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Investigation of the effect of rollbond evaporator design on the performance of direct expansion heat pump experimentally

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ABSTRACT

In this study, the rollbond evaporator design which gives maximum coefficient of performance for the direct expansion solar assisted heat pump (DX-SAHP) water heater is investigated experimentally on the three separate heat pump systems due to the lack of studies on the effect of collector-evaporator design to the system performance. Three DX-SAHP systems are identical except collector-evaporator design. Aluminum is preferred for the evaporator material and R134a as the working fluid.

Maximum COP value was obtained as 3.30 for System-1 while COP values for System-2 and System-3 were 3.14 and 2.42 respectively at the same conditions. An empirical correlation which gives the COP value of the System-1, which provides highest COP, with respect to the solar radiation and outdoor temperature of the system has been found using the experimental results obtained during the study. The correlation was found to be in good agreement with the average deviation of 9% with the experimental data.

1. Introduction

Energy used for heating water is an important part of domestic energy consumption. Therefore, number of studies on the efficient water heating systems has been increased. Water heaters can be classified in four main groups as storage water heaters, instantaneous water heaters, heat pump water heaters and solar assisted water heaters. Solar assisted heat pumps, which combine the advantages of both heat pumps and solar assisted water heaters, can be examined in two separate classes. One of them is the applications of the traditional solar assisted water heaters integrated with the air-source heat pump; the other is the direct-expansion solar assisted heat pumps with the evaporator combined with solar collector (DX-SAHP).

A direct expansion solar assisted heat pump (DX-SAHP) water heater experimental set-up is introduced and analyzed by Li et al. [1]. The DX-SAHP water heater system, which mainly consists of 4.20 m^2 direct expansion type collector/evaporator, R-22 rotary-type hermetic compressor with rated input power 750 W, 150 L water tank with immersed 60 m serpentine copper coil and external balance type thermostatic expansion valve, were tested under typical spring climate in Shanghai. Results showed that the COP of the DX-SAHP water heater system can reach 6.61 when the average temperature of 150 L water is heated from 13.4 °C to 50.5 °C in 94 min with average ambient temperature 20.6 °C and average solar radiation intensity 955 W/m^2. The seasonal average value of the COP and the collector efficiency was measured as 5.25 and 1.08, respectively. Furthermore, some methods are suggested to improve the thermal performance of each component and the whole DX-SAHP water heater system. Then, a small-type DX-SAHP water heater with rated input power 400 W was built, tested and analyzed by Li et al. [2]. In both studies, exergy analysis for each component of DX-SAHP water heater was performed and the highest exergy loss has been determined in the compressor, followed by collector/evaporator, condenser and expansion valve, respectively. Furthermore, a methodology for the design optimization of the collector/evaporator was introduced and applied. In order to maintain a proper matching between the heat pumping capacity of the compressor and the evaporative capacity of the collector/evaporator under widely varying ambient conditions, the electronic expansion valve and variable frequency compressor are suggested to be utilized for the DX-SAHP water heater.

Huang and Chyng [3], investigated the performance of an integral-type solar assisted heat pump water heater (ISAHP) with usage of thermosypon loop to transfer heat from the condenser to the water storage tank and found highest COP value as 3.83 for the value of 15.1 °C ambient temperature and 1282.5 kJ/m^2 solar radiation. An ISAHP using a bare collector and a small R134a reciprocating-type compressor with rated input power 250 W was built and tested in the further study of Huang and Chyng [4]. The ISAHP was designed to operate at an evaporating temper-

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Nomenclature

c_p	specific heat of water (J/kg K)	T_e	evaporation temperature (K)
COP	coefficient of performance	$\dot{W}_{comp}$	power consumption of compressor (W)
I	solar radiation intensity (W/m^2)	ΔT	temperature difference for water between inlet and outlet of the condenser
$\dot{m}_w$	mass flow rate of water (kg/s)		
$\dot{Q}_c$	heat released from the condenser (W)		

ature lower than the ambient temperature and a matched condition. A performance model is derived for the ISAHP. The COP for the ISAHP built in the present study lies in the range 2.5–3.7 at water temperature between 61 and 25.8 °C. The study of the Chyng et al. [5] focuses on the performance of an ISAHP designed and fabricated previously by Huang and Chyng. A simulation technique was used to analyze the daily performance of an ISAHP for 1 year. It is shown that the daily total COP (COP) is o around 1.7–2.5 year around for the ISAHP, depending on seasons and weather conditions. COP is higher than 2.0 for most of the time in a year and the daily operating time varies from 4 to 8 h. Using the 1-year simulation results, a universal daily performance correlation of the ISAHP was derived and shown experimentally to be applicable to another design of ISAHP. A long-term reliability test of an integral-type solar-assisted heat pump water heater (ISAHP) was carried out by Huang and Lee [6]. They have been reported that the prototype has been running continuously for more than 13,000 h with total running time >20,000 h without any mechanical problem.

A simple linear correlation for the performance evaluation of different ISAHP water heater is derived by Huang and Lee [7]. They have verified the correlation using the long-term outdoor field test data of four different ISAHP and proposed a standard performance test method. The test method suggests that only the measurement of instantaneous solar incident radiation on horizontal surface, ambient temperature, hot water temperature in the storage tank, total mass of water in the storage tank and total power input to the ISAHP are required.

Analytical and experimental studies were performed on a solar assisted heat pump water heating system, where unglazed, flat plate solar collectors acted as an evaporator for the refrigerant R134a under meteorological conditions of Singapore by Hawlader et al. [8]. Results show that, average values of COP ranged from about 4–9 and solar collector efficiency was found to vary between 40% and 75% for water temperatures in the condenser tank varying between 30 °C and 50 °C. A simulation model has been developed to analyze the thermal performance of the system. A series of numerical experiments have been performed to identify important variables. Results indicate that the performance of the system is influenced significantly by collector area, speed of the compressor and solar irradiation.

A solar assisted heat pump dryer has been designed, fabricated and tested by Hawlader et al. [9]. Their study presents the comparison of the performances of the evaporator collector and the air collector when operated under the same meteorological conditions. It was found that the evaporator- collector performed better than the air collector in a solar assisted heat pump drying system. The range of efficiency of the air collector, with and without dehumidifier, was found to be about 0.72–0.76 and 0.42–0.48, respectively when operated under the meteorological conditions of Singapore. The results showed that the evaporator–collector efficiency increases with increasing refrigerant mass flow rate.

Enaburekhan and Yakasai [10] have tested three identical small-scale solar water heating systems using refrigerants R-134a, R12, and ethanol under various environmental and load conditions in Nigeria. The results show that the maximum water temperature increases of 28 °C, 37 °C and 40 °C for R12, ethanol and R-134a, while the maximum collection efficiencies computed were 40.63%, 50.78% and 56.59% for R12, ethanol and R-134a respectively.

Ito et al. [11] have performed theoretical and experimental studies on the thermal performance of a heat pump that used a bare flat-plate collector as the evaporator. The analysis used empirical equations to express the electric power consumption of the compressor and coefficient of performance (COP), as functions of temperature of evaporation at the evaporator and that of the heat transfer medium (water) at the inlet of the condenser.

They have reported that, around noon in winter the evaporator temperature was found to be about 17 °C higher than the ambient air temperature of 8 °C, and a COP of about 5.3 was obtained when the water temperature at the condenser inlet was 40 °C.

Chata et al. [12], have performed thermodynamic analysis of a direct expansion solar assisted heat pump for a variety of refrigerants. The thermal performance, as characterized by the coefficient of performance (COP), is determined for a variety of pure refrigerants as well as refrigerant mixtures. The performance degradation due to switching from R-12, a chloro-fluorocarbon refrigerant, to hydro-fluorocarbon refrigerants is investigated. The results show that R-12 produces the highest value of COPH, followed by R-22 and R-134a. The system performance degradation is about 2–4% in the 0–20 °C collector temperature range when R-12 is replaced with R-134a. For the mixture refrigerants, R-410A is shown to be more efficient than either R-407c or R-404a but not as good as R-134a and the refrigerant R-410a produces COPH values that are 15–20% lower than those obtained with R-134a.

Chow et al. [13], examined the potential application of a unitary type direct-expansion solar-assisted heat pump (DX-SAHP) system was examined. A numerical model of the DX-SAHP system was first introduced. From the simulation results with the use of the Typical Meteorological Year (TMY) weather data of Hong Kong, the system was found achieving a year-average coefficient of performance (COP) of 6.46.

Performance of a direct expansion solar assisted heat pump (DX-SAHP) water heater with rollbond evaporator is investigated experimentally under the conditions in November of 2010 in the province of Bilecik by Cerit and Erbay [14]. According to the experimental results, maximum COP value has obtained for the outdoor temperature of 18 °C and solar radiation of 448 W/m^2 as 3.69.

The purpose of this study is to investigate the effects of the rollbond collector-evaporator design to the performance of DX-SAHP systems and determine the evaporator design which gives the maximum coefficient of performance among the three separate heat pump systems experimentally. The study provides basement

Table 1
Specification of the main components.

Name	Type
Compressor	Danfoss SC15GHH, reciprocating
Condenser	Alfa Laval CBH-30, plate type
Evaporator	Aluminum plate, 1 m^2
Thermostatic expansion valve	Danfoss, TEN 2 type