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Experimental study and thermal analysis on an integrated solar-air source heat pump system

Sujie Liu[1], Huan Zhang [1], Zhimeng Qi [1], Shijun You [1], Wandong Zheng [1*]

1 School of Environmental Science and Engineering, Tianjin University, Haihe Education Area, Jinnan District, Tianjin 300350, PR China

ABSTRACT

Compared with air source heat pumps, solar assisted heat pumps have attracted more attention due to the efficient utilization of solar energy. As an important component of SAHP system, the design of collector-evaporator is mainly focused on improving the absorption of solar energy, and neglect the effective utilization of air energy. Low solar radiation cannot provide enough heat to meet users' demand on cloudy or rainy days. Therefore, a new type of integrated solar-air source heat pump system is proposed, taking into account the utilization of solar energy and air energy at the same time. To study the heating performance of the SASHP system, an on-site measurement is carried out. The results show that the collector-evaporator has higher evaporation temperature than the traditional evaporator, and the evaporation temperature increases as the ambient temperature rises. Furthermore, the SASHP system COP is 4%-7% higher than that of the traditional ASHP system.

Keywords: collector-evaporator, solar assisted heat pump, experimental study, heating

1. INTRODUCTION

According to the statement released after the Central Economic Work Conference, China had put forward a scheme for peaking carbon dioxide emissions before 2030, which focuses on opening up new energy and renewable energy. Solar energy is generally considered to be the most effective form of renewable energy, and it is being used directly or indirectly all over the world [1].

Solar assisted heat pump (SAHP) can be regarded as an important technology of solar thermal utilization as well as a heat pump application [2]. The SAHP system is mainly classified as two types: the indirect expansion SAHP (IX-SAHP) system where the solar collector is coupled with the heat pump, and the direct expansion SAHP (DX-SAHP) system where the solar collector acts as an evaporator in the traditional heat pump system [3]. Some studies indicated that the DX-SAHP system offered several advantages over the IX-SAHP system, such as simplified the system, reduced the cost and improved the system efficiency [4].

Many researches have been performed on the DX-SAHP system, such as collector-evaporator analysis [5, 6], refrigerant selection [7, 8] and system control [9, 10]. As an essential component of DX-SAHP system, collector-evaporator is an equipment that the refrigerant absorbs solar energy directly in the solar collector [11]. Researchers have shown special interests in different types of collector-evaporators, such as covered flat plates [12], uncovered flat plates [13-15], heat-pipe collector-evaporators [16] and collector-evaporators with spiral-finned tubes [17]. At present, the design of collector-evaporators focusses on improving the absorption of solar energy, and neglect the use of air energy. Some collector-evaporators are equipped with a glass cover, layers of heat preservation, or finned tubes with low rib effect coefficient. Besides, heat exchange between air and collector-evaporators is natural convection, and thus the utilization of air energy is not enough. When it is cloudy or rainy day, low solar radiation cannot provide enough heat to meet users' demand. Therefore, taking into account the utilization of solar energy and air energy at the same time is an important way to improve the stability and efficiency of heat pump.

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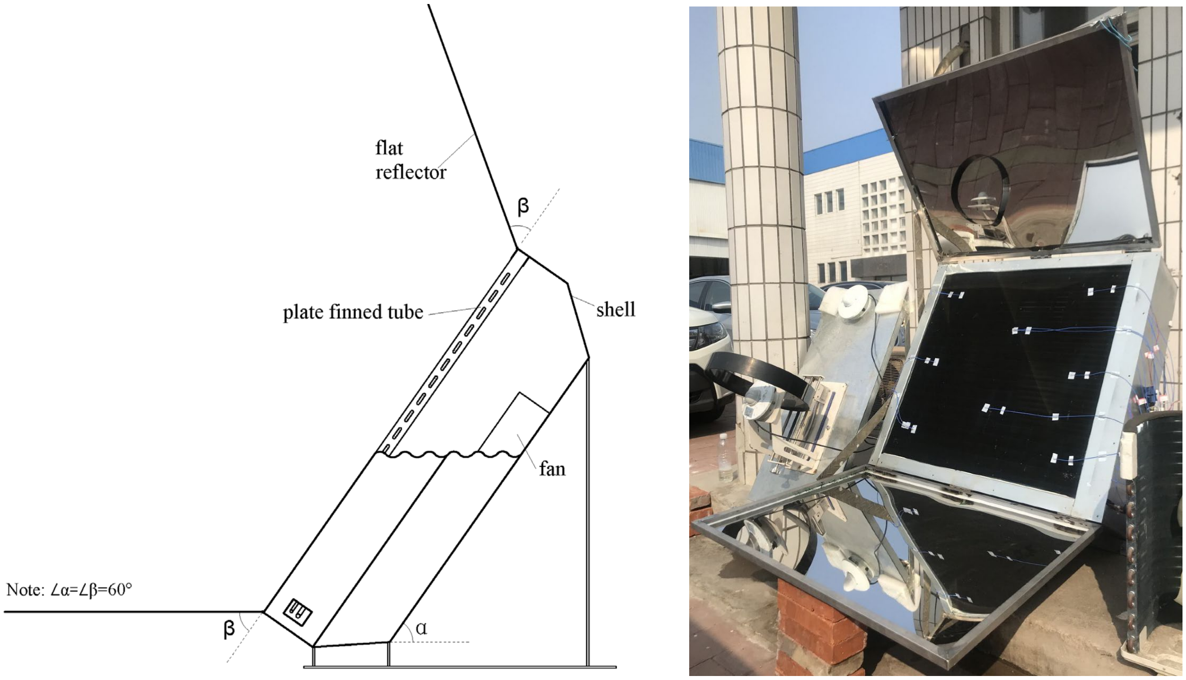

Fig 1 Structure of the collector-evaporator.

This study proposes an integrated solar-air source heat pump (SASHP) system, and the collector-evaporator is equipped with plate finned tubes and a fan to enhance heat exchange with air. The thermal performance of SASHP system is tested by on-site measurement. In addition, a comparative study between the collector-evaporator and the traditional evaporator is conducted through on-site measurement.

2. EXPERIMENTAL SETUP AND TEST APPARATUS

To study the performance of SASHP system, a prototype of the collector-evaporator has been set up, as shown in Fig 1. In order to enhance the convective heat transfer with air, the collector-evaporator is equipped with plate finned tubes with high rib effect coefficient, and a fan behind the finned tubes. To strength the absorption of solar energy, the entire device is placed obliquely, and the angle α is the complementary angle of solar zenith angle of the average midday in winter. The fins and copper pipes are sprayed with solar selective absorbing coatings, with the characteristics of high absorptivity and low reflectivity. The material of two plat reflectors is mirror stainless steel, and the angle β is calculated from the length of the reflector and solar zenith angle.

The experimental room is 3 m × 4.5 m × 3.5 m (L × W × H). The collector-evaporator, an indoor air conditioner, a rotor compressor and a solenoid valve are selected as the main components of the SASHP system. the collector-evaporator is placed facing the south, and its connection with other devices is shown in Fig 2 and Fig 3.

The measuring parameters in the experiment include: refrigerant temperature, refrigerant pressure, mass flow rate of refrigerant, air temperature, relative humidity, air flow rate, solar irradiation and power. The measurement devices and their accuracies are listed in Table 1.

The experimental measurements were carried out from January to March in 2021. The measurement period was selected from 9:00 to 16:00 every day, and tests were conducted after the system runs stably. According to the test standards for collectors and heat pumps, and


Fig 2 The SASHP system.

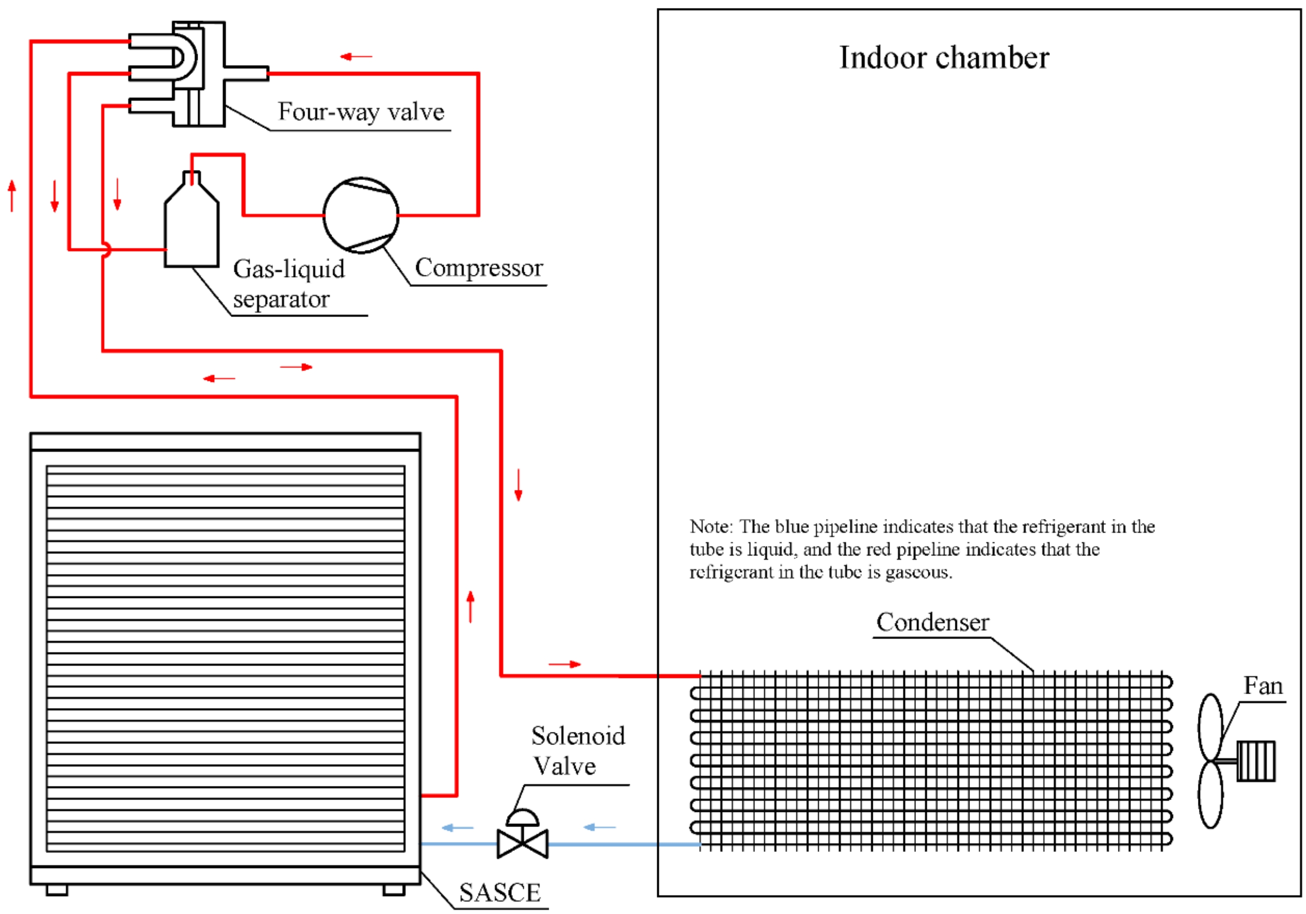

Fig 3 Schematic diagram of the SASHP system.

the test period was 40 minutes. The data was recorded every 2 minutes.

3. EXPERIMENTAL SETUP AND TEST APPARATUS

3.1 Comparative study between the SASHP system *and the ASHP system*

In order to compare the performance of the SASHP system and the traditional ASHP system, comparative tests are conducted by connecting the collector-evaporator and the traditional evaporator to the same heat pump unit. There are 6 sets of tests, and the environmental parameters are listed in Table 2. The solar radiation is 900 W/m^2 on conditions with SASHP system.

The evaporation temperature and COP of are shown in Fig 4 and Fig 5. The collector-evaporator has higher evaporation temperature than the traditional evaporator, as shown in Fig 4. Besides, the evaporation temperature of the collector-evaporator is 2.2 °C, 1.5 °C, and 1.3 °C higher than that of the traditional evaporator

Table 1
Specifications of the measurement devices.

Parameter	Device	Accuracy	Operational range
Dry bulb temperature and relative humidity	Temperature and humidity data loggers	0.4 °C, 1% RH	-20-70 °C
Solar irradiation	Radiation sensor	0-2000 W/m^2	3 W/m^2
Air temperature and air flow rate	Thermal anemometer	0.25-30 m/s	0.02 m/s
Refrigerant temperature	Copper constantan thermocouple	-200-200 °C	0.1 °C
Refrigerant pressure	Pressure sensor	0-38 bar	1%
Mass flow rate of refrigerant	Flowmeter	0-100 kg/h	Level 0.2
Compressor power	Power meter	0-4000 W	Level 1.0

Table 2
The environment parameters of different conditions.

System type	Ambient temperature (°C)	Relative humidity
ASHP system	3.2	37%
SASHP system	3.2	35%
ASHP system	8.7	29%
SASHP system	8.7	28%
ASHP system	10	23%
SASHP system	10	21%

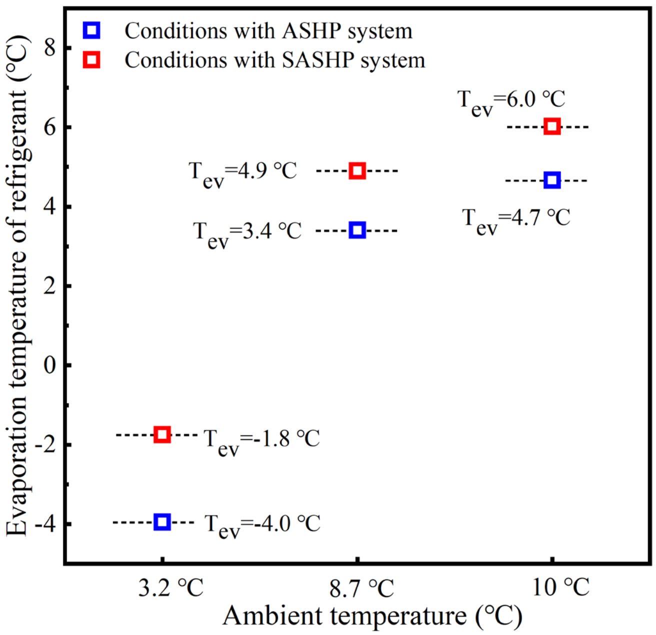

Fig 4 The evaporation temperature of different conditions.

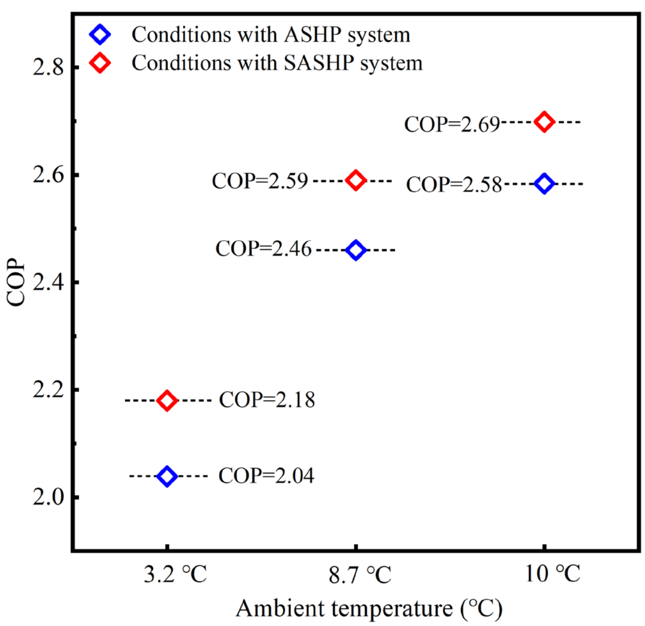

Fig 5 COP of different conditions.

respectively when the ambient air temperatures are 3.2 °C, 8.7 °C, and 10 °C. Therefore, the evaporation temperature difference between collector-evaporator and traditional evaporator decreases as the ambient air temperature increases. Similarly, COP of the SASHP system is higher than COP of the ASHP system. Compared with conditions with traditional evaporator, COP on conditions with SASHP system increases 7%, 5%, and 4% respectively when the ambient air temperatures are 3.2 °C, 8.7 °C, and 10 °C. Therefore, the increment of COP decreases as the ambient air temperature increases. Consequently, the heating performance of the SASHP system is better than the ASHP system.

3.2 The influence of ambient temperature

In order to study the influence of ambient air temperature on the performance of the SASHP system. The environment parameters are set as: T_a = 3.8 °C, 7.9 °C, and 10.6 °C, RH = 39%, 36%, 35%, I = 800 W/m^2. The variation of evaporation temperature and COP at the ambient air temperature is shown in Fig 6 and Fig 7. The evaporation temperature of refrigerant increases as the ambient temperature rises, as shown in Fig 6. The temperature difference between the evaporation temperature and ambient air temperature decreases with the increase of ambient air temperature, and the increments are 4.7 °C, 4.1 °C, and 3.8 °C respectively when the ambient air temperatures are 3.8 °C, 7.9 °C, and 10.6 °C. As shown in Fig 7, the system COP rises as the ambient air temperature increases. Consequently, the performance of system is enhanced under higher ambient temperature.

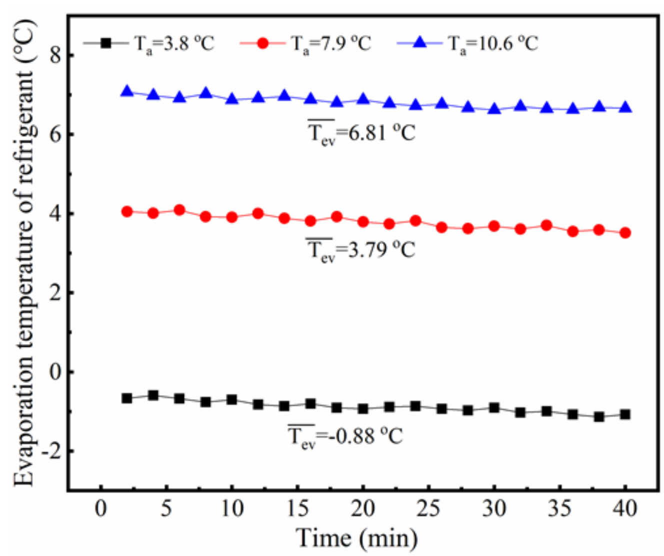

Fig 6 The variation of the evaporation temperature of refrigerant at different ambient air temprature.

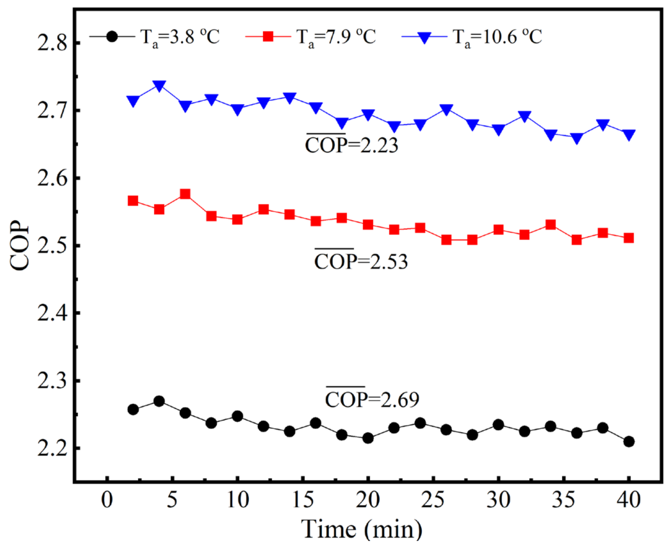

Fig 7 The variation of COP at different ambient air temprature.

4. CONCLUSION

In this study, field experiment of the integrated solar-air source collector-evaporator is carried out. Its thermal performance is studied, and the main findings of this research can be summarized as follows:

(a) The collector-evaporator has higher evaporation temperature than the traditional evaporator. The COP of SASHP system is 7%, 5%, and 4% higher than that of ASHP system respectively under the ambient air temperatures of 3.2 °C, 8.7 °C, and 10 °C.

(b) With the increase of ambient air temperature, the evaporation temperature and COP increases. The COPs of SASHP system are 2.23, 2.53 and 2.69 respectively when the ambient air temperatures are 3.8 °C, 7.9 °C, and 10.6 °C.

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