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Energy conservation effects of a multi-stage outdoor air enabled cooling system in a data center

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ABSTRACT

Energy consumption rates in a data center have increased year by year, and by this, the introduction of energy conserving cooling systems is rapidly emerging all over the world. In this study, a multi-stage outdoor air enabled (MOA) cooling system is proposed as the safer and more energy conserving system for a data center. An MOA cooling system is composed of the combination of water-side economizer, air-side economizer and mechanical cooling. Effects of an MOA cooling system are investigated by energy simulation from various viewpoints. The results show that the MOA cooling system can save cooling energy consumption rates by about 21%, and if combined with a special rack enclosure, by about 33%. Introducing outdoor air flow into the MOA cooling system decreases energy use to about half of that of the air-side economizer, and if combined with the rack enclosure, by about 9%. Thus, the concerns about particulate and gaseous contamination can be reduced. Continuous operating time of the humidifier drops to about 3 days, and if combined with the rack enclosure, to '0' day. These results make it possible to remove the humidifier as part of the MOA cooling system.

1. Introduction

With the rapid development of IT (information technology) industries over recent decades, the needs for data centers has grown steadily. Server rooms in a large data center are composed of many server racks which house server computers, storage and other systems. Heat generation rates per rack have increased year by year through the improvement of server computer performance, and it is anticipated to become even larger with the appearance of the blade server. Based on predictions, the power consumption rates of data centers constitutes over 0.5% of the total power use around the globe [1]. The data center market is growing very fast. Michael Rutberg et al. mentioned by citing a 2011 report from Microsoft that annual market size for data center construction was about $15 billion for the U.S. and $50 billion globally, and will be growing to $80 billion globally by 2020 [2,3].

Cooling energy need in a data center accounts for about 30% of the energy consumption of an average data center [4,5]. There may be several ways to conserve cooling energy. Economizer cycles using free cooling can be an effective energy saving method. Efforts to reduce cooling energy consumption by economizer cycles have been conducted by many researchers. Steven Pelley et al. developed an analytic framework for modeling total data center power and abstract models that replace key simulation steps with simple parametric models [6]. Jinkyun Cho et al. compared the energy performance of a water-side economizer and air-side economizer in temperate or subtropical regions, and estimated their improvement of energy performance at 16.6% and at 42.4% in each [7]. Hao Tian et al. investigated the water-side free cooling potential in a combined system of multi-stage heat pipe and water loop with serially connected multi cold sources. They found that energy efficient cooling could be expected, and confirmed that the annual cooling cost reduction is approximately 46% through a comparative measurement [8]. Christy Sujatha.D et al. estimated energy consumption in a data center using a conventional cooling system, air-side economizer and water-side economizer for three different zones whose outside air is relatively cool for most of the year, and found that water-side economizers were consistently outperforming an air-side economizer [9]. Aayush Agrawal et al. examined energy savings potential of water-side economizer and indirect

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evaporative cooler for the 17 worldwide climate zones defined by ASHRAE 90.1, and found that more than 30% energy savings could be achieved by indirect evaporative cooler in climate zones 3–7, and more than 25% by water-side economizer in climate zones 4 and 5 [10]. Bruce A. Hellmer analyzed the electrical and water consumption for cooling systems of telco/data centers located in various cities throughout the United States, and found that water-side economizers are less effective than air-side economizers at improving energy efficiency and reducing refrigeration dependency. They also found that air-side economizers with steam humidifiers are an energy wasteful design because more power was consumed by the steam humidifiers than is saved by the air-side economizers [11].

Jayantha Siriwardana et al. investigated cooling potential of air-side economizers in 20 cities of Australia, and demonstrated sizable potential for significant savings on cooling costs [12]. Kuei-peng Lee et al. examined the potential energy savings by air-side economizer with differential enthalpy control in 17 world climate zones. Their results show that energy consumption of fan and the humidification/dehumidification system substantially reduced the benefit of free cooling, and therefore, the air-side economizer could not be an optimal or suitable solution in some climate zones [13]. Sang-Woo Ham et al. investigated an energy optimization process for the air-side economizer in a modular data center with respect to various parameters, and suggested the optimum supply air temperature range of 18–23 °C [14]. They also studied the applicability of various air-side economizers in modular data centers, and found that total cooling energy savings of 47.5% to 67.2% were possible [15], and in an examination of water-side economizer and cold aisle containment in a modular datacenter, they found that the energy savings of a water-side economizer combined with cold aisle containment are much greater than without containment [16]. Milnes P. David et al. tested a chiller-less data center experimentally where server-level cooling is achieved through a combination of warm water cooling hardware and re-circulated air, and characterized an average cooling energy use of 3.5% of the total IT energy use [17]. Hiroshi Endo et al. examined the use of fresh-air cooling to reduce energy consumption in container data centers. They confirmed that direct fresh-air cooling combined with evaporative cooling and waste heat from IT equipment is available even when the outside air conditions were out of acceptable server setting ranges [18].

Baptiste Durand Estebe et al. investigated the effects of cooling plant energy conservation by a strategy of regulating supply air temperature in the case of an Integrated Water Side Economizer system, and showed that 17% of electric energy used by the cooling plant could be saved [19,20]. Eduard Oró et al. investigated an energy saving potential of the integration of direct air free cooling strategy and thermal energy storage system in data centers located at different European locations, and showed that the operational cooling cost could be drastically reduced when thermal energy storage was used in combination with an off-peak electricity tariff [21]. They also summarized renewable energy integration into data centers and its characterization using numerical models [22]. Ali Habibi Khalaj et al. analyzed the effectiveness of energy and exergy, and the environmental and economic impact of the cooling system with various economizers for 23 locations across Australia. They found that the energy saving potential increased for locations further south in Australia [23].

Jinkyun Cho et al. investigated each technical component's influence on energy-optimized data centers, and derived how the prioritization of system selection should be made [24]; they proposed an analytical approach methods for the energy efficiency optimization of high density data center for four different climate regions [25].

An air-side economizer is a very efficient system for the cooling energy conservation in a data center. However, there are concerns of particulate contamination and gaseous contamination. Water-side economizers on the other hand is a safe solution, but its available operation hours are very limited. In the researches so far, an air-side economizer or water-side economizer has been investigated in terms of their energy conservation effect individually or in combination with other mechanical systems. Authors recognize that the merits and demerits of air-side economizers and water-side economizers are contrary to each other. In this study, by integrating the merits of air-side economizers and water-side economizers, a multi-stage outdoor air enabled (MOA) cooling strategy was established, and its cooling energy conservation effects are investigated. The MOA cooling strategy is based on the combination of air-side economizers, water-side economizers and mechanical cooling, and by virtue of the combination, more efficient and less risky cooling for data centers is expected.

2. Economizer cycles

Economizer cycles are free cooling systems utilizing outdoor air under certain conditions to allow chillers and/or other mechanical cooling systems to be shut off or operated at reduced capacity [26].

2.1. Air-side economizers

An air-side economizer is an energy conserving system for cooling by direct introduction of outdoor air under proper conditions. Fig. 1 shows the schematic of air-side economizers. In an air-side economizer, outdoor air is introduced to a computer room by computer room air handler (CRAH) units when the enthalpy of outdoor air meets the requirement for cooling. Air-side economizers can be operated fully or partially, and it needs an additional fan for the exhaust air. Comparing with water-side economizers, in general, air-side economizers are more energy efficient, and their available operation is longer. There have been four concerns with the use of air-side economizers in data centers [11] which can be summarized as:

- Increased particulate contamination and/or increased maintenance cost on filters.
- Increased gaseous contamination.
- Loss of humidity control during economizer operation and loss of a vapor seal during non-economizer operation.
- Temporary loss of temperature control during economizer switchover with non-integral economizers.

A study by LBNL showed that particulate concentrations in data centers could be kept to those of current data centers by applying MERV 11 filters, and that the humidity was within ASHRAE's recommended range in most data centers [27].

2.2. Water-side economizers

Water-side economizers are operated by the aid of cooling towers. When outdoor wet-bulb temperature meets the facility's cooling requirements, a computer room can be cooled only by condenser water. There are two types of water-side economizers, i.e. direct and indirect. In case of direct economizer, the condenser water flows into the chilled water circuit. Even though the direct economizer is a more energy efficient system, there may be tube fouling concerns [26]. Indirect economizer needs heat exchanger between condenser water and chilled water, and, therefore, its efficiency is lower than the direct economizer. Fig. 2 shows the schematic of the indirect water-side economizer. Water-side economizers, compared with air-side economizers, are the safer system with no concerns mentioned in the previous section. But their available use is shorter.