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Performance Investigation and Field Test on an Integrated System of Mechanical Refrigeration and Thermosyphon for Free Cooling of Data Centers

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Abstract

The energy consumption of data centers is increasing rapidly and has become a global concern in recent years. Nearly 50% of total energy use in a dater center is consumed by the cooling system. Therefore, it is necessary to develop free cooling system for data centers, which can use the outdoor cooling source in cold seasons. Integrated system of mechanical refrigeration and thermosyphon based on three-fluid heat exchanger is an ideal solution to use free cooling at low ambient temperature and mechanical refrigeration at high ambient temperature. In this paper, the experimental results of this system are presented. Moreover, field test is conducted in a dater center in three periods of time in summer, autumn and winter, respectively, in Beijing. The laboratory test results show that the cooling capacity of thermosyphon mode reaches 8.1 kW and the EER is 16.8 when indoor and outdoor temperature difference is 19 ^{o}C. The cooling capacity of refrigeration mode is higher than 5.0 kW in the tested temperature range and its EER is similar to traditional air conditioners. The cooling capacity of dual mode is relatively high while it is not appropriate for working when the indoor and outdoor temperature difference is lower than 6 ^{o}C. The field test results show that the system can work reliably for a long period. The average EER in summer, autumn and winter is 3.52 W/W, 5.19 W/W and 12.25 W/W, respectively. It can be seen that the EER of the system is much higher than traditional air conditioners during most time all year around.

Keywords - data center; free cooling; thermosyphon; integrated system

1. Introduction

The number and energy consumption of data centers are increasing rapidly throughout the word. In a typical data center, nearly 50% of total energy use is consumed by the cooling system [1]. It is necessary to utilize efficient cooling technology to cut down this part of energy consumption. Free cooling is one of these technologies, which means using natural cold source to cool data centers when the outdoor temperature is low. Thermosyphon has been proved to be a good equipment for free cooling [2,3], and it is convenient to be integrated with mechanical refrigeration.

Several integrated system of mechanical refrigeration and thermosyphon (ISMT) have been proposed by researchers [4-7]. However, most of the above systems rely on solenoid valves for mode switching and cannot achieve the simultaneous working of mechanical refrigeration and thermosyphon [4-6].

We proposed a novel ISMT based on three-fluid heat exchanger to avoid the above problems, which is shown in Fig. 1 [8]. The system consists of two circulation loops: a refrigeration loop and a thermosyphon loop. A three-fluid heat exchanger is used to connect the two loops, which has three flow channels for the fluid of refrigeration loop, the fluid of thermosyphon loop and outdoor air respectively. This system has three working modes. It works in refrigeration mode in warm season, the fan of the three-fluid heat exchanger stops and the compressor starts to cool the thermosyphon working fluid. Dual mode in transition season, all the fans and the compressor work to utilize both natural cold source and mechanical cold source. Thermosyphon mode in cold season, only the fans of three-fluid heat exchanger and evaporator work to cool the data center using natural cold air. A prototype has been developed and tested in the laboratory.

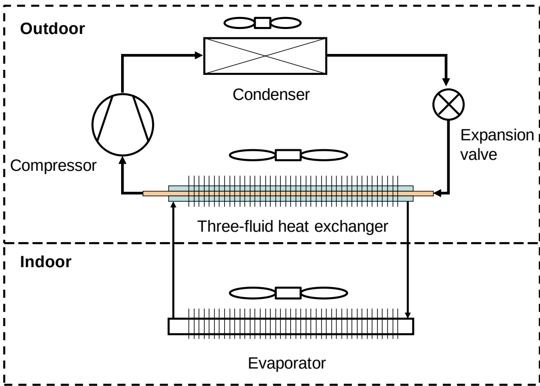

Fig. 1 Integrated system of mechanical refrigeration and thermosypon based on three-fluid heat exchanger [8]

However, the cooling capacity of the original design is not very sufficient [8]. Therefore, we have been working to improve the design and capacity. In this paper, the geometric parameters of newly developed components of the system are presented and the performance is investigated. Moreover, the system is tested in a dater center in three periods of time in summer, autumn and winter, respectively, in Beijing.

2. Performance Investigation

A tube-fin evaporator is newly designed to improve the cooling capacity and processability. Also, a new three-fluid heat exchanger is designed to reduce the flow resistance of thermosyphon loop. The specifications of the evaporator and the three-fluid heat exchanger are shown in Table 1. Details for other components in the system please see also Ref. [8]. During the experiment, the height difference between the bottom of the three-fluid heat exchanger and the top of the evaporator is 1.0 m. R22 is used as the working fluid of both the refrigeration loop and thermosiphon loop in the system, and the indoor temperature is set to 24 ^{o}C, according to a Chinese standard [9].

Table 1. Specifications of the evaporator and the three-fluid heat exchanger

Three-fluid heat exchanger		Evaporator	
Parameter	Value	Parameter	Value
Tube length (mm)	900	Tube length (mm)	920
Inner tube outside diameter (mm)	6.35	Tube outside diameter (mm)	12.7
Inner tube wall thickness (mm)	0.7	Tube wall thickness (mm)	0.75
Outer tube outside diameter (mm)	12.7	Tube number of each row	32
Outer tube wall thickness (mm)	0.75	Number of rows	3
Tube number of each row	24	Tube pitch (mm)	30.0
Number of rows	2	Row pitch (mm)	30.0
Tube pitch (mm)	31.5	Fin pitch (mm)	1.5
Row pitch (mm)	27.3	Fin thickness (mm)	0.12
Fin pitch (mm)	1.5		
Fin thickness (mm)	0.12		

The experiment is conducted in a laboratory based on heat balance method, which is shown in Fig. 2. The indoor room is heated by a known heating power therefore when the indoor temperature remains unchanged, the power is equal to the cooling capacity of the system.

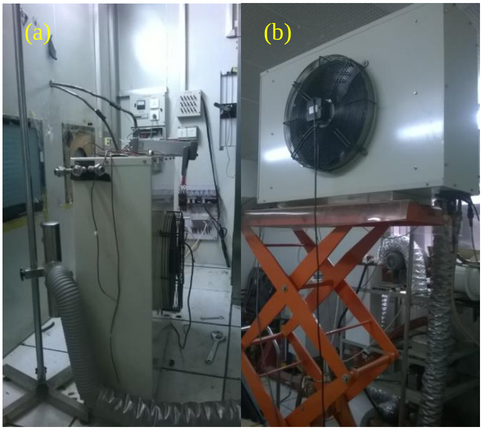

Fig. 2 Experimental setup (a) Indoor (b) Outdoor

The cooling capacity of the three modes varied with indoor and outdoor temperature difference is shown in Fig. 3. The cooling capacity of thermosyphon mode is 1.8 kW when the temperature difference is only 4 ^{o}C. This cooling capacity in small temperature difference is helpful for utilizing outdoor cold source in transition seasons. With the increase of temperature difference, the cooling capacity of themosyphon mode almost increases linearly and it reaches 8.1 kW when the temperature difference is 19 ^{o}C. The cooling capacity of refrigeration mode increases slightly with increasing temperature difference and it is higher than 5.0 kW in the tested temperature range. The cooling capacity of dual mode also increases with increasing temperature difference while the slope is lower than that of thermosyphon mode. It can also be seen that when the temperature difference is lower than 6 ^{o}C, the cooling capacity of dual mode is lower than refrigeration mode. The reason is that in this situation, the outdoor air is not cold enough and the working fluid in the thermosyphon loop is heated by the outdoor air. This situation should be avoided in application.

The input power of the three modes varied with indoor and outdoor temperature difference is shown in Fig. 4. In thermosyphon mode, only the fans consume energy and the input power stays at around 0.45 kW. In refrigeration mode and dual mode, the input power both decrease with increasing indoor and outdoor temperature difference, which is due to the decreasing power consumption of the compressor.

The energy efficiency ratio (EER) of the three modes varied with indoor and outdoor temperature difference is shown in Fig. 5. The EER of thermosyphon mode is much higher than those of the other two modes. It reaches 16.8 W/W when the temperature difference is 19 ^{o}C. The EER of refrigeration mode is 3.0~4.5 W/W, similar to traditional air conditioners.

The EER of dual mode is higher than 3.0 W/W except when the temperature difference is lower than 6 ^oC. Dual mode is not suitable for this condition. If inverter compressor is utilized, the compressor can merely supplement the capacity of thermosyphon in dual mode and this EER will be even higher.

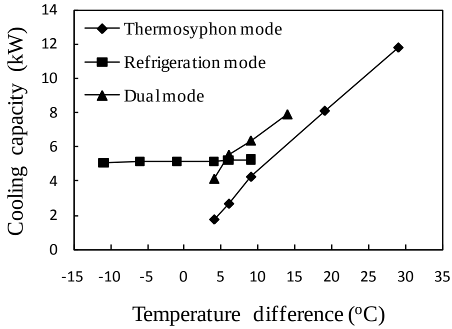

Fig. 3 Cooling capacity varied with indoor and outdoor temperature difference

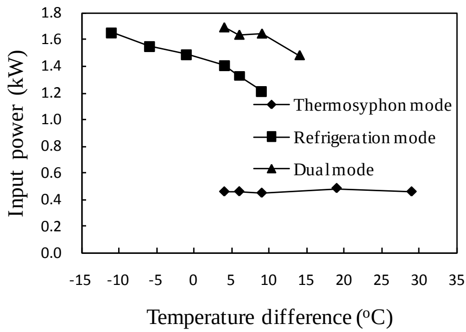

Fig. 4 Input power varied with indoor and outdoor temperature difference

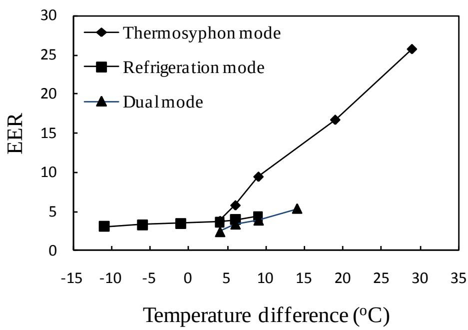

Fig. 5 Energy efficiency ratio varied with indoor and outdoor temperature difference

3. Fielt Test

In order to investigate the energy-saving potential of the ISMT, a field test is conducted in a small data center in Beijing, as shown in Fig. 5. The evaporator is placed between two rows of racks in the data center. The condenser and the three-fluid heat exchanger are hanging on the exterior wall. The air inlet, outlet temperatures of the evaporator and the outdoor temperature are measured by temperature recorders and the input power is recorded by an electricity meter. The air flow rate of the evaporator is known therefore the cooling capacity can be calculated. The ISMT is tested in three periods of time in summer, autumn and winter, respectively.

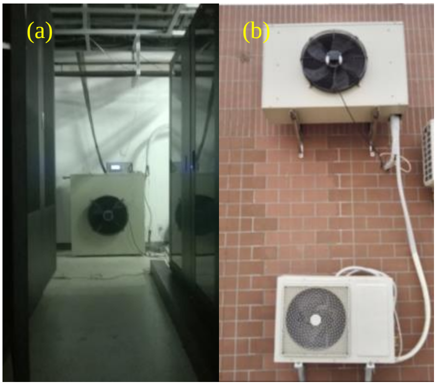

Fig. 5 Field test (a) Indoor (b) Outdoor

The air inlet temperature, outlet temperature of the evaporator and outdoor temperature in summer are shown in Fig. 6. In this period of time in July and August, the total cooling quantity is 2496 kWh, the electricity consumed is 708 KWh. The average EER is 3.52.

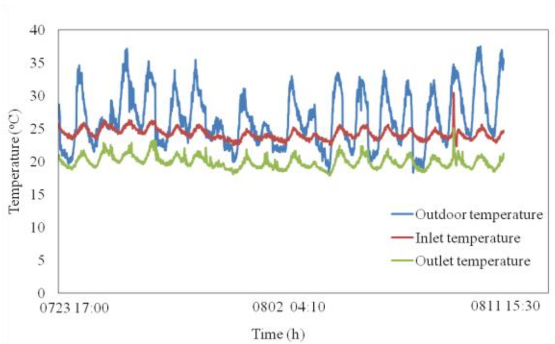

Fig. 6 Field test results in July and August

The testing data in autumn are shown in Fig. 7. In this period of time in November, the total cooling quantity is 561 KWh, the electricity consumed is 108 KWh. The average EER is 5.19. The testing data in winter are shown in Fig. 8. In this period of time in December and January, the total cooling quantity is 3504 KWh, the electricity consumed is 286 KWh. The average EER is 12.25. Therefore, the EER of the system is much higher than traditional air conditioners during most of the year.

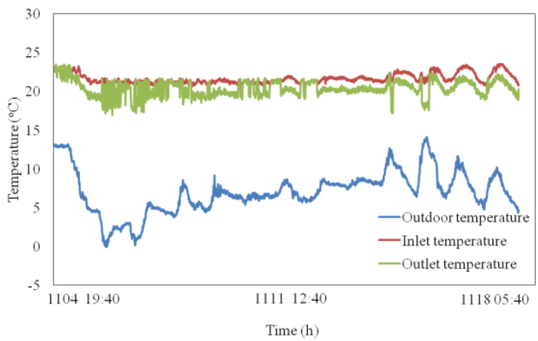

Fig. 7 Field test results in November

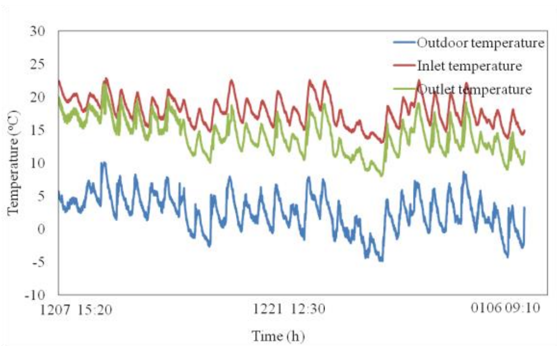

Fig. 8 Field test results in December and January

4. Conclutions

The integrated system of mechanical refrigeration and thermosyphon (ISMT) is an ideal solution to reduce the cooling energy consumption of data centers. In this paper, experimental results and field test data of a recent developed ISMT based on three-fluid heat exchanger are presented. The main results are concluded as follows:

1) The cooling capacity of thermosyphon mode reaches 8.1 kW and the EER is 16.8 W/W when indoor and outdoor temperature difference is 19 °C.

The cooling capacity of refrigeration mode is higher than 5.0 kW in the tested temperature range and its EER is similar to traditional air conditioners. The cooling capacity of dual mode is relatively high while it is not appropriate for working when the indoor and outdoor temperature difference is lower than 6 ^{o}C.

2) The field test results show that the system can work reliably for long time. The average EER in summer, autumn and winter is 3.52 W/W, 5.19 W/W and 12.25 W/W, respectively. It can be seen that the EER of the system is much higher than traditional air conditioners during most time of the year, therefore it has good energy-saving potential for application in data centers.

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