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Free cooling of data centers: A review

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ABSTRACT

The growing demand for electricity and the increasing size of the carbon footprint of data centers worldwide bring a severe challenge to sustainable development of human civilization. The cooling energy consumption takes up around 30–50% of the total consumption of data centers due to the inefficient cooling system. Free cooling is an effective solution for reducing the power consumption of cooling systems. This paper reviews the advancements of data center free cooling mainly focusing on configuration features and performances. Three kinds of free cooling methods, airside free cooling, waterside free cooling and heat pipe free cooling are discussed and performance characteristics of each are analyzed. Further, the criteria of performance evaluation for free cooling of data centers are summarized, and an overview of free cooling systems based on these criteria is demonstrated in order to help researchers acquire the latest developments in this area.

Contents

1. Introduction

Ever since the third industrial revolution, the rise of information technology (IT) has brought great reform to human life. Data centers, which include all the buildings, facilities, and rooms that contain data servers, telecommunication equipment, cooling equipment and power equipment [1], are developing quickly as an important part of IT industry [2,3]. However, increasingly serious energy crisis comes with the rapid expansion of the number of data centers. Electricity used by data centers worldwide doubled from 2000 to 2005; Even though the 2008 financial crisis caused economic slowdown, this number increased by about 56% from 2005 to 2010 [4]. In 2010, total electricity used by data centers was of about 1.3% of all electricity use for the world. For US, it was 0.12% in 2000 [5] and 2% in 2010 [4].

As mentioned above, cooling equipment is one of the main facilities in data centers. Data centers must be adequately cooled

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Nomenclature

Q	heat dissipation (W)
Q_{con}	heat dissipation of condensation(W)
Q_{exp}	heat dissipation of evaporation(W)
Q_{pcm}	heat stored in phase change material(W)
Q_w	heat stored in water(W)
T_a	ambient temperature (°C)
T_e	enclosure temperature (°C)

Abbreviations

BMS	battery management system
COP	coefficient of performance
CRAC	computer room air conditioner
CRAH	computer room air handler
DX	direct expansion
IACT	Integrated air conditioner with thermosyphon
IT	information technology
PCM	phase change material

because heat dissipation has become a major determinant factor of availability and reliability. Traditional cooling equipment of data centers is a computer room air conditioner (CRAC) based on mechanical vapor compression refrigeration. Its energy consumption takes up around 30–50% of the total consumption of data centers [6–8]. An example of data center energy split is shown in Fig. 1 [7].

Traditional cooling system consumes a large quantity of energy due to three main reasons:

(1) High energy consumption of cold source. Traditional vapor compression system needs to work all the year round, even at night or in winter when the temperature is low.
(2) Large energy consumption in piping system. A lot of energy is used by pumps and fans to transport cold water or air. Meanwhile, long distance transportation results in a loss of cold source.
(3) Mixing of cold and hot air streams. Entrainment of the hot air into the cold aisles is widely seen due to the lack of airflow control devices [9].

We can improve the efficiency of the cooling system from these three aspects. For the second and third aspects, control methods proposed by scholars include utilizing frequency conversion fans [10], ceiling coolers [11] and rack backdoor coolers [12], optimizing the structure of perforated tiles [13–16], relative position of racks [17,18] and mode of supply and return air [19–21]. For the first aspect, free cooling technology is an ideal solution.

Free cooling, which is commonly known as economizer cycle, involves using the natural climate to cool the data center as opposed to the more traditional method of using conventional systems such as air-conditioning [22,23]. That is, when the outside air (or water) is cool enough, it can be used as a cooling medium or the direct cold source of data centers. For the vast majority of regions, the outdoor temperature is lower than that of the data center in a long period of the year. When the outdoor temperature is sufficiently below the data center temperature, the heat will naturally flow to the outside without the need of the "temperature boost" provided by the compressor and the vapor-compression refrigeration system, so its function is unnecessary. Therefore, under favorable conditions, the compressor can be bypassed, which can save energy significantly. When the compressor is bypassed, economizers are used to utilize natural cold source. Two categories of economizers are in use currently, waterside economizer and airside economizer. In recent years, a new kind of free cooling system, heat pipe cooling system, has been developed and come into service.

For a long period, free cooling application in data centers was restricted because the environment demands of data centers were so harsh that the outside environment was not appropriate for free cooling in most time in a year. However, ASHRAE class changes in 2008 and 2011expanded the use of chillerless data centers [24–26]. The 2011 ASHRAE classes for data centers are shown in Fig. 2 [26]. 2011 classes A1 and A2 are identical to 2008 classes 1 and 2. Two allowable environmental classes, A3 and A4, are added to expand the environmental envelopes for IT equipment. Data center operators can choose an appropriate class to operate in the most energy efficient mode and still achieve the reliability. These changes bring a good opportunity for free cooling, which is considered to be one of the most prominent ways to make data centers more efficient [27] and has a great potential in data center cooling applications.

Nowadays, free cooling technology of data centers is developing rapidly. The aim of this paper is to provide basic background knowledge and a review of existing literatures on free cooling system of data centers, which is grouped into three categories: airside free cooling, waterside free cooling and heat pipe free

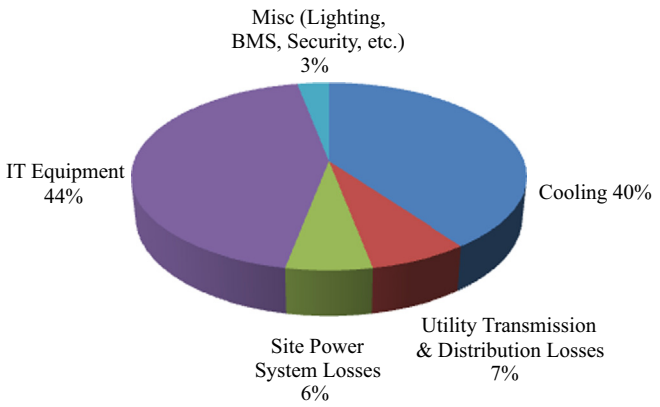

Fig. 1. Example of data center energy split [7].

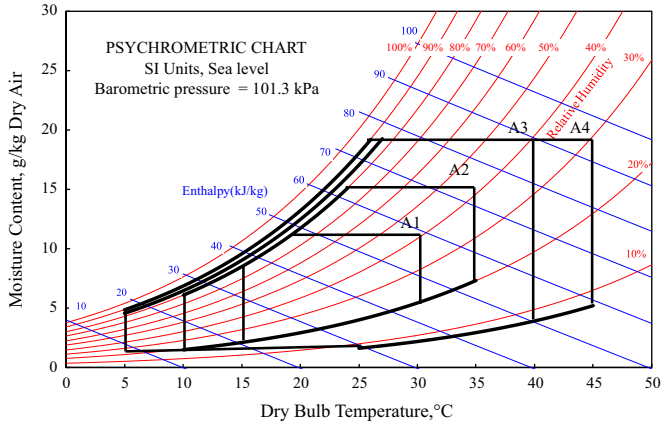

Fig. 2. ASHARE environmental classes for data centers [26].