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Research Paper

A review of current status of free cooling in datacenters

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ABSTRACT

In this study, an overview of current status of the free cooling technologies applicable for datacenters had been discussed, including airside economizers, waterside economizers, and heat pipe technology. By introducing the free cooling technologies, the compressor loading of refrigeration system can be partially or completely relieved. Utilization of airside or waterside free cooling relies strongly on the ambient conditions, yet either airside free cooling or waterside free cooling may be integrated with other systems such as absorption, solar system, adsorption, geothermal, evaporative cooling, and the like to extend its performance. On the other hand, thermosiphon heat exchangers and pulsating heat pipes feature unique characteristics to transfer heat at small temperature difference are quite promising for datacenter free cooling.

1. Introduction

In recent years, electrical power consumed in data centers has experienced a dramatic increase, and it is expected to pose critical influence on information technology (IT) now and in the coming future [1]. The energy demand for datacenter surged more than 100 times higher as compared to related infrastructures such as typical buildings [2]. Datacenters normally comprise buildings, rooms, and facilities that contain enterprise servers, server communication equipment, cooling equipment and power equipment, have an average energy consumption of 872 kW h/m^2 by 2011 [3]. On the other hand, from 2006 to 2011 energy consumed by data center servers and related infrastructure equipment has doubled in the United States and worldwide [4]. In 2006, US Environmental Protection Agency (UPA) predicted that the costs of all US data centers were 4.5 billion dollars, yet by 2011 was 7.4 billion dollars [5]. Moreover, the average power density of datacenters is currently about 6 kW per rack. According to power trend of datacenter, with the rapid growth of the datacenter infrastructures accompanied with the development of higher power density server components, the average power density of datacenters is expected to reach 50 kW per rack by 2025 [6,7].

Meanwhile, the energy consumption of traditional cooling systems of datacenters infrastructures normally takes up about 50% of the total energy consumption and can be even more severe in some situations [8–10]. A typical breakdown of the current datacenter total energy consumption is shown in Fig. 1 [1]. In this regard, implementing efficient cooling systems, strategies, and methods which can help to reduce the energy costs of traditional cooling systems, is imperative for datacenters. Traditional cooling systems which depend on vapor compression cycle by which may consume large quantities of electrical power subject to some subsequent reasons. Firstly, this cycle needs to work all the year round, and even during winter season when the ambient temperature is low. Secondly, mixing of cold and hot air streams, that is happening due to the lack of airflow control devices. Thirdly, datacenter cooling systems, especially waterside cooling systems, require mechanical piping system, which consumes a lot of energy through pumps and fans to transport cold water or air, regardless long distance transportation could result into appreciable loss [11]. The efficiency of datacenter cooling systems can be improved through elimination/reduction of long distance transportation. Some previous studies had found various solutions for such problems, such as using rack backdoor coolers [12], ceiling coolers [13], and inverter controlled fans [14], structure of the perforated tiles optimization [15–18], supply and return modes [19–21], and some particular rack arrangement [22,23]. These methods had been used to ease concerns of the second and third aforementioned problems. For resolving the firstly mentioned problem, a common widely used energy efficiency strategy is the so called free cooling technology, which is known as economizer cycle. By employing this concept, utilization of either computer room air conditioner (CRAC) units or chiller plants can be reduced or potentially eliminated, resulting in substantial savings in the total cooling energy requirement [24,25]. Economizer cycle makes use of the ambient climate

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Nomenclature

AHU	air handler unit	NSIDC	national snow and ice data center
ASHRAE	American society of heating, refrigerating and air-conditioning engineers	PHP	pulsating heat pipe
CES	cold energy storage	PUE	power usage effectiveness
COP	coefficient of performance	RH	relative humidity
CRAC	computer room air conditioner	TS	thermosiphon heat exchanger
CRAH	computer room air handler	US	United States of America
DX	direct expansion	UK	United Kingdom
HE	heat exchanger	UPA	environmental protection agency
IBM	international business machines corporation	TES	thermal energy storage
ISMT	integrated system of mechanical refrigeration and thermosiphon	UPS	uninterruptible power supply
IT	information technology	VFD	variable frequency drive

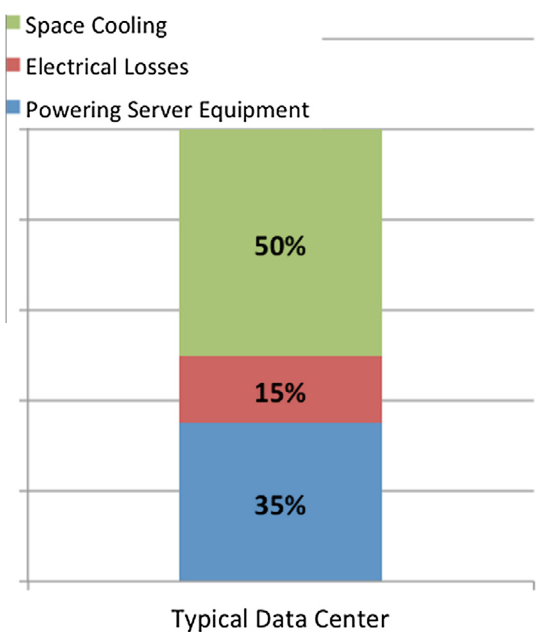

Fig. 1. Typical energy use breakdown of datacenter energy consumption [1].

especially in mild and cold climates areas to relief the need of the CRAC/chiller plant inside data centers facilities. This is because normally the outside temperature in the vast majority of regions is lower than that inside datacenters. However, when the outside temperature is high, the refrigeration cycle must be employed, and the ambient dry bulb temperature and relative humidity may play essential role on the refrigeration system. Therefore, under certain favorable conditions and careful manipulation, the compressor can be bypassed, which can lead to a considerable energy savings. Many studies have examined the potential of using free cooling economizers in datacenter infrastructures [3,4,8–10]. The current economizers utilized in the datacenters can be divided into three categories, namely the airside economizers, waterside economizers, and heat pipe cooling systems which had recently been introduced to datacenters. The airside free cooling cools the datacenter by either directly bringing the cold air into the datacenter or indirectly through some heat exchange equipment. Hence some filters or heat exchangers (e.g. fin-and-tube heat exchangers, rotary wheel, air-to-air heat exchangers and the like) are required. The waterside free cooling adopts cooling tower, water pump, and relevant infrastructures to circulate colder water into the CRAC.

However, there are three remarkable factors that impact the utilization of economizers. The first factor is the geographic location; airside economizer can be easily implemented in the mild and cold climate areas, while it is hard to apply in hot and/or humid areas and in the areas of rapidly changing climate. The second factor is the allowable operating range. Before 2008, the range for ambient temperature and humidity is comparatively narrow according to the ASHRAE regulation, limiting embodiment of airside economizer. However, ASHRAE in 2011 had relaxed the operating conditions such as, dry-bulb temperature, humidity ranges and maximum dew point [26]. Accordingly, it had appreciably boosted the use of airside economizer for more operational hours during the whole year, resulting in substantial energy and efficiency savings. Table 1 and Fig. 2 depicted the associated ASHRAE regulations for environmental classes [27]. In order to achieve higher reliability of economizers, datacenter operator must choose an appropriate class to operate in the most energy efficient mode. The third factor which affects the economizers is the arrangement in the datacenter. The most crucial importance comes from how to avoid mixing of hot and cold air stream, and this can be made available through some efficient separation of cold air supply from hot air supply. Two types of commonly used cold- and hot-aisle containments are shown in Fig. 3 [28]. In the past the economizers were used as a supplement of operation that could gain some better energy savings and efficiencies during certain time of the year. Nowadays, the use of economizers is becoming primary mode of operation to ease the loading of mechanical refrigeration-based system since it can reduce or even eliminate the runtime of compressor, thereby yielding highly efficient datacenter cooling systems. The purpose of this paper is to provide an overview of the recent used datacenter economizers, modes and options, and to develop guidelines for selecting the proper economizer to match different situations and conditions of datacenter infrastructures.

Table 1
2011 ASHRAE environmental classes for data centers applications [27].

Range	Class	Dry-bulb temperature	Humidity range, non-condensing
Recommended	All A	64.4–80.6 °F	41.9 °F DP to 60% RH and 59 °F DP
Allowable	A1	59–89.6 °F	20–80% RH
	A2	50–95 °F	20–80% RH
	A3	41–104 °F	10.4 °F DP and 8% RH to 85% RH
	A4	41–113 °F	10.4 °F DP & 8% RH to 90% RH
	B	41–95 °F	8% RH to 80% RH
	C	41–104 °F	8% RH to 80% RH

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