Modified Solar-Assisted Ejector Cooling System

Bin-Juine Huang, Hua-Wei Ko, Wei-Zhe Ton, Chen-Chun Wu,
Hsien-Shun Chang, Hang-Yuen Hsu, Jen-Hao Liu, Jia-Hung Wu, Rue-Her Yen
Department of Mechanical Engineering, National Taiwan University, Taipei, Taiwan

Abstract

Solar-assisted cooling technology (SACH) was developed using a solar heat-driven ejector cooling system (ECS) to cool the condenser and reduce the power consumption of an inverter-type air conditioner (IAC). IAC provides cooling capacity for cooling load of a room, while ECS acts as a means of energy saving for IAC. A perfect system matching design of SACH is difficult since incident solar radiation is unpredictable and unstable. At high solar radiation, the cooling capacity provided by ECS can be larger than the condensing heat of the IAC. A modified SACH (named "SACH-y") is proposed in the present study, which adds another evaporator of the ECS to supply additional cooling capacity to the room. The measured net electrical COP_e of SACH-y (using an IAC with COP 3.25) reaches 5.54. If the modern advanced IAC with COP 5.7 was used, the total net COP_e will exceed 10.

Keywords: solar cooling, ejector cooling, solar ejector cooling

1. Introduction

Many solar cooling researches focus on the heat-driven cooling technology such as absorption/adsorption cooling which needs a backup heater to supply heat to run the cooling system when solar radiation is not available. This is complicated and expensive.

NTU (National Taiwan University) developed solar-assisted cooling technology (SACH) using ejector cooling system (ECS) which is driven by solar thermal collector. The ECS is used to cool the condenser of the inverter-type air conditioner (IAC) to improve its COP (coefficient of performance) and reduce the power input to the IAC. In SACH, IAC provides cooling capacity for cooling load, while ECS acts as a means of energy saving for IAC. No backup heater is required. Several types of SACH have been developed. SACH-k2 (Fig 1) was designed in package for commercialization, in which ECS is in series connection with IAC (Huang *et al*, 2014).

This research is focused on the reduction of power consumption by peripherals including cooling tower fans, refrigerant pump, water pumping of solar heating system in order to obtain an overall system COP lower than that of conventional IAC to achieve energy saving (Huang *et al*, 2014). An evaporator temperature control technology was also developed for optimal performance under variable solar radiation (Huang et al, 2010). A tracking control system (maximum-power-point tracking, MPPT) was developed for optimal pumping power consumption in solar heating system which reduces the pumping power by 73% without decreasing the solar energy collection (Huang et al, 2012). The test results show that the overall COP of SACH-k2 reaches 4.5. However, it was found that at high solar radiation, the cooling capacity provided by ECS can be larger than that required to remove the condensing heat of the IAC. This causes cooling capacity loss of ECS. Hence, a modified SACH (named "SACH-y") is proposed. An additional evaporator of the ECS was added to supply additional cooling capacity to the room.

doi:10.18086/eurosun2018.04.04 Available at http://proceedings.ises.org

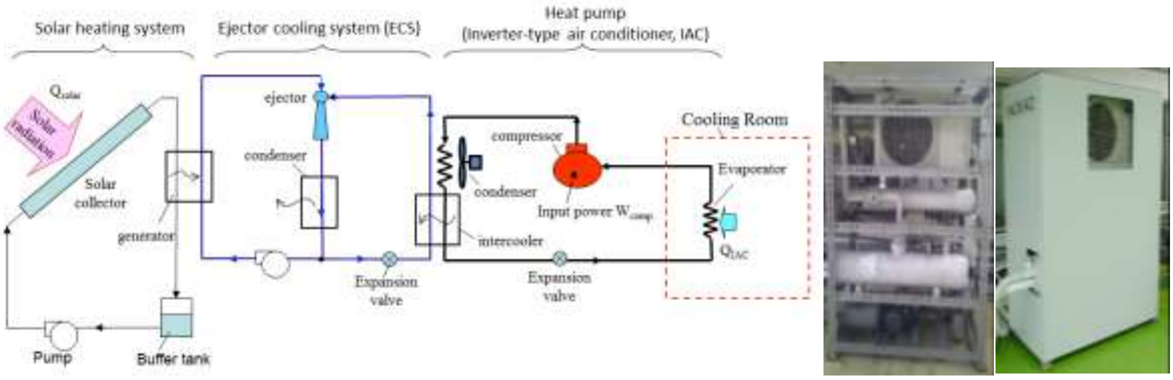

Fig. 1: SACH-k2 (package type) (Huang *et al*, 2014)

2. Design of a modified SACH (SACH-y)

SACH-y is a modified system from SACH-k2. SACH-k2 consists of 3 major parts: solar heating system, ejector cooling system (ECS) with water-cooled condenser, and inverter-type air conditioner (IAC). The schematic diagram is shown in Fig 1. ECS is coupled with IAC at the intercooler, which is the evaporator of ECS or the sub-cooler of IAC. The cooling load of the cooling room is 3.5 kW (1RT) which matches the rated cooling capacity of the IAC used. The cooling capacity of the ECS is 5.6 kW which is able to cool the condenser of the IAC at a lower condnsing temperature to increase the COP of IAC. The system design specification of SCH-k2 is shown in Tab 1. R245fa is used as the working fluid of ECS. Tab 2 shows the design specification of ECS. Tab 3 shows the specification of IAC used. Tab 4 shows the design of shell-tube intercooler.

The solar heating system used in SACH-k2 is the same as that used in the study of MPPT (maximum-power-point tracking) control of circulation pump (Huang *et al*., 2012). The solar heating system (Fig.2) consists of 24 flow-through vacuum-tube collectors (Model EZL100-6) with 26 m^2 total absorber area. Eight collectors are connected in series and three in parallel. Glycol solution is pumped from the buffer tank through the solar collector and absorbs solar energy to heat the generator of ECS. An inverter for rotational speed control of the circulation pump was installed to control flowrate and a PC-based control system was developed for the MPPT control of the circulation pump.

The solar heating system can supply hot water at temperature 70-130^{o}C to drive the ejector cooling system. A buffer tank (200L) is used as a storage for stablizing flowrate. The test of solar collector shows that the thermal efficiency of the solar heating system is 0.6 at inlet water temperature 100^{o}C (Huang *et al*, 2010).

Fig. 2: Vacuum-tube solar collector of SACH (Huang *et al*., 2012).

Tab. 1: System design specification of SACH-k2.

Design Specification of IAC	
IAC model:	MA732BVY8
Refrigerant:	R22
Condenser temperature, °C:	54
Evaporator temperature, °C:	8
Condenser heat rejection, kW:	8
Cooling capacity, kW:	1.2~4.5
Compressor input, kW:	0.4~1.125
COP_{IAC}:	3.25
Design Specification of ECS	
Refrigerant	R245fa
Generator temperature, °C	100
Condensing temperature, °C	40
Evaporator temperature, °C	20
Generator heat input, kW	8.9
Condenser capacity, kW	14.6
Evaporator capacity, kW	5.6
COP_{ECS}	0.63

Tab. 2: Design specification of ECS

Refrigerant	R245fa
Cooling capacity (kW)	5.6
Operating temperature:	
Generator temperature (°C)	100
Evaporator temperature (°C)	20
Condenser temperature (°C)	40
Flowrate:	
Primary flowrate (kg/s)	0.030
Entrained flowrate (kg/s)	0.022
Compression ratio	2.04
Entrainment ratio	0.73
Heat transfer rate:	
Generator (kW)	8.9
Evaporator (kW)	5.6
Condenser (kW)	14.5
COP_{ECS}	0.63

Tab.3: Specification of IAC.

IAC model:	MA732BVY8
Refrigerant:	R22
Condensing temperature, °C:	54
Evaporating temperature, °C:	8
Condenser heat rejection, kW:	5.6
Cooling capacity, kW:	1.2~4.5
Compressor input, kW:	0.4~1.125
COP_{IAC}:	3.25

Tab. 4: Design of intercooler.

	inlet	outlet	inlet	outlet
temperature (°C)	25	35	78	40
pressure (MPa)	0.1013	0.1013	0.143	0.121
flowrate (kg/s)	0.26	0.26	0.052	0.052
enthalpy (kJ/kg)	104.83	146.63	462.43	252.57
Max heat rate (kW)	10.9			

Tab. 5: Overall system performance of SACH-k2 (Huang *et al*, 2014).

date	05/09		05/18		05/26		05/29	
Test condition	IAC	SACH-k2	IAC	SACH-k2	IAC	SACH-k2	IAC	SACH-k2
Ambient temperature, °C	34		29.4		28		25	
IAC subcooling, °C	-	15	-	15.2	-	14.8	-	15.2
IAC power, kW	1.09	0.6	0.96	0.51	1.03	0.63	0.93	0.48
Total peripheral power, kW	-	0.32	-	0.29	-	0.27	-	0.34
Cooling capacity, kW	3.2	3.7	3.2	3.6	3.1	3.8	3.0	3.6
COP_o	2.94	4.06	3.3	4.50	2.96	4.22	3.24	4.32

The test results (Tab 5) show that the overall COP of SACH-k2 reaches 4.5. It was also found that it is difficult to obtain a perfect system matching design of SACh-k2 since solar radiation variation is unpredictable and unstable. ECS is used to cool the condenser of IAC for sub-cooling to increase the COP of IAC. At high solar radiation, the cooling capacity provided by ECS can be larger than the condensing heat of the IAC. That is, excess cooling capacity of ECS is available in good weather.

To improve the cooling efficiency, we modified SACH-k2 by adding another evaporator (fan-coil unit) of the ECS to supply additional cooling capacity (Q_{ECS}) to the room (Fig. 3), named "SACH-y". SACH-y combines the design of SACH-2 (parallel configuration) (Huang *et al*, 2010) and SACH-k2 (series configuration) (Huang *et al*, 2014).

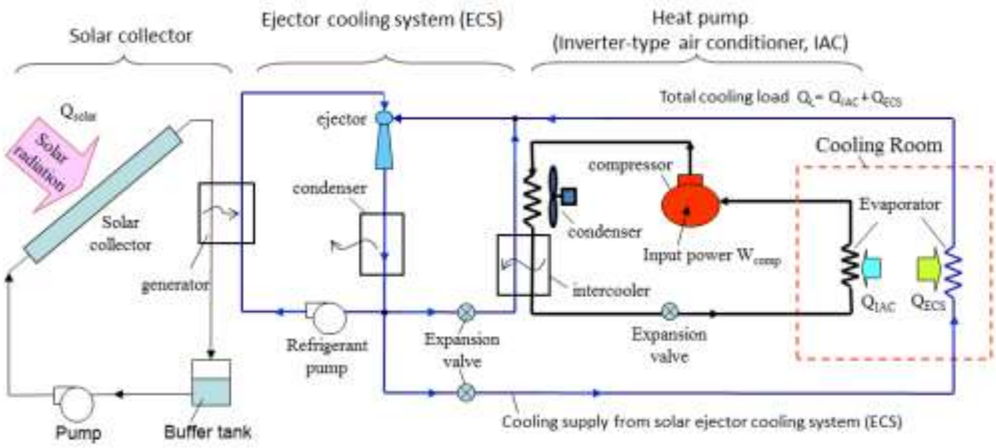

Fig. 3: Schematic of modified SACH (SACH-y).

3. Test results

The measured total electrical COP_e of SACH-y reaches 5.54 (Tab. 5) using an IAC with measured maximum COP 2.63. The technology of SACH-k2 and SACH-y has been developed quite well after a series of researches on ejector design, selection of working fluid, optimal control for stable and optimal performance under variable solar radiation, and optimal control for minimum energy consumption of all peripherals. The present result has shown a better performance than solar cooling systems using absorption/adsorption technology and falls in the target area identified by Wiemken (2010) (Fig.4). If the modern IAC with COP 5.7 was used in SACH-y, the total net COP_e will exceed 10 (Fig. 4).

Tab. 6: Test results of SACH-y.

Operating Mode	Date (ambient temp)	T_g of ECS (°C)	T_e of ECS (°C)	IAC condensing temperature (°C)	IAC intercooler temperature (°C)		Power consumption of IAC (W)	Total power consumption (W)	Cooling capacity by IAC (W)	Cooling capacity by ECS (W)	COP_e
					inlet	outlet					
IAC alone	2012/5/22	-	-	45.9	33.4	31.8	998	998	2629	-	2.63
SACH-y	(27°C)	93	16.7	31.4	29.0	18.6	417	772	2274	2002	5.54
IAC alone	2012/5/23	-	-	49.1	35.6	35.0	1061	1061	2603	-	2.45
SACH-y	(29.4 °C)	97.1	19.6	35.1	32.6	21.3	506	906	2443	1629	4.55
IAC alone	2012/5/23	-	-	49.1	35.6	35.0	1061	1061	2603	-	2.45
SACH-y	(29.2 °C)	98.3	18.9	34.1	31.7	20.8	441	855	2378	1833	4.93
IAC alone	2012/5/26	-	-	51.9	34.9	36.0	1083	1083	2370	-	2.17
SACH-y	(30 °C)	91.7	20.6	37.3	34.6	26.2	525	936	2310	1838	4.46
IAC alone	2012/5/26	-	-	51.9	34.9	36.0	1083	1083	2370	-	2.17
SACH-y	(30 °C)	92.8	21.4	35.7	33.4	23.8	455	871	2318	1839	4.77

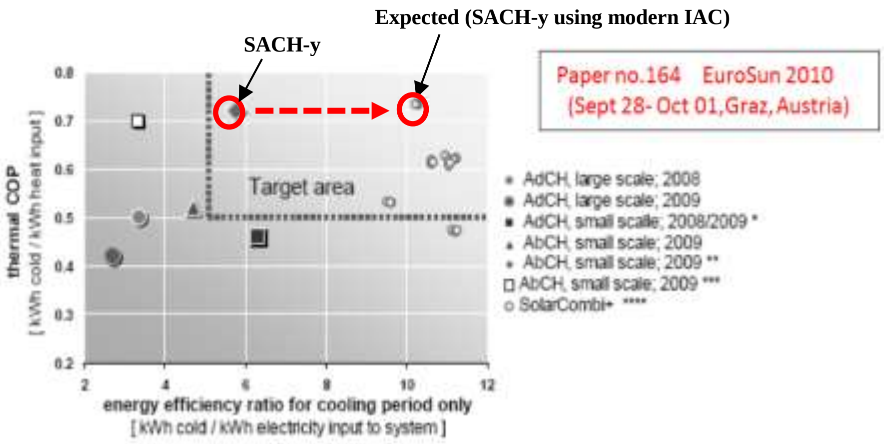

Fig.4: Performance of SACH-y inside the target area of solar cooling technology (Wiemken, 2010).

4. Conclusion

In the present study, a solar-assisted cooling technology (SACH) was developed using ejector cooling system (ECS) which is driven by solar thermal energy. SACH-k2 consists of solar heating system, ejector cooling system (ECS) with water-cooled condenser, and inverter-type air conditioner (IAC). ECS is coupled with IAC at the intercooler, which is the evaporator of ECS or the sub-cooler of IAC. Solar heat-driven ECS is used to cool the condenser and reduce the condensing temperature and power consumption of IAC. But, a perfect system matching design of SACh-k2 is difficult since solar radiation variation is unpredictable and unstable. At high solar radiation, the cooling capacity provided by ECS can be larger than the condensing heat of the IAC. This causes cooling capacity loss of ECS. Hence, a modified SACH (named “SACH-y”) is proposed in the present study. It was modified from SACH-k2 by adding another evaporator of the ECS to supply additional cooling capacity to the room. The measured total electrical COP_e of SACH-y reaches 5.54 using an IAC with COP 2.63. If a modern IAC with COP 5.7 was used in SACH-y, the total net COP_e will exceed 10.

References

Huang B.J., Yen C.W., Wu J.H., Liu J.H., Hsu H.Y., Petrenko V.O., Chang J.M., Lu C.W. 2010. Optimal control and performance test of solar-assisted cooling system. Applied Thermal Engineering 30, 2243-2252 http://doi:10.1016/j.applthermaleng.2010.06.004

Huang Bin-Juine, Ton Wei-Zhe, Wu Chen-Chun, Ko Hua-Wei, Chang Hsien-Shun, Yen Rue-Her, Wang Jiunn Cherng. 2012. Maximum-power-point tracking control of solar heating system. Solar Energy 86, 3278-3287 http://dx.doi.org/10.1016/j.solener.2012.08.019

Huang, Bin-Juine, Ton, Wei-Zhe, Wu, Chen-Chun, Ko, Hua-Wei, Chang, Hsien-Shun, Hsu, Hang-Yuen, Liu, Jen-Hao, Wu Jia-Hung, Yen Rue-Her**.** 2014. Performance Test of Solar-Assisted Ejector Cooling System. Int J Refrigeration 39, 172-185 http://dx.doi.org/10.1016/j.ijrefrig.2013.06.009

Wiemken, E. Performance and perspectives of solar cooling. EuroSun 2010, Sept. 28-Oct.1, 2010. Graz, Austria.

Acknowledgment

This publication is based on the work supported by Award No.KUK-C1-014-12, made by King Abdullah University of Science and Technology (KAUST), Saudi Arabia.