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A simplified power consumption model of information technology (IT) equipment in data centers for energy system real-time dynamic simulation

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HIGHLIGHTS

- A power consumption model of IT equipment in data centers is built.
- It predicts how IT equipment design and operation change a data center's power consumption.
- It only needs data from the design of data center and manufacturer specification.
- It can be used in dynamic and real-time energy system simulation.

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ABSTRACT

Due to the rapid rise of power consumption of data centers in recent years, much work has been done to develop energy-efficient design, controls and diagnosis of their cooling systems, while the energy system simulation is used as an effective tool. However, existing models of information technology (IT) equipment of data centers cannot well represent the effects of IT equipment design and operation status on the data center cooling demand, and this hinders the development of the energy saving cooling technologies of data centers. To address this issue, this paper introduces a power consumption model of IT equipment in data centers with coefficients and modeling script provided for immediate use in data center energy system simulation. This energy model can be used to simulate energy performance of typical IT equipment in data centers under real-time dynamic operation conditions conveniently and effectively without the need of data other than the specifications of a data center design and IT equipment manuals. Its use with a commonly used building simulation program is demonstrated with a building model of a typical large office in a subtropical area. The results show that the model can represent the change of power consumption of data centers with different IT equipment designs and operation appropriately.

1. Introduction

Energy consumption of data centers is increasing every year. In 2010, their electricity consumption was around 1.3% of the total of the whole world [1], and Shehabi et al. estimated their energy consumption would be tripled in a decade if the demand on their services continued to increase and their energy efficiency remained unchanged [2]. Since the top two energy consumers in data centers have been its information technology (IT) equipment and cooling systems and each consumes around 30% to 60% of total electricity use of the data centers [3–5], many researchers have developed technologies to reduce energy use of these two components in data centers rapidly in recent years [6–14].

Before applying these technologies to a design of a data center, one needs to ensure that the technologies can provide sufficient cooling to maintain the reliability of operation of the data center. This is done by estimating the power consumption of its IT equipment and its cooling load. In the literature, the modeling is usually performed in three ways:

- Constant thermal load density model
- Using actual cooling data
- Detailed modeling of thermal load of IT equipment in data centers

Constant thermal load density model: Building engineers usually estimate the cooling load required in data centers based on their functions and the manufacturing year of the equipment as shown in Table 1 [15–17].

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Nomenclature

a_i	ith empirical coefficient [unit varies]
C	network traffic load [Gbit/s or Gbps]
E	annual electricity consumption [kWh]
LF	load factor
N	number of data points
P	power consumption [W]
Q	total cooling delivered in a year [kWh]
S	average speed [MHz]
T	time variable [s]
u	utilization rate [dimensionless]
y	dependent variable of a model [unit varies]

Subscripts

ac	air conditioning system
dist	power distribution
cpu	processor
dc	data center
ethernet	the ethernet layer
full	full capacity
idle	idle
IP/MPLS	internet protocol/multiprotocol label switching layer
IT	information technology
link	links between routers
measured	measured
network	network equipment
op	operating
otn	optical transport network
predicted	predicted
rat	rated capacity
router	routers
server	server
supply	rated power supply

Acronyms

COP	coefficient of performance
IP/MPLS	internet protocol/multiprotocol label switching
IT	information technology
OTN	optical transport network
PDU	power distribution unit
PUE	power usage effectiveness
UPS	uninterruptible power supply

While energy system engineers can easily apply this method in their projects because the method does not require additional knowledge and information of the IT equipment in a data center, the method may overestimate the thermal load in the data center significantly and leads to oversizing of cooling equipment [18]. It also does not model the changes of power consumption of data centers due to the changes of operation statuses of the computing equipment [5,19], removing the possibility to design cooling systems and the related control systems to cope with these changes. In other words, the model does not allow optimal design and control of cooling systems in data centers.

Using actual cooling data: Studies have also shown that energy system engineers can use actual cooling load profiles of a data center to forecast its performance in the future [20] and to avoid oversizing of cooling equipment [21]. However, the designers can only use this approach after the operation of a data center begins, and they cannot use this method to design data center cooling systems that have not yet been operational.

Detailed modeling of thermal load of IT equipment in data centers: Multiple studies have also been conducted to examine the relationship between the thermal load of the IT equipment and their operating status, and they have discovered that the on/off status of the IT equipment and the utilization rate of the processors has a significant effect to their power consumption and hence the thermal load ([5,19,22–26]). To avoid overestimating the thermal load of a data center, engineers can model the effect of processor utilization rate and on/off status of equipment to the thermal load through detailed models of IT equipment (i.e. modeling servers, server fans, processors, memory, network, uninterrupted power supply (UPS) and power distribution units (PDUs) separately). While the mathematical models of the equipment are available [26–28], the models require detailed specification from each IT equipment or parameters beyond what are usually available in the specification. Since energy system engineers may not have sufficient understanding in these subjects, they need to work closely with IT engineers to use these models which seldom occurs in data center energy system design projects. Some of these models even require extra tests of equipment to define their inputs. There are other models that estimate power consumption based on workload of data and web traffic, but these models also require a variety of inputs such as web and data usage of servers that is difficult to be accessed by data center energy system engineers at the design stage of a data center [29–31]. Due to the difficulty to gather the inputs required by these models, these modeling approaches are rarely used for actual data center design.

The modeling approach may also need engineering judgement of the IT engineers on the operating status of the IT equipment and may be too subjective for engineering designs [32]. For example, IT engineers may use the power supply rating in the specifications of servers to estimate the maximum power consumption of the servers, but a study of server testing data of their actual maximum power consumption, as shown in Fig. 1, can easily show that the rating overestimates the power consumption.

Table 1
Constant thermal load densities used in building simulation software [15–17]

Year of construction	Core data center (space full of server racks)	Server racks in a computer room (space with IT equipment and office desks)
Before 2014	646 W/m^2	232 W/m^2
After 2014	484 W/m^2	215 W/m^2

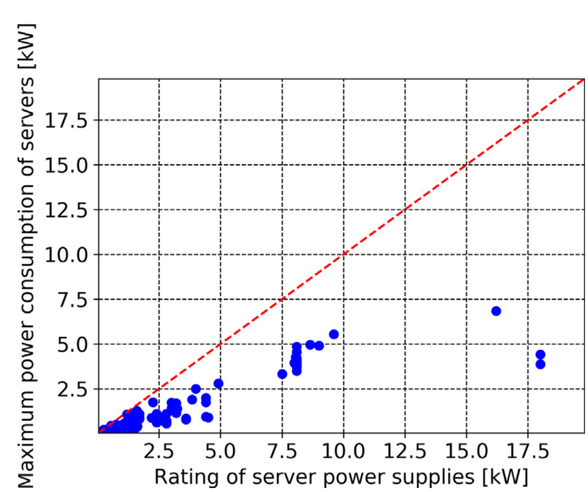

Fig. 1. Comparison of the maximum power consumption of servers and their power supply rating.

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