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Transient simulation of wet cooling strategies for a data center in worldwide climate zones

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A B S T R A C T

A promising way to significantly reduce the total cost of ownership (TCO) of a data center is to minimize the cooling system energy consumption. To come up with the most energy efficient cooling system design, detailed analysis of various configurations based on local climate data is crucial. In this paper, an enterprise data center of 180 ton (TR) cooling load is modeled using a transient energy analysis software *TRNSYS* with the operating environment in the data center maintained as per the guidelines of ASHRAE TC 9.9. Promising cooling strategies including water side economizer and indirect evaporative cooler (IEC) are modeled and analyzed for the 17 worldwide climate zones defined by ASHRAE 90.1. Energy savings potential of these strategies is presented. Amount of water consumed and the number of hours the strategy is active in a year is also estimated. Results indicate significant energy saving potential of water side economizer and IEC in most of the zones. As compared to air cooled chiller systems, more than 30% energy savings can be achieved in climate zones 3–7 by using IEC. Also, more than 25% energy savings can be achieved by using water side economizer in climate zone 4 and 5.

1. Introduction

Data centers are specifically designed confined spaces to retain, organize, and process copious amount of digital data and information with reliability. The pre-eminent concern about a data center is its colossal amount of energy requirement for operating the IT equipment and the cooling system. Extensive studies have been carried out to estimate the power requirement of a data center. By benchmarking 22 data centers, Greenberg et al. [1] showed that data centers can be more than 40 times energy intensive as compared to normal office spaces. Later, Koomey [2] showed that in 2010 the worldwide data center electricity usage accounted for about 1.1–1.5% of the total. As the increment in data management and processing requirement is undeniable, there is a crucial need for finding out and employing energy saving strategies to keep a check on energy consumption. Pertaining to the immense energy requirement, data center energy efficiency has always remained a very sought after problem. Multiple studies for benchmarking standards and finding out improved cooling strategies have been performed at individual and organizational level.

PGEC [3], BEE [4], and Greenberg et al. [1] analyzed the current best practices and provided a set of efficient baseline design approaches for data center cooling systems. The cooling technologies like chilled water system, air side economization, water side economization, etc, were examined. The role of air management, centralized air handling, and cooling plant optimization in energy savings was scrutinized and it was shown that chilled water systems are more energy effective as compared to direct expansion (DX) systems. Furthermore, the usage of centralized air handling was suggested which leads to reduction in fan and motor power, improves redundancy of the system, and reduces the uncontrolled alternate humidification–dehumidification problem.

Most of the energy efficient data centers of the world make use of outside cold air, directly or indirectly, to enhance their energy savings and this technique is termed as free cooling. Free cooling can be achieved via usage of air-side or water side economizers. Free cooling can be employed in climate zones where wet bulb temperature (WBT) is less than 12.78 °C (55 °F) for more than 3000 h per year [1]. Lee and Chen [5] analyzed the free cooling potential of air side economizer in 17 different climate zones, defined by ASHRAE [6], by analyzing different outdoor to supply air ratio. The supply air was kept at conditions defined by ASHRAE [7]. They showed that energy savings are maximum in marine climate and minimum in dry climate, as much energy is expended to humidify the mixed air. They also showed that energy savings can be further increased if allowable supply air temperature is increased as

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Nomenclature

AHU	air handling unit
ASHRAE	American society of heating, refrigerating and air-conditioning engineers
COP	coefficient of performance (kW/kW)
DBT	dry bulb temperature (°C)
DX	direct expansion systems
h	enthalpy
IEC	indirect evaporative cooler
LCWT	leaving chilled water temperature (°C)
L/G	water to air mass flow rate ratio for cooling tower (kg/s/kg/s)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	power consumption (kW)
RH	relative humidity (%)
TCO	total cost of ownership
TR	tons of refrigeration (3.5167 kW)
WBD	wet bulb depression (°C)
WBT	wet bulb temperature (°C)

Greek symbols

Δ	change in quantity
ϵ	effectiveness of IEC
ω	humidity ratio (kg/kg)

Subscripts

vap	vaporisation
w	water
1	primary air
2	secondary air

the economization hours will increase. Bulut and Aktacir [8] and Siriwardana et al. [9] carried out regional studies to find energy saving potential of air side economizer (both free and partial cooling) for the climatic conditions of Istanbul, Turkey and selected key Australian cities, respectively. Therefore, it is evident that the cooling system working efficiency highly depends upon local climatic conditions.

Other than air side economization, a promising energy saving technique is water side economization. It has huge energy saving potential but can only be used in regions with significant wet bulb depression (WBD). PGEC [3] has listed down two different approaches for free cooling via water side economization, one with a single cooling tower both for water side economization and heat extraction from water cooled chiller and another with two cooling towers out of which one is dedicated for economization only. The two configurations have superiority upon one another depending upon the climatic conditions which needs to be considered. Usage of water side economizer ensures minimal interaction of indoor and outdoor air as compared to air side economizer. Hence, it minimizes requirements for air filtering and humidification/dehumidification of indoor air. But, increased infrastructural cost and huge water requirement are associated with it. Garday [10] considered all these factors in his study and recommended the usage of water side economizers for reducing cooling cost. He presented two case studies showing energy savings obtained by using a cooling tower coupled and decoupled with the chiller. For the case study with coupled cooling tower, annual savings of 144,000 USD was realized for a data center of 5.83 MW. For the decoupled system, an increase of 104% in the ratio of IT equipment power to cooling power was realized.

Indirect evaporative cooler (IEC) is another option for reducing cooling energy load. IEC utilizes the concept of cooling through evaporation of water. Similar to water side economizers, this system is also used where there is significant WBD. Maheshwari et al. [11] estimated the cooling capacity of an IEC using analytical models for the inner and coastal regions of Kuwait. They showed that the energy savings differ from place to place and is more in relatively dry areas. Delfani et al. [12] also carried out a similar analysis using IEC to pre-cool the exhaust air for four major cities of Iran having different climatic conditions. They reported that IEC could provide up to 75% of cooling load in cold climate and could save about 55% electrical energy.

Even if energy savings obtained with a cooling system are high, the infrastructural and the operational costs associated with the cooling system also need to be considered. The wet cooling strategies like water cooled chiller, water side economization, and IEC consumes large amount of water for their operation making them infeasible for use in regions having scarcity of water. Apart from these, many energy saving cooling strategies are present but the implications of these strategies on functioning and reliability of data centers is the major factor which limits their potential. For example, the cold water from cooling tower is not used for direct liquid cooling of data center, even though it would give more energy savings, as there is problem of fouling. Similarly, direct evaporative cooler (which is more efficient) is not preferred because of humidity constraints.

The analytical or numerical studies conducted so far were all focused upon determining the energy saving potential of a particular cooling strategy for a single or multiple climate zones. However, different cooling strategies should be compared for a particular climate zone to find the most efficient cooling strategy. With this aim, potential cooling strategies are devised and compared in this study. These strategies are air cooled chiller, water cooled chiller, water economizer with single and double cooling towers and IEC. These cooling strategies which utilize water as the heat removal media are termed as wet cooling strategies. For each of them a quantitative estimation of energy and water consumption is done. To estimate the energy requirements for the cooling strategies, these are modeled using transient energy simulation software *TRNSYS*. The performance data from commercial units of the components is used to model the actual performance of the cooling system. The calculations are performed for a typical data center of 180 TR heat load in the 17 worldwide climate zones as defined by ASHRAE [6]. The climate data available with *TRNSYS* is used to perform simulations on hourly basis for the entire year. The inlet temperature and humidity conditions for the data center are maintained according to the ASHRAE [7] guidelines. Apart from energy and water consumption, the number of hours a cooling strategy is active in the particular climate zone is also presented to know the suitability of the cooling strategy in different climate zones.

2. Data center operating environment

Different classes of data centers have been defined by ASHRAE based on type of IT equipment employed and the level of environmental control required. The data center air inlet temperature and humidity conditions are identified as the crucial parameters for the reliable functioning of IT equipment. With the help of performance data obtained from commercial IT equipment manufacturers, ASHRAE [7] established recommended and allowable range of inlet air temperature and humidity. The allowable and recommended range for different classes of data centers is provided in Table 1. Here, focus of the study is on data centers with enterprise servers and storage products working in tightly controlled conditions for reliable functioning. For simulations of different types of cooling strategies the ASHRAE guidelines are followed by maintaining the air inlet conditions in the data center as 24 °C and 50% RH.