air flow (MAF) in the solar chimney. In this study, a mathematical model is first established for the solar chimney system. Then, an experimental setup is established to evaluate the MAF angle for the solar chimney. The solar chimneys under MSR and MAF angles are finally analyzed and compared. The results mainly show that in solar collector system with MAF angle, with the collector angle increasing, although the air temperature rise decreases gradually at the collector outlet, the air flow rate generally decreases after a long-term increase. And taking the solar radiation at Lanzhou City as a case study, the MAF angle was  $60^\circ$ , whereas the MSR angle was  $30^\circ$ .

### Introduction

Nowadays, sustainable development has been accepted as a worldwide focus. Environmental sustainable development is proposed mainly to deal with the air pollution, the water poison and the atmosphere protection. Solar energy, one of the most promising renewable and sustainable energy, has drawn high attention all over the world. Several solar energy technologies, such as the solar collector, the solar chimney, the solar Trombe, etc. have been industrially utilized in solar energy systems. Among them, the surface receiving the solar energy is the energy source for the system. Correspondingly, the surface angle is of high importance to the solar energy systems. For the solar collector, the solar energy entering the collector area is a core parameter. Whereas for the solar chimney, the air flow rate is of high importance. There are many studies concentrating on optimizing the solar collector angles to absorb maximum solar radiation (MSR). El-Maghlany et al. analyzed the orientation of the greenhouses for maximum capture of solar energy in North Tropical Region[1]. Abbassi and Dehmani carried out experimental and numerical study on thermal performance of an unvented Trombe wall associated with internal thermal fins[2]. Shojaeizadeh et al. investigated an  $Al_2O_3$ -water nanofluid based flat-plate solar collectors[3]. With respect to the solar chimney, conventional solar chimneys are laid on the center of a horizontal solar collector or solar Trombe[4]. Inclining the tilted angle of the solar collector or solar Trombe would increase the incident solar radiation on its surface but too large tilted angles would lead to the decrease of air flow rate. The angle at which the maximum air flow (MAF) is generated in the solar chimney has rarely been studied in the literature[4]. Considering this, purpose of this study is to make clear the difference of the MSR and MAF angles for the solar chimney system. Main tasks in this study can be summarized as: 1) to establish a mathematical model through basic heat transfer and solar radiation principle; 2) to develop an experimental setup to analyze the MSR and MAF angles; and 3) to compare the MSR and MAF angles for on specific location.



where  $f$  is the friction loss coefficient,  $L_{th}$  is airflow channel length,  $D$  is the hydraulic diameter of the airflow channel,  $\rho_{avr}$  and  $V_{avr}$  are the average density and airflow speed respectively,  $\gamma$  is the inlet loss coefficient and  $x$  is the turbine pressure drop coefficient.

### Experimental setup

The experiment setup, as shown in Fig. 2(a), is made up of four parts: the bracket, the electrical-simulated solar collector, the chimney and the adjust system. The bracket ensures to stabilize the table during the experiment. Solar radiation is simulated by electrical heating, and the circuit diagram is shown in Fig.3 (b). The angle of the collector could be changed by the adjustment system. The solar radiation data in this experiment is adapted from Lanzhou City. The solar radiation data used in the experiment are annually average global solar radiation from the National Meteorological Data Sharing Centre [7]. The conversion between the solar energy and electrical voltage is shown in Table 1. It is found from Table 1 that the MSR angle for Lanzhou is  $30^\circ$ .

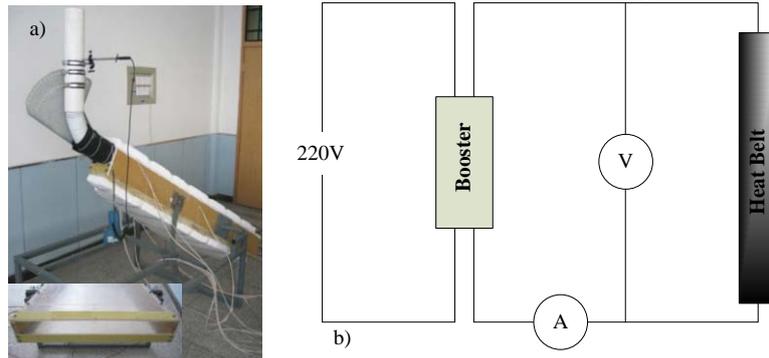


Fig. 2 Experiment setup: (a) the experimental components and (b) the circuit diagram  
Table 1. Conversion between the solar radiation and its matching voltage

Angle ( $^\circ$ )	Solar radiation ( $MW \cdot m^{-2}$ )	Voltage (V)
20	620.6	173.3
25	624.5	173.8
30	625.3	173.9
35	622.8	173.5
40	617.1	172.8
45	608.3	171.5
50	596.3	169.8
55	581.4	167.7
60	563.6	165.1
65	543.1	162.1
70	520.1	158.6
75	494.8	154.7

### Results and discussion

The air temperature rise, the air speed and the air mass flow are experimentally measured under different collector angles. The theoretically calculated temperature rise in the solar collector, the air speed at the outlet of the collector and the air mass flow rate in the chimney are compared with the experimental results in Fig. 3(a), (b) and (c) respectively. It is found from Fig. 3(a) that the temperature increases when the collector angle changes from  $20^\circ$  to  $75^\circ$ . The differences between the simulation and experiment results are within 10%. It is found from Fig 3(b) that the tendencies of the two groups of values are the same. There is a peak when the angle is near  $53^\circ$ . However, the differences between the calculated and experimented results are larger, reaching up to 20%. One possible reason for this is the usage of the corrugated hose at the connection area of inclined solar collector and vertical chimney, which slows the airspeed down. Another possible reason is that the calculated temperature rise in the solar collector is smaller than that in the experiment, while the calculated airspeed is higher than that in the experiment. The corrugated hose slows down the

airspeed and the air is heated at this area for a longer time. Fig. 3(c) shows the air mass flow in the chimney under different collector angle conditions. The simulated highest mass flow rate appears at  $60^\circ$ . And the experimental maximum air mass flow rate locates at  $55^\circ$ . It is thus concluded the MAF angle for the solar chimney system is near  $60^\circ$ . From Table 1 and Fig. 3(c), it is indicated that there is large difference between the MSR and MAF angles, as the MSR and MAF angles for Lanzhou are  $30^\circ$  and  $60^\circ$  respectively.

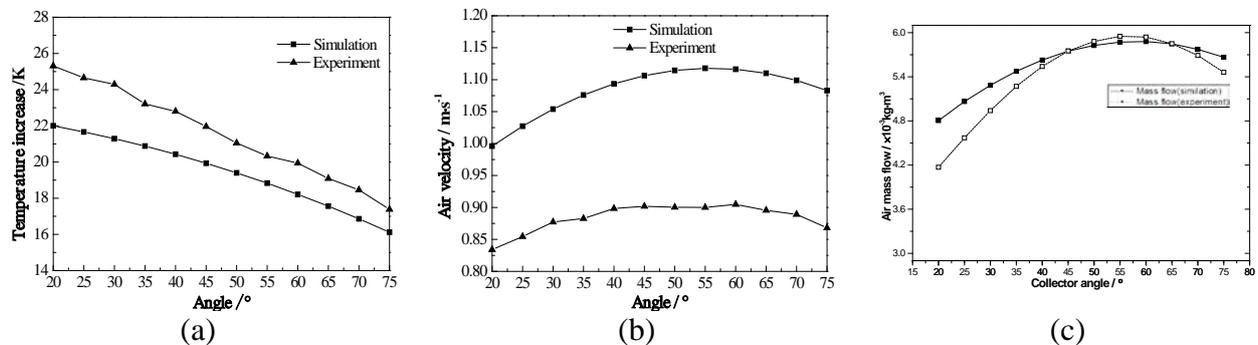


Fig. 3 Simulation and experiment results of (a) temperature rise in the collector, (b) airspeed at the collector outlet and (c) air mass flow inside the chimney

## Conclusions

In this study, a mathematical model is built for the solar collector and solar chimney. An experimental setup is also built to valid the difference between the MSR and MAF angles. It is found from the experimental and analytical study that with the collector angle increasing, although the air temperature rise is decreasing at the collector outlet, the air mass flow generally decrease after a long-term increase. For Lanzhou City, the MAF angle for the solar collector is  $60^\circ$ , while the MSR angle for the solar chimney is  $30^\circ$ .

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