# A HEAT PIPE SOLAR COLLECTOR SYSTEM FOR WINTER HEATING IN ZHENGZHOU CITY, CHINA

by

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*A heat pipe solar collector system for winter heating is investigated both experimentally and theoretically. The hourly heat collecting capacity, water temperature and contribution rate of solar collector system based on Zhengzhou city typical sunshine are calculated. The study reveals that the heat collecting capacity and water temperature increases initially and then decreases, and the solar collector system can provide from 40% to 78% heating load for a 200 m$^2$ villa with in Zhengzhou city from November to March.*

Key words: *heat pipe, winter heating, hourly character, contribution rate*

## Introduction

Solar energy is regarded as one of the main contributors to the world's clean energy supply due to its wide and abundant availability. In recent years, extensive researches have been carried out in finding wider applications for solar heat collection. Ayompe *et al.* [1] investigated the thermal performance of a solar water heating system with heat pipe evacuated tube collector over a year-long field trail. Hayek *et al.* [2] in the Lebanese market, compared two types of evacuated tube solar collectors, and the results showed that heat pipe based collectors performed better than the water in glass design, but the payback periods for water-in-glass collectors were relatively short. A comparative study by Budihardjo *et al.* [3] showed that the performance of a typical 30 tube evacuated tube array was lower than a typical two panel flat plate array for domestic water heating in Sydney, Australia. Houri *et al.* [4] measured the energy produced from a thermosyphon solar water heating system with an evacuated tube collector in an inhabited domestic dwelling in Lebanon. Russo *et al.* [5] carried out the application of renewable energy sources to greenhouse heating and climate control. Zhang *et al.* [6] studied an evacuated tube solar collector accounting the thickness of polyurethane insulation and the tube length to make a comparison of the thermal performance. Xu *et al.* [7] simulated the heat transfer progress in heat pipe, posted the distributing orderliness of temperature field and flow field, and analyzed the influence factors of temperature field and flow field. Busato *et al.* [8] made a research of a multisource heat pump system, which included evaluation and analysis of the data obtained through real time monitoring of the working system in operation, for a period of approximately two heating seasons. Azad [9] tested three different types of heat pipe flat plate collectors (HP-FPC), and compared their instantaneous efficiency. Xiao *et al.* [10] put forward a new high

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efficiency open heat pipe evacuated tubular solar collector. According to the problems existed in inner Mongolia, Li *et al.* [11] proposed the solar energy heat pump space heating system which could be used in the agricultural and pastoral areas. Nkwetta *et al.* [12] evaluated the thermal performance of an evacuated tube collector (ETC) with an internal low-concentration heat pipe, they also compared the performances of heat pipe and direct flow augmented solar collectors. Jafarkazemi *et al.* [13] provided a detailed theoretical method for energy and exergy analysis of a heat pipe evacuated tube solar collector. However, in the open literature related, such a simulation model about heat pipe solar collector system was rare and very preliminary, and there was little study on heating using heat pipe solar collector. This paper is to establish a steady-state simulation model, and optimize relevant parameters.

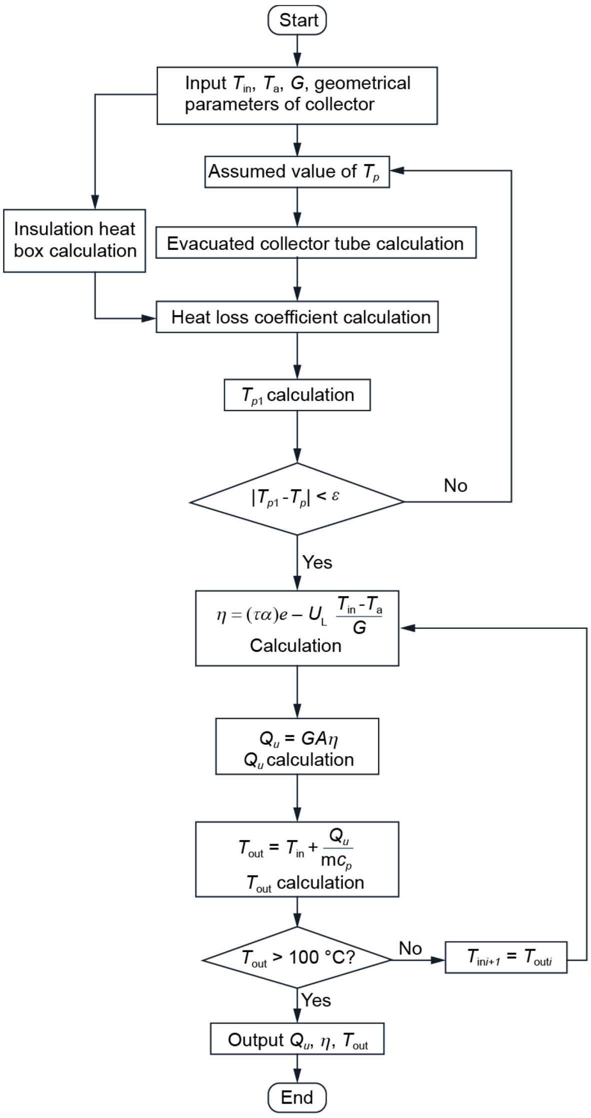


**Figure 1. Flow chart of the modeling program**

## Mathematical model

The solar collector system consists of a solar collector, a heat storage water tank, circulating water pump, *etc.* The simulation program of heat pipe solar collector system was established based on the EES software. The program flow diagram is shown in fig. 1.

The heat collecting efficiency, $\eta$, is determined from:

$$\eta = (\tau\alpha)_e - U_L \frac{T_{p1} - T_a}{G} \tag{1}$$

The heat collecting capacity, $Q_u$, is determined from:

$$Q_u = GA\eta \tag{2}$$

where $(\tau\alpha)_e$ is the product of transmittance, $\tau$, and absorption, $\alpha$, $U_L$ – the heat loss coefficient, $T_{p1}$ – the temperature of absorber plate, $T_a$ – the ambient temperature, $G$ – the hourly solar radiation, and $A$ – the collector area.

The outlet water temperature, $T_{out}$, is determined from:

$$T_{out} = T_{in} + \frac{Q_u}{mc_p} \tag{3}$$

where $m$ is the mass of water in water tank, $c_p$ – the specific heat capacity, and $T_{in}$ and $T_{out}$ – the inlet and outlet water temperature, respectively.

The energy balance equations of heat storage water tank is:

$$Mc_p \frac{\mathrm{d}T_m}{\mathrm{d}\tau} = (m_1 c_p)(T_{f,\mathrm{o}} - T_m) - (UA)_s (T_m - T_\mathrm{a}) - Q \tag{4}$$

where $T_m$ is the temperature of water in water tank, $m_1$ – the water flow rate, $\tau$ – the time, $T_{f,\mathrm{o}}$ – the outlet water temperature of water tank, $(UA)_S$ – the product of the heat loss coefficient, $U$, tank and the surface area of water tank, and $Q$ – the load of heat storage water tank.

## Experimental set-up

The solar collector system is mainly composed of heat pipe solar collector system and measurement data collection system. The system sketch map is shown in fig. 2. The insolation area of solar collector is 15.5 $\mathrm{m}^2$, which is composed of 90 heat pipe vacuum tube facing south, with a 45° to the horizontal. The system also includes a 650 L water tank.

Temperature, solar radiation, and flow rate were the main measured parameters during the experiment. The Pt100 sensors were installed as shown in fig. 2. For water temperature measurement, and the degrees of accuracy were calibrated within 0.2 °C. Solar radiation and ambient temperature were measured using automatic weather station with an accuracy of ±2%. The water flow rate was measured by an electromagnetic flowmeter with 4-20 mA output and accuracy of 0.5%. Measurement devices were connected to a data acquisition board to obtain simultaneous readings. By connecting the board to the computer, all readings were recorded automatically and monitored by the computer. All devices used for data acquisition were calibrated.

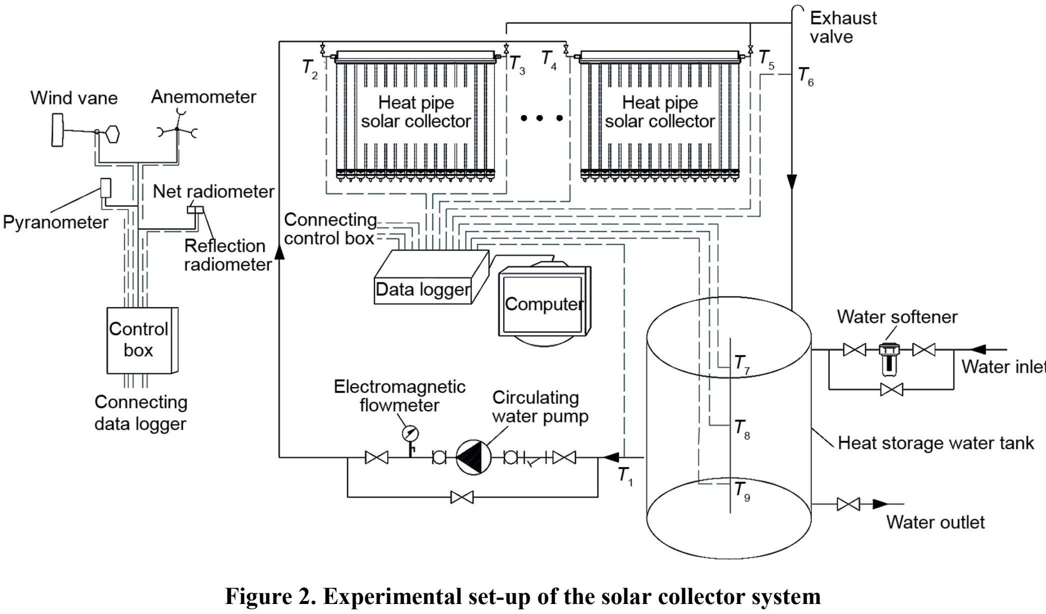


**Figure 2. Experimental set-up of the solar collector system**

## Data reduction

The thermodynamic performance of the solar collector experiment system is evaluated by the heat collecting efficiency, $\eta$, calculated:

$$\eta = \frac{Q_u}{GA} \tag{5}$$

The $Q_u$ can be determined:

$$Q_u = \rho v c_f (T_{\text{out}} - T_{\text{in}}) \tag{6}$$

where $Q_u$ is the heat collecting capacity, $\rho$ – the average working fluid density, $v$ – the volume flow of working fluid, and $c_{\text{f}}$ – the specific heat capacity corresponding to the average working fluid temperature.

In the present experiment, the error propagation method was used for uncertainty estimation [14, 15]. The experimental condition ($v$ = 15 L/min, $G$ = 800 W/m$^2$, $T_{\text{in}}$ = 60 °C, $T_{out}$ = 68 °C) was selected for uncertainty estimation, error propagation for all the calculated variables are:

The uncertainty of $Q_u$ is

$$\frac{\Delta Q_u}{Q_u} = \sqrt{\left(\frac{\Delta v}{v}\right)^2 + \left(\frac{\Delta T_{\text{in}}}{T_{\text{in}}}\right)^2 + \left(\frac{\Delta T_{\text{out}}}{T_{\text{out}}}\right)^2} = 1.4\% \tag{7}$$

while the uncertainty of $\eta$ can be expressed

$$\frac{\Delta \eta}{\eta} = \sqrt{\left(\frac{\Delta Q_u}{Q_u}\right)^2 + \left(\frac{\Delta G}{G}\right)^2} = 1.4\% \tag{8}$$

Based on the measurement inaccuracies, a detailed error analysis was conducted based on the errors in measurement of temperature and mass flow rate. The uncertainty of the water temperature calculation was 0.2%, the uncertainty of the working fluid mass flow rate calculation was 0.2%, the uncertainties of heat collecting capacity, $Q_u$, and heat collecting efficiency, $\eta$, were all 1.4%.

## Results and discussion

Validation of the mathematical simulation model is carried out for the heat pipe solar collector system with the variation of water temperature. Figure 3 shows the simulated results were found to be in good agreement with the experimental data with relative error less than 6.1%.

Combined meteorological parameter of typical days of Zhengzhou city (taken one day from November to March which has the largest amount solar radiation as the typical meteorological day), and analyzed the system heating performance in winter.

Figure 4 showed the variation of the heat collecting capacity on typical days. From fig. 4, it can be seen that the hourly variations of overall $Q_u$ on the typical day indicate similar trends. The $Q_u$ increase first and then decline by the time sequence, and reaches the maximum value between 12:00 and 14:00, it can be contributed to the influence of the solar radiation and the ambient temperature. The maximum $Q_u$ can arrive at 8.02 kW on March 14$^{\text{th}}$, and the minimum $Q_u$ occur on December 28$^{\text{th}}$.

Figure 5 represent the hourly variation of water temperature. According to the figures, the water temperature increases initially and then decreases, and reaches the maximum value between 15:00 and 16:00. The results showed that the maximum temperature rise is 58.4 °C on December 28$^{\text{th}}$, and the water temperature can reach 82.7 °C.

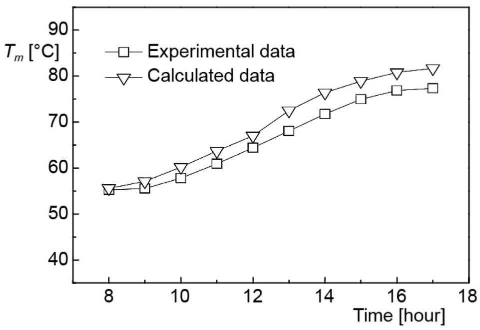


**Figure 3. Validation of the model**

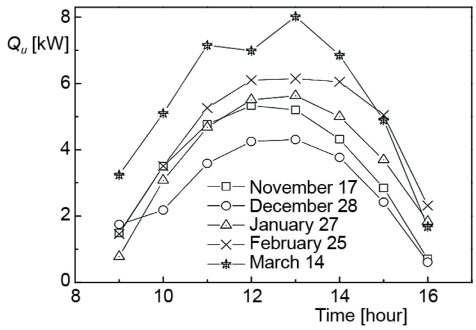


**Figure 4. Hourly variation of the heat collecting capacity on the specific days**

Combined with a villa with 200 m$^2$ in Zhengzhou city, the winter heating performance of the heat pipe solar collector system was analyzed from November to March. The variation of the average heat load, *q*, and the average heat collecting capacity, *Q*, were shown in fig 6. According to the figure, the maximum value of heat load is 5.64 kW in January, and the average heat collecting capacity increase slowly from November to March, which due to the influence of solar radiation, the ambient temperature, wind velocity, *etc.* In addition, the calculation predicts that the contribution rate (the ratio of heat collecting capacity and heat load) fluctuated between 40% and 78%, and the maximum value is 78% in March.

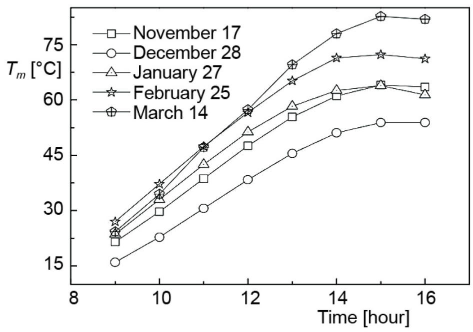


**Figure 5. Hourly variation of the water temperature on the specific days**

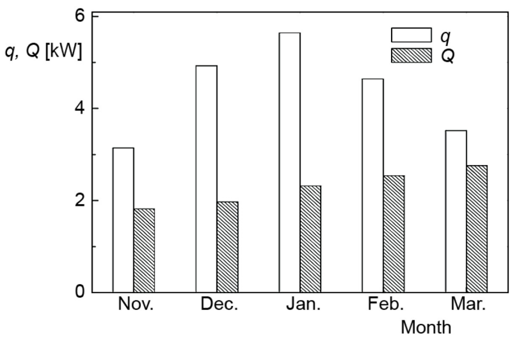


**Figure 6. Variation of *q* and *Q***

## Conclusion

A model was established for the heat pipe solar collector system, and the winter heating performance was also studied. Research show that: the heat collecting capacity and water temperature increases initially and then decreases, the maximum heat collecting capacity and water temperature rise are 8.02 kW and 58.4 °C, respectively. Under Zhengzhou climate condition, the average heat load increases first and then descreases, and the average heat collecting capacity increase slowly during the heating period. When the heat pipe solar collector area equals to 15.5 m$^2$ and the area of villa located in Zhengzhou region equals to 200 m$^2$, it is determined that the solar collector system can provide 40% to 78% heating load for the villa from November to March.

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