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Improving energy efficiency of dedicated cooling system and its contribution towards meeting an energy-optimized data center

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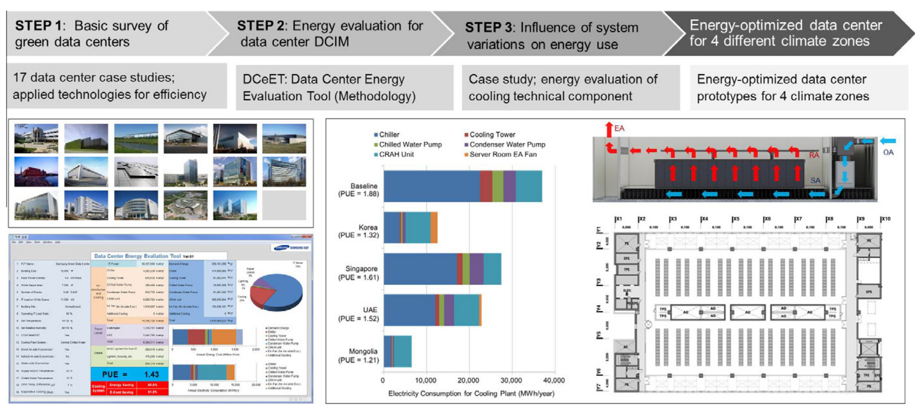
HIGHLIGHTS

- Energy-optimized data center's cooling solutions were derived for four different climate zones.
- We studied practical technologies of green data center that greatly improved energy efficiency.
- We identified the relationship between mutually dependent factors in datacenter cooling systems.
- We evaluated the effect of the dedicated cooling system applications.
- Power Usage Effectiveness (PUE) was computed with energy simulation for data centers.

GRAPHICAL ABSTRACT



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ABSTRACT

Data centers are approximately 50 times more energy-intensive than general buildings. The rapidly increasing energy demand for data center operation has motivated efforts to better understand data center electricity use and to identify strategies that reduce the environmental impact. This research is presented analytical approach to the energy efficiency optimization of high density data center, in a synergy with relevant performance analysis of corresponding case study. This paper builds on data center energy modeling efforts by characterizing climate and cooling system differences among data centers and then evaluating their consequences for building energy use. Representative climate conditions for four regions are applied to data center energy models for several different prototypical cooling types. This includes cooling system, supplemental cooling solutions, design conditions and controlling the environment of ICT equipment were generally used for each climate zone, how these affect energy efficiency, and how the prioritization of system selection is derived. Based on the climate classification and the required operating environmental conditions for data centers suggested by the ASHRAE TC 9.9, a dedicated data center energy evaluation tool was taken to examine the potential energy savings of the cooling technology. Incorporating economizer use into the cooling systems would increase the variation in energy efficiency among geographic regions, indicating that as data centers become more energy efficient, their locations will have an increasing effect on overall energy demand. The proposal for the most energy-optimized data center is given by each climate zone.

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1. Introduction

Data centers are large infrastructures housing hundreds of IT servers running 24/7/365. With the constantly increasing equipment performance, their energy consumptions are quickly raising. According to prediction, the overall energy absorption should reach 100 billion kW h around the year 2016 [1]. Therefore, for environmental and economic considerations, numbers of researches are carried out to lower the overall energy needs. It is well known that energy supply is one of the crucial issues of data centers secure, uninterruptable and high performance [2].

In an average data center, the IT equipment itself uses only about half of the total energy, with the remaining 50% overhead being used for non-IT equipment (cooling and electrical power delivery) [3,4]. The dominating factor in the 50% overhead is the mechanical cooling plant, accounting for roughly 33% of the total energy consumption of a data center facility [5]. Along with differences in data center space type, the location of an operating data center could affect the energy demand of non-IT equipment. Cooling systems are the most important dominant component of non-IT energy demand, owing to the large amount of heat generated by the IT equipment that must be removed from the interior space [6]. In contrast to other general buildings, data centers have a stable cooling demand throughout the year irrespective of the weather conditions and seasonal changes in temperature. Data centers generate massive amount of heat through their continuous operation that requires to be removed. Demands on cooling systems have increased substantially in recent years as server densities have risen to unprecedented levels. This change has not only created the need for increased cooling system capacity, but also has exposed inefficiencies in existing approaches to data center cooling. As a result, cooling now represents the second highest opportunity for energy cost savings in many facilities.

In this paper, we study the potential for using accessible energy saving solutions for dedicated cooling of a data center using a data center energy evaluation tool with hourly weather data for four climate zones. Study has been conducted applying the energy or environmental standards and integrated whole building approach which is to ensure that the most current knowledge and creativity are implemented through every phase of analysis and design. Whole building approach, known also as the integrated building design, in the case of data center is to encompass the data center infrastructure management (DCIM). The aim of the study is to find through simulation, an adaptive design strategies that will constantly optimize the energy performance by adjusting the IT environmental conditions and the cooling applications. Also, the energy-optimized data center prototype was derived for each climate zone.

2. Literature reviews

The data center industry and researchers have been focused in reducing the cooling demand using the well know techniques as hot and cold aisle containments [7], increase the allowable IT temperatures [8] and air/water side free cooling [9,10]. In the current background, using cool and dry weather conditions, when available, to cool data centers, also known as economizer cycle, would save on the cost of cooling energy. With an economizer cycle, the benefits of a low ambient temperature and low relative humidity can be utilized for a significant proportion of the year in many climates [9]. One of the most used energy efficiency strategies is so called direct air free cooling technology which uses the cold outside air directly to remove the heat generated inside these facilities. Lee and Chen [10] used a dynamic building energy simulation program to examine the potential energy saving of using direct air free cooling in data centers for 17 climate zones. The results showed a significant potential for data center locations in mixed-humid and warm-marine climate zones. But in the zones with lower dew point temperatures such as very-cold and cold, dry climate zones, the power and water consumed by the humidification system can be important and they should be accounted. In a similar study, Siriwardana et al. [9] investigated the use of direct air free cooling in different Australian climate conditions. Durand-Estebe et al. [11] investigated a method to lower the cooling plant energy consumption by modifying its regulation while keeping all the IT equipment in the ASHRAE allowable environment. Water side economizer is added to minimize the energy consumption the regulation and the chilled air production is simulated. According to Depoorter et al. [12], the use of direct air free cooling strategy is proved to be beneficial in any location reducing the energy consumption of the entire data center between 5.4% and 7.9%, depending on the location. Choo et al. [13] suggested four energy conservation measures (ECMs) to reduce energy consumption by optimizing the thermo-fluid flow in a medium-size primary data center: (1) eliminate unnecessary CRACs; (2) increase the return air temperature at the CRACs; (3) add cold aisle containment; (4) implement fresh air cooling. Energy-efficient free cooling technology should be employed when the outdoor air temperature is sufficiently low to use as the cooling medium [14]. David et al. [15] developed a chiller-less cooling which represents greater than 90% reduction in the cooling energy usage compared to conventional refrigeration based systems. Lu et al. [16] examined one data center in Finland including a long-term (one year) measurement of IT power and facility power, were conducted to evaluate air management and cooling performance. Results show that inlet conditions (temperature and humidity) for racks in the data center were all within the ASHRAE recommended or allowable ranges. And Ham et al. [17] conducted energy simulations of nine types of air-side economizer alternatives. The various air-side economizers yielded cooling coil load savings of 76–99% in comparison to conventional cooling systems in data centers, and the total cooling energy savings of the economizers ranged from 48% to 67%. Indirect air-side economizers with high-effectiveness heat exchangers were found to yield significant energy saving 64%. They highlighted that there is a potential use of this strategy in some states that could lead to significant energy saving. The uniqueness of the data center in consideration of applying energy-saving techniques and quantitative impact of dedicated cooling systems on the energy to implement a data center was studied by Cho et al. [18]. This research is defined by energy analysis process, numerical studies, and simulation studies to assess each technical component's influence in order to create energy-optimized data centers for Korea climate condition. And a data center energy evaluation program was developed to analyze the contribution level in energy performance by each technology, energy cost, system implementation, and equipment applicability by algorithm in consideration to their inter-relationship.

It can be presumed that there is a lot of potential for energy conservation strategies when providing cooling to data centers, given the weather conditions in climate zones. However, the multi-potential of variable cooling solutions has not been studied in previous literature.

3. Energy performance of data center

3.1. Design considerations for PUE

Data centers are fifty times more energy-intensive than conventional office buildings [19]. Over the past decade, the industry has made great strides in identifying the fundamental challenges of