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A review on thermosyphon and its integrated system with vapor compression for free cooling of data centers

Hainan Zhang[a,b], Shuangquan Shao[a,b,*], Changqing Tian[a,b], Kunzhu Zhang[c]

[a] CAS Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing 100190, China
[b] Beijing Key Laboratory of Thermal Science and Technology, Technical Institute of Physics and Chemistry, CAS, Beijing 100190, China
[c] Tsinghua University, Beijing 100084, China

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ABSTRACT

The increasing energy consumption of data centers has become a global concern. Over 30% of the total energy use in a data center is consumed by the cooling system and it is necessary to reduce this consumption by efficient cooling techniques. Free cooling is an alternative method, which means utilizing natural cold source when the outdoor temperature is lower than the indoor temperature to achieve energy-saving. Thermosyphon and its integrated system have distinct advantages over other free cooling methods and have great application potential. In this paper, the states of the art are reviewed and overviews are presented for thermosyphon and its integrated system, respectively. The features of existing designs are compared and shortcomings of current studies are concluded. This paper will be helpful for researchers in this field and promote the application of this new free cooling method.

1. Introduction

Global warming brings an urgent need of energy conservation worldwide. In recent years, the increasing demand for data processing, data storage systems and digital telecommunications, coupled with the advances in computer and electronic technology have resulted in rapid growth in data center industry, which is an increasingly important field of energy conservation [1,2]. The energy consumption of data centers in 2010 is almost three times of that in 2000, and now accounts for 1.3% of the total electricity use worldwide [3]. Data center electricity consumption is projected to increase to roughly 140 billion kW h annually by 2020 [4].

The generalized definition of data center includes all the buildings, facilities, and rooms that contain data servers, telecommunication equipment, cooling equipment and power equipment [5]. Cooling equipment is the biggest energy-consumption auxiliary facility in a data center, and its consumption usually accounts for 30–50% of the total energy consumption [6–8]. Traditional cooling system of data centers is computer room air conditioner (CRAC) with cold/hot aisle layout as shown in Fig. 1 [9,10]. It has low energy efficiency mainly due to airflow mal-distribution [11,12], energy consumption of piping systems [13] and year round working of compressors [14,15]. For the former two issues, air flow optimization methods [16], liquid cooling systems [17] and variable frequency fans [18,19] have been proposed and utilized. As to the last issue, free cooling technology, which means using natural cold source to cool a data center when the outdoor temperature is lower than the indoor temperature [20], is an ideal method and attracts more and more attention. The core idea of free cooling is find a suitable way to introduce outdoor cold source without destroying the indoor environment. Existing ways include introducing outdoor air or water directly inside, utilizing outdoor cold source by heat exchanger, rotary heat wheel or two-phase thermosyphon [21–23]. Among these methods, free cooling based on thermosyphon has advantages, which are summarized as follows:

(1) It does not disturb indoor air quality and humidity as introducing outdoor air directly inside does [24–26];
(2) It will not bring risk of short circuit when leaks occur, as introducing water directly inside does [27–29];
(3) It has better heat transfer ability compared with ordinary heat exchangers used in other free cooling methods [30,31].

Just like other free cooling methods, thermosyphon can only work when enough temperature difference exists between indoor and outdoor environment therefore vapor compression system must also be equipped to achieve environment control throughout the year. Control difficulty of the two sets, increase of initial investment and installation area restrict the further application of thermosyphon free cooling

* Corresponding author at: CAS Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing 100190, China.
E-mail addresses: zhanghn@mail.ipc.ac.cn (H. Zhang), shaoshq@mail.ipc.ac.cn (S. Shao).

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Nomenclature

Abbreviations

CRAC	computer room air conditioner
EER	energy efficiency ratio
HX	heat exchanger
ISVT	integrated system of vapor compression and thermosyphon
PUE	power usage effectiveness

equipments [32]. Therefore in recent years, integrated system of vapor compression and thermosyphon (ISVT) attracts more and more attention. This kind of system can selectively work in vapor compression mode and thermosyphon mode according to the indoor and outdoor temperature difference. It is an ideal method of free cooling and energy-saving, and has great application prospects in data centers.

Until now, many designs of thermosyphon and ISVT for free cooling have been proposed and many corresponding experimental and numerical investigations have been carried out. In this paper, the states of the art in both of these two kinds of systems are summarized. This review paper is presented in four sections. In the first section, the significance of energy-saving in data center cooling is explained and the necessity of researching on thermosyphon and ISVT is presented. In the second section, the unique features of thermosyphons in data center free cooling and the advances in recent studies are analyzed. In the third section, the existing ISVTs are presented and divided into three types. The advantages and disadvantages of each type, along with current research results are analyzed to provide the readers with a detailed knowledge about the research status. In the final section, the conclusions are summarized and future research points are suggested to help the researchers and stakeholders in this field. Meanwhile, we hope this review on thermosyphon and its integrated system can help extend their application to free cooling of other types of buildings.

2. Thermosyphon for free cooling of data centers

Two-phase thermosyphon refers to a wickless heat pipe in which the condensed liquid moves to the condenser by gravity [33,34]. It can be divided into two-phase closed thermosyphon and two-phase open thermosyphon. Only two-phase closed thermosyphon has been used in data centers because it does not need water jacket like two-phase open thermosyphon. Two-phase closed thermosyphon includes two-phase closed integral thermosyphon and two-phase closed loop thermosyphon, both of which can be applied in free cooling. The former, two-phase closed integral thermosyphon, refers to thermosyphon of which the evaporator and condenser are integral, the schematic diagram of which is shown in Fig. 2(a). There are three different sections: an evaporating section, a condensing section and an adiabatic section. The liquid in the pool inside the evaporating section evaporates under outside heating power. Then, vapor flows upward to the condensing section. Film condensation starts at the condensing section and a liquid film increases its thickness downwards, counter to the vapor under gravity. The latter, two-phase closed loop thermosyphon, refers to thermosyphon that has separate evaporator and condenser and the working fluid circulates in a loop, the schematic diagram of which is shown in Fig. 2(b). The working fluid evaporates in the evaporator and flows up through the riser. Then it condensates in the condenser and flows back through the down comer under gravity. Counter flow of liquid and vapor does not exist owing to the loop structure.

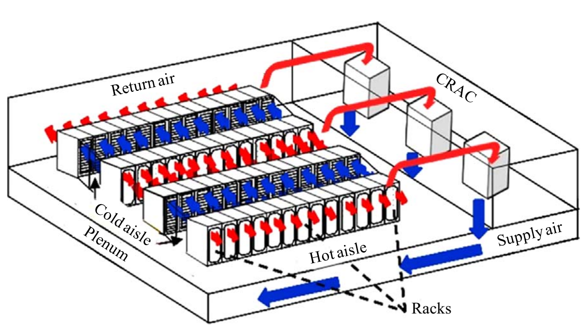

Fig. 1. Data center with CRAC and cold/hot aisle layout [9].

The application field of thermosyphon has been applied in electronic cooling [35,36], energy storage systems [37,38], solar collector [39,40], waste heat recovery [41,42], etc., for a long period. However, the studies and application of thermosyphon in data center free cooling developed mainly in the past decade with the increasing energy consumption of data centers. Thermosyphons for free cooling have their own characteristics compared with those applied in other fields. They usually transfer heat with air in both the condensation side and the evaporation side, in order to utilize outdoor cold air to cool the indoor air. To make better use of free cooling source, they often work in small temperature difference, therefore the heat flux is normally small. Meanwhile, the size is larger than the common thermosyphons for electronic cooling to transfer heat in a long distance [43]. Also, the

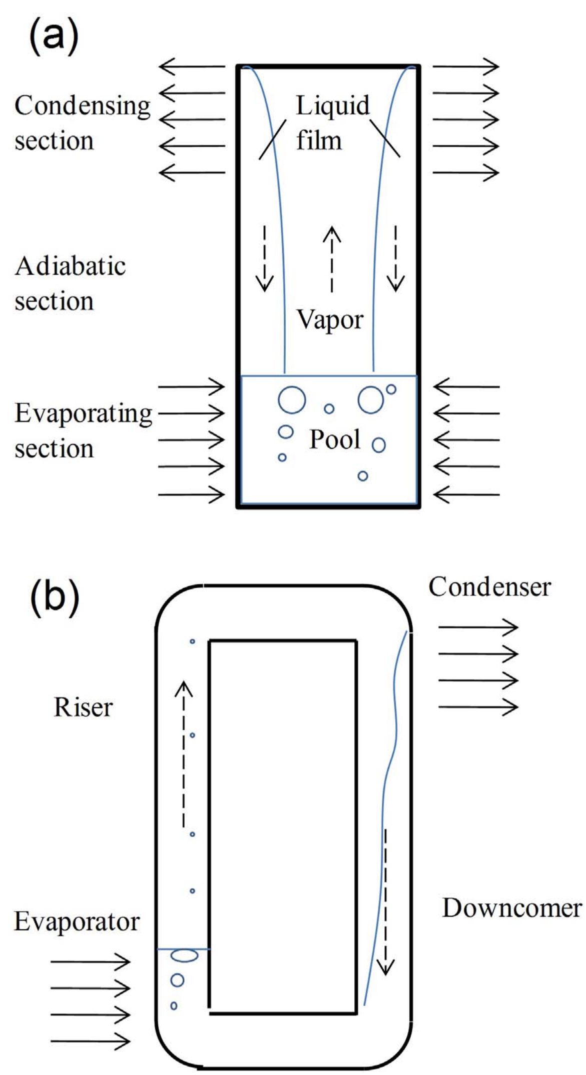

Fig. 2. Schematic of Schematic of two-phase closed thermosyphon: (a) Two-phase closed integral thermosyphon; (b) Two-phase closed loop thermosyphon.