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Numerical investigation on integrated system of mechanical refrigeration and thermosyphon for free cooling of data centers

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A B S T R A C T

The cooling energy consumption of data centers is increasing rapidly and free cooling attracts growing concern. To achieve the independent running of free cooling system all the year round, integrated system of mechanical refrigeration and thermosyphon (ISMT) is an ideal method. In this study, a distributed-parameter simulation model of an ISMT is built and validated by experimental data. The simulation results show that for thermosyphon mode, the cooling capacity increases with increasing air flow rate, temperature difference and pipe diameter, while decreases with increasing pipe length. For refrigeration mode, decreasing outdoor air temperature or increasing indoor air flow rate will improve the cooling capacity and reduce the input power of the compressor. For dual mode, applicable outdoor temperature range and indoor air flow rate range exist and the cooling capacity drops below that of refrigeration mode beyond these ranges. The critical values are 19 °C and 0.5 $m^3 s^{-1}$, respectively.

Etude numérique d'un système intégré de froid mécanique et de thermosiphon pour le refroidissement naturel des centres de données

Mots clés : Froid mécanique ; Thermosiphon ; Free cooling ; Simulation; Centre de données

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Nomenclature

DM	dual mode
EER	energy efficiency ratio
G	mass flow rate [kg s^{-1}]
h	enthalpy [kJ kg^{-1}]
ISMT	integrated system of mechanical refrigeration and thermosyphon
M	fill charge [kg]
p	pressure [Pa]
Δp	pressure drop [Pa]
Q	heat transfer rate/cooling capacity [kW]
RM	refrigeration mode
T	temperature [°C]
THE	three-fluid heat exchanger
W	input power
x	vapor quality

Subscripts

act	actual
c	condensation
cal	calculated
cap	capillary
cp	compressor
c1	cold fluid 1
c2	cold fluid 2
e	evaporation
eva	evaporator
h	hot fluid
in	inlet
out	outlet
rl	refrigeration loop
sup	supposed
tl	thermosyphon loop

1. Introduction

Energy consumption of data centers is increasing rapidly with the development of information industry. This energy consumption in 2010 is more than three times of that in 2000 and it continues to increase (Koomey, 2011). The energy-saving of data centers has been a topic of wide concern.

Main equipment in data centers are IT equipment, cooling system, UPS and other auxiliary equipment (Qian et al., 2015). IT equipment in data centers run 24 h a day and 365 days of the year, therefore cooling system must work constantly to maintain the indoor environment. At present, the energy consumption of cooling system usually accounts for more than 30% of the total energy use in a data center (Koomey, 2008; Meijer, 2010). Cutting down the cooling energy consumption is an urgent need and many solutions have been proposed by researchers, including utilizing ceiling coolers (Patel et al., 2001) and rack-level coolers (Almoli et al., 2012), using waste heat, geothermal energy and other sustainable energy source to drive cooling systems (Garimella et al., 2013; Haywood et al., 2012; Kaniyal et al., 2012), indoor airflow analysis (Cho et al., 2009; Fakhim et al., 2011; Patankar, 2010; Qian et al., 2015) and so on. One of these solutions is free cooling (Dai et al., 2012; Medved et al., 2014), which means using natural cold source to cool data centers instead of mechanical refrigeration when the outside climate is cool enough. Free cooling systems can be divided into three categories: airside free cooling, waterside free cooling and heat pipe (includes thermosyphon) free cooling (Zhang et al., 2014). Among these categories, heat pipe free cooling is a new focus of recent study (Samba et al., 2013; Tian et al., 2015; Zhou et al., 2011, 2013; Zhu et al., 2013). Some of the heat pipe free cooling systems have been applied in data centers (Tian et al., 2015; Zhou et al., 2011) and the annual energy-savings are 30–50% for middle latitude regions. Although the energy-saving potential may be less than direct airside free cooling (Ferrero et al., 2013, 2015), it has advantages in some regions. It has no disturbance on the indoor environment, which is more suitable for regions with poor outdoor air quality. Also, for regions with large temperature differences between day and night, heat pipe free cooling avoids the drastic indoor temperature changes of utilizing direct airside free cooling.

When the outdoor temperature is relatively high, heat pipe (includes thermosyphon) free cooling system cannot work therefore an auxiliary mechanical refrigeration system is needed. To avoid the double space, double investment and control difficulty brought by two sets of equipment, an ideal solution is integrated system of mechanical refrigeration and thermosyphon (ISMT), which is a new concept. Okazaki et al. (1999) and Okazaki and Seshimo (2008) developed an ISMT which had two working modes: mechanical refrigeration mode and thermosyphon mode. In their design, the two modes shared an evaporator and a condenser, and a solenoid valve was used to switch between the two modes. However, the cooling capacity of the thermosyphon mode was small which limited its application. Lee et al. (2009) designed a similar system with more solenoid valves however the cooling capacity of thermosyphon mode was also small. Han et al. (2013) proposed an improved ISMT and applied it in cooling of data centers. A self-operated 3-way valve, a new evaporator and different connection pipes were developed to improve the performance. The cooling capacity of thermosyphon mode increased significantly and the energy-saving rate was 30% compared with traditional cooling systems based on four field tests in China. In order to fully analyze the energy consumption and applicability of ISMT, they built energy consumption model for the ISMT and the simulation results showed that it had good application potential in most regions of China (Han et al., 2014; Zhang et al., 2015b).

The above systems contribute to the development of ISMT while they have two disadvantages: They rely on solenoid valves to switch between different working modes which will bring reliability risk. Also, they cannot achieve the simultaneous work of mechanical refrigeration and thermosyphon which limits their energy-saving potential. Zhang et al. (2015a) developed an ISMT without any solenoid vale. Also, it achieved the simultaneous work of mechanical refrigeration and thermosyphon. The system had three working modes: thermosyphon mode, mechanical refrigeration mode, and dual mode. Experiments showed that all the three working modes had efficient cooling capacity.

Most of the above studies on ISMT are carried out by experiments. The two simulation studies (Han et al., 2014; Zhang et al., 2015b) are annual energy consumption simulation, which