Renewable Energy 87 (2016) 1053–1058

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Performance of a solar air composite heat source heat pump system

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ARTICLE INFO

Article history:
Received 21 March 2015
Received in revised form
23 August 2015
Accepted 1 September 2015
Available online 6 September 2015

Keywords:
Heat pump
Composite system
Solar energy
Air source

ABSTRACT

For the shortcoming of air source heat pump in heating condition, a composite heat exchanger was designed which integrates fin tube and tube heat exchanger, and it can achieve synchronous and composite heat exchange in one heat exchanger between working fluids, gaseous and liquid heat source. With the above composite heat exchanger as the core component, the Solar Air Composite Heat Source Heat Pump System (SACHP) was developed which has three working modes, including single solar heat source mode, single air heat source mode and solar air dual heat sources mode. A SACHP experiment table was established and conducted a comprehensive experimental study of three working modes of this system in the standard enthalpy difference laboratory. The results show that when the ambient temperature was −15 °C, compared to the single air heat source mode, the dual heat source mode increased 62% in heat capacity and 59% in COP; when the temperature difference of combined heat transfer was 5 °C, compared to the single air heat source mode, the dual heat source mode increased 51% in heat capacity and 49% in COP. Experimental results demonstrate that the application of the solar air composite heat pump technology can accelerate the application process of the solar heat pump in air conditioners for buildings.

1. Introduction

Solar energy is the most important and basic energy among a variety of renewable energy sources and it is a priority source used as renewable resource because it is clean, inexhaustible, affordable, and free from regional restriction and high quality [1]. Solar heat pump is an effective way for air conditioning system to utilize solar energy, but in general, the researchers have found that solar energy is an intermittent energy which changes greatly depending on time and weather, for this reason, supplementary heat source is required to ensure the continuous and reliable operation of solar heat pump [2,3].

Since the advent of air source heat pump, it has become the research focus and has been rapidly popularized and applied, owing to its unique advantages of energy conservation and environment protection. Air heat source is gradually obtaining the largest market share in the application of building energy by virtue of its unique advantages [4–6]. However, the application of single air source heat pump is also subject to weather conditions, and especially in winter when the evaporating temperature decreases with the temperature fall of outdoor air heat source, there will be a significant drop in the ratio of heating capacity of heat pump and energy efficiency, or even a severe frosting, as a result, the machine may fail to work properly [7].

Since solar heat pump and air source heat pump had their respective advantages and disadvantages, the researchers combined the solar heat pump with the air source heat pump to develop a composite heat source heat pump system, in order to improve the reliability of the system. The current composite heat source heat pump system is provided with multiple different heat exchangers to utilize different heat sources, involving more complicated equipment, causing higher cost and other related issues, and making it impossible to simultaneously utilize various heat sources [8–14]. Badescu designed thermal energy storage device integrated into a solar assisted heat pump system for space heating, established model and simulates the working characteristic [15–17].

Aimed at the disadvantages of solar heat source heat pump, air source heat pump and composite heat source heat pump with multiple heat exchangers, a heat exchanger was designed that can achieve synchronous composite utilization of solar heat source and air heat source in one heat exchanger. With this heat exchanger as

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http://dx.doi.org/10.1016/j.renene.2015.09.001
0960-1481/

the core component, SACHP was designed. Then, the experimental table of SACHP was established and the experimental study was done in the standard enthalpy difference laboratory. The results of the experiment have indicated that the composite heat pump has been obviously improved in cooling capacity and performance compared with the single air source heat pump; the margin of increase was increasing with the decrease of outdoor ambient temperature. Under the ultra low temperature heating condition at the outdoor ambient temperature of −7 °C specified in the national standard, the heating capacity and performance of the composite heat pump both increased by over 50% than that of the single air heat source heat pump.

2. Meteorological and actinometrical data

According to the Meteorological Library of China Meteorological Administration Meteorological Information Center [18], the average sunshine of Zhengzhou is 2400 h/year, the total annual solar radiation energy for 5771 MJ/(m^2·a), the total heating season solar radiation energy to 1740 MJ/m^2. According to solar radiation data, Zhengzhou's daily sunshine is shown in Fig. 1, the total daily solar radiation shown in Fig. 2, a month solar radiation shown in Fig. 3. Zhengzhou's daily average sunshine curve shows that the average of sunshine is 4.8–7.9 h year around. The average sunshine time is high from April to August, and it is about 8 h a day. In winter, however, the average sunshine time is 5 h a day. Annual daily average sunshine has little fluctuations. In comparison, Fig. 2 shows the solar irradiation day-by-day all year in Zhengzhou. The curve shows that solar irradiation day-by-day all year has the same trends as the curve of monthly daily average sunshine in Zhengzhou. The summer's daily solar irradiation is higher than other season. However, the fluctuation of the solar irradiation day-by-day all year is not outstanding.

The curve of the monthly average solar irradiation is shown in Fig. 3. The solar irradiation ranges are from 11.724 MJ/(m^2·day) to 18.504 MJ/(m^2·day) when the solar collector installed tilted at latitude. Where H*t* is monthly averaged, daily total solar irradiation on horizontal surface (MJ/m^2·day), H*d* is monthly averaged, daily diffuse solar irradiation on horizontal surface (MJ/m^2·day), H*b* is monthly averaged, daily direct solar irradiation on horizontal surface (MJ/m^2·day), H is monthly averaged, daily total solar irradiation on surface tilted at latitude (MJ/m^2·day), H*o* is monthly averaged, daily total solar irradiation above the aerosphere (MJ/m^2·day).

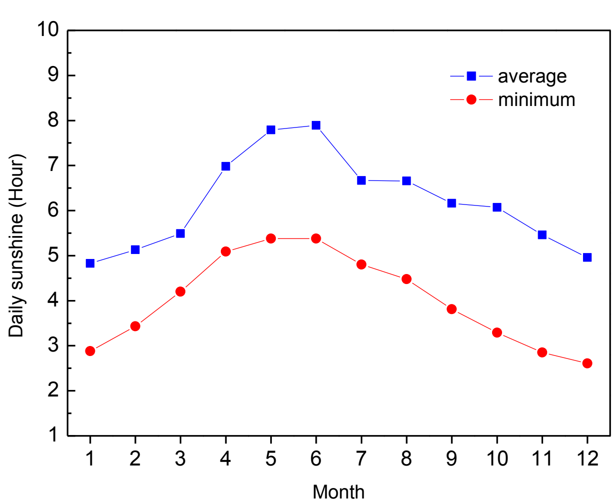

Fig. 1. Monthly daily sunshine in Zhengzhou China.

3. Description of the solar-air composite heat source heat pump system

SACHP comprises of two parts, one is the part of solar heat collection and heat accumulation, another is the composite heat source heat pump, among which the solar heat collection and heat accumulation include solar collector, hot water accumulator, tank for domestic water, heat exchange coil, circulating pump and connecting pipe and valves; the composite heat source heat pump includes compressor, composite heat exchanger, heat exchanger for user, combined throttle device, four way reversing valve, connecting pipe, valve, etc. It can be observed in Fig. 4.

The dual heat source composite heat exchanger is the core component of this system. Fig. 5 shows the schematic diagram of structure. According to the characteristics of fin tube heat exchanger and tube heat exchanger, and based on fin tube heat exchanger, this heat exchanger was made by inserting another heat exchanger tube into the heat exchanger tube of fin tube heat exchanger, forming three medium channels, including the cavity of inside tube working as the solar water channel, space between the outer wall of inside tube and the inner wall of outside tube as the heat pump refrigerant channel and the space between the fins and outer surface of the outside tube as the air channel.

SACHP is provided with the composite heat source heat exchanger that combines solar heat collection and heat accumulation with composite heat source heat pump in a scientific and reasonable way. In summer, the part of solar heat collection and heat accumulation and composite heat pump system work individually, and in winter, these two parts work together. The dual heat source composite heat exchanger (as an evaporator) can use either or both air source and low solar heat as the heat pump heat source, for this reason, the solar energy collected in the daytime can be used by the heat pump at night, which contributes to solve problems where solar energy is unavailable at night as an intermittent energy, eliminate the effect of low temperature on air source heat pump, greatly enhance the working efficiency of heat pump in winter and improve the reliability of heat pump system.

4. Experimental study of the solar-air composite heat source heat pump system

4.1. Description of experimental system

Solar air composite heat source heat pump system is equipped with a compressor with an air displacement of 16.7 ml/rev and has a cooling capacity of 2770 W under the standard air conditioning conditions. Throttle device is a combined throttle device which comprises of two capillary tubes with a tube diameter of 2 mm and a length of about 2 m for each one and one FD-4-type one-way valve with a design flow of more than 3.2 L/min. Heat exchanger for user has wall-mounted fan coil, and the dual heat source composite heat exchanger has heat exchanger tubes in single-row arrangement, among which, the outside tube is rifled copper tube with a tube diameter of 15.7 m and a thickness of 0.5 mm, and the inside tube is copper tube with a tube diameter of 9.52 mm and a thickness of 0.3 mm; these 16 tubes with a length of 600 mm for each tube are split into two groups in symmetrical design from top to bottom, allowing for the counter flow heat exchanging between solar heat medium (ground water) and heat pump working medium (refrigerant). The fins are 0.115 mm-thick hydrophilic aluminum foil corrugated fins with a spacing of 2 mm, a width of 32 mm and a height of 608 mm. It has a design face velocity of 2 m/s, air volume of 2500 m^3/h, input power of 45 W and pressure of 30 Pa. To meet the requirement for continuous testing, this system used hot water accumulator to simulate solar heat source, and the hot water