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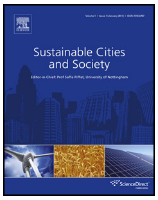

Economic analysis of data center cooling strategies

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ABSTRACT

Advancements in information technology have led to an increasing demand for data centers (DCs), and the energy consumption of DCs has gained attention worldwide. Many researchers have attempted to develop efficient DC cooling systems to reduce the energy required for cooling DCs, however, there are limitations in identifying the effect of such systems from the economic perspective. Subsequently, project owners find it difficult to decide whether to apply these systems to their particular DCs. The present research aims to analyze the economic performance of seven cooling strategies developed by the combinations of widely used DC cooling systems. The economic performance of each strategy is estimated by the life cycle cost analysis technique, and the analysis results show that Strategy 5 (A2_M: air-side economizer and supplementary cooling by a mechanical system) yields economic benefits of 26.84% in comparison to the conventional cooling system. The proposed research methodology and obtained results are expected to aid project owners in making effective decisions regarding the selection of an appropriate cooling strategy from an economic perspective.

1. Introduction

Data centers (DCs) are centralized facilities that store information technology (IT) equipment such as servers, data storage devices, network devices, and monitors to perform various functions such as storage, management, processing, and exchange of digital data and information. A DC is an essential facility for information and communication technology (Sun & Lee, 2006). Mobile and wireless networks and web-based, social, and multimedia applications are the driving forces of the currently ongoing paradigm shift from communication-centric to information-centric internet. Conventional IT infrastructures are challenged by cloud networks with distributed DCs that make full use of multicore processing and large storage capacities; this facilitates fast access to data, search, and business process applications (Kuehn & Mashaly, 2015). From this viewpoint, the size and load density of DCs have been increasing sharply in the last decades, and subsequently, the energy consumption of DCs has become a significant issue (Phan & Lin, 2014; Fulpagare & Bhargav, 2015). The energy consumption of DCs is typically much larger than that of other building types, and it has been reported that DCs can consume up to 100 times more energy than a standard office building (Phan & Lin, 2014). Thus, it is crucial to manage the energy usage in DCs.

With this background, several researchers attempted to solve the problem of the large energy consumption of DCs through various methods such as individual component modeling of DCs and design of the layouts of each component of DCs. Such methods can be roughly classified into the following categories (Fulpagare & Bhargav, 2015): (i) raised-floor plenum airflow modeling and rack layout, (ii) DC cooling strategies, and (iii) programming-based optimization of DCs.

Research related to the first category is focused on improving the thermal performance of a DC by applying alternative air circulation methods in accordance with various designs of a raised-floor plenum and rack layout. Generally, a configuration with hot and cold aisles—which is obtained by raised floor plenum airflow modeling and rack layout—is a widely accepted DC layout because the design of airflow patterns strongly influences the overall energy performance of a DC (Fulpagare & Bhargav, 2015). Consequently, several researchers attempted to determine the optimal cooling scheme for a given DC building by evaluating the thermal performance of dynamic design alternatives of the raised-floor plenum and rack layout (Cho, Yang, & Park, 2014a; Karki & Patankar, 2006;

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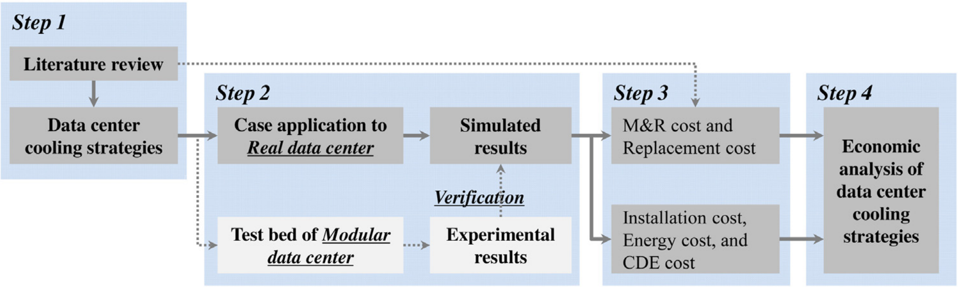

Fig. 1. Flowchart of research.

Patankar, 2010; Phan & Lin, 2014; Qian et al., 2015; Rambo & Joshi, 2007; Samadiani, Rambo, & Joshi, 2010; Schmidt & Cruz, 2005).

In research related to the second category, methods to conserve the energy efficiency of DCs were explored in consideration of dynamic cooling strategies. In general, two strategies can be adopted to refrigerate IT equipment: the use of air-cooled systems and the use of liquid-cooled systems. Liquid-cooled systems are considered to provide better performance at sufficiently high water temperatures of supply facilities (Fulpagare & Bhargav, 2015; Oro, Depoorter, Garcia, & Salom, 2015). Although liquid-cooled systems are relatively more energy efficient for cooling DCs, more advanced methods that facilitate a considerable reduction in cooling demands are necessary owing to the large energy consumption of DCs. As such, the industry and researchers are exploring various effective techniques to reduce the energy required to refrigerate IT equipment. Attempts to this end include the following (Ham, Kim, Choi, & Jeong, 2015; Lee & Chen, 2013; Oro et al., 2015; Priyadumkol & Kittichaikarn, 2014; Siriwadrana, Jayasekara, & Halgamuge, 2014; Zhang, Shao, Xu, Zou, & Tian, 2014): (i) application of air-side or water-side free cooling, (ii) construction of hot and cold containment aisles, (iii) application of variable airflow, and (iv) reduction of inefficiencies of the equipment.

Research related to the third category is based on the development of various optimization methodologies that focus on minimizing the power utilization and workload of DCs. Researchers attempted to develop an appropriate methodology and then reduce the energy demands for DC operation by considering the following aspects (Durand-Estebe, Bot, Mancos, & Arquis, 2013; Kuehn & Mashaly, 2015; Lopez & Hamann, 2011; Song, Murray, & Sammakia, 2013; Wang, Tolia, & Bash, 2010; Wang, Khan, & Dayal, 2012): (i) temperature management to maintain the server in the allowable American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) range (from 17 °C to 30 °C) and (ii) optimization algorithms and models for control of the power usage in cooling equipment and IT equipment.

As described above, even though a number of studies have proposed valuable methods for reduction of the energy consumption of DCs, analysis of the economic effects of the improved energy performance achieved by the existing methods is necessary. That is, DC owners still find it difficult to understand how much economic benefit the existing methods can provide when applied and what types of cooling systems and methods can provide better economic efficiency. This study aims to identify the economic performance of different DC cooling strategies developed using combinations of widely used DC cooling systems.

The economic performance of different DC cooling strategies was evaluated in four steps, as shown in Fig. 1. In step 1, generally accepted cooling strategies were identified by literature review. In total, seven cooling strategies were developed in consideration of both the recommended ASHRAE temperature range (ASHRAE, 2009) for a DC and the types of economizers required for refrigerating the server room (i.e., air-side economizer, water-side economizer, and a combination of both). In order to acquire the cost information necessary for evaluating the economic performance of these developed strategies, in step 2, they were applied to a target DC under operation. Then, a simulation study was conducted for each strategy in order to estimate several cost items, which were the components of a subsequent economic analysis. Concurrently, an experimental measurement of a modular DC constructed for this research was performed. The simulation results for the target DC were verified by comparison with the results of the experimental measurements. In step 3, on the basis of the verified simulation results, an economic analysis was performed using the life cycle cost (LCC) analysis technique. In step 4, the obtained results for the developed cooling strategies were discussed and the findings were noted.

2. DC cooling strategies

The representative energy-saving cooling system for DCs is an economizer cycle; this cycle involves a free cooling system that utilizes outdoor air, water, or both for cooling a DC (Fulpagare & Bhargav, 2015). Water-side economizers employ outdoor wet-bulb conditions to obtain cool condenser water that can meet the cooling requirements of the facility partially or completely; consequently, cooling towers are necessary for water-side economizers. These economizers are safer than air-side economizers because outdoor air is not introduced directly into the computer room. However, the available time for their use is shorter than that for air-side economizers. Air-side economizers introduce outdoor air directly into a computer room when the outdoor air meets a certain criterion. In general, air-side economizers are more energy efficient, and their available time is longer (ASHRAE, 2009). However, there are some concerns regarding the use of air-side economizers in DCs: (i) an increase in particulate contamination, maintenance cost, or both of filters; (ii) an increase in gaseous contamination; (iii) loss of humidity control during economizer operation and loss of the vapor seal during non-operation of the economizer; and (iv) temporary loss of temperature control during switchover from the air-side economizer to a non-integral economizer (ASHRAE, 2009). The advantages and disadvantages of water-side economizers are in contrast to those of air-side economizers. Safer and more efficient economizer cycles can be achieved if these two types of economizers can be combined. From this point of view, Kim, Chang, Jung, Cho, and Augenbroe (2017) proposed multistage outdoor air enabled (MOA) cooling, which combines the advantages of the two aforementioned economizer cycles. A detailed explanation of the MOA system can be found in their paper (Kim et al., 2017), which reports precedent research of the present work and is focused on the development of MOA cooling.

On the basis of the operating conditions of the water-side and air-side economizers and the MOA cooling strategy, seven oper-