

System performance and economic analysis of solar-assisted cooling/heating system

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Abstract

The long-term system simulation and economic analysis of solar-assisted cooling/heating system (SACH-2) was carried out in order to find an economical design. The solar heat driven ejector cooling system (ECS) is used to provide part of the cooling load to reduce the energy consumption of the air conditioner installed as the base-load cooler. A standard SACH-2 system for cooling load 3.5 kW (1 RT) and daily cooling time 10 h is used for case study. The cooling performance is assumed only in summer seasons from May to October. In winter season from November to April, only heat is supplied. Two installation locations (Taipei and Tainan) were examined.

It was found from the cooling performance simulation that in order to save 50% energy of the air conditioner, the required solar collector area is 40 m² in Taipei and 31 m² in Tainan, for COP_j = 0.2. If the solar collector area is designed as 20 m², the solar ejector cooling system will supply about 17–26% cooling load in Taipei in summer season and about 21–27% cooling load in Tainan. Simulation for long-term performance including cooling in summer (May–October) and hot water supply in winter (November–April) was carried out to determine the monthly-average energy savings. The corresponding daily hot water supply (with 40 °C temperature rise of water) for 20 m² solar collector area is 616–858 L/day in Tainan and 304–533 L/day in Taipei.

The economic analysis shows that the payback time of SACH-2 decreases with increasing cooling capacity. The payback time is 4.8 years in Tainan and 6.2 years in Taipei when the cooling capacity >10 RT. If the ECS is treated as an additional device used as a protective equipment to avoid overheating of solar collectors and to convert the excess solar heat in summer into cooling to reduce the energy consumption of air conditioner, the payback time is less than 3 years for cooling capacity larger than 3 RT.

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1. Introduction

The ejector cooling system (ECS) using low boiling point refrigerant is suitable for solar cooling application due to its simple design and low cost. Huang et al. (1998, 1999) has shown that the COP of an ECS using R141b, with a proper design of ejector and system structure, can reach 0.54 at generator temperature 84 °C, condenser

temperature 28 °C, and evaporator temperature 8 °C. This makes the ECS become competitive to the sorption (absorption or adsorption) system that is much more complicated in design and more expensive (Arbel and Sokolov, 2004; Nguyen et al., 2001; Sokolov and Hershgal, 1990a, b, 1991; Sun, 1997).

If the ECS was driven by solar energy, it always requires a back-up system to make up the heat to keep a constant cooling capacity for space cooling during cloudy or rainy periods (Fig. 1). Heat supplied by fossil fuel or electricity was generally adopted. This however causes a problem of

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Nomenclature

A_c	solar collector area (m^2)	Q_{jmax}	designed maximum cooling capacity of ECS (kW)
B_t	the value of yearly energy saving at t year, NTD (1 USD = 30 NTD)	Q_{load}	designed cooling load of the cooling space (kW)
E	the present value of the total energy saving in N years, NTD	r_{loss}	Q_j/Q_{load} , fraction of system heat loss (dimensionless)
C	total installation cost, NTD	t_i	initial time of daily solar heating process (h)
COP_j	coefficient of performance of the ejector cooling system (ECS) (dimensionless)	t_f	final time of daily solar heating process (h)
COP_o	coefficient of performance of the air conditioner alone (dimensionless)	V_w	daily hot water supply at ΔT_w (L day^{-1})
C_v	heat capacity of water ($\text{kJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$)	W_{co}	input power of air conditioner alone (kW)
i	interest rate	W_{c2}	input power of air conditioner in SACH-2 (kW)
I_T	solar incident radiation upon the collector slope (W m^{-2})	ΔW_{c2}	$W_{co} - W_{c2}$, energy saving of SACH-2 in cooling performance (kW)
Q_e	cooling capacity of the air conditioner (kW)	ΔT_w	water temperature rise in heating performance of SACH-2 ($^\circ\text{C}$)
Q_g	heat input to the generator of ejector cooling system (kW)	ρ_w	water density (kg m^{-3})
Q_j	cooling capacity of ejector cooling system (kW)	η	solar collector efficiency

additional investment of heaters and low efficiency in heat supply.

Another problem has been noted recently that a solar heating system installed essentially for space heating in winter seasons will produce too much heat in summer while cooling is required. ECS can thus provide a promising solution to convert the excess heat into cooling in summer.

Huang et al. (2010) proposed a solar-assisted heating/cooling system (SACH) to cope with the above problems. The solar ejector cooling system is used as the boosting cooling device to provide part of the cooling load to reduce the energy consumption of the air conditioner.

The solar-assisted ejector cooling/heating system (SACH-2) was studied in the present research, in which a conventional inverter-type air conditioner (heat pump) made of variable-speed compressor are connected in parallel with a solar ejector cooling system as shown in Fig. 2. When solar irradiation is high enough to drive ECS, the cooling load is directly supplied by the ECS and the energy consumption of the compressor can be reduced by regulating the rotational speed of the inverter-type air conditioner.

During cloudy or rainy periods or at night, SACH-2 will provide the entire cooling load from the inverter-type air conditioner (heat pump) as usual. SACH-2 can also produce hot water from the solar collector.

Extensive research on the engineering design, optimal control, and performance test of SACH-2 was carried out by Huang et al. (2010). Since ejector is a simple device which can be easily and cheaply manufactured, it seems that the solar ejector cooling system can be competitive to other solar cooling technologies such as absorption or adsorption systems. However, the coefficient of performance (COP) of ejector cooling system is still not very high. So, there may be an optimal system design of SACH-2 which is most economical. The present research continues to study this problem through the system simulation and economic analysis.

2. Analytical model

The system performance of SACH-2 can be carried out from the input of solar radiation data and given design parameters of SACH-2. The long-term system performance

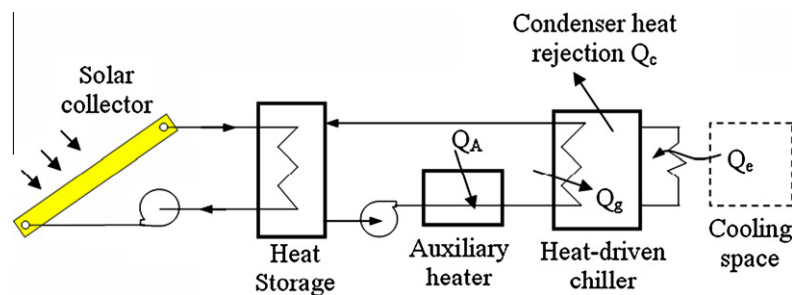


Fig. 1. Conventional solar cooling system.

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