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A critical analysis of Power Usage Effectiveness and its use in communicating data center energy consumption

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ABSTRACT

Data centers represent an increasingly popular construction project type, supported by the continued growth in internet-based services. These facilities can, however, consume large amounts of electricity and—especially if growth trends continue—put strain on utility grids and energy resources. Many metrics have been proposed to evaluate and communicate energy use in data centers. In many cases, the goal is that these metrics will be used to develop energy conscious behavior and perhaps data center energy rating systems or building codes to reduce average energy use. In this paper, we examine one of the more popular metrics, Power Usage Effectiveness (PUE), and discuss its shortcomings toward effectively communicating energy consumption. Our inference is that PUE is an instantaneous representation of electrical energy consumption that encourages operators to report the minimum observed values of PUE. Hence, PUE only conveys an understanding of the minimum possible energy use. Instead, we propose the use of energy-based metrics or average PUE over a significant time period—e.g., a year—to better understand the energy efficiency of a data center and to develop energy rating/ranking systems and energy codes

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1. Introduction

Human influences on global climatic change [1] and threat of fossil fuel depletion [2] have increased sociological movements toward adopting more energy-efficient and ecologically friendly lifestyles during the past three decades. With regard to the built environment, the building energy codes in many countries have evolved to reduce energy usage in new construction projects [3]. In addition, a number of voluntary building rating systems and construction guidelines continue to be developed that aggressively push environmentalism (e.g., Leadership in Energy and Environmental Design or "LEED" rating systems).

Coinciding with the ramping movements in environmentally friendly building design is the rapid growth of data center construction. These facilities can be very power-hungry and although most jurisdictions treat data center construction as building projects, many of the power-consuming elements of the facilities are not (and are difficult to) curb using conventional building energy codes. Furthermore, the utility-value seen through adopting voluntary rating systems in other building projects may not translate well for data centers. Many metrics have been proposed to evaluate and communicate energy efficiency in data centers. In many cases, the hope is that these metrics can be used to develop behavior, rating systems, and/or building codes to reduce average data center energy use. In this paper, we discuss some of these metrics, focusing on one of the more popular metrics, i.e., Power Usage Effectiveness (PUE). We illustrate a few of the issues involved with using PUE to communicate energy usage and what can be done to address some of these issues. Before continuing our examination into data centers, PUE, and related metrics, we first present some of the building codes and systems that promote energy management and reduction in the built environment. This discussion should develop an understanding of the effectiveness and concepts behind these building energy codes and rating systems in order to support analyses presented later in this paper.

2. Building energy codes and rating systems

Building energy codes typically allocate maximum power allowances to certain energy consuming building subsystems—such as lighting and heating/cooling—thereby providing guidelines for the associated engineering efforts in a construction project. These power allowances convey the maximum potential energy consumptions of the associated building subsystem and provide a general idea of the actual energy consumption, when factoring in utilization rates. Building energy codes help limit electricity use in new construction to an amount found suitable by the relevant governmental jurisdiction(s), since

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meeting or surpassing building codes is mandatory to complete the construction initiative. Building-plan-checkers review engineering designs and analyses against the corresponding building energy codes in order to determine if the construction project is fit for realization.

To develop an understanding of building energy code provisions we can look at their development and application in the U.S. construction industry. Two primary baseline energy standards govern building construction in the U.S. [4]: (1) The International Energy Conservation Code (IECC), and (2) the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1 [5]. These standards are adopted and—in some cases—expanded upon by states and local ordinances to create building energy codes. Perhaps one of the most notable building energy codes in the U.S. is the California Energy Code or "Title 24," which since its first release in 1974, has aggressively pushed energy reduction in lighting and mechanical subsystems beyond IECC and ASHRAE prescriptions in its tri-annual updates. Like ASHRAE, Title 24 allocates maximum power allowances to building types or spaces based on the type of use and expected occupancy. For example, office building lighting power densities have to be less than 9.15 W/m^2 (0.85 W/ft^2) as per the 2010 version of Title 24 [6]; this translates to a maximum potential lighting energy consumption of approximately 80.2 kW h/m^2/year (7.45 kW h/ft^2/year) assuming that lights are never switched off.

Although building codes have been effective channels for building energy reduction, they can be ineffective at developing energy conscious behavior. Often such codes are treated as an exhaustive set of technical requirements [7], therefore limiting innovational thinking toward further reducing energy consumption and other considerations. The codes can take many years to be updated and, as a result, often become regulations late in the lifecycle of energy reducing technologies. Also, building energy codes often do not cover all of the energy consuming elements of a building, e.g., no power allowances are placed on plug-loads in the dominant building energy codes in the U.S. Voluntary rating systems such as LEED and 'EnergyStar' attempt to address the voids and limitations in building energy codes. Most of these rating systems allocate "points" to the extent of reduction beyond the governing energy standards and use these points to compare buildings or communicate energy efficiencies to investors or end-users of a building project. Essentially, these systems attempt to use societal demand for more environmentally sustainable buildings to create a utility for points, rankings, or certifications in the promise of increased building occupancy or occupant happiness. Unfortunately, although this can work well for typical commercial (and maybe residential) buildings, this may not work as well to curb energy use in data centers since the primary purpose of these facilities is not to house humans.

3. Data centers

Data centers can be defined as any space whose main function is to house servers [8] or computing devices that are in-use, i.e., are powered on and performing functions. Although a small computing room within a multipurpose building can be considered as a data center, the term is conventionally used to describe buildings whose sole purpose is to house these servers. In this conventional sense, human occupancy is limited to small Information Technology (IT) support groups who may have office space within the building—these office spaces are small relative to the total size of the building. These facilities differ greatly from most buildings from a construction perspective. For example, mechanical and electrical systems account for 70% of construction costs in data centers, in contrast to only 15% of costs in commercial buildings [9].

Today's data centers are mainly used for internet or network-based activities. They contain servers that store and process electronic data, communicate with other computer networks, and/or manage user interactions with server-based software tools and web portals. Quite often, data centers are used to manage data and operations that are considered to be sensitive or important, such as email correspondences and company/government databases. As a result, reliability—i.e., its ability for the servers to be functioning properly and not lose data—is a critical concern for many data centers. This reliability is strongly linked not only to the characteristics of the servers used but also to that of the data center data center "infrastructure", which includes the power distribution and mechanical—i.e., Heating Ventilation and Air Conditioning (HVAC)-systems. That is, the servers need a constant supply of electricity and are less susceptible to hardware breakdown when operating below a certain temperature. (It is important to note that the servers can generate substantial amount of heat and, as a result, data centers often have large cooling loads [10].) Therefore, in addition to having redundant computing setups, most facilities use redundant power distribution networks, Uninterruptable Power Supply (UPS) and Automatic Transfer Switch (ATS) devices, and specialized mechanical cooling systems in order to minimize the probability of server failures. The extent of redundancy in the power distribution network and mechanical systems are often used to rank and compare the reliability of data centers. This is referred to as the data center 'Tier level' [11] where higher Tier levels represent greater redundancy.

Achieving reliability through power/cooling redundancy and the use of UPS and ATS devices increase the electrical energy used by a data center. In contrast, other buildings typically do not need such redundancies and devices. In addition, data center operators often try to optimize floor space usage by maximizing the number of servers that they can fit in the facility. Therefore, data centers tend to have high power densities, sometimes greater than 1.08 kW/m^2 (100 W/ft^2) [12], in comparison to the 75–108 W/m^2 (7–10 W/ft^2) seen in typical office buildings [13]. As a result, although there are far fewer data centers than other buildings and energy loads, data centers accounted for approximately 1.1% to 1.5% of global electricity usage in 2010 [14].

As the use of internet-based services grows, data center construction has increased. During the period 2000 to 2010, the annual construction of data centers (in terms of money spent) increased over 300%, from approximately $15 billion USD to $50 billion USD [15]. Some of this increased spending is attributable to more data centers being built per year, while others is attributable to increased redundancy in the newer data centers. That is, a 'Tier 4′ data center can cost $22 million USD/MW in comparison to $10 million USD/MW for a 'Tier 1′ facility [15]. With focus and spending placed on ensuring reliability, matters related to energy consumption and efficiency are often secondary or tertiary considerations in construction and operation. Data center energy use grew by 16.7% per year globally between 2000 and 2005 [8] and 56% over the five years 2005–2010 [15], or 11.6% per year. Over this entire ten-year period, the project size and power densities of data centers have increased. Therefore the slight difference in the rate at which energy use increase between 2000–2005 and 2005–2010 is likely a result of the use of more energy efficient components or building systems as developers push for greater energy efficiencies.

3.1. Energy efficiency in data centers

As stated, data centers can consume large amounts of electricity, strain utility grids, and accrue significant electrical bills. With increasing societal movements toward energy sustainability, poor economic climates, etc., there has been a push in the data center industry to better evaluate and communicate the energy usage with

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