Energy and Buildings 68 (2014) 270–279

Contents lists available at ScienceDirect

Energy and Buildings

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

Evaluation of air distribution system's airflow performance for cooling energy savings in high-density data centers

Jinkyun Cho[a,*], Joonyoung Yang[b], Woopyoung Park[a]

[a] Construction Technology Center, Samsung C&T Corporation, Seoul 135-935, South Korea
[b] M&E Engineering Center, Samsung C&T Corporation, Seoul 137-070, South Korea

ARTICLE INFO

Article history:
Received 23 July 2013
Accepted 9 September 2013

Keywords:
Data center
Standard module
Air management system
Cooling efficiency
Air-flow performance
Performance index
CFD simulation

ABSTRACT

The goal of air management system in high-density data centers is to minimize hot air re-circulation and cold air by-pass in data centers. If successfully implemented, both goals will result in energy savings and enhanced thermal conditions. Air management helps to reduce operating costs by enhancing economizer utilization and improving cooling system efficiency. Metrics play a significant role in providing performance indices, which include Supply/Return Heat Index (SHI/RHI), the rack cooling index (RCI) and the return temperature index (RTI), of air management systems. CFD simulation estimates temperature and airflow in the data center as well as to provide wealth of information to evaluate airflow performance. This study defines four performance metrics that analyzes air management systems. These metrics were computed with CFD modeling of 46 different design alternatives to evaluate the thermal environment in a typical data center module. Advanced and comprehensive evaluation index of cooling efficiency was also derived as well-crafted metrics will undoubtedly play an important role.

1. Introduction

1.1. Background and objectives

What has been data center of focus in the past, which is to maintain reliable operation, is still a fundamental basis in present data center design but additional efforts are provided to compete in the increasing business demand within limited operation expense. Therefore, savings in operation expense are under research, where the largest as well as the fastest increasing cost factor is electricity consumed by IT servers and cooling systems. Sharp increase of demand in data center and energy consumption has led to concerns at a national level regarding energy efficiency. In general, one large internet data center consumes approx. 10–20 MW of electricity. In the past 10 years, energy consumption in data centers doubled every 4 years, therefore, increase in electricity usage and heat reduction is expected to become critical concerns for customers [1]. Steady increase of IT server's heat density led to increase in energy consumption of cooling systems to approx. 40% of data center's energy consumption [2]. Maintaining efficient airflow for IT server cooling can provide high efficiency with minimal effort. However, most of the data centers do not realize the opportunity to improve cooling efficiency as temperature rise in the IT server room, even with sufficient cooling capacity, is resolved by installing additional mechanical equipment. As a result, both equipment size and energy consumption are increased with emphasis on the significance of efficient air management system selection and planning. Air distribution system's efficiency and performance are associated with heat removal from the IT servers [3]. The goal of this study is to propose an overall, objective performance index that evaluates and improves the efficiency of air distribution system in a high-density data center.

1.2. Research methodology and procedure

This study is to reduce energy consumption in high-density data centers by improving efficiency of cooling and air distribution. Therefore, design factors that affect the IT server room's airflow efficiency, individual effects of these design factors, and performance index were derived. Research procedure and methodologies are shown in Fig. 1. First, in order to objectively evaluate data center's air distribution efficiency, international design standard and airflow performance index were reviewed. Due to the fact that data centers are modularized and have clear design standards, configuration, such as IT server room's floor plan, section, and width of space, are similar to each other. Therefore, if cooling efficiency is considered early on with measures to design variables and then design for a conventional data center can be proposed without any major errors. Second, overall performance index and basic module for simulation analysis were proposed to evaluate air management

* Corresponding author. Tel.: +82 2 2145 6999; fax: +82 2 2145 7660.
E-mail address: maxjcho@yonsei.ac.kr (J. Cho).

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.09.013

Nomenclature

Q	total dissipation from data center components (W)
C_p	specific heat of air at constant pressure (Pa)
m	mass flow rate of air through a rack (CMH)
T	temperature (°C)
n	total number of intakes
x	intake x

Superscripts

r	rack
c	CRAC unit

Subscripts

in	inlet
out	outlet
ref	CRAC supply
i,j	Cartesian direction
max-rec	maximum recommended/ASHRAE TC9.9 (2008)
max-all	maximum allowable/ASHRAE TC9.9 (2008)
min-rec	minimum recommended/ASHRAE TC9.9 (2008)
min-all	minimum allowable/ASHRAE TC9.9 (2008)
Return	return air (weighted average)
Supply	supply air (weighted average)
Equip	rise across the ICT equipment (weighted average)

efficiency. In addition, 23 design alternatives based on the standard module were analyzed regarding architectural design variables, such as cooled air supply and return location, raised floor height, ceiling height etc., and cooling systems variables, such as CRAC unit's supply air temperature, physical containment of cold aisle or hot aisle, etc. These conditions' supply air volume is adjusted for 46 Computational Fluid Dynamics (CFD) simulations including standard modules. Last, air management system's performance index is derived based on the simulation result where overall design adequacy is evaluated in consideration to individual effects.

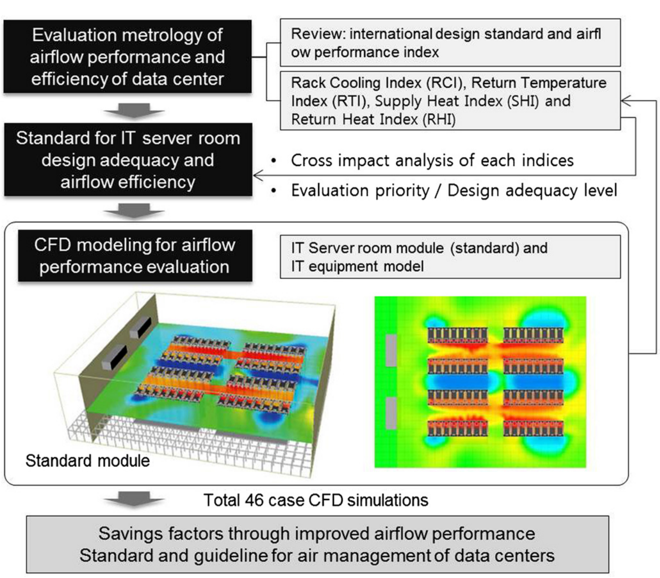

Fig. 1. Research methodology and procedure.

2. Data center thermal management

2.1. The necessity for airflow efficiency analysis

The basic flow of server room's air management starts with air supply from the CRAC unit to IT server, heat removal, and ends with hot air return back to the CRAC unit. However, in reality, air streams are obstructed by factors, such as air re-circulation or by-pass, as shown in Fig. 2, decreasing cooling efficiency and creating vicious cycle of rise in local temperature [4]. The IT server room, which is the most critical space in a data center, is generally designed to the international standard, TIA-942. In addition, layout of IT servers (racks) is designed to minimize air re-circulation, mixing, by-pass, etc., to separate airflow of IT equipment's supply air in the cold aisle from exhaust air in the hot aisle. Furthermore, spacing requirement follows the global design standard shown in Table 1 [5]. Therefore, once the data center's level (Tier 1–4) is decided, architecture, such as floor plan, section, etc., is generally similar within a certain boundary. In order to analyze the air distribution efficiency of a data center, the most objective method of evaluation is through the performance index. It is important to evaluate the adequate supply of air temperature to reduce the heat load in the servers through CFD analysis based on the server room's design standard. In the past, design standard used to focus on the IT equipment's reliability, but wasted energy, such as over cooling, has also become a significant evaluation factor in recent days. It is possible to derive an overall performance index of cooling efficiency through objective evaluation by adjusting design variables, such as IT server room's architectural and mechanical design elements, etc., from traditional data center design requirements. Due to the typical characteristics of modularized data center, the gathered data will reduce time and effort in deciding design as well as deriving and proposing energy efficient design alternatives.

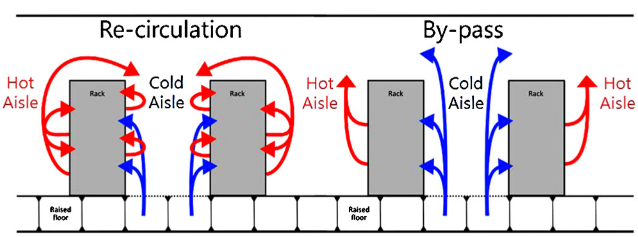

Fig. 2. Out of control airflow in server rooms; re-circulation and by-pass airflow.

Table 1
Aisle pitch allocation and rack arrangements.

	Tile size	Aisle pitch	Cold aisle size	Hot aisle size
US	2 ft (610 mm)	14 ft (4267 mm)	4 ft (1220 mm)	3 ft (914 mm)
Global	600 mm (23.6 in.)	4200 mm (13.78 ft)	1200 mm (3.94 ft)	914 mm (3 ft)
Seven title aisle pitch, equipment aligned on cold aisle