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Simulation on the performance and free cooling potential of the thermosyphon mode in an integrated system of mechanical refrigeration and thermosyphon

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HIGHLIGHTS

- A simulation model of the thermosyphon mode in an ISMT is built and validated.
- The performance of different parameters and temperature differences are studied.
- The free cooling potential and energy-savings in 31 cities of China are simulated.
- The free cooling percentages are 30–70% in most studied cities of China.
- The ESR is 16–49% for a telecommunication base station of 4.5 kW.

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ABSTRACT

Free cooling based on thermosyphon is a promising technology for energy-saving in data centers. Integrated system of mechanical refrigeration and thermosyphon does not need auxiliary refrigeration system, therefore it is an ideal way of free cooling based on thermosyphon. To study its free cooling performance and potential, it is built that a distributed-parameter model of the thermosyphon mode in an integrated system of mechanical refrigeration and thermosyphon and validated by experimental data. The simulation results show that the cooling capacity and circulation flow rate increase with the increase of height difference mainly due to higher driving force of gravity, while the increase is little when the height difference is higher than 0.5 m. The cooling capacity and circulation flow rate decrease with the increase of connection pipe length due to higher flow resistance, therefore the connection pipe should be as short as possible. The cooling capacity increases rapidly with the temperature difference and reaches 5.3 kW when the temperature difference is 15 °C, with an EER of 14.3. Also with the performance model and weather data of China, annual free cooling potential in China and corresponding energy-saving and economic benefits are analyzed. For the studied cities in China except those in the hot summer & warm winter zone, the free cooling percentages are approximately 30–70%, the annual energy-saving rates are 16–49% and the payback period is 1.7–4.3 years. Therefore, free cooling based on integrated system of mechanical refrigeration and thermosyphon has great application potential for energy-saving of data centers.

1. Introduction

With the rapid development of data centers, increasing energy consumption of them has become a topic of wide concern. Data centers include all the buildings, facilities, and rooms that contain data servers, telecommunication equipment, cooling equipment and power equipment [1]. Nowadays, the energy consumption of data centers accounts for 1.1–1.5% of the world's total electricity usage [2], and industry predictions suggest that the annual increase in data center power demand can be as high as 15–20% [3].

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Nomenclature

A	area (m^2)
B	benefit (RMB)
e	electricity price (RMB kW h^{-1})
G	mass flow rate (kg s^{-1})
h	enthalpy (kJ kg^{-1})
I	investment (RMB)
k	heat transfer coefficient (kW m^{-2} °C^{-1})
M	filling quantity (kg)
n	total number of free cooling numbers
P	payback period (year)
p	pressure (Pa)
Q	heat transfer rate (kW)
T	temperature (°C)

Greek symbol

Δp	pressure drop (Pa)

Subscripts

act	actual
c	capacity
cal	calculated
cr	critical
d	dissipation
g	ground
i	indoor
l	load
o	outdoor
r	roof
sup	supposed
w	wall

Abbreviations

CRAC	computer room air conditioner
EER	energy efficiency ratio
ESQ	energy-saving quantity
ESR	energy-saving rate
FCP	free cooling percentage
ISMT	integrated system of mechanical refrigeration and thermosyphon
TAC	traditional air conditioner
THE	three-fluid heat exchanger

In a typical data center, 30–50% of the total energy is consumed by cooling system [4,5], much higher than other auxiliary equipments. Currently, most cooling systems of data centers are CRAC units with floor plenums. In this configuration, recirculation air flow and bypass air flow often exist in data centers, which lead to a poor indoor thermal environment. Moreover, CRAC units utilize mechanical cooling all the year round, without free cooling function in cold seasons [6]. As a result, traditional cooling systems are low in energy efficiency. Utilizing effective methods to cut down the consumption is essential.

Several solutions have been proposed by researchers to improve cooling efficiency, including air flow prediction and optimization methods [7–11], rack cooling solutions [12–14], absorption refrigeration utilizing waste heat in data centers [15,16,5] and so on. In these solutions, a solution called free cooling attracts more and more attention, which means using natural cold source to cool data centers when the outside climate is cool enough. Existing free cooling methods can be divided to different categories: airside free cooling [17], waterside free cooling [18] and free cooling based on thermosyphon [19–21].

Airside free cooling means drawing the outside air directly inside or utilizing the cooler outside air indirectly by air to air heat exchangers. Free cooling by air to air heat exchangers takes much space and investment therefore the application is limited. By contrast, drawing air directly inside is more feasible and its energy-saving potential in various regions across the world has been investigated by researchers, including America [22,23], Europe [23], Australia [23,24] and Korea [25]. These studies showed that airside free cooling has good energy-saving potential in most of the above regions. However, ventilation may introduce disturbance to the indoor air quality [6]. Especially in countries with poor air quality such as China, its applicability remains in doubt and the reliability risk is difficult to forecast. Waterside free cooling means utilizing natural cold source through a cooling water infrastructure. This kind of system has been developed by many air conditioning manufacturers and used in large and medium data centers, and its energy-saving potential is widely demonstrated [26]. Free cooling based on thermosyphon is a new technology, which does not affect the indoor air quality and can utilize outdoor cooling source more efficiently than waterside free cooling for the heat transfer ability under small temperature difference of thermosyphon [6,27].

As thermosyphon can only work in cool seasons, mechanical refrigeration systems have to be equipped for hot seasons. To avoid two sets of equipment, integrated system of mechanical refrigeration and thermosyphon (ISMT) is an ideal solution and several designs have been proposed [28–31]. Zhang et al. proposed a new type ISMT, which overcomes the short comings of the former design and achieves high energy efficiency [32].

Thermosyphon mode is the most important working mode and determines the application potential of ISMT. Its performance and energy-saving contribution are worthy of investigation. Until now, most recent studies in this field are experimental studies [28–32] while few simulation studies have been conducted [33,34]. Also, the exiting simulation studies only focus on the design [33] or energy consumption in several certain areas [34]. Its application method and potential is not clear, which limits its application. Considering the effectiveness of simulation for refrigeration systems [35,36], there is a lack of comprehensive simulation study in this field, especially on application method and potential.

In this paper, a simulation model of the thermosyphon mode in the ISMT proposed by Zhang et al. [32] is built and validated by experimental data. The effects of some geometric parameters in practical applications and indoor and outdoor temperature differences are simulated. With this performance model and weather data of China, annual thermosyphon free cooling potential in 31 cities across China and corresponding energy-saving and economic benefits are analyzed. The results are also summarized for using in other regions of the world. This paper offers a simulation method for thermosysphon mode of ISMT and meaningful data for application. It is hoped that this study will attract more attentions to ISMTs and free cooling based on thermosyphon.

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