ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Data Center Metrics: A Model for Energy Efficiency

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Abstract

What energy efficiency metrics can be used by IT managers to measure and maintain the implementation of cost savings and green initiatives in data centers? This paper looks at the background of the problem and explores the reasons why energy savings in the data center is an important issue. Included are interviews and survey results from IT professionals serving at four unique organizations. A model of the measureable components of a data center is created to provide a framework for organizing metrics and communicating results throughout the corporation. The strengths and weaknesses of two of the most common data center metrics, PUE and DCP, are examined closely. Finally, the paper concludes with future metric recommendations and a proposed credit-based system that could be applied to encourage closer management of these metrics.

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Introduction

What metrics could a company use to measure the effectiveness of their green initiatives for energy savings in data centers? To examine this problem, one needs to consider how important it is to measure the efficiency of energy use in data centers. Today's data centers are big energy consumers and they're filled with high-density, power-hungry equipment. Gartner warns: "If they are not fully aware of the problem, data center managers run the risk of doubling their energy costs between 2005 and 2011. If we assume that data center energy costs continue to double every five years, they will have increased 1,600 percent between 2005 and 2025" (Kumar, 2008). In a report released at the end of September, IDC found that almost half of 459 European companies they surveyed had put in place a strategy for incorporating green IT and that cost savings along with regulations were ranked as the main drivers for going green (GreenerComputing, 2008).

Data centers use nearly 10-30 times more energy per square foot than office space (Caldow, 2008). Like the energy costs, the energy use in data centers is also doubling every five years. If compared in terms of "equivalent houses", a medium scale 21500 sq ft 4000 kW load data center built in 2005 would have an annual energy consumption today equivalent to as many as 3000 three bedroom houses. Considering delayed capital investments, there could be no more emphasis on energy efficiency becoming a key measure of operational effectiveness for data centers (EPA, 2007).

In most organizations, the utility bill for the data centers is not considered in the IT budget. It is aggregated as a part of the facilities management budget. In companies where the data center is not a separate facility from the rest of the business, the data center's energy consumption is not separated from office and manufacturing consumption. This makes the job of measuring the data centers energy consumption complicated.

The U.S and other governments are trying to quantify and address these issues. In the near future there will be various government sponsored guidelines and/or regulations that companies will have to follow to address these issues. The need for metrics and methods for facilitating energy consumption and efficiency is critical for these green initiatives to succeed. Management will need a method to evaluate the current and on-going progress of various energy saving programs. This paper will seek to identify the most common metrics adopted by the industry to measure the energy efficiency initiatives in their data centers. These could also serve as benchmarks for other enterprises that are trying to embark on this journey of energy efficiency, greening and savings.

Background

What is a Data Center

The Data Center Journal states that a data center (also called a computer room) can be defined as the room where infrastructure related to hosting software applications resides (Data Center Journal). The infrastructure can range from a few computers to racks of servers depending on the complexity of the business, business strategies and the value perceived by the stake holders of the business.

Associated to this infrastructure are other components such as networks, environmental controls (air conditioning, fire suppression, etc.), failover mechanisms like redundant/backup equipment, redundant data communications; and security. The data center can be perceived to be the nerve center of the organization, and it is very essential for it to be reliable, cost effective and scalable for the success of the business.

The criticality of the data center places an important responsibility on the data center managers. Data center managers are expected to protect the expanding volumes of data and support a wide variety of mission critical applications including widely heterogeneous and highly complex environments. By leveraging various technologies and processes across this infrastructure, data center managers can help protect data and applications, enhance data center service level agreements, improve storage and server utilization, and drive down capital (TCO) and operational costs.

The Data Center Journal likens data centers to energy hungry monsters whose proportions expand as the requirements increase.

“Attempts are being made to tame the data center monster so that they perform to their maximum possible ability while consuming the least possible amount of power by having the maximum possible energy efficiency. But then there needs to be certain parameters which define the efficiency and give a standard way to measure it.”

This further emphasizes the industries’ need for standard metrics and methods to take the measurements before energy costs get out of control.

Data centers are found in nearly every sector of the economy: financial services, media, high-tech, universities, government institutions, and many others use and operate data centers to aid business processes, information management, and communications functions.
The U.S. data center industry is in the midst of a major growth period stimulated by increasing demand for data processing and storage. The demand is driven by global growth of the Internet, electronic transactions in financial servers, eCommerce, high performance scientific computing, and the shift to using electronic medical records for health care, among many others. Between the years 2000 and 2006, the number of servers installed grew from 5.5 million to 10.9 million (Koomey, 2007).
The inaugural Data Center Demonstration Project 2008 was launched by the Silicon Valley Leadership Group (SVLG) , the Lawrence Berkley National Laboratory (LBNL), California Energy Commission, Department of Energy and Sun Microsystems as a response to the EPA’s call to action on objective and credible information on the performance of new technologies and the best practices and its effects on the data center availability. The project included 11 technological initiatives and 17 case studies across the industry. The results were computed in terms of energy savings, costs and implementation realties. It was understood that as of 2006, the electricity use

attributable to the nation’s servers and data centers was nearly 61 billion kWh, nearly 1.5% of the total US electricity consumption, nearly double that of year 2000 consumption levels and amounting to nearly $4.5 billion in costs. Shipments of higher computing power servers increased nearly 20-30 percent CAGR - a significant increase considering the overall server market. (Tung, 2008)

Literature Review

Power Distribution and Utilization in a Data Center

According to Matt Stansberry of SearchDataCenter, Data Center Pros are looking for metrics to measure and manage the data center, those metrics being more from the perspective of performance and data center reliability.

A major part of the data center operating costs would be in the areas of power usage of the IT equipment as well as the cooling equipment, in addition to other ancillary equipment.

To better understand and manage where the power that goes into the data center is consumed the components that make up a data center need to be analyzed. Figure 1 illustrates the basic components found in a data center. (Silicon Valley Leadership Group)

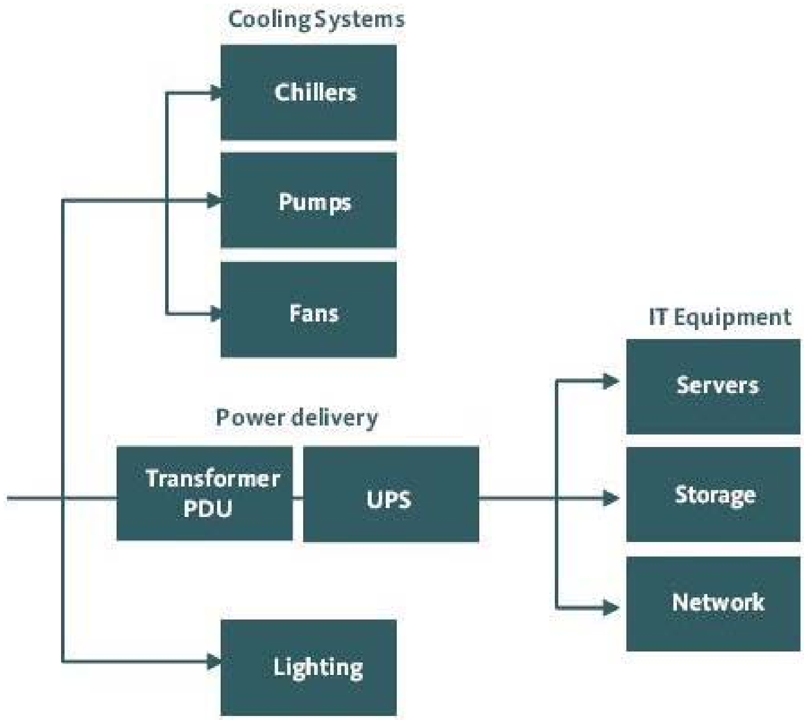

Figure 1. Typical Electrical Components in the Data Center (Tung, 2008, SVLG)

The source of the electricity to the data center is normally from the main supply electricity grid or the back up generator. A switch distributes the power to the lighting, cooling and IT equipment. Each of these broad categories breaks down further into individual components within the data center such as fans for cooling (Pratt, 2007), light bulbs for lighting, and servers. The power that comes in to the data centers has to be transformed to match the needs of the components it is powering. It is there transformations that result in lost power due to inefficiencies.

Heat is also one of the byproducts of the power delivery process to the IT equipment, and can have a significant negative impact on the life of the IT equipment. It is for this reason that cooling is the largest facility investment in the data center, as shown in

Figure 2. Cooling can be accomplished through fans, pumps and chillers and optimizing these components can yield significant cost savings.

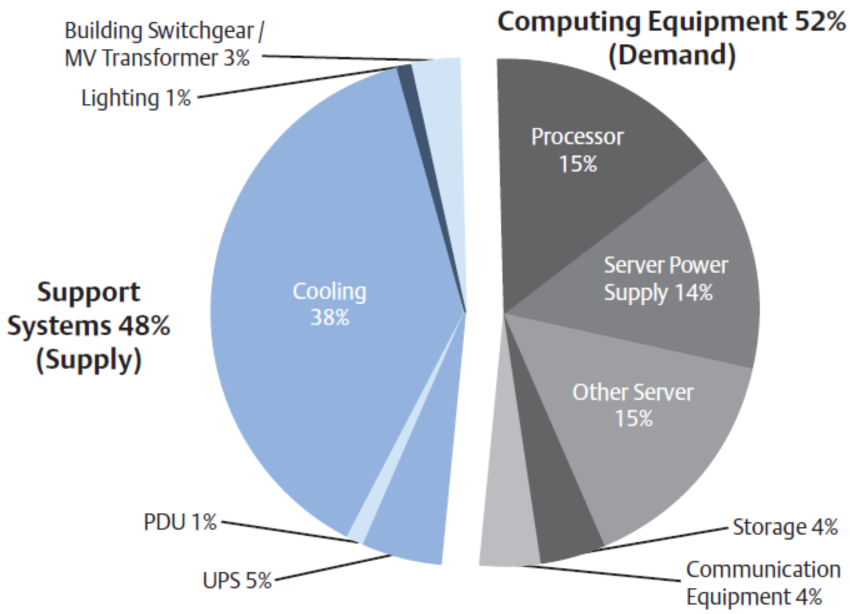

Figure 2. Power usage in the data center (Emerson Network Power, 2008)

Impact of data center power usage on the Environment

In 2005 the power used by data centers was 1 percent of the world's total electricity. Nearly half of the energy used by data centers is for infrastructure equipment. Currently the US and Europe have the largest data center power usage but the Asia Pacific region is rapidly catching up (Fehrenbacher, 2008).Currently, IT equipment generates approximately 2 percent of the world C02 emissions (Gartner, 2008). The large impact data centers are having on the world has raised concern amoung environmental groups, including the Environment Protection Agency (EPA). Unfortunately, due to the differences in energy policies amongst its states, the US does not have a single dominant entity responsible for energy efficiency programs (Blumstein, 2007).

The EPA defined five different scenarios to show the annual electricity usage based on actions taken by data centers to improve efficiency. The scenarios ranged from no changes to the current trend to using state of the art energy efficient components. The figure below shows the historical and projected growth along with opportunities for potential energy savings.

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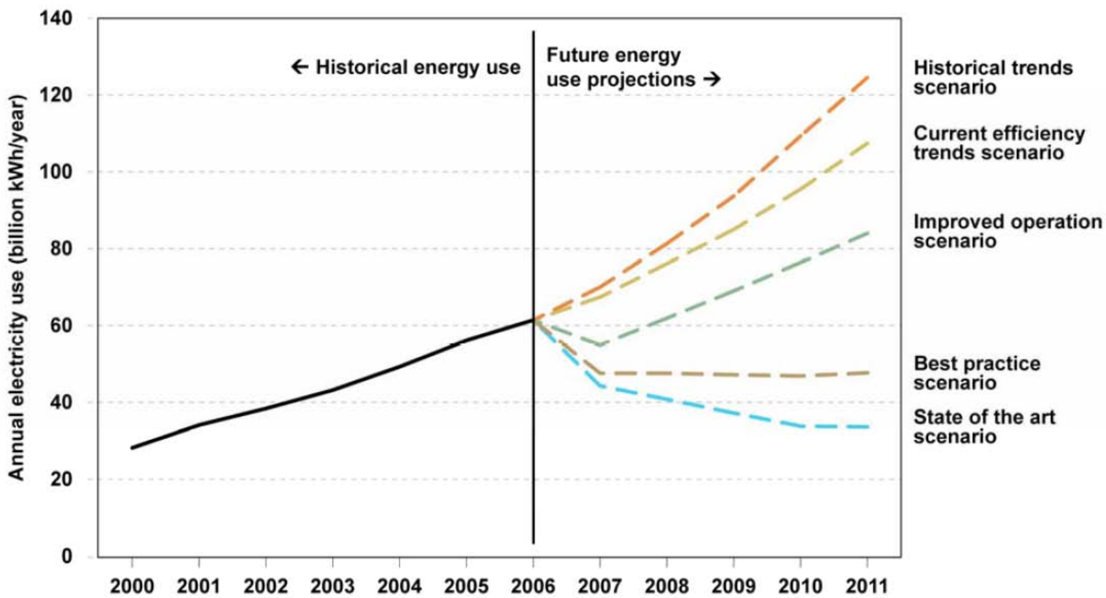


Figure 3. Comparison of Projected Electricity Use, 2007 to 2011 (Emerson Network Power, 2008)

By just moving the industry to the "Improved Operation Scenario" the EPA projected an estimated annual savings of 23 to 74 billion kWh, translating to annual electricity costs savings by $1.6B to $5.1B. This would also reduce the CO2 emissions by 26 to 58 million metric tons by 2011 (EPA, 2007).

Considering the large potential for savings, further investigation is needed to determine whether organizations in the United States are aware of energy efficiency metrics that could lead to improved energy use.

A Need for Metrics to manage Power Usage

Purchasing IT and facilities equipment with greater energy efficiency will help an organization along with its goals. However, the Rebound Effect (Ockwell, 2008) could potentially occur, causing increased power consumption because people overuse or misuse the equipment now that it is deemed energy efficient. Avoiding the Rebound Effect is one of many reasons why monitoring energy savings metrics is important.

Publications by InfoTech Research Group in January 2008 have revealed that the US still has a long way to go in the awareness, establishment and monitoring of metrics.

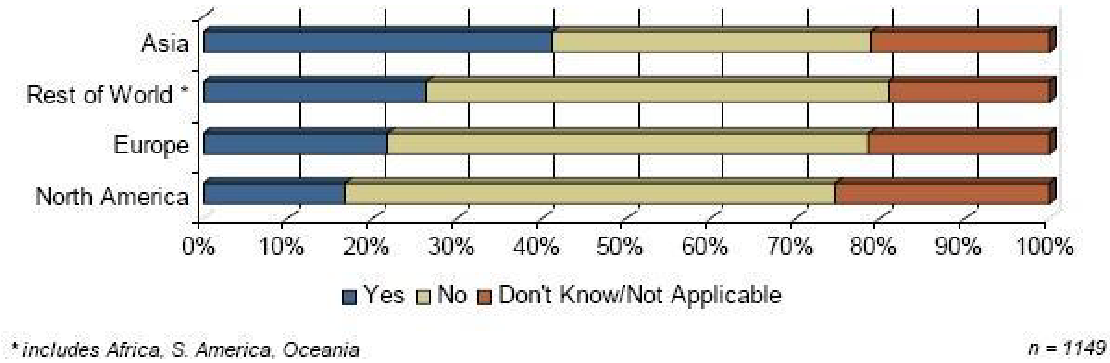


Figure 4. "My Company has an IT power consumption efficiency metric" (Info-Tech Research Group, 2008)

From this publication and a series of other third party surveys too, it seems that the overall data center costs were considered as overhead facility costs rather than a separate cost center for effective control.

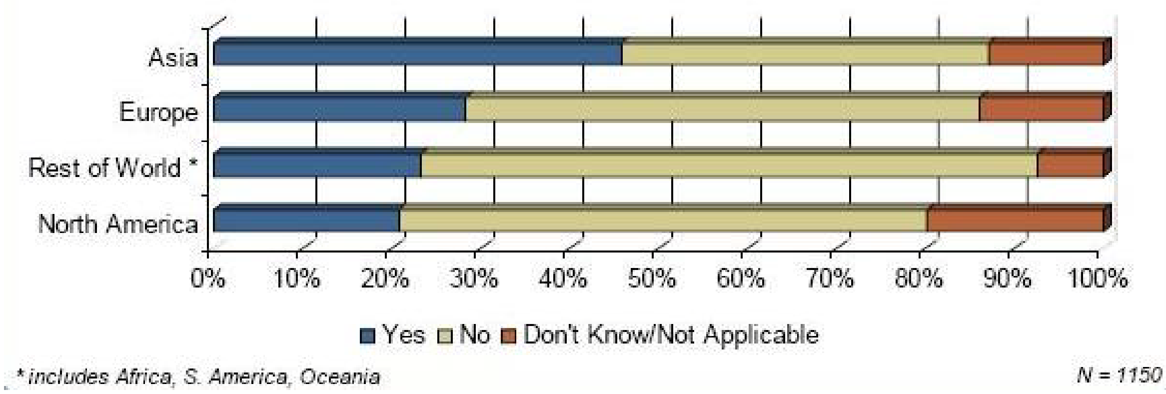


Figure 5. "In my company, electricity costs are the responsibility of IT" (Info-Tech Research Group, 2008)

From these results it seems imperative that the government and the industry as a whole have to invest substantial time and effort to raise the awareness of energy efficiency metrics towards achieving not only cost savings but also to reduce emissions.

To mitigate the problems associated with a multitude of metrics and thereby inconsistent measurements of data center performance, the US Department of Energy (DOE) and the EPA conducted a workshop in July 2008 regarding the collaboration between the government and IT industry to improve energy efficiency in Data Centers. (National Data Center Energy Efficiency Strategy Workshop, 2008) The areas of improvement that were discussed include:

a. Defining energy efficient data centers, creating better transparency in the energy use in data centers and IT equipment through metrics, standards, and best practices.

b. Advancing energy efficient data centers: Focusing on adoption of energy efficient technologies and practices in data centers through knowledge creation and management

c. Rewarding energy efficient data centers: To help organizations better quantify and understand internal rewards from energy efficiency.

The target areas for the US DOE and the US EPA would be:

a. Complete Energy Star specification for computer servers

b. Initiate a workgroup to start researching a Tier 2 server specification

c. Continue research into specifications for other IT equipment
d. Finish data collection effort on data center energy use. The EPA has over 125 companies that have pledged to regularly collect data on over 240 data centers in US and abroad
e. Pursue completion of research into a benchmark rating system for data centers that could be used for an ENERGY STAR buildings program for data centers
f. Engage in a dialogue with telecommunication companies for a rating system for telecom facilities

A gap analysis was done at the workshop to show the need to have consistent and standard metrics. (National Data Center Energy Efficiency Strategy Workshop, 2008).

DEFINING ENERGY EFFICIENT DATA CENTERS
(● = MOST CRITICAL GAPS)

EXHIBIT 1 – GAPS	
• Efficiency data for computing and infrastructure equipment - servers, chillers, ups, etc. ●●●●●●●●●●●●●●●●●●●● • Technical metrics must be converted to business/financial metrics/incentives ●●●●●●●●● • Lack of instrumentation and connectivity of the data ●●●●●●●● • Vendor neutral technology benchmarks ●●●●●● • Need standard definition for DC productivity ●●●●●● • Dynamic baseline ●●●● • Computing output needs to be defined and made part of the equation. Idle servers don't count in POE. Source of energy should matter, especially if on-site generation become common ●●● • Water use - metric ●●● • What is the definition of "Useful Work?" this is needed to develop a productivity metric (or set of metrics) ●●● • "Productive work output" hard to standardize - going to be different for a web farm than for an archival storage oriented application (metrics) ●●● • Clear and consistent metrics; overall performance metrics vs. metrics for diagnosing problem areas, or areas of efficiency opportunities; benchmark metrics for cooling	• Agreement and adoption of appropriate metrics for measuring and driving energy efficiency - how to incorporate functionality into energy efficiency management. Promulgation of industry standards for measuring energy efficiency ●● • Data center productivity metric that drives the right behavior - how do you drive the right IT behavior for improving efficiency? ● • Lack of decision making process ● • Productivity and bits (data) developed have economic value. Any efficiency metric, process, or standard must enhance that economic value ● • Business drivers (more than cost) to drive change ● • IT buyers/managers do not see full life cycle cost of their decisions ● • Standards - classify servers ● • Proxy for IT productivity ● • Exactly what do you measure to determine efficiency (standards)? ● • Productivity = $ gross income from IT services • Inconsistent best practices • Useful work needs to be measured as work per unit in chargeback, e.g. data stored $ per GB/PB watts per GB/PB, data trans - $ per MB/GB watts per MB/GB tx transferred (not bandwidth), data computed in CPU hours watts per CPU hr. - transactions (total # not per second), possibly various rates as new CPU's improve i.e., set a baseline • Define "useful work", getting vendors to agree on

Figure 6. Defining Energy Efficienct Data Centers (National Data Center Energy Efficiency Strategy Workshop, 2008)

What is a Metric?

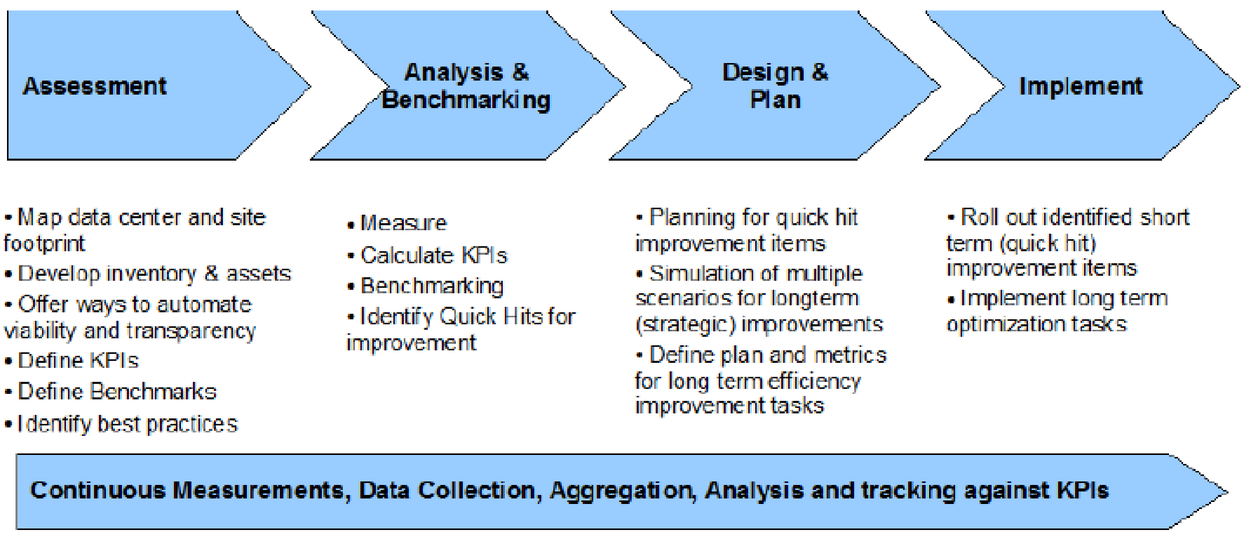
The previous section showed that a major barrier to improving energy efficiency in data centers is the lack of appropriate metrics. At this point it is important to define what a metric is and the characteristics that make a metric useful.
Metrics are instruments to measure and serve as an indicator of progress. The importance of rational, measurable metrics therefore becomes imperative to measure and manage the data center.

From this definition a criteria for a good metrics to use in the data center can be derived. The Green Grid has defined the following characteristics that a data center metric should possess (Greed Grid, 2009):

- The Metric name should be clear
- Be Intuitive
- The metric should be capable of scaling according to the purpose for which it was initially created and should factor technological, economic, environmental changes etc..
- Scientifically accurate and used precisely
- Granular enough to analyze individual aspects
- Should be capable of providing data driven decisions

This criteria is important to keep in mind when researching the current industry metrics. By having a clear understanding what a metric is measuring and the factors that will change it, data center managers can make informed decisions on which metric is appropriate for their data center.

The basic steps that help define and improve a metric would be as follows:
(Uptime Institute, CSRWARE)



Role of Industrial Consortiums in setting metrics?

The recent findings of the EPA of potential cost savings and effect data centers are having on the environment has fueled the rise of several industry consortiums whose missions are to increase the usage of energy efficient materials and/or components in IT organizations. This section introduces the five most influential groups at this time.

LEED Certification

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System was developed by the U.S. Green Building Council (USGBC), a non-profit organization that promotes sustainability in how buildings are built and operated. LEED is a voluntary rating system designed to accelerate the global adoption of sustainable green building through the creation of universally accepted performance criteria. The

LEED rating system is based on achieving a certain number of points, which are allocated for design choices defined within the standard. There are 6 sections to LEED that target specific design criteria:

1. Site Selection
2. Efficient use of Water
3. Energy and Atmosphere
4. Materials and Resources
5. Indoor Environmental Quality
6. Innovative Design

Depending on the number of points achieved, the building can attain Platinum (52 – 69 points), Gold (39 – 51 points), Silver (33 – 38 points) or LEED certified (26 – 32 points) status. (U.S. Green Building Council, 2008).

An example of a data center seeking LEED certification is IBM's Blue Waters project, launching in 2011. Blue Waters will be the world's first petaflop system, capable of 1 quadrillion calculations per second and enable new leaps in knowledge and scientific discovery. Energy efficiency is an integral part of the Blue Waters project and as part of this commitment, Blue Waters will achieve LEED's Gold certification. (Melchi, 2008)

Climate Savers

Climate Savers Computing Initiative was started by Google and Intel in 2007 as a nonprofit group of eco-conscious consumers, businesses and conservation organizations. Their mission statement is to reduce global CO2 emissions from the operation of computers by 54 million tons per year by 2010, equivalent to a 50% reduction in power consumption by computers and committed participants could collectively save $5.5 billion in energy costs (ClimateSaversComputing, 2009). Members must purchase computers that meet or exceed the current ENERGY STAR specification and are graded as Bronze, Silver, or Gold.

Green Grid

Founded in 2007, the Green Grid is a global consortium dedicated to developing and promoting energy efficiency for data centers by developing standards, measurement methods, processes and new technologies to improve performance against the defined metrics

Green Grid created the Power usage effectiveness (PUE) and the reciprocal Data center infrastructure efficiency (DCiE) metrics which help end-users separate and measure their facility power consumption from their IT power consumption. Going forward the Green Grid members will explore different methods for measuring and reporting energy efficiency and data center productivity (DCP).

On February 4th, 2009 announced Green Grid's new Data Center 2.0 guide. "It's meant as an end-to-end guide, from the IT equipment all the way through to the facility infrastructure that supports it, and as a top-to-bottom guide, from measurement and management through to operations and how you run the datacenter," Mark Monroe, a Green Grid board member said. The Data Center 2.0 program will also include a recognition program for end-users reporting their PUE or DCiE measurements within the stated guidelines. (Greed Grid, 2009)

Uptime Institute
The Uptime Institute has been providing educational and consulting services for Facilities and Information Technology organizations interested in maximizing their data center uptime. The Institute has pioneered various industry innovations, such as the Tier classification for data center availability which serve as industry standards today. The institute also conducts sponsored research and product certifications for the industry's manufacturers.

Role of the Government and its initiatives

The findings of the EPA got the attention of the government as well as the public. One of President Obama's primary platforms is the support for green energy. On his agenda is a goal of having all new buildings carbon neutral by 2030, and also establish a national goal of improving new building efficiency by 50 percent and existing building efficiency by 25 percent during the next decade to reach the 2030 goal. To encourage businesses to meet these goals President Obama plans to create a competitive grant program to award to states and localities that take the first steps in implementing new building codes that prioritize energy efficiency (Obama, 2008).

Energy Star
The U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) have initiated a joint national data center energy efficiency information program. On August 2^{nd}, 2007 the EPA presented a report to Congress projecting near-term growth of data centers in the United States and assessing opportunities for energy efficiency improvements. It also recommends potential incentives and voluntary programs to promote energy-efficient computer servers and data centers.
The EPA's ENERGY STAR specification released Draft 4 on February 20^{th}, 2009 for review by the industry. The specification is divided into two Tiers. Tier 1 goes into effect May 1^{st}, 2009 and only applies to single socket (1S), 2S and 4S servers, Tier 1 servers are measured by the following criteria: Power Supply Efficiency and Idle Power. Blade Servers are excluded until benchmarks are available that can measure Blade Server Idle power (Environmental Protection Agency, 2009). Tier 2 of the specification goes into affect October 1^{st}, 2010. The objective of Tier 2 is to add an Energy Efficiency Performance Metric so all servers would qualify based on their consumption of energy for a given amount of work completed (i.e., energy efficiency performance benchmark approach). If a metric can't be found in time a provisional Tier 2 specification will go into affect with revised Idle power levels.
Today, it is only mandated for federal government and public procurement purchases in the US and EU (all 27 member nations), but the demand for certified systems is growing as the cost of energy increases and awareness for environmental conservation grows. One study projects that Energy Star labeled products will save 12.8 EJ (10^{18} Joules) during the years 2007 through 2015 (Sanchez, 2008).

Data Collection

Steps to a Green Data Center Research

Preliminary research consisted of reviewing several industry news reports on creating a green data center. It was found that many of the articles take the form of "# Steps to a Green Data center". By consolidating the articles into the table below it can be seen which steps are considered the most important by the industry

Table 1. Steps to a Green Data Center

	Monitoring Tools	Consolidate Servers	Use Power Management	Upgrade Hardware	High Efficiency PSUs	Facilities /IT Management	Follow Standards	Advocate for change	Turn Off Idle Servers	Data Center Cooling	Move Data to Tape Storage	Assign "Green" owner	Floor Plan Design
Computer World (Mitchell, 2007)		1	1	1	1	1	1	1					
Information Week (McDougall, 2007)		1	1	1	1	1			1	1			
Sun (Sun Microsystems, 2009)			1	1			1		1	1	1		
Datacenter Journal (Coleman, 2007)			1			1	1	1	1			1	
NetworkWorld Asia (Ann, 2008)		1			1			1		1		1	1
NetworkWorld Asia (Wilson, 2008)		1	1							1			1
eWeek (Melerud, 2008)	1	1		1		1							
GreenerComputing (Gralla, 2008)	1								1	1			
ZDNet (Whittle, 2007)		1	1	1	1					1	1		1
IBM (IBM Corporation, 2009)	1	1	1	1						1			
Total	**3**	**7**	**7**	**6**	**4**	**4**	**3**	**3**	**4**	**7**	**2**	**2**	**3**

From Table 1, three items have received the most focus in the industry. Finding metrics for Server Consolidation, Power Management, and Data Center Cooling should be a priority for IT managers with Upgrading Hardware as a close second.

Company Interviews

Interviews were conducted of several key individuals at various companies. They included High Tech companies, Intel and Motorola, a Health Care organization, Providence Health Systems and a Transportation company, Con-Way. A questionnaire was created ask uniform questions. The goals were to find out what the companies were doing for energy saving and how important Green Initiatives were for their Data Center Operations.

Table 2. Survey Interviewees

Name	Company	Title
Kim Brown	Intel Corp	Director of Data Center Operations
Bradley Ellison	Intel Corp	Data Center Architect
Sally Wellsandt	Intel Corp	IT Green Initiatives Program Manager
Jon Haas	Intel Corp	Director of ECO- Technologies
Thomas Litterer	Intel Corp	Operations Manager
Don Bartell	Motorola	Sr. Director Environmental Initiatives
John Lesniak	Motorola	Sr. IT Manager
Praveen Sharabu	Con-Way	VP of Enterprise Infrastructure
Bob Simons	Con-Way	IT Data Center Manager
Bill Hodges	Providence Health Systems	Data Center Manager

Key questions included:

- How important different attributes were in their data centers. The attributes included performance, energy efficiency, high availability, security, location and any attributes that they felt were important, but were not on the list.
- What formal green initiatives they were following in their organizations and if so, what led them to consider those initiatives. If green initiatives were in place, what the priority of green initiatives and the components that were studied.

All of the companies were aware of different green initiatives and had formal initiatives in their companies. Some, such as Providence Health system, had co-located their data center to one of the “greenest” data centers in the country. Others, such as Motorola had chosen to outsource theirs to a 3rd party hosting company to improve the efficiency.

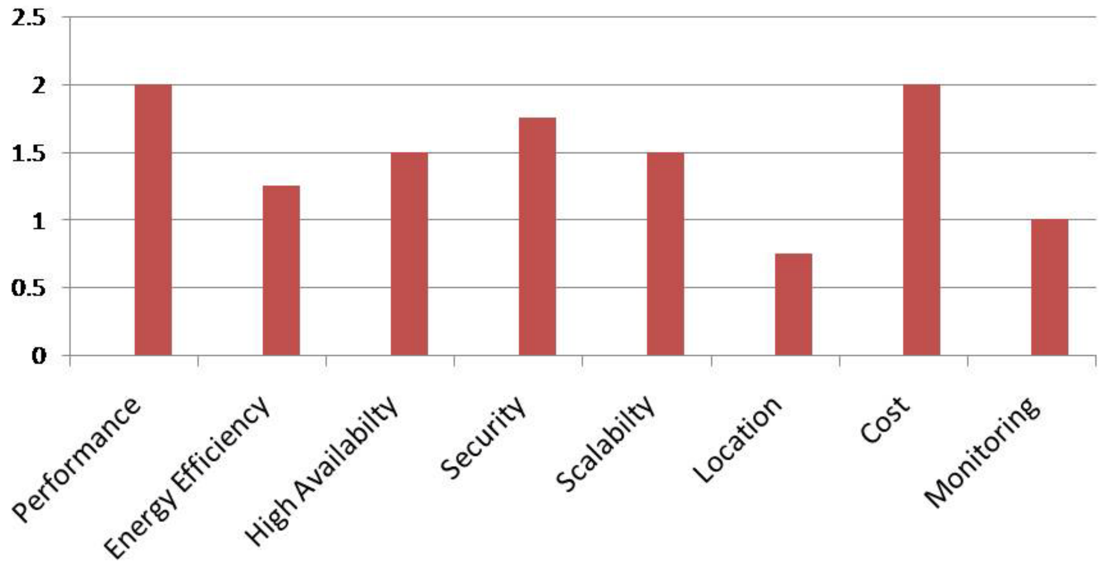


Figure 7. Survey Results (Normalized)

What seemed surprising in the results when the data was normalized the performance and cost were the most important attributes. Energy efficiency was 5th of the top 6 attributes. This was explained that managing capital costs and operating expenses are vital to a company's viability. Green initiatives, though important, need to have their costs justified. The energy savings alone were not enough; the initiatives had to pay for themselves. An ROI (Return On Investment) relating to a pay back period of 2-3 years was expected.

When asked about metrics, the PUE (Power Usage Effectiveness) was the metric most companies were a aware of, if the most used, if any were used. When asked what would be a good green metric, one suggestion for a good metric would be something that measures the efficiency, the sustainability and the cost of a green initiative.

Developing the Model

Through our research, we accumulated a wealth of metrics and benchmarks that could all be applied to data center management. While some of the metrics addressed individual components, others were system level metrics that encompassed larger abstract subsystems. One of the early struggles faced in this project was relating these metrics so that we could see the tradeoffs during a critical analysis. For example, retiring a redundant server may save space and decrease facilities power usage, but system reliability will take a hit when the primary server crashes.

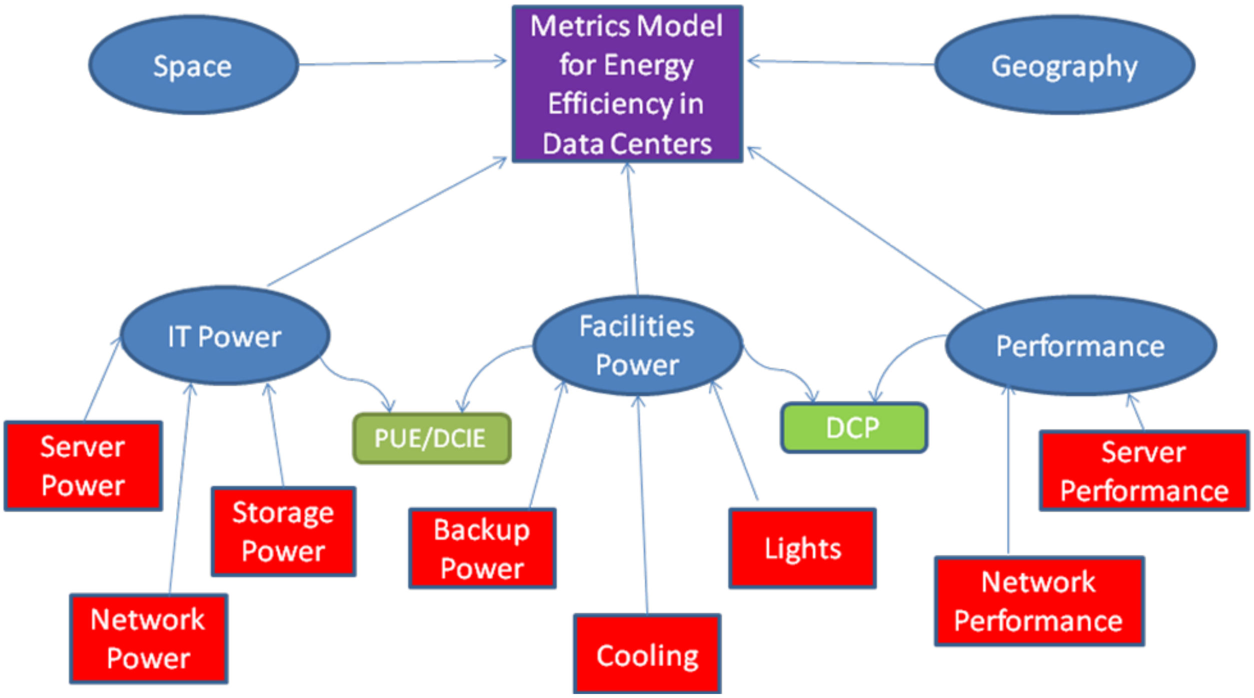
Our first step in developing a model to capture these relationships was to populate the measureable categories in the data center. We identified these areas to be IT power consumption, facilities power consumption, performance of the system, space used within the facility, and the geographical location of the facility. This became the system layer in our model and it is denoted by blue ovals.

Under each of the elements in the system layer, we could now develop a component layer by categorizing the metrics that apply to individual modules. For example, under IT Power, we have subsections for Server, Network and Storage Power. Each of these has an associated set of metrics that deal solely with that component. Appendix A provides examples of possible metrics that could be applied at the component layer. Each element in the component layer is identified in the model with a red rectangle.

Some metrics that we found relate the major modules of the system. Examples of this include PUE and DCP. These are metrics that sum up the relationships between major constituents of the data center. This is the relational layer and is associated with the green boxes in the model.

This model can be useful in communicating the management of energy efficiency outside of the IT organization. The metrics used in the relational layer (green boxes) are the ones that would typically be communicated to the corporate ranks on a continuing basis. When established goals are not met for these metrics, the component layer of the model can be used for further analysis to figure out what went wrong. While the IT organization may analyze the component layer metrics on a frequent basis, they would only be exposed to the corporate level, when a deeper understanding of the Data Center is desired.

Model for Data Center Metrics



Space and Geography

Note that two of the modules in the system layer (Space and Geography) have no relationship to elements in the component layer. Metrics involved with these two categories would generally be associated with abstract aspects of the facility rather than components within the facility.

Space in the data center is always at a premium. Growth is usually limited by existing facilities (floor space, cooling, electricity, etc). Building a new data center has a huge impact on IT budgets, so having free space to grow in a data center is a major concern for IT managers. Once free space is gone, the cost of facility renovations generally hinders further growth. One of the bonuses of green initiatives is that space is typically freed up.

Geography is another important aspect of the Data Center. Facilities in cooler environments generally have less overhead expenses than facilities in warm environments. However, the tradeoff is that performance may decrease as data has to travel further between server and client.

Data Analysis

Our research found that improving the efficiency of a data center can be achieved by looking at metrics in three areas:

- Power.
- Productivity.
- Server Performance

Power

Two power related metrics have been developed and introduced in the industry by the Green Grid. They are the **Power Usage Effectiveness** and **Datacenter Efficiency**.

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

$$DCE = \frac{\text{IT Equipment Power}}{\text{Total Facility Power.}}$$

Total Facility Power

Total Facility Power is defined as the power measured at the external utility meter, specifically, the power dedicated to the data center. The components included in the Total Facility Power can be seen in figure 8 below.

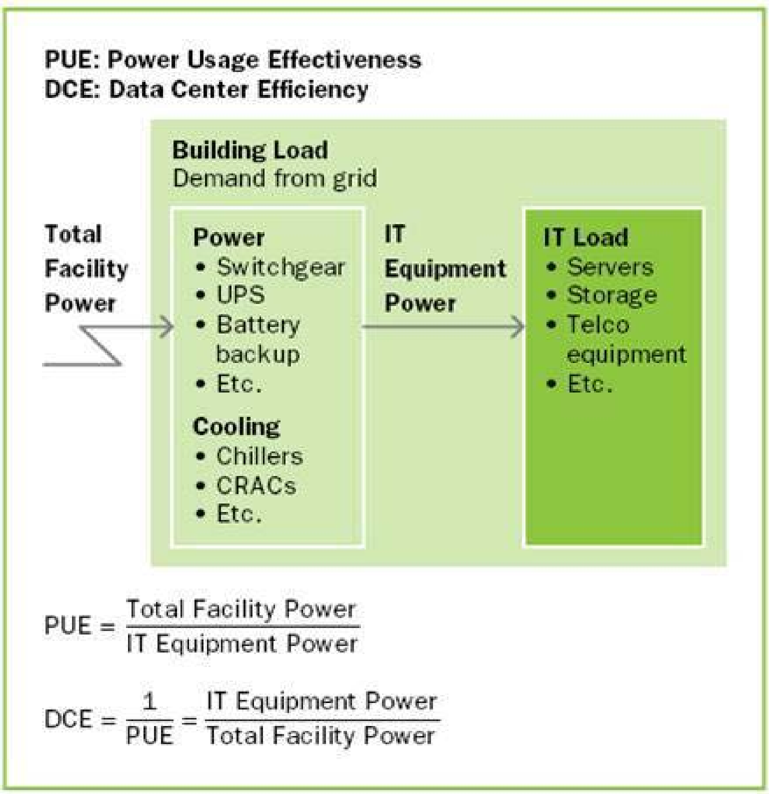


Figure 8. Illustration of how PUE and DCE would be calculated in a data center (Greed Grid, 2009).

This should represent the total power consumed in the data center. The building utility meter should only measure the data center only portion because power that is not intended to be consumed in the data center would result in faulty PUE and DCE

metrics. For example, if a data center resides in an office building, total power drawn from the utility will be the sum of the Total Facility Power at the Data Center, and the Total Power consumed by the non datacenter offices.
In this case the datacenter administrator would have to measure or estimate the amount of power being consumed by the non data center offices(an estimation will obviously introduce some error into the calculations)

IT Equipment Power.
This includes the load associated with all of the IT equipment, such as Servers, Storage and Network equipment along with supplemental equipment like KVM Switches Monitors and Workstations. Figure 8 above illustrates how IT equipment power fit into the equation.
IT Equipment Power should be measured after all Power Conversion, Switching and conditioning is competed and before the IT Equipment itself. The most likely measurement point would be the output of the computer room power distribution units (PDUs). This measurement would represent the total power delivered to the computer equipment racks in the Data Center.

Analysis of PUE
PUE provides opportunities to improved data center operational efficiency and can be used to compare your data centers with competitive data centers. It also provides opportunities to repurpose energy for additional IT Equipment. While both the PUE and DCE metrics are essentially the same, they can be used to illustrate the energy allocation in the Data Center differently.
For example if the PUE of a data center is determined to be 3.0 then the data center demands 3 times greater the energy than to power the IT equipment. Say a server in this data center demands 500 watts, then the power from the utility grid to deliver this 500 Watts for this server would be 1500 Watts (500*3).
DCE is also useful. Using the values in the example above, a DCE score of 0.33 (equivalent to 3.0 PUE) suggests the IT equipment consumes only 33% of power in the data center.

Significance of PUE Value.
The PUE can range from 1.0 to infinity. A PUE value approaching 1.0 would indicate 100% efficiency meaning all power is used by the IT equipment only. Currently there is no comprehensive data that show the true spread of PUE in data centers. The preliminary research done by Green Grid indicates that many data centers may have a PUE of greater than 3.0. However PUE values of 2.0 are achievable by proper design. To understand why some data centers have higher PUE values we have to understand where the rest of the power goes in the data center by looking at the power flow diagram below. The datacenter represented here is a dual power path data center, operating at 30% efficiency. Note that much less than half the electric power feeding this data center is actually delivered to the IT Loads. The rest of the power fed to the data center ends up as heat.

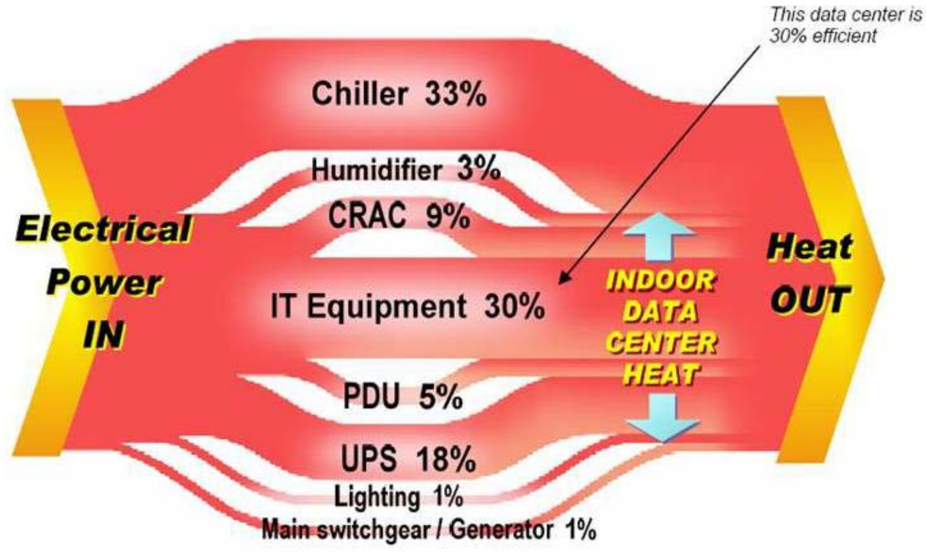


Figure9. Power flow in a typical data center

Limitations of PUE.

While PUE is a good indication of the energy efficiency of a data center, there are some cases where the results can be misleading. When comparing two data centers with respect to their PUE values, PUE doesn't take redundant generators and battery backups into account. A Government data center hosting secure servers has to comply on more redundant backup power, which may not be the case with a corporate data center which would rely only on its primary backup power. When we compare these 2 data centers by using PUE as the criteria of evaluating its energy efficiency, then it doesn't reflect the true value.

Also, in some rare scenarios, improvement in IT equipment efficiency could result in an increase of PUE.

Current State

Green Grid is developing different levels of certification for PUE. It will distinguish companies based on the frequency of obtaining the PUE data. Green Grid plans to provide a means for organizations to publicly report their measurements, which would require companies to comply with the following:

- Record their PUE measurement data to The GreenGrid.
- Provide background information about the data center, reporting the results and the manner in which, and conditions which, the data was collected.
- Green Grid will provide a portal through which organizations can view summary details on publicly reported PUE results.

The use of PUE to measure data center energy efficiency has received broad adoption in the industry (Belady, 2008). As the benchmark becomes an industry standard more IT managers will make it a priority for their employees to improve energy efficiency within the data center and create initiatives and task forces to find improvements. As mentioned previously, in most cases these projects to improve energy efficiency will result in a better PUE score but there are cases that actions taken to improve IT productivity may actually result in an increase in PUE if they reduce power utilized by the IT equipment. (Azevedo & Rawson, 2008)

Industry green initiatives including Energy Star and Green Grid have found similar inconsistencies with the PUE benchmark. By 2010, Energy Star hopes to derive a data center metric incorporating power use, work completed, and the time needed to perform that work. (Environmental Protection Agency, 2009) The Green Grid consortium acknowledges that to address both infrastructure and IT productivity needs, we need one or more metrics to complement PUE / DCiE (Azevedo & Rawson, 2008). To begin to address this issue the Green Grid defined the Data Center Productivity Ratio as the useful work that a data center produces relative to the quantity of any resource that it consumes to produce this work.

Productivity Metric

Data Center Productivity (DCP) in simple terms can be defined as the methodology for quantifying the useful work that a data center produces relative to the quantity of any resource that it consumes to produce the work (Greed Grid, 2009).

It can be expressed mathematically as

$$\text{DCP} = \frac{\text{Useful Work Produced by Data Center}}{\text{Resource Consumed Producing the Work}}$$

Green Grid Corporation is the source of this metric. They looked at DCP to be a tool which would allow a data center operator to baseline their own data center and compare its productivity today with yesterday. Useful work here is defined as completed tasks that have value to the end user or business supported by the data center. To be specific the work output in money terms is some willing to pay for that work.

Although a comparative metric between data centers is desired, Green Grid's immediate goal was to provide a tool that would allow a data center operator to baseline their own data center and compare its productivity today with yesterday. In this form, useful work is defined by the data center operator of each individual data center, current suggestions include: customer transactions, employee headcount, or number of sales (Info-Tech Research Group, 2008).

This benchmark poses a number of issues for managers. The first problem is how a manager is to choose which metric will be considered the useful work of the data center. Since this is a subjective choice most managers would choose an area that has stable growth, resulting in an improving DCP score over time.

For Example:

- Online marketplaces such as Amazon.com or Ebay.com could choose customer transactions as the measure of their useful work.

- An engineering college with a data center used for student research would not have customer transactions to measure but could choose student enrollment as a way to measure the number of data center users.

Both these examples make sense at the individual level but make it impossible to compare the DCP scores. It might also lead to misleading changes in the DCP score. During holidays the number of customer transactions at Amazon.com would increase dramatically, giving the impression that the efficiency of the data center had improved. The ultimate goal is create a standard for useful work and to enable the comparison of disparate data centers (Azevedo & Rawson, 2008)

Server Performance

SPECpower_ssj2008 is a server benchmark developed by the Standard Performance Evaluation Corporation (SPEC), a non-profit group of computer vendors, system integrators, universities, research organizations, publishers, and consultants. It is designed to provide a view of a server system's power consumption running Java server applications. (SPEC)
In general, the test methodology compares the measured performance with the measured power consumption running at different target load levels. This reflects the fact that datacenter server systems run at different load levels relative to maximum throughput.

Test Workload

The application begins by running a calibration phase designed to determine the maximum throughput of the system by generating transactions at the full rate that they can be completed.
After the maximum throughput has been determined, the application then calculates the throughput values that correspond to each target load (100%, 90%… 20%, 10%, 0% of maximum as calibrated). The 0% target load is also referred to as “Active Idle”. In this case, the system is ready to accept transactions, but none are being issued. The EPA’s Energy Star Server specification leveraged this definition to determine idle power.

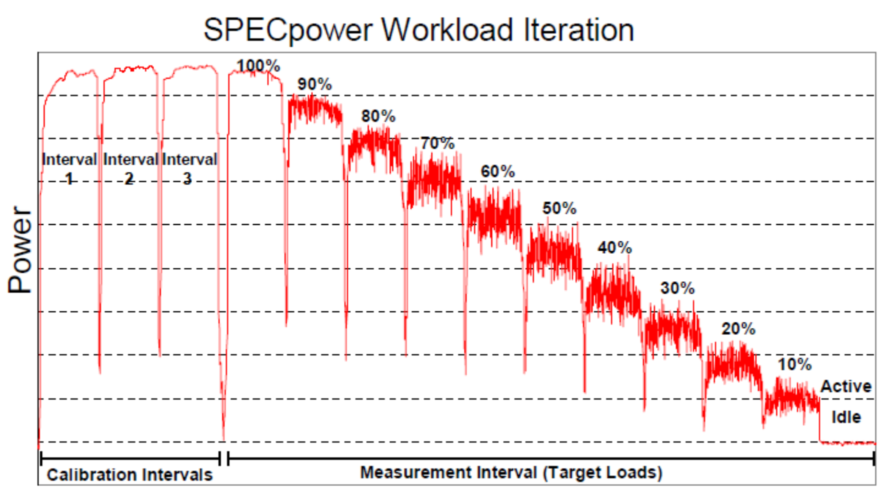


Figure 10. SPECpower Workload Iterations

SPECpower_ssj2008 Metric

The performance to power ratio of the target loads is a measurement of the number of ssj_ops (throughput) processed per watt of power consumed. The more ssj_ops a server can produce with one watt of power, the better the efficiency. The SPECpower_ssj2008 metric is calculated as the sum of all ssj_ops scores for all target loads, divided by the sum of all power consumption averages (in watts) for all target loads, including the active idle measurement interval.

The unit of the SPECpower_ssj2008 metric is “overall ssj_ops / watt”.

Summary

It’s important to note that one benchmark only satisfies one business model. It is not possible for a single benchmark to represent the energy efficiency for all of the possible combinations of an IT environment. Similarly, it would be very difficult to use benchmark results to predict the power characteristics of an IT environment, unless the environment is very closely replicated by the configuration of the benchmark. However, it is possible for a single benchmark to give an indication of the relationship between power and performance for the components that the benchmark stresses. A benchmark that focuses primarily on the processor within a server should not be ignored just because it does not focus on disk or networking. Rather, it should be viewed as a focused view of the processor component, with the knowledge that there may be other components that are not quantified in the benchmark.

Recommendations

The analysis pointed to a number of gaps in the existing industry metrics. In regards to data center power there has not been a standard defined for the equipment in a data center. Server performance has a similar issue in that different businesses run different workloads, making meaningful comparisons difficult. Our proposal to fill these gaps includes two components:

- A total system benchmark to measure server performance
- Credit based system to make allowances for data centers that do not meet the standard

Total System Benchmark

As discussed earlier, the SPECpower_ssj2008 server benchmark is the current industry standard in measuring the performance per watt of standalone servers. As the SPEC website explains, SPECpower_ssj2008 is only intended to be representative of server side Java applications - not webservers, file servers, HPC or transactional or analytic databases (SPEC, 2008). One of the future goals for SPECpower is to expand the types of workloads and more form factors. For instance, the SPEC Graphics and Workstation Performance Group has announced that they are working to adapt SPECpower to support workstation applications. A future version of SPECpower that could handle multiple workloads would be a good candidate for a total system benchmark
SPECpower is also limited in the types of configurations that are supported. The benchmark can only run on a single server system but for data centers the most efficient server solution is implementing blade servers. A SPECpower methodology that can be applied to blade servers would be a valuable tool for IT purchasers, especially if it can establish comparisons to rack-mount or pedestal servers.

The proposed total system benchmark would be an industry approved workload(s) that could test the overall system and find the performance per watt of the system before it is installed at the data center. As a standard, OEMs or resellers would be able to perform the test on their system and post the result as part of the products specification. This would allow IT purchasers to know what the performance output of each system in the data center, enabling them to calculate the total theoretical performance per watt of the data center.

Credit System

To create a standard that will apply across all types of data centers and workloads a method to resolve exceptions needs to be developed. Energy Star and LEED each have found a way to account for differences while maintaining an industry standard. They accomplished this by implementing a credit system. This type of system allows a server or facility that had to sacrifice energy efficiency for business reasons to maintain a competitive score with other data centers

The Energy Star specification has excluded some of these exceptions found at the server hardware level. For example Fully Fault Tolerant Servers are systems where each component is replicated in two nodes running identical and concurrent workloads. If one node fails the second can continue to run without interruption to avoid downtime.

These types of systems are frequently used in mission critical applications (EPA, 2009). Due to the extra hardware these systems would not meet the Idle power targets set by Energy Star and are excluded from the specification. For companies that build 1S or 2S servers with hardware beyond the base configuration, defined by Energy Star, there are power allowances. Hard drives, memory and I/O devices each receive an allowance.

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a credit based rating system. Each building starts with a score of zero and adds points for met criteria. For example one criterion in the Sustainable Site section of the New Construction certification is 3 points for using 12.5% renewable energy.
A similar point system could be developed to gives credits for server and data center configurations that differ from the standards agreed upon by the industry. Credits would be given based on a strict criteria defined in the specification of the benchmark. Criteria should be based on the business model of the data center. Before certification is awarded each submission should be reviewed to ensure accuracy. It is recommended that an energy efficiency performance metric offers credits at two levels – individual servers and facility.

Creating an Energy Efficiency Performance Metric

The creation of a new benchmark that can be used to measure data centers across the industry should start with the existing standard: PUE. To account for different data center configurations the PUE benchmark should implement a credit system similar to the one mentioned in the previous section. To measure the energy efficiency performance of a data center, find the PUE value and then apply any facility level credits necessary.

Proposed PUE:

$$= \frac{\text{Total Facility Power}}{\text{IT Equipment Power}} - \text{Facility Credits}$$

The energy efficiency for data centers model illustrates the need for a performance benchmark that measures the total system performance for a variety of workloads. The SPECpower_ssj2008 benchmark is a good example but only runs one workload and focuses on the CPU. The energy efficiency performance metric recommendation will use a theoretical Total System Benchmark to measure the performance per watt of an individual server.

Total System Metric:

$$= \frac{\text{Server Perf}}{\text{Server Power}} - \text{Server Credit}$$

Using the credit system in the previous section any individual server credits that apply would be applied to the Total System Benchmark to normalize the results.
The Data Center Performance per Watt is the sum of the Total System Benchmark results and represents the total performance of the data center and the total power used by the IT equipment.

Data Center Perf/Watt:

$$= \sum \text{Total System Metric}$$

Dividing this result by the Power Usage Effectiveness ratio yields the following results:

$$= \frac{\text{Data Center Perf/Watt}}{\text{Proposed PUE}} = \frac{\dfrac{\text{Data Center Perf}}{\text{IT Equipment Power}}}{\dfrac{\text{Facility Power}}{\text{IT Equipment Power}}}$$

Simplifying the equation yields our metric:

$$\text{Energy Efficiency Performance Metric} = \frac{\text{Data Center Performance}}{\text{Facility Power}}$$

This result represents the total data center performance output per watt.

Other Considerations

Data Center Collocation and Outsourcing

In order to deal with rising energy costs and the high price of facility expansion, two strategies have emerged as popular solutions. Data center collocation and outsourcing have the shared goal of reducing overall corporate expense for data management. Both of these solutions have the added advantage of economic flexibility during difficult financial phases. Since both answers involve sharing or moving accountability to a third party, they add an additional layer of complexity for corporate green and energy savings initiatives.

Collocation

A collocation data center is a shared facility where multiple customers house their data center equipment with the goal of minimizing cost and complexity of overhead. Such facilities typically range from 4500 to 9000 square meters. Companies find their IT and communications facilities in safe, secure hands. They enjoy less latency and the freedom to focus on their core business. Increasingly, organizations are recognizing the benefits of collocating their mission-critical equipment within a data center. Collocation is becoming popular because of the time and cost savings a company can realize as a result of using shared data centre infrastructure. Since collocation data centers are built from the ground up, they are designed keeping energy efficiency and reliability in mind. The recently built Sabey-Data Center at Tukwila-Seattle, which one of our interviewees (Providence) has collocated, is the recipient of a Power Player's award from Seattle City Light for its innovations in energy conservation. From our research we understand the Sabey Data Center has real-time monitoring software to supervise the PUE value.

Collocated data centers control only the facilities part of the data center. Companies who are moving their servers to collocated data centers have to take advantage of the energy efficient infrastructure by optimizing the rack space and using efficient server hardware. An example of making the servers energy efficient is moving toward blade servers and virtualization of servers. That will significantly boost the PUE value. On the other hand if companies do not focus and move their old, inefficient server hardware to the collocated data center, then there would not be much improvement in their PUE value. From our research and analysis we find that companies see collocation as another alternative. The main selling point for companies to move toward this alternative is on reliability, scalability, energy efficiency and redundancy of their data centers. There is a good possibility to see this trend grow in the future as collocated data centers provide the solution for companies to meet their green initiatives as the focal point in decision making. (Ford, 2009)

Outsourcing

One of the trends in data management that one might expect to see is the continuing outsource of data management. Outsourcing differs from collocation in that the management of the data will now be handled by a third party. While IT equipment generally follows the principle of Moore's Law, facility and energy expenses do not (Brill, 2007). Motorola is an example of a large company that has outsourced nearly all of their data housing and management to third-party organizations. This arrangement could possibly transfer the responsibility for being green from one corporation to the next. The following questions should be considered before entering into an outsourcing contract.

1. What accountability for energy efficiency should a company have when they outsource their data management?

2. What accountability does a contractor have when they accept the management of data?

3. I can see the desire for a company to pay somebody else to worry about this problem, but what factors are out of the third-party's control?

4. Should data efficiency metrics be a part of such a contract?

Conclusion

We have shown the need for the industry to develop standards and metrics for measuring energy efficiency in data centers. Such metrics will be vital tools for managers to use when assessing the performance of their facilities and determining where resources should be focused to create improvement.

As the environment continues to be affected by data center emissions, governments will start to regulate the energy use and force data centers to make improvements. By taking initiative and creating metrics the industry can be prepared to demonstrate progress toward energy efficiency.

We discussed a couple alternative models businesses could use for managing their data. Finally, we concluded with a couple future metric recommendations that could be applied to normalize data centers across the industry.

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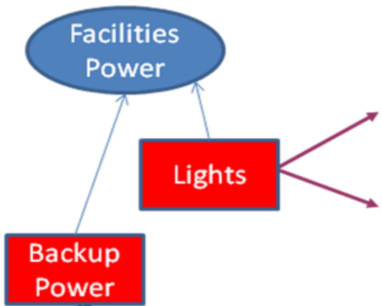
Appendix A: Example of Component Layer Metrics

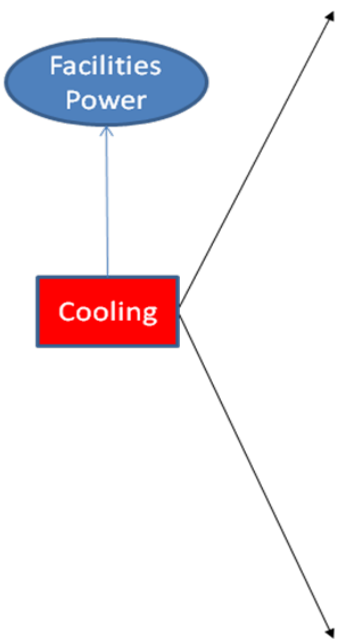
This section goes into more detail on the model, showing component level metrics available for each category.



Metric Name	Unit	Data Required
Actual Lighting Power Density	W/sf	Data Center Lighting Power Data Center Floor Area

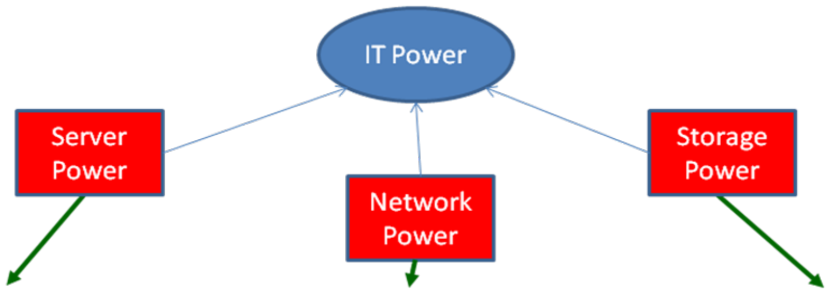
Metric Name	Unit	Data Required
UPS Load Factor	-	UPS Input kW UPS rating
UPS System Efficiency	%	UPS Output kW UPS Input kW
Transformer Efficiency (upstream UPS system) Efficiency	%	XFMR Transformer Output XFMR Transformer Input
PDU (with built-in transformer) System Efficiency	%	PDU Output PDU Input

Figure 2. Backup Power and Light Metrics



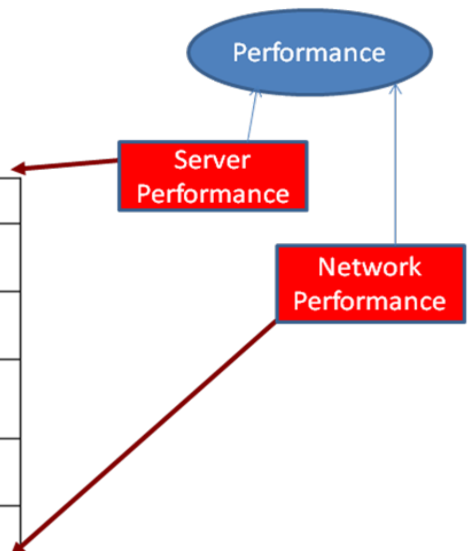
Metric Name	Unit	Data Required
CRAC/CRAH/AHU Temperature Differential	F	Average Supply Air Temperature Average Return Air Temperature
Average Rack Temperature Rise	F	Rack Intake Temps, Rack Exhaust Temps
Return Temperature Index (RTI), measure of by-pass air and recirculation air.	%	Average Supply Air Temperature Average Return Air Temperature Average Rack Temp Rise
Rack Intake Temperatures	F	Rack Intake Temperatures
Rack Cooling Index (RCI), measure of conformance with an intake temperature specification (e.g., ASHRAE, NEBS).	%	Rack Intake Temperatures Recommended Temp Range Allowable Temp Range
Supply Heat Index (SHI)	-	Rack Intake Temperatures Rack Exhaust Temperatures Average Supply Air temperature
CRAC/CRAH/AHU Moisture Differential	lbs	Entering Absolute Humidity Leaving Absolute Humidity
Airflow Efficiency	W/cfm	CRAC Power / AHU Power CRAC Airflow / AHU Airflow
Ratio of Total System Flow to Total Rack Flow	None	Total System Airflow Total Rack Airflow
System Pressure Drop	in. w.g.	Supply Side Pressure Drop Return Side Pressure Drop
Fan motor efficiency	%	Fan Motor Efficiency (Nameplate)
Econ Utilization Factor	%	Cooling Load Served w/ Econ Total Cooling Load Served

Figure 3. Cooling Metrics



Metric Name	Unit	Data Required
IT Peak Power Density	W/sf	IT Peak Power DC Floor Area
IT Ave Power Density	W/sf	IT Avg Power DC Floor Area
IT Peak Power Density (design)	W/sf	IT Peak Power (design) DC Floor Area
IT Rack Power Density	kW/rack	IT Peak Power Rack quantity
IT Rack Power Density (design)	kW/rack	IT Peak Power (design) Rack quantity

Figure 4. IT Power Metrics



Potential Performance Metrics for the next generation Data Center

Metric Name	Unit	Data Required
Data Center Density	CPU Cycles/ Sq Ft	Rack Density etc.. Space Utilization
Automation (to measure data center automation)	HumanOperators/ Data Center Density	Number of Human Operators, Density /Sq Ft
Storage Utilization (measured to track change over time)	% of Storage Used	Application level Storage used, Storage Not used, High Speed Live Racks, back-up/disaster-recovery storage
Storage Density (measures if best utilization of space is done)	Storage Utilization/Sq ft	Storage Utilization, Data Center space in Sq ft
Storage Automation (measures level of storage automation)	Number of Human Operators/Storage Density	Storage Utilization, Data Center space in Sq ft, Number of Human Operators

Figure 5. Peformance Metrics

Metric Name	Unit	Data Required
Site Energy Use Intensity	Site BTU/sf-yr	Total DC Energy Use (Site) DC Floor Area
Source Energy Use Intensity	Source BTU/sf-yr	Total DC Energy Use (Source) DC Floor Area
Purchased Energy Cost Intensity	Energy $/sf-yr	Total DC Energy Cost DC Floor Area
Peak Electrical Demand Intensity	Peak W/sf	Total DC Peak Elec Demand DC Floor Area

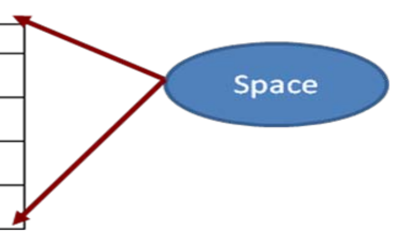


Figure 6. Space Metrics

Appendix B – Additional Resources

This section provides links to additional resources found during research done for this study

Standards, Compliance and Recommendations for Data Centers and Management

[courtesy: The DataCenter Journal]

Below you will find a listing of standards, codes, compliance and recommendations for data centers. We are continuing to compile a complete list of global standards and best practices for you. If you have one or a list of official standards and best practices that you utilize that we can include in our database then we would like you to share that information with us. Please note that it does not matter the country of origin of the standard, code or best practice.