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Performance assessment of cooling systems in data centers; Methodology and application of a new thermal metric

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ABSTRACT

This paper introduces a comprehensive cooling index to assess performance of cooling systems in data centers and demonstrates its application on a real case by using CFD (computational fluid mechanics) method. The proposed methodology provides a metric for comparing and ranking of the cooling efficiency of the air distribution configurations among available designs alternatives.

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1. Introduction

Data center is a facility containing computer equipment and related devices such as storage systems of a telecommunication system. These devices consist of power supply, air conditioner, fire-fighting devices and security systems [1]. Air conditioner of data centers should work full time all over the year to remove the heat added to the system by operation of different devices. Development of telecommunication industry, therefore, made data center a common element for either general or dedicated usage [2]. Heat propagation increases the temperature and causes damage to rack servers; therefore protection of system and prolonging their life by cooling the inherent devices is of crucial importance. In other words, it's very significant to design an appropriate air conditioner to protect data center from destruction caused by heating. For proper operation of devices, they should be held on a certain and proper temperature. Each IT server should receive certain amount of cool air enough for the removal of the produced heating [3]. Appropriate operation of equipment depends on proper distribution of cool air on data center and the response of supply air to the demand of components.

Computational fluid dynamics is an assisting tool to configure the hall of devices. Some indexes are used for quantitative assessment of efficient performance of cooling systems. In practice, influence of the design factors is quantified using cooling indexes such as SHI, RHI, RCI and RTI (described in detail later in Section 2) for different models where each index indicates specific aspect of operation in the cooling systems; however in some cases the mismatch among existing approaches might end up with irrelevant results which makes decision making process a challenge. To overcome the

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deficiencies of this area, this article proposes a new framework for the quantification and ranking of the performance of cooling systems in data centers by using the results of CFD analysis.

In the sequel, first we will review the existing cooling indexes and the theory behind them. Then a new cooling index is proposed for more efficient estimation of the cooling performance of the data center and finally, its application will be elaborated on a real case in Iran considering different configurations for the design of cooling system.

2. Indexes for assessing data center cooling

Shrivastava et al. [4] introduced a dimensionless parameter that is a norm of cooling performance in rack level. Noh et al. [5] used three different methods to design data center with 5–6 KW racks. In communication equipment centers three states 'horizontal air supply and return flow system model', 'underfloor air supply and overhead return flow system model', and 'overhead air supply and underfloor return flow system model' were investigated and results showed that 'underfloor air supply and overhead return flow system model' state has better performance. Cho et al. [6] assessed the performance of air distribution system to reduce energy consumption in high-density data centers. 46 models for air distribution were studied and results showed that temperature of output air of package has the most pronounced effect on flow efficiency. In addition, it stated that closing the chamber of aisle can increase the temperature of output air of package up to 22 °C (without decreasing the efficiency).

2.1. Return heat index (RHI) and supply heat index (SHI)

Sharma et al. [7] introduced two dimensionless parameters called supply heat index (SHI), and return heat index (RHI) which are used to assess the temperature performance of data center. These indexes can be used for investigation of convective air flow in equipment room with raised-floor. Energy efficiency depends not only on the type of cooling system but also on the configuration of equipment room that influences the mixing of cold and hot air. Herrlin [8] studied the return heat index (RHI) that is a measure of net level of by-pass air or net level of recirculation air in data center. Both of them have deficient effects on total energy and temperature efficiency of air in that area.

RHI and SHI indicate the mixing of input cool air flow to the rack and output hot air flow from the rack. These indexes are formulated as follows:

$$SHI = \left(\frac{\delta Q}{Q + \delta Q}\right) \tag{1}$$

$$RHI = \left(\frac{Q}{Q + \delta Q}\right) \tag{2}$$

where Q is the total heat propagation of racks and indicates the amount of cool air enthalpy increase before its entering to the rack, i.e.:

$$Q = \sum_{j} \sum_{i} m^{r}_{i,j} C_p \left(\left(T^{r}_{out}\right)_{i,j} - \left(T^{r}_{in}\right)_{i,j} \right) \tag{3}$$

where $m^{r}_{i,j}$ is the entrance flow to the ith rack in the jth row. The relation between RHI and SHI is shown below:

$$\text{SHI+RHI} = 1 \tag{4}$$

As much RHI increases, SHI will decrease and the design will approach to the ideal design of cooling system for data center. This condition shows less mixing of cool air with the output hot air from the rack. Usually RHI $\geq$ 0.8 (80%) is acceptable.

2.2. Rack cooling index (RCI)

Rack cooling index has been introduced by Herrlin [9]. RCI is a measure of rack cooling and consists of two equations; one indicates allowable area for low rack temperature (RCI_{LO}) and the other for high rack temperature (RCI_{HI}) [5]. As Table 1 implies, RCI_{HI} more than 95% is desirable.

Table 1
Rack cooling rate (RCIHI and RCILO) [6].

100%	Ideal
≥96%	Good
91–95%	Acceptable
≤90%	weak

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