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Datacenter Efficiency Measures

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***Abstract*—This document answers the questions, "What are relative energy efficiency measures (percentage of energy reductions) that are available to data centers for improving energy efficiency?" and, "What types of certifications are now available to data centers?"**

Keywords— data center energy efficiency measures; green computing; green data center certifications

I. INTRODUCTION

Data center energy efficiency is one of the largest challenges in data center management. The largest expenses in the data center are power and cooling. Managing the efficiency of the data center means fewer expenses that do not produce income. Cost savings translate into competitive advantage.

One of the reasons that managing data center energy efficiency is a challenge is the fact that while there are methods to measure data center energy efficiency, the metrics available are not adequate. Effective and simple means to measure data center efficiency is the subject of years of research and much ongoing debate.

Data center managers cannot wait for this ongoing debate to be settled before attempting to understand and manage energy efficiency. According to a management adage, "You can't control what you can't measure." This document will introduce data center energy efficiency concepts, certifications, and tools.

II. DATA CENTER ENERGY EFFICIENCY MEASURES

A. Power Usage Effectiveness

The most widely accepted measure of data center efficiency is Power Usage Effectiveness, more commonly referred to as PUE. PUE attempts to measure how much of the energy consumed by the data center is being used for processing.[1] The ideal PUE is one; a PUE of one represents 100 percent efficiency. This would mean that all energy consumed in the data center was used for processing.

$$PUE = \frac{Total\ Power}{Total\ IT\ Equipment\ Power}$$

The average data center PUE reported by the Uptime Institute in 2011 is 1.8 representing about 20 percent efficiency. This represents an improvement, as in 2009 the Energy Star program reported an average PUE of 1.91. This means that for every watt used for computing processes nearly another was used as overhead. According to 2006 Gartner press release, "traditional datacenters typically waste more than 60% of the energy they use to cool equipment.[1]

B. Data center infrastructure efficiency

Data center infrastructure efficiency (DCiE) is a less commonly used measure. The DCiE is the inverse of the PUE and is represented by a percentage.[2]

$$DCIE = \frac{IT\ Equiptment\ Power}{Total\ Facility\ Power}$$

Table I displays PUE and the corresponding DCiE

TABLE I. PUE VS DCIE [3]

Datacenter Type	***PUE***	***DCiE***
Best in Class	1.28	78%
Target	2.00	50%
Average	3.00	33%

C. Power to Performance Effectiveness

Power to Performance Effectiveness (PPE) was created by Gartner to help identify efficiency at the device level.[4] This measure addresses the server usage to power usage paradox. Server usage to power usage is typically not a linear relationship. A server at 20% usage may use 80% of its potential power draw. PPE "measures server performance per kilowatt"[5].

D. Corporate Average Datacenter Efficiency

Corporate Average Datacenter Efficiency (CADE) was developed by McKinsey & Company and the Uptime Institute. CADE "is the product of facility efficiency (in effect, DCiE) and IT asset efficiency, the latter being derived from a combination of the utilization and efficiency of the IT equipment."[6]

$$CADE = IT\ Efficency\ x\ Facility\ Efficency$$

Another possible representation of CADE is:

$$CADE = DCiE\ x\ Average\ Facility\ CPU\ utilization$$

The aim of CADE is to "determine how fully the physical equipment installed at the facility is being used".[3] "The basic measurement concept is the useful IT work/IT watts. Since industry-wide definitions of useful IT work are still under development, CADE uses an arbitrary baseline value of 5% for IT energy efficiency."[3] Figure 1presents an example CADE calculation.

CADE has a rating system that is comprised of five tiers illustrated in Table II. A CADE level 1 would represent poor efficiency of 5% or less. Conversely a level 5 CADE would represent this most efficient data centers those that are 40% efficient or more.[3]

CADE: Servers Only baseline Year Calculations

IT Efficiency

IT asset utilization* (10% on active apps, 8.5% overall)

IT energy efficiency (assume 5% for base year)

Facility Efficiency

Site asset utilization* (55%)

Site energy efficiency 12 month average** (46%)

CADE=8.5% x 5%x55% x 46% x 100 = 11

*Asset utilization = IT Plug load/site asset capacity

**Same as DCiE

Figure 1 Example CADE calculation [7]

TABLE II. CADE TIERS[3]

CADE Tiers	*CADE Value*
Level 1	0-5%
Level 2	5-10%
Level 3	10-20%
Level 4	20-30%
Level 5	>40%

E. Performance per Watt

Performance per Watt (PPW) "uses a relative performance indicator for each individual asset. This indicator is calculated by the types of hardware and capabilities learned from an asset inventory of that device. This Performance Indicator (PI) is a simple measurement for getting relative performance of the device in question." The PI metric is then multiplied by the average device usage per watt to get the PPW.

$$PPW = PI\ x\ \frac{Average\ Device\ Usage}{Watts}$$

Higher numbers of PPW indicate higher efficiency and are therefore more desirable.

F. Criticism of measures

CADE and PPE were developed because "neither PUE nor DCiE takes into account the energy efficiency of the IT equipment"[6] The CADE and PPE measures claim to address the shortcomings of PUE and DCIE. PPE is conspicuously lacking a widely published equation despite the many industry articles announcing its superiority over the PUE. CADE has been criticized because it is expensive to implement. The PPW claims to have the advantage over CADE by because it is less expensive to implement while providing device level metrics. It is apparent that developing the PIs required for all devices will involve some additional cost. There are certainly more measures than presented in this document and it appears that PUE will remain the standard until a clearly superior measure emerges.

Proposed and accepted data center measures share one criticism; the method to obtain to measure is not proscribed. The result of the lack of proscribed techniques to collect data to produce the metric is wide variation. For PUE there is debate concerning the possibility of achieving a PUE of less than 1.0. Many argue that a PUE of less than 1.0 is impossible as this represents 100% efficiency. The argument against a PUE of less than 1.0 is that it is not possible to use less energy than enters the facility. Others disagree and at least one data center claims to have achieved a PUE of less than 1.0.[7] Claims of sub 1.0 PUE are based on the exclusion of renewable energy produced on site. For example subtracting on site wind or solar energy produced from the power used in the data center.

These variations in measurement of data center efficiency call into question the reliability of PUE as a measure of efficiency across data centers. "This disparity could suggest that PUE, while useful as an internal metric, is not the most effective form of comparison between data centers." [8]

> *"'Energy efficiency metrics should continue to remain in-house and be utilized as benchmarks of performance and not for publication in any magazine or online forum,' Gabe Andrews of Greater St. Louis said. ' As an enterprise, it may be acceptable to have a PUE of 3.3 based on the multiple levels of redundancy built into the facility to ensure a lack of downtime. In the market this single number is outlandish and inefficient.'"*[9]

III. FACTORS IMPACTING MEASUREMENT ACCURACY

The time of year an efficiency measurement is taken can have a profound impact on the outcome of the final metric. Measurements taken in Indiana in August during the state's time of highest heat and humidity are going to be very different from measurements taken in February when the heat and humidity is low for the state. Similarly, the time of day would have an impact. Measurements taken at 2 am are probably going to appear to be more favorable than measurement taken at 2pm in most of the world.

In addition, the point of measurement is important, measurements taken where the power enters the facility will not include any power transformations that may occur within the facility. These transformations are typically inefficient, therefore measurements taken after the transformations may appear to be more efficient than those taken after

transformations from 480 volt to 220 volt or 110 volt. In addition, what is counted as energy consumed will impact the final metric. A facility that subtracts energy produced onsite will appear to be more efficient than a data center that does not subtract onsite energy production.

IV. Factors Impacting Efficiency

Many factors impact the energy efficiency of a data center. As processing power, increases often power consumption increases. What this means is that a data center that has a hardware refresh may have an increase in PUE. This does not mean the data center has become less efficient despite the fact that the over all energy consumption has increased. This is because while the energy use has increased the processing capability has increased substantially more than the energy consumption. In reality, the datacenter may be processing more loads than ever saving the organization time and money. Therefore the equipment is more efficient, the PUE is simply not capable of expressing this type of efficiency gain because it measures energy not processing.

Redundancy can negatively impact efficiency metrics such as PUE because the additional equipment will generally result in increase energy loads. As mentioned in the Gabe Andrews quote above, this increase in operating load may be acceptable depending upon the need of an organization. For example, even seconds of down time is incredibly expensive to a bank therefore, it makes little sense to strive for a low PUE at the expense of availability. It should be noted that redundancy via geoclustered sites might reflect a lower PUE than intradatacenter redundancy. Geoclustered redundancy that is configured as active-active will result in lower PUE per data center as well as increased availability. However, the overall PUE for the organization could be higher.

Resource utilization is also a factor in data center efficiency. Servers powered on but at low usage are not as efficient as those with 40-70% utilization in most cases. This is something that PUE does not include, but is certainly a factor to be considered in data center efficiency. In addition, de-duplication is equally important. Even if all servers are maintained at 40-70% utilization the data center is losing efficiency if the servers are all dealing with unnecessary data redundancy. Data de-duplication could reduce the hardware necessary to process and store data thereby reducing energy consumption. Efficiency of software also is a factor on energy efficiency in terms of resource utilization. The issue of software efficiency is complex, but should be addressed at the operating system level minimally.

Lastly, data center location and cooling equipment type will impact efficiency. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has increased the allowable range for free cooling which now allows most of the world to take advantage of using air side economizers rather than the more traditional CRAC units. Data centers using airside economizers or other means of free cooling will be more efficient than those using CRAC units. As will data centers located in areas with low year round temperatures. Data centers with equipment rated for higher temperatures will allow the use of free cooling during more of the year and in more locations. Datacenters that operate at higher temperatures will also have higher energy efficiency.

V. How to use Efficiency metircs

Despite the weaknesses of the efficiency measures, they can provide a baseline from which to improve if used effectively. Most important to obtain useful metrics is to be consistent in the methods used to create efficiency metrics. Each set of metrics should be obtained from the same sources at the same time of day in order to reduce the effects of variations that do not reflect true change in energy efficiency.

VI. Tools for measuring datacenter efficiency

Tools and devices used to measure data center energy efficiency vary widely. In many cases, power meter readings are used in combination with Power Distribution Unit (PDU) readings. As interest in Data Center Infrastructure Management (DCIM) has increased, a greater number of products have become available to assist in the monitoring and control of energy consumption. Data Center Management (DCM) tools provide this capability at the device level and some even provide component level information. DCM tools typically use hardware, firmware, and software to provide energy monitoring and control. DCM tools use integrated Intelligent Platform Management Interface (IPMI) subsystems to allow system administrators to set policies such as power capping. Talented systems administrators can use log data provided by IPMI to implement custom policies to limit CPU use or maximize storage use by integrating a job scheduler. The use of these tools can provide insight and control to optimize server use and energy efficiency.

A. Firmware: Advanced Configuration and Power Interface (ACPI)

The purpose of ACPI is to enable Operating System Power Management (OSPM) to be developed and employed. ACPI is a voluntary industry standard for hardware that allows operating systems to develop independently of hardware or BIOS. The most recent version is Advanced Configuration and Power Interface Specification revision 5.0 released December 6th 2011. [11] The compatibility created via the ACPI specification enables operating systems to manage complex power management features. The goal of the power management features is to reduce power consumption though management of the hardware components.

ACPI provides power management states for processors, devices, and thermal management. System wide sleep and wake states are also provided through ACPI. Power and related data collection are also enabled through this specification. The various levels of control allow a computer to be managed in granular manner that fits the machine's usage to best conserve energy. Data collected can allow power management features to be optimized for the computer's unique function. The implications for servers are addressed in the ACPI 5.0 Specification.

> *Server machines often get the largest absolute power savings. Why? Because they have the largest hardware configurations and because it's not practical for somebody to hit the off switch when they leave at night.* [11]

The take away is that having ACPI compliant hardware and operating systems means energy savings. These savings implemented on a large scale have the potential to have a major positive impact on the bottom line.

VII. Datacenter Certifications

Certifications for "green" data centers are still in the developmental phase. Energy Star has created a newer standard more specific to data centers. They have added a data center assessment to their online Portfolio Manager tools. This efficiency certification system is based on a 100-point scale. "Those that score 75 or higher can request an audit from the EPA, which then awards the Energy Star certification."[12]This efficiency measurement takes into account accepted data center metrics such as PUE.

Another and perhaps more common certification is Leadership in Energy and Environmental Design (LEED) There are various LEED rating systems such as those for new construction, existing buildings, retail, and homes. The rating system's 100-point scale, shown on the LEED Certification Levels Table, includes sustainable site selection, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, locations and linkages, awareness and education, innovation in design and regional priority.[13]

TABLE III. LEED Certification Levels

Certification Level	***LEED Score***
Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80+

The British Computer Society (BCS), a non-profit organization dedicated to improving information technology worldwide, developed the Certified Energy Efficiency Data Center Award (CEEDA). This award certifies that data centers are following the European Union Code of Conduct for Data Centres best practice originally published in 2008.[14] CEEDA assessments measure performance areas shown in:

- Datacenter utilization
- IT Equipment and services
- Cooling
- Datacenter power equipment
- Datacenter building
- Monitoring

This award is internationally recognized and has three levels: bronze, silver, and gold. The Gold Award is the highest level of this award and is the only level with a PUE requirement. To be awarded the CEEDA Gold a data center must have a PUE of less than 1.5 during the previous 12 months.[15]

VIII. Conclusion

There are several measures of data center energy efficiency. Any can be used to provide a baseline for improving energy efficiency if used effectively. Each has it advantages based on granularity and ease of implementation. Data center managers are advised to choose the measure that is most appropriate for the organization and apply it uniformly. The important thing is to create a reliable and valid measure from which to measure meaningful energy efficiency improvements. Failure to collect data consistently will invalidate the results any of metrics produced. Manipulation of efficiency measures to achieve desired results will not result in meaningful efficiency gains. Long term cost savings will not be achieved if efficiency data is not consistently collected.

It is not necessary to adopt an existing measure to make efficiency gains. Many organizations have developed their own measures and have achieved improvements. It is apparent that using measures such as PUE to benchmark an organization's efficiency against the rest of the industry is not practical.

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