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Reducing Backup Electricity Consumption of Solar Water Heater Using Heat Pump

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ABSTRACT

Solar-assisted heat pump (ISAHP) and heat pump-assisted solar heater (HPAS) were developed in the present study in order to reduce the backup electricity consumption of solar water heater. Test results show that the electricity consumption per liter of hot water at 55°C is 0.021 kWh/L for ISAHP and less than 0.01 kWh/L for HPAS. This energy consumption is much less than conventional solar water heater.

INTRODUCTION

Solar water heater cannot make hot water at cloudy or rainy days. Users need to install an electric heater as the backup and utilize expensive electricity during cloudy or rainy days. The reduction of backup electricity of a solar hot water heater is thus quite important. A solar-assisted heat pump water heater (ISAHP) can reduce the backup electricity of a conventional solar water heater, if properly designed [1-2]. An ISAHP was designed and fabricated in the present study. Furthermore, the integration of an air-source heat pump with a conventional solar heater, called *heat pump-assisted solar heater* (HPAS), can also reduce the electricity consumption. In the present study, both systems are designed and tested to measure the actual electricity consumption.

DESIGN AND TEST OF ISAHP

As shown in Figure 1, the ISAHP consists of a Rankine cycle unit, a collector/evaporator unit, and a heat exchanger/condenser unit that combines the condenser of the Rankine cycle and the heater of a thermosyphon loop. The ISAHP is of direct expansion type that absorbs energy from solar radiation and ambient air simultaneously and transports the heat to the storage tank through the Rankine cycle. For obtaining high reliability and reducing cost, a heat exchanger/condenser unit is designed with a thermosyphon loop to transfer the heat from the condenser to the water storage tank. The condenser releases condensing heat from the Rankine cycle to the waterside of the heat exchanger for producing a natural-circulation flow in the thermosyphon loop. The compressor is the only component with moving parts in the ISAHP.

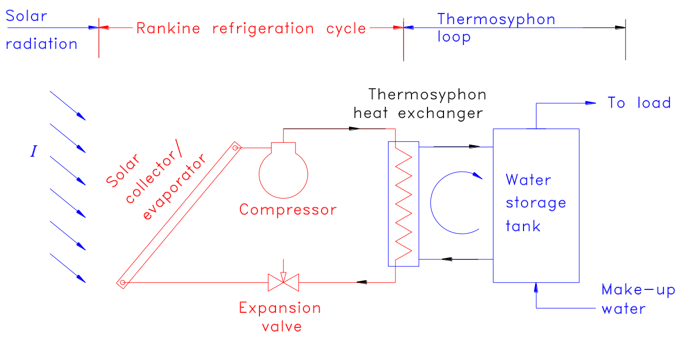

Figure 1 Schematic diagram of an ISAHP

The unglazed solar collector is divided into 4 parts: top(50cm×74cm), front(50cm×120cm) and two sides(50×60cm). The total collector area is 1.44 m^2. The capacity of water storage tank is 105 liter. The ISAHP utilizes an R134a compressor (250W, 110VAC) commonly used in household refrigerator for the Rankine cycle. A counter-flow heat exchanger is used as the condenser/heat exchanger unit.

This laboratory-made ISAHP (Figure 2) was equipped with some instruments to monitor the long-term performance. To simulate the daily hot water load, we installed an automatic hot water drainage system in order to discharge the hot water and feed cold water to the water tank every day before sunrise. The drained hot water is around 80 liters daily that is about 80% of the designed capacity. A temperature controller is used to shut down the heat pump when water temperature has reached the designated value. The water temperature setting was 57°C in the test. A power meter was installed to record the total electric energy consumption of ISAHP during operation. A water meter was also installed to measure the total water consumption.

Figure 2 Prototype of ISAHP.

Figure 3 is the measurement of long-term performance of ISAHP. The electricity consumption per liter hot water (57°C) ranges from 0.01 to 0.03 kWh/L depending on the weather conditions and daily hot water load. The average value is 0.021 kWh/L. The electricity consumption is related to the daily solar irradiation as shown in Figure 4. In addition, this ISAHP has passed 20,000 hours test without any mechanical failure.

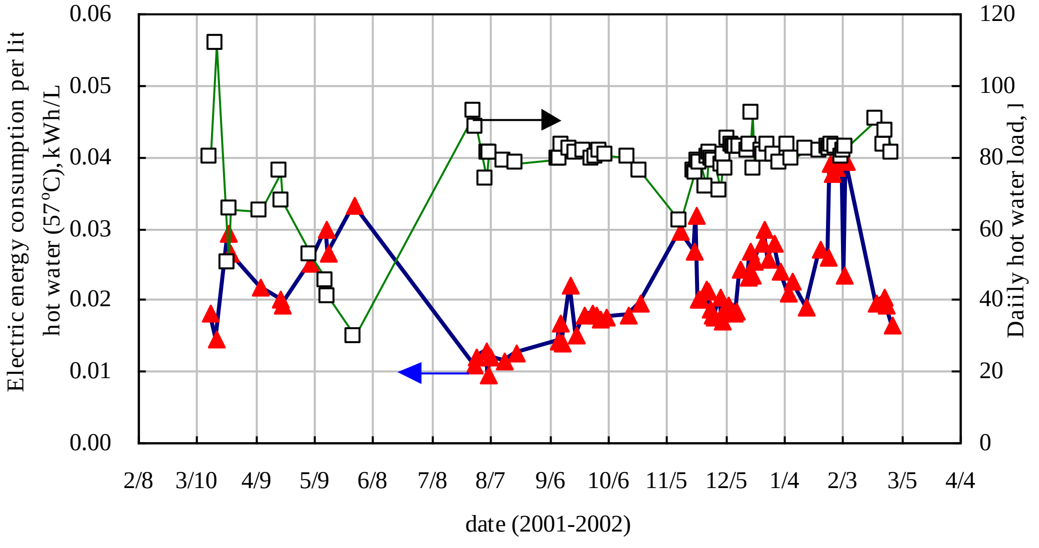

Figure 3 Long-term electricity consumption of ISAHP.

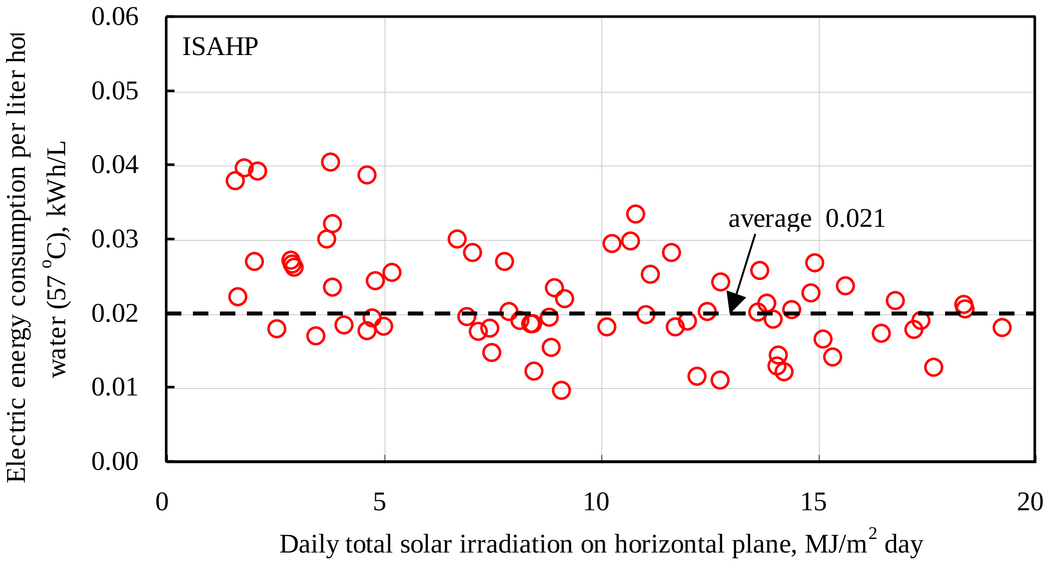

Figure 4 Electricity consumption versus daily solar irradiation.

DESIGN AND TEST OF HEAT PUMP-ASSISTED SOLAR WATER HEATER (HPAS)

A conventional solar water heater uses electric heater as the backup. If this electric heater is directly replaced by an air-source heat pump, this yields a so-called *heat pump-assisted solar heater* (HPAS). In the present study, we design a HPAS using a conventional solar water heater coupled with an air-source heat pump (Figure 5). The major specifications of HPAS are as follows:

Water capacity: 450 liters
Collector type: all-glass vacuum collector
Collector area: 4 m^2
Air-source heat pump: R134a compressor (250W/110VAC)
condenser coil: 8m/10mm i.d. copper pipe
evaporator: copper tube/aluminum fin

Figure 6 shows that the electricity consumption of HPAS is below 0.01 kWh/L in cloudy or partly cloudy days (H_t<12 MJ/m^2day). In clear days (H_t>15 MJ/m^2day), HPAS consumes electricity less than 0.007 kWh/L. Figure 7 shows that the COP of HPAS is around 3.5 in cloudy days (H_t<12 MJ/m^2day). In partly cloudy or clear days (H_t>12 MJ/m^2day), COP is higher than 4.0.

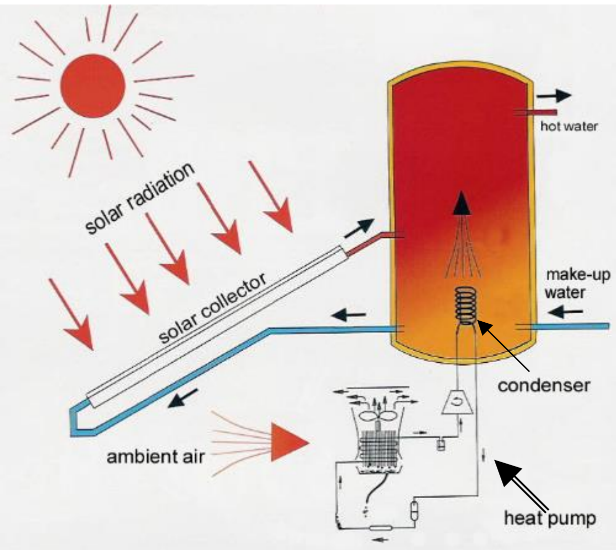

Figure 5 Design configuration of HPAS.

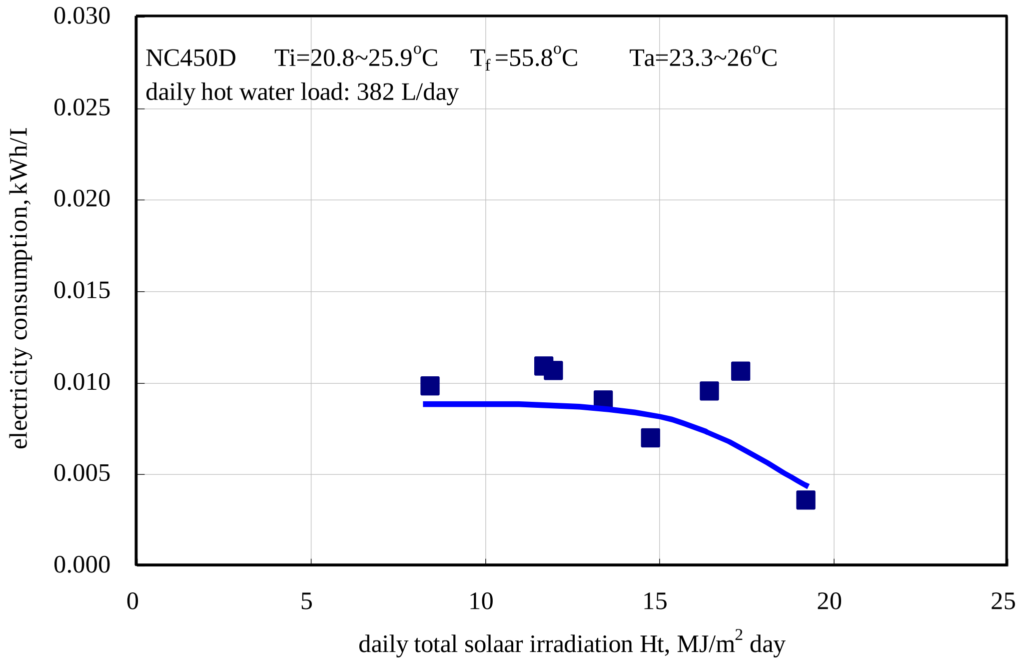

Figure 6 Electricity consumption of HPAS.

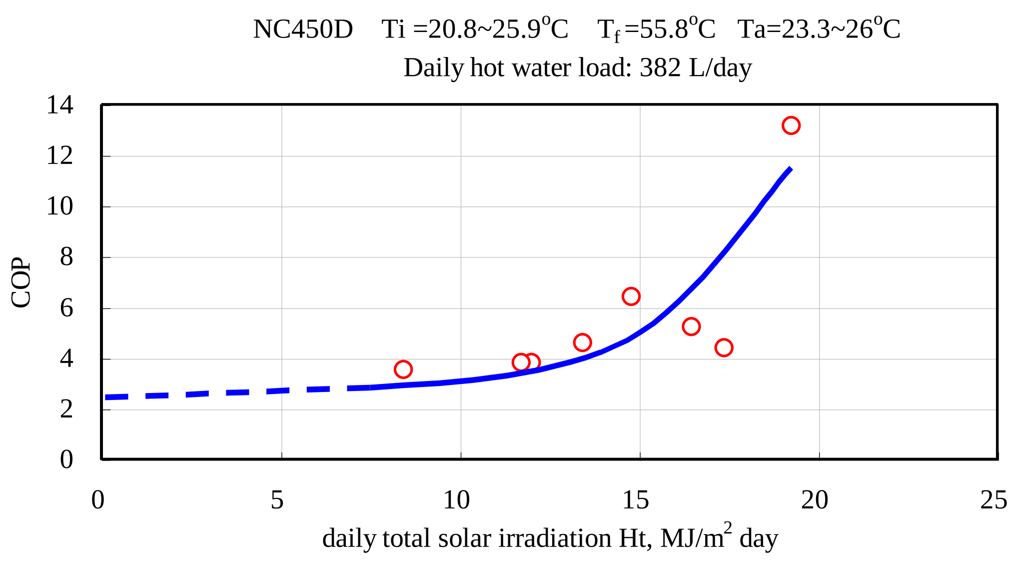

Figure 7 COP of HPAS

PERFORMANCE COMPARISON OF ISAHP AND HPAS

The two solar heat pump water heaters, ISAHP and HPAS, were continuously run for a month in winter to compare their performance. It is seen from Figure 8 that the electricity consumption of HPAS is much less than that of ISAHP. This is due to the facts that HPAS uses an all-glass solar collector for solar energy collection that has a very good thermal insulation property. ISAHP is a direct expansion solar-assisted heat pump. A bare collector is used in ISAHP that has a larger heat loss.

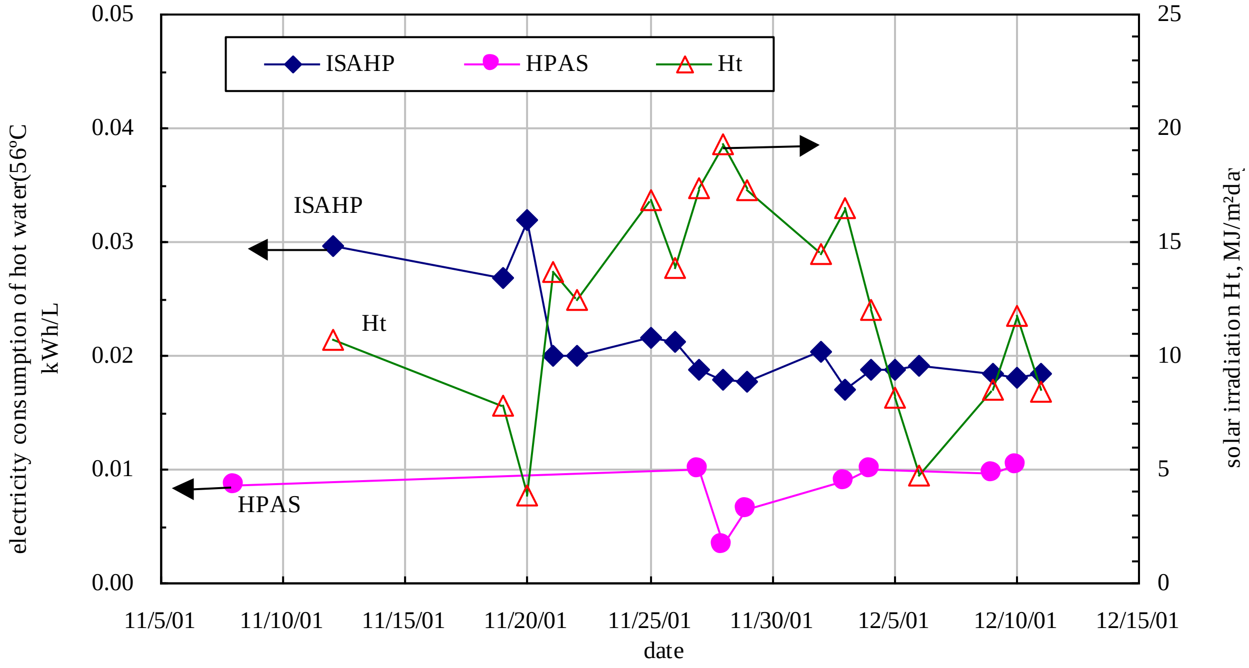

Figure 8 Performance comparisons of ISAHP and HPAS.

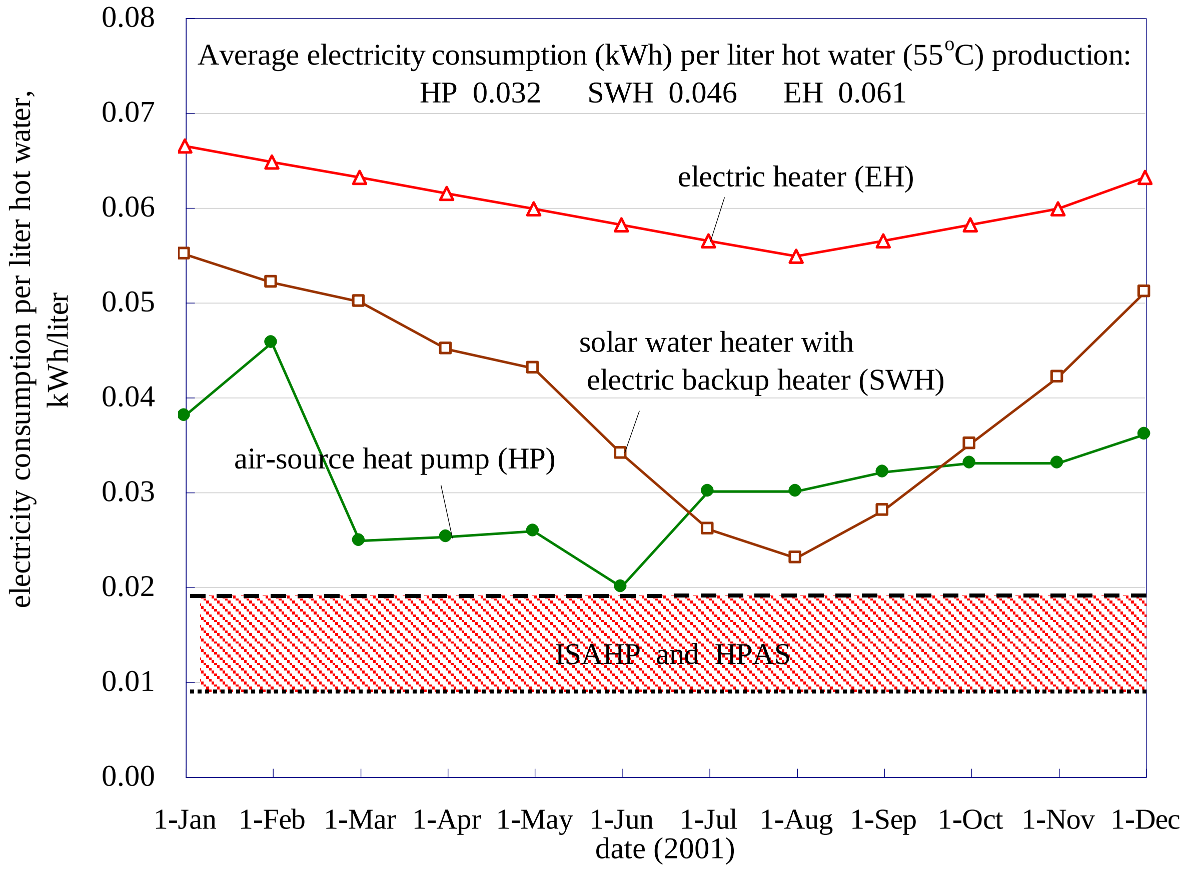

Figure 9 Electricity consumption of various water heaters.

A long-term test for determining the electricity consumption of an electric heater, an air-source heat pump and a solar water heater with electric backup was also carried out in the present study. The results are compared with ISAHP and HPAS. Figure 9 shows that ISAHP and HPAS consumes much less electricity than the others.

DISCUSSIONS AND CONCLUSION

The present study has shown that electricity consumption for a conventional solar water heater can be greatly reduced by using heat pump. The electricity consumption for solar-assisted heat pump (ISAHP) is less than 0.02 kWh/L that is much less than the conventional solar water heater. For HPAS, the energy consumption is lower than 0.01 kWh/L. Though HPAS exhibits a superior performance to ISAHP, the cost will be higher since HPAS integrates two systems (solar collector and air-source heat pump) together. HPAS needs on-cite assembly. ISAHP is a direct-expansion solar-assisted heat pump that is simple in design and can be manufactured in factory. The reliability of ISAHP will be higher since there is only one component (compressor) with moving parts. HPAS has one more moving part (fan for evaporator heat exchanger) in addition to compressor. The performance of ISAHP can be further increased using a better system design. ISAHP has passed 20,000 hours field test without any mechanical failure. Both ISAHP and HPAS are ready to be commercialized.

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