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Strategies for data center temperature control during a cooling system outage

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ABSTRACT

Data centers have grown explosively due to the rapid development of the information technology (IT) industry during the past ten years, with more and more businesses in other industries like Financial, Government, Energy and Traffic, relying on the continuous operation of data centers. So, controlling the temperature rise during the power failure is particularly crucial to data center availability and business development for those industries. This paper discusses the negative effect of temperature rise caused by industry trends and best practices on emergency cooling performance. In order to analyze the temperature rise characteristics, a real-time transient thermal model is developed to demonstrate the heating of a data center following the loss of utility power. Meanwhile, strategies like placing critical cooling equipment on backup power, choosing equipment with shorter restart time, maintaining adequate reserve cooling capacity, and employing thermal storage, are provided and checked whether they can handle the power outages in a predictable means using this model. Finally, a proper strategy is recommended according to each cooling system characteristics to achieve the desired temperature control during the power outages.

1. Introduction

Data centers have grown rapidly both in size and number during the last decade, consuming more power and dissipating a larger amount of heat. According to a survey performed by the Association for Computer Operation Managers (AFCOM) and Inter Unity Group, data center power requirements are increasing by 8% per year on average, and 20% per year in the largest data centers [1]. According to another analytics press, the global energy consumption of data centers increased by about 56% between 2005 and 2010, accounting for about 1.3% of the world's electricity usage [2].

Meanwhile, the rack power densities also increased which can be up to 30 kW per rack due to the compaction of information technology (IT) equipment in the data centers [3]. It means that the same amount of heat will be dissipated by the rack. So, data center power and cooling supply systems are encountering significant challenges right now, which include how to provide sufficient cold air to the front of racks, how to eliminate hot spots for high density racks, and how to improve the efficiency and reduce the energy cost of the cooling system. Therefore, increasing concerns have been focused on the airflow distribution and air management [4–12], cooling efficiency [13–16], and inner environment [17–19]. Meanwhile, many investigations have been carried out using computational fluid dynamics (CFD) software or models to predict the cooling performance and temperature distribution [20–26].

Challenges exist not only under the normal operation of the cooling system; actually, the biggest challenge will be the temperature control during a cooling system outage. Because more and more businesses such as financial companies, Government, and Traffic departments require the continuous operation of data centers, the availability of the data centers plays a very vital role on those organizations. Uninterruptible power supplies (UPSs) are commonly used to power the IT equipment during a utility power outage, but, the cooling components are generally not connected to the UPSs. As a result, the heat dissipated by the racks cannot be moved to outdoors, and temperature in the data centers will

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Abbreviation: AFCOM, association of computer operation managers; ATS, automatic transfer switch; CFD, computational fluid dynamics; CRAC, computer room air conditioner; CRAH, computer room air handler; DX, direct expansion; IT, information technology; UPS, uninterruptible power supply.

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Nomenclature

A	total surface area (m^2)
c_p	specific heat ($kJ\,kg^{-1}\,{}^\circ C^{-1}$)
f	heat exchanger coefficient ($W\,m^{-2}\,{}^\circ C^{-1}$)
h	convection heat transfer coefficient between the air ($W\,m^{-2}\,{}^\circ C^{-1}$)
$\dot{M}_w$	chiller water flow rate ($kg\,s^{-1}$)
$M_{storage}$	total mass of the chilled water buffer storage (kg)
t	time (s)
Q_{IT}	total load in the data center (kW)
$\dot{Q}_{chiller}$	total cooling load provided by chillers (kW)
$T_{p,a}$	fully mixed plenum air temperature (°C)
$T_{r,a}$	fully mixed room air temperature (°C)
$T^*_{r,a}$	room air temperature before the time interval Δt (°C)
$T_{r,a}$	room air temperature after the time interval Δt (°C)
T^*_E	equipment surface temperature before the time interval Δt (°C)
T_E	equipment surface temperature after the time interval Δt (°C)
$T^*_{p,a}$	plenum air temperature before the time interval Δt (°C)
$T_{p,a}$	plenum air temperature after the time interval Δt (°C)
T^*_B	plenum objects surface temperature before the time interval Δt (°C)
T_B	plenum objects surface temperature after the time interval Δt (°C)
$T^*_{s,w}$	temperature of water flow entering the coolers before the time interval Δt (°C)
$T_{s,w}$	temperature of water flow entering the coolers after the time interval Δt (°C)
$T_{s,a}$	cooler supply air temperature (°C)
T_B	plenum objects surface temperature (°C)
$T_{r,w}$	temperature of water flow leaving the coolers (°C)
$T_{h,w}$	temperature of the water flow entering the chillers (°C)
$T_{c,w}$	temperature of the water flow leaving the chillers (°C)
U	overall U value of the coils in the coolers
V	volume of the air (m^3).

Greek

ρ_a	density of air ($kg\,m^{-3}$)
Δt	small time interval

Subscripts

a	air
B	plenum objects
c	leaving the chillers
E	equipment
h	entering the chillers
IT	information technology
p	plenum
r	room, or leaving the coolers
R	air in the room
s	supply, or entering the coolers
w	water

Superscripts

$*$	before the time interval Δt

rise quickly during the power outage, and finally the high temperature may lead to the shutdown of the data centers, or even destroy the IT equipment. So, power outage is one of the core problems affecting the availability of the data centers. However, extremely few researches have been focused on temperature rise during power outages. Sullivan et al. [27] from IBM only provided twenty-seven general things which can be adopted to meet “24 by Forever” expectations. Garday et al. [28] from Intel used a case study to investigate the thermal storage system on emergency data center cooling. Hence, tools for predicting the temperature rise during a power failure are very scarce, and strategies for different data centers have not been studied.

Therefore, in this paper, based on the energy conservation law, a real-time transient thermal model is developed to study the temperature characteristics during the cooling system outage, and some effective strategies are proposed for the temperature control to keep the IT equipment from unexpected damage for different kinds of data centers.

2. Negative impact on emergency cooling performance due to industry trends

Some data center trends and best practices – most aiming at improving performance, efficiency, and manageability under normal operating conditions – may adversely affect operating conditions following a power outage.

2.1. Right-sizing cooling capacity

Right-sizing (i.e. aligning capacity to the actual IT load) capacity of the overall cooling system provides several benefits including increased energy efficiency and decreased capital costs. However, extra cooling capacity is desired when encountering unacceptably high temperatures following a power outage. In fact, if the total cooling capacity perfectly matches the heat load, the facility theoretically could never be cooled to its original state because there would always be heat in excess of the IT load after a power outage occurred. Just as multiple-window air-conditioners cool a bedroom more quickly than a single unit, additional computer room air handler (CRAH) or computer room air conditioner (CRAC) helps restore the data center to the pre-power-failure conditions quickly. Note that for all architectures, the cooling distribution (airflow) must be such that CRAH or CRAC capacity can actually be utilized (i.e. by use of blanking panels, brush strip, hot and/or cold aisles, etc.).

2.2. Increasing power density and virtualization

Compaction of IT equipment produces increased rack power densities in the data center. The installation of high-density equipment like blade severs and certain communications equipment can result in rack power density exceeding 40 kW per rack. Another technology trend, virtualization, has significantly increased consumption of compute power. For example, virtualization can increase the CPU utilization of a typical non-virtualized server from 5% to 10% to over 50%.

Both increasing the rack power density and virtualization will not only dissipate more heat in a given space, but also reduce the response time available to data center operators before the IT inlet temperatures reach the critical levels due to a power outage.

2.3. Increasing IT inlet and chiller set point temperatures

ASHRAE Technical Committee 9.9 (Mission Critical Facilities, Technology Spaces and Electronic Equipment) developed and expanded the recommended thermal operating envelope for data centers. Increasing the IT inlet and chilled water set point