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A review of air conditioning energy performance in data centers

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ABSTRACT

During the last years, many countries are experiencing rapid expansions in the number and size of data centers to keep pace with their internet and cloud computing needs. High energy consumption of the data center has gradually attracted public attention. However, there are no common efficiency standards governing the design or operation of data centers and the associated air conditioning systems. And the statistical research on air conditioning energy performance is still sorely lacking. This paper presents a summary of 100 data centers air conditioning energy performance. Energy efficiency metrics and benchmarks are also provided so that operators can use these information to track the performance of and identify opportunities to reduce energy use of air conditioning systems in their data centers. The collected data from articles and reports show that the average of HVAC system effectiveness index is 1.44. More than half of the data centers' air conditioning systems are inefficient. In total, HVAC systems account for about 38% of facility energy consumption. The range for this usage was 21% for the most efficient system and 61% for the least efficient system. Moreover it would be necessary to review some currently available energy efficiency strategies such as economizer cycles, airflow optimization, energy management, and simulations tools.

Contents

1. Introduction

A data center is a facility housing computer systems and

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associated components, such as telecommunications and storage systems. It generally includes backup power supplies, redundant data communications connection, environmental controls (e.g., air conditioning and fire suppression) and various security devices [1]. During the last years, many countries are experiencing rapid expansions in the number and size of data centers to keep pace with their internet and cloud computing needs. Because the high density of information technologies equipment (ITE) and the fact that they run 24 h a day, the 365 days of the year, the energy consumption of data center is tremendous. The energy demand per square meter of data centers, which is up to 100 times higher than for office accommodations, increased significantly during recent years [2]. In an Environmental Protection Agency (EPA) report to Congress in 2007, 1.5% of the total United States' energy consumption of 61 billion kWh was attributed to data centers in 2006 [3]. In 2013, U.S. data centers consumed an estimated 91 billion kWh of electricity. Data center electricity consumption is projected to increase to roughly 140 billion kWh annually by 2020 [4].

ITE exposed to high temperature, or to high thermal gradients, can experience thermal failure, particularly when repeatedly exposed to such high thermal gradients. The high heat density of the equipment combined with its thermal sensitivity is a volatile combination, and any loss or disruption to temperature and humidity control, even for a very short time, can lead to ITE damage or loss of data [5]. An interruption caused by ITE failure would entail costly repairs and replacement. Any disruption to ITE operation typically results in a loss of revenue for the end user. The business may lose thousands or even millions of dollars for every minute of downtime [6]. The air conditioning systems that provide for environmental control of temperature, humidity and air contaminant are essential to data centers.

The predominant cooling load of air conditioning system in almost all data centers is the sensible ITE load. The heat density of certain types of ITE is increasing dramatically. The projected heat load growth of 1U compute servers is 20–45% from 2010 to 2020. The 2U compute servers with two-socket configuration has the highest percent growth from 2010 to 2020 of all the servers: 67% [7]. The increase of ITE heat load lead to many uplift of air conditioning system energy consumption. Case studies of 44 data centers conducted by Salim and Tozer showed that the air conditioning system accounted for an average of 40% of the total energy consumption of the data center. The range for this usage was 24% for the most efficient system and 61% for the least efficient system [8]. This means that close attention needs to be given to air conditioning systems to minimize data center energy consumption. But there are little research on air conditioning energy performance in data centers.

Efficiency standards are required for performing a serious analysis of energy efficiency. However, there are no common efficiency standards governing the design or operation of data centers and the associated air conditioning systems, and no consistent test procedures for checking compliance. In order to evaluate the performance of a data center facility and analyze the best energy efficiency strategies, personnel who have responsibility for managing energy use in existing data centers need to compare it to similar facilities. Comparisons are a quick and easy way to identify poorly operating areas, which typically have the highest potential for economical modifications that reduce operating cost and increase the load capacity of a data center.

The intent of this study is to provide the reader with detailed information on the energy performance of air conditioning systems in data centers. The air conditioning system accounted for an average of a large part of the total energy consumption of the data center. However, the statistical research on air conditioning energy performance is still sorely lacking. Meanwhile, energy efficiency standards governing the design or operation of air conditioning systems in data centers are also lacking in the industry. Consequently, it is hard to evaluate the practical energy efficiency of a data center. In this article, the statistical data of air conditioning energy performance and its associated metrics' benchmark value are provided. So operators could compare their data center to peers and identify the effectiveness of its air conditioning systems. This review paper is presented in three sections. In the first section, a comprehensible literature review is given in environmental guidelines, cooling methods, and air distribution. In the second sections, energy efficiency metrics and benchmarking values are summarized so that readers can use these information to track the performance and identify opportunities to reduce energy use of data center air conditioning systems. This section also presents a detailed review of air conditioning energy performance which provides the reader with a broad and detailed background on data center energy operating conditions. In the third sections, many energy efficiency strategies are explained through a review of the past, current, and projected future growth trend of data center industry. It is hoped that this paper will be helpful to researchers in this field.

2. Air conditioning

2.1. Indoor thermal guidelines

The indoor thermal conditions have a significant impact on air conditioning energy consumption. The air conditioning systems control the temperature, humidity and air contaminant in data centers. Wang et al. estimated the energy consumption of air conditioners at different temperature set points. The results shown that the percentage of energy saving was 4.3–9.8% for every 1 °C rise in temperature set points [9]. However, the long-term effect of operating in the high temperatures will result in shortened life of the ITE [5]. So many owners have yet to implement higher ITE intake temperatures within their data centers [10]. Raising temperatures requires a systemic engineering and commissioning approach because each data center, its ITE, air conditioning systems, etc., are unique [11]. High relative humidity (RH) may cause various problems to ITE, such as tape media errors and corrosion. Low RH increases the magnitude and propensity for electrostatic discharge (ESD), which can damage ITE [12]. Compared with absolute humidity, RH is more important [13]. The RH change from 25 to 8% will increase the probability of ESD-related failure in a data center 1–3 times [14]. In addition to temperature and humidity control, dust and gaseous contamination should also be monitored and controlled. These additional environmental measures are especially important for data centers located near industries and/or other sources that pollute the environment [15].

The thermal standard for data centers is strict in China. The recommended environment range of dry-bulb temperature is 22–24 °C. And the RH range is 40–50%. The strict environmental guideline makes no contribution to the goal of reduced energy consumption in data centers. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) created the first edition of *Thermal Guidelines for Data Processing Environments* in 2004. In order to give guidance to data center operators on maintaining high reliability and also operating their data centers in the most energy efficient manner, ASHRAE updated this guideline in 2008 and 2011 [16]. The edition currently available is the third edition, published in 2012 [17]. The suitable environmental conditions for ITE are summarized in Table 1. Moreover, Fig. 1 shows the temperatures and RH recommended in a psychrometric chart. The revision of this envelope allows greater flexibility in facility operations, and contributes to reducing the