Applied Thermal Engineering 109 (2016) 466–474

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Experimental study of solving thermal heterogeneity problem of data center servers

S.A. Nada *, Ali M.A. Attia, K.E. Elfeky

Department of Mechanical Engineering, Benha Faculty of Engineering, Benha University, Benha 13511, Egypt

HIGHLIGHTS

- Increasing server power density increases its surface temperature heterogeneity.
- Variation of servers air flow rates leads to better thermal performance.
- Uniform increase of server's air flow rates enhances thermal performance.
- Proper scheme of servers air flow rates maintains all servers at the low temperature.

ARTICLE INFO

Article history:
Received 17 May 2016
Revised 1 August 2016
Accepted 18 August 2016
Available online 20 August 2016

Keywords:
Data center
Energy management
Heterogeneous temperature management
Servers fans speeds

ABSTRACT

Desirable thermal management of data center requires uniform temperature distribution along the servers. Hot air recirculation and cold air bypass in data center leads to non-homogeneous cold air distribution along the servers of the racks which may lead to heterogeneous temperatures distribution along the servers. The present work aims to experimentally study the possibility of controlling these heterogeneous temperature distributions by controlling the cold air flow rates along the servers. A physical scaled data center model was used to conduct this investigation. The effectiveness of thermal management of the servers racks of the data centers has been expressed in terms of intake, rare and surface temperature distributions along the rack servers and the supply and return heat indices (commonly symbolized as SHI and RHI; respectively). Excessive tests were firstly performed under uniform servers fans speed (uniform air flow rates through the different servers). Then the air flow rates distributions along the racks servers has been changed by regulating the server's fans speeds using different schemes of fans speeds regulations at different data centers power densities. It is concluded that a uniform increase of server's flow rate from the bottom to the top of servers rack cabinet provides (i) the lowest temperature at both cooling aisle (around 10%) and exhaust aisles (around 5%), (ii) the best uniform surface temperature of all rack servers (as the standard deviation is reduced from 10 to around 2), and (iii) the best values of thermal management metrics (SHI and RHI) typically SHI is reduced by around 20% while RHI is increased by around 3% to approach the targeted values; 0.1 and 0.9, respectively.

1. Introduction

Huge and high speed data processing needed in a wide variety of human life sectors such as industrial, educational, and administrational services in addition to other private sectors is performed using data centers. These facilities are composed of racks hosing servers with different configurations and/or different capacities. To maintain the efficiency of these servers, proper thermal management is required to keep their operation within targeted temperature values. For this reason great part of power consumed is directed for cooling of these facilities throughout the computer room air conditioning (CRAC) unit (almost 40–50% total power consumed [1]). Under proper thermal management operation about 10–15% of this total energy consumption can be saved [1]. Additional challenge for data center thermal management is how to also maintain the surface temperature of the different servers within the allowable limits [2]. Typical server hardware [2,3] is rated for allowable operating temperature envelope of 35 °C for most data centers with some control; for general applications ASREA has recommended the operating temperature envelope to be from 18 °C to 27 °C. Thus the main scope of data center manufacturer is to remove the hot air exhaust from servers to improve the system cooling efficiency [4].

* Corresponding author.
E-mail address: samehnadar@yahoo.com (S.A. Nada).

http://dx.doi.org/10.1016/j.applthermaleng.2016.08.097
1359-4311/

Nomenclature

Cp	constant pressure air specific heat (J/kg k)
CRAC	computer room air conditioning
Q	server heat dissipation rate (W)
L	length (m)
$\dot{m}$	air flow rate (kg/s)
N	total number of servers intakes
RHI	return heat index
SHI	supply heat index
T	temperature (°C)
T_{ref}	reference temperature (°C)
U	air velocity (m/s)
X	intake x

Superscripts

C	CRAC
R	rack

Subscripts

i, j	Cartesian direction
In	air inlet to servers
Ti	mean temperature at intake x (°C)
Out	air outlet from server

Different techniques are used for data centers cooling; the most common techniques uses raised-floor configuration where the cooling air is supplied to the data center from the under-floor plenum through perforated tiles (see Fig. 1). The raised-floor arrangement provides unlimited flexibility regarding cooling air flow configurations. The most efficient configuration is the one that depends on separating cold and hot aisles [5,6] to avoid hot air recirculation and cold air bypass. In their study on different data center configurations, Shrivastava et al. [7] found that using raised floor to supply the cold air and extracting the discharge hot air from the ceiling is the efficient data center air distribution system. This flow configuration becomes the standard practice for data center cooling where server racks are commonly arranged in properly oriented-rows to be placed on both sides of the cold aisle. Thus the hot air from neighboring two rows of racks is exhausted into the hot aisle. Then hot air from different hot aisles is collected and returned to CRAC unit. As the server racks have their internal fans, the supplied cooling airflow rate through perforated tiles shall be equal (or greater) than the required airflow rates of these fans to ensure effective cooling process.

Many investigations were performed to provide the best conditions that should provide high cooling efficiency of data centers. Cho et al. [8] studied air distribution in high power density data centers and they concluded that as human thermal comfort is not the aim of data center cooling, supply air velocity is a critical factor in data center. VanGilder and Schmidt [9] studied flow uniformity from data center floor perforated tiles and they reported that 25% perforated tiles opening ratio with 0.61 m plenum depth or more is the optimum for air flow uniformity. In other work, it was reported that reducing system fan speed and increasing air

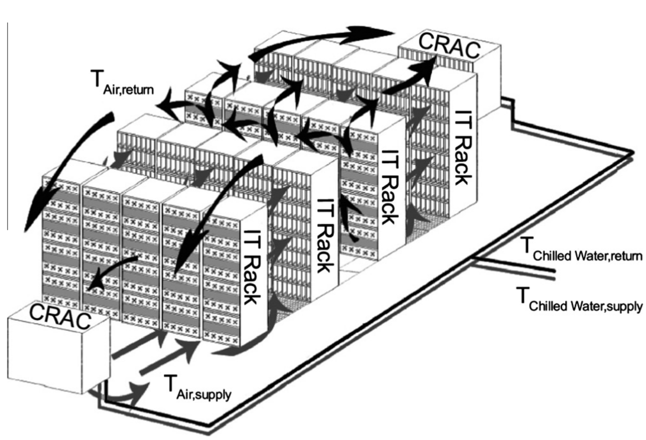

Fig. 1. Typical open aisle data center [4].

temperature rise across the server increase the energy efficiency in data centers [10,11]. In this case the mean temperature of hot air is raised across the data center room leading to a concern on the system reliability due to approaching the thermal limits of the system.

Effective data center thermal management can be attained when proper cooling air distribution throughout the room is maintained. In this regard many controlling parameters should be studied; including cooling air flow pattern, temperature distribution inside data center, and server fan air flow rate. The later parameter is interrelated with the server power loading and/or processing load to maintain the server surface temperature within the predefined value as specified by manufacturer or as targeted by standards whichever is more stringent. There are many metrics used for thermal management evaluation in data centers [12–15]. Herrlin [16] concluded that the cooling efficiency of racks depends mainly on the data center room environment, correspondingly the use of performance metrics can help in analyzing these interdependencies.

The most commonly used metrics are those used to evaluate the mixing level between cold and hot air streams in the hot-aisle and cold-aisle arrangement related; namely supply heat index (SHI) and return heat index (RHI). These metrics evaluate the extent of cold and hot air mixing in data center; SHI is the ratio of the heat gained by cold aisle air before entering the racks to the total heat gained by the air in the data center while RHI is the ratio of the heat gained in the air during passing in the rack relative to the total heat gained by the air in the data center. These two metrics have been used by many investigators while studying or attempting to improve data center cooling efficiency [15].

Boucher et al. [17] have experimentally found that racks at the row end exhibit higher temperature than those inside due to hot air recirculation. The study concluded that proper control of CRAC supply temperature, CRAC fan speed, and plenum vent tile openings can greatly improve the energy performance of data centers. Kumar and Joshi [18] found that to overcome the escaping of cold air from the top of cold aisle other methods should be considered rather than the increase of air flow rate through perforated tile which may not be the best way to confirm high efficiency cooling of data center. Cho et al. [19] concluded that the separation of cold and hot air aisles not only minimize the hot air recirculation but also increase the chance of hot air short-circulation over severs especially when the temperature at server backs approaches 35 °C. Patterson [20] reported that cooling system efficiency in data centers strongly depends on flow distribution and air temperature rise across the racks. Durand-Estebe et al. [21] proposed a new temperature adaptive control strategy to minimize the energy need while investigating the effect of increasing server room temperature on the cooling plant energy consumption. Nada et al.