Applied Thermal Engineering 77 (2015) 163–179

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Optimum supply air temperature ranges of various air-side economizers in a modular data center

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HIGHLIGHTS

- Energy optimization process of air-side economizer for data centers is established.
- Supply air conditions, server thermal characteristics, and cooling systems are analyzed for energy simulation.
- Annual cooling energy simulation is conducted in 16 locations in South Korea by considering various parameters.
- Optimum supply air temperature ranges are suggested for various air-side economizers in each location.

ARTICLE INFO

Article history:
Received 24 August 2014
Accepted 10 December 2014
Available online 18 December 2014

Keywords:
Modular data center
Air-side economizer
Optimum supply air temperature ranges
Energy simulation

ABSTRACT

In order to reduce data center cooling energy, ASHRAE Technical Committee 9.9 expanded thermal environmental ranges for data centers and recommended using the economizer, and it has reduced data center cooling energy successfully. The main purpose of this research is to establish an energy optimization process for the air-side economizer in a modular data center with respect to various parameters (supply air conditions, server thermal characteristics, cooling system configurations, and heat exchange effectiveness), and to determine optimum supply air ranges through simulation. The cooling energy simulation is conducted for three types of air-side economizers by changing the supply air temperature (SAT) and heat exchanger effectiveness at 16 locations in South Korea based on the three thermal environmental ranges. The simulation result shows that the lowest cooling energy consumption appears when the computer room air handler (CRAH) SAT is within 18–23 °C, and at higher SAT conditions, the cooling energy consumption increases, since chiller energy reduction is offset by the increase in CRAH fan energy.

1. Introduction

1.1. Purpose of the study

With the recent development of information and telecommunication technology (IT) and its demand, data centers account for 1.12–1.15 % of total global electricity consumption [1]. Many studies have been conducted on reducing data center cooling energy, which accounts for about 30% of data center operation energy [2]. The general method of reducing cooling energy in a data center is to utilize an air-side economizer, which uses relatively cold outdoor air to save chiller energy during intermediate or winter seasons [2].

Scofield [3] analyzed the effect of the air-side economizer with a direct evaporative cooler on cooling energy reduction in the data center. Sullivan et al. [4] showed that the indirect air-side economizer using the heat wheel heat exchanger could bring more energy savings than the existing direct air-side economizer or water-side economizer. Niemann et al. [5] indicated that among various types of economizers, the indirect air-side economizer with evaporative cooling is the most energy efficient. Ham et al. [6] analyzed energy saving potential of eight types of air-side economizers in a modular data center and concluded that the indirect air-side economizer with a high-performance heat exchanger is recommended due to its simple configuration and energy performance.

In the meantime, studies on the impact of regional climate characteristics on energy savings by economizer operation have also been conducted. Christy and Abimannan [7] analyzed the energy saving effect of an air-side economizer and a water side-

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http://dx.doi.org/10.1016/j.applthermaleng.2014.12.021
1359-4311/

Nomenclature

A	heat exchanger heat transfer area (m^2)
c_p	specific heat (kJ/kg °C)
CAPFT	chiller capacity function (–)
CS	outdoor air temperature (°C)
CWS	chilled water supply temperature (°C)
e_{ult}	ultrasonic humidifier power per unit water (kW/kg)
EIRFT	chiller electric power function (–)
EIRFPLR	chiller electric power in part-load operation (–)
h	convective heat transfer coefficient (kW/m^2 K)
h_m	mass transfer coefficient (kg/s m^2)
i	enthalpy of air (kJ/kg)
$\overline{K}$	ratio of enthalpy and wet-bulb differential at IEC wet-side (m)
L_{IEC}	length of IEC (m)
$\dot{m}$	mass flow rate (kg/s)
NTU	Number of transfer unit (–)
NTU*	modified number of transfer unit (–)
p	static pressure loss (Pa)
P	power (kW)
PLR	chiller part-load ratio (–)
$\dot{Q}$	heat (kW)
Rows	number of heat pipe rows
T	temperature (°C)
$\dot{V}$	volumetric airflow (m^3/s)
WB	wet-bulb temperature (°C)

Greek symbols

α	server heat generation coefficient
β	server airflow coefficient
δ	combined thickness of water film and thin wall in IEC (m)
ε	effectiveness (–)
η	efficiency (–)
θ	ratio of OA to RA (–)
ρ	fluid density (kg/m^3)
Δ	difference operator

Subscripts

air	air
avail	available chiller
fan	CRAH fan
hp	heat pipe
hum	humidification
i	index
peak	full-load condition
pump	chiller chilled water pump
ref	reference condition
RI	rack inlet air
ult	ultrasonic humidifier
w	water

Abbreviations

CA	conditioned air
CRAH	computer room air handler
DBT	dry-bulb temperature
DP	dew point
IEC	indirect evaporative cooler
MERV	minimum efficiency reporting value of filter
OA	outdoor air
PDU	power distribution unit
RA	CRAH return air
SA	CRAH supply air
SAT	supply air temperature
UPS	uninterruptible power supply

economizer for data centers in Chicago, Atlanta and Phoenix, and both economizers showed the highest energy savings in the colder climate (Chicago). Harvey et al. [8] showed that data center cooling can be achieved without the chiller operation for 100% of operating time in the U.S. and Canada, and more than 90% of the time in Japan when the air-side economizer is operated within ASHRAE allowable thermal environmental ranges of A2 and A3 classes, revised in 2011 [9].

Newcombe [10] analyzed the effect of supply air temperature (SAT) on chiller operating hours and the server heat generation of various air-side economizers in 20 cities around the world. The results indicated that air-side economizers save energy effectively in most cities, but the changes in server heat generation variation with supply air temperature are not significant.

Strutt [11] proposed the operational guideline for a direct air-side economizer in a data center with respect to the SAT, regional climate characteristics, and the server's reliability and heat generation rate. Tozer and Flucker [12] estimated power usage effectiveness and energy savings of various air-side economizers in the U.S. Siriwardana et al. [13] evaluated the data center chiller energy savings of direct air-side economizers in 20 locations in Australia, and their results showed that free cooling is possible for more than 60% of the year in cool southern areas.

Lee and Chen [14] analyzed energy saving potentials of direct air-side economizers in 17 cities in each climate zone in the world, and the air-side economizer effectively reduces cooling energy in the most cities. However, humidification is necessary in dry climates, and accordingly, the energy savings decreases. Also, if the data center cooling set point temperature is lowered, cooling energy is reduced by 2.8–8.5% for every 2 °C decrease.

As a study on the supply air conditions for reliability and energy saving of IT equipment, Atwood and Milner [15] tested the reliability of 32 commercial blade servers and the cooling energy savings of an air-side economizer for 10 months with a dry-bulb temperature of 18–33 °C and a relative humidity of 4–90%, and found cooling energy savings 74% with no significant difference in failure rate, compared to a conventional cooling strategy to cool recirculated indoor air.

Patterson [16] stated that the chiller energy consumption is reduced more by a supply air temperature of 30 °C than of 20 °C, but the total energy consumption of the entire data center might rather increase due to the increased leakage current and server internal cooling fan energy when the central processing unit (CPU) temperature and cooling fan airflow increases. Moss and Bean [17] experiments the changes of energy consumption of the server rack, composed of servers with different server cooling fan control algorithms, with different SATs. As a result, the SAT of 23–27 °C is the optimum ranges that could minimize energy consumption of servers and their cooling fans.

On the other hand, Intel [18] recently released a server that can operate even with a SAT of 40 °C by optimizing the server internal flow path. In Ahuja's simulation research [19], data center cooling was achieved without chiller operation when the SAT of the air-side economizer was set to 35 °C, resulting in energy savings of 22%.