Guide for Reducing Data Center Physical Infrastructure Energy Consumption in Federal Data Centers

White Paper 250

Revision 0

by Ellen Kotzbauer, BEP and Dennis Bouley

> Executive summary

In an effort to create a clean energy economy, recent US presidents and congress have issued a series of legislation and executive orders requiring federal agencies to increase energy efficiency and reduce carbon emissions in government facilities. Vivek Kundra, Federal Chief Information Officer, is supporting that effort by establishing a Federal Data Center Consolidation Initiative to help reduce energy consumption in over 1,100 Federal data centers. US Federal data center managers are on a timeline to respond with their final consolidation plan. This paper analyzes the implication of these mandates and offers recommendations for how to improve energy efficiency in Federal data centers. This paper is written for a US-only audience.

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Introduction

The Energy Independence and Security Act of 2007 (EISA 2007), along with the more recent Executive Order 13514, ask Federal government agencies to improve their environmental, energy and economic performance. The typical data center consumes 50x the amount of energy of the average office space and is an obvious target for action. In fact, Federal Chief Information Officer Kundra cites an EPA report stating that Federal servers and data centers consumed 6 billion kWh of electricity in 2006[1]. If the current trend in energy consumption is allowed to continue, that consumption could exceed 12 billion kWh by 2012. One of Kundra's goals is to "promote the use of Green IT by reducing the overall energy and real estate foot print of government data centers." The federal government is looking for "game-changing approaches" to deal with the problematic growth in data centers rather than "brute force consolidation."

So what do these high level mandates mean for Federal facility managers, IT managers and energy managers? Federal data center stakeholders will have to assess the energy situation within their own particular data centers and then formulate short-term and long-term plans for changes to their existing practices and existing infrastructure. This paper will focus on energy efficiency gains that can be realized through optimization of physical infrastructure (i.e., power and cooling equipment). Physical infrastructure accounts for more than half of the total energy consumption of a typical data center (see **Figure 1**[2]). Approaches for improving IT equipment efficiency (i.e., servers, storage, telecommunications devices) are NOT within the scope of this paper.

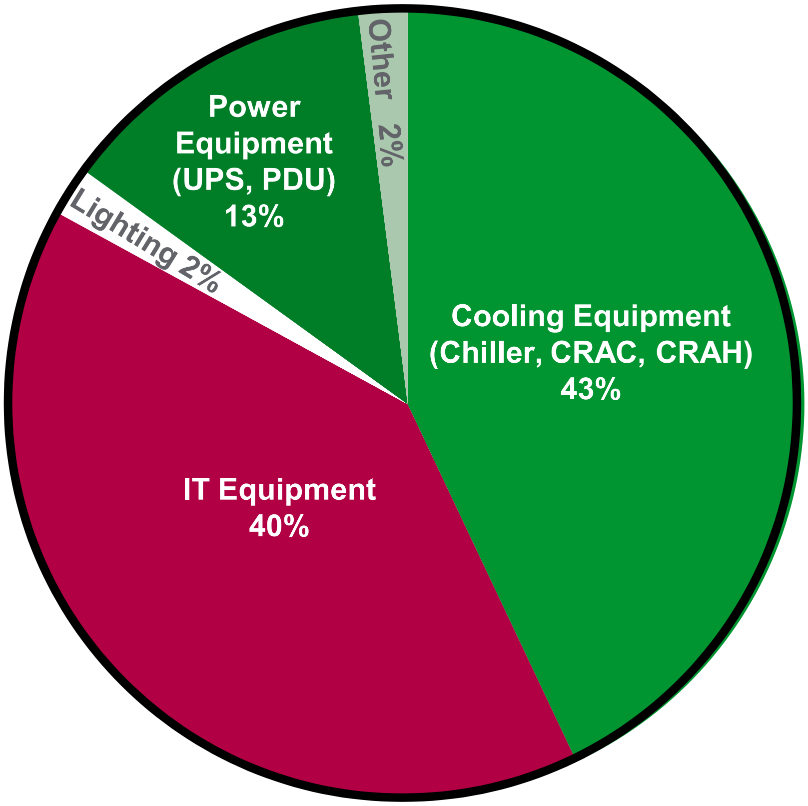

Figure 1

Breakdown of Sources of Data Center Energy Consumption

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[1] EPA Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431, U.S. Environmental Protection Agency ENERGY STAR program, August 2, 2007

[2] US Department of Energy, "Creating Energy Efficient Data Centers", U.S. Department of Energy, May 2007

The challenge of energy efficiency

The goal of achieving greater efficiency (lower energy consumption) will be a significant challenge for many existing Federal data centers. Some data centers are saddled with the constraints of outdated facilities (the building that houses the data center), or outdated designs that are not capable of supporting the high densities required for optimum utilization of footprint. They are also faced with existing limits to power capacity and cooling capacities.

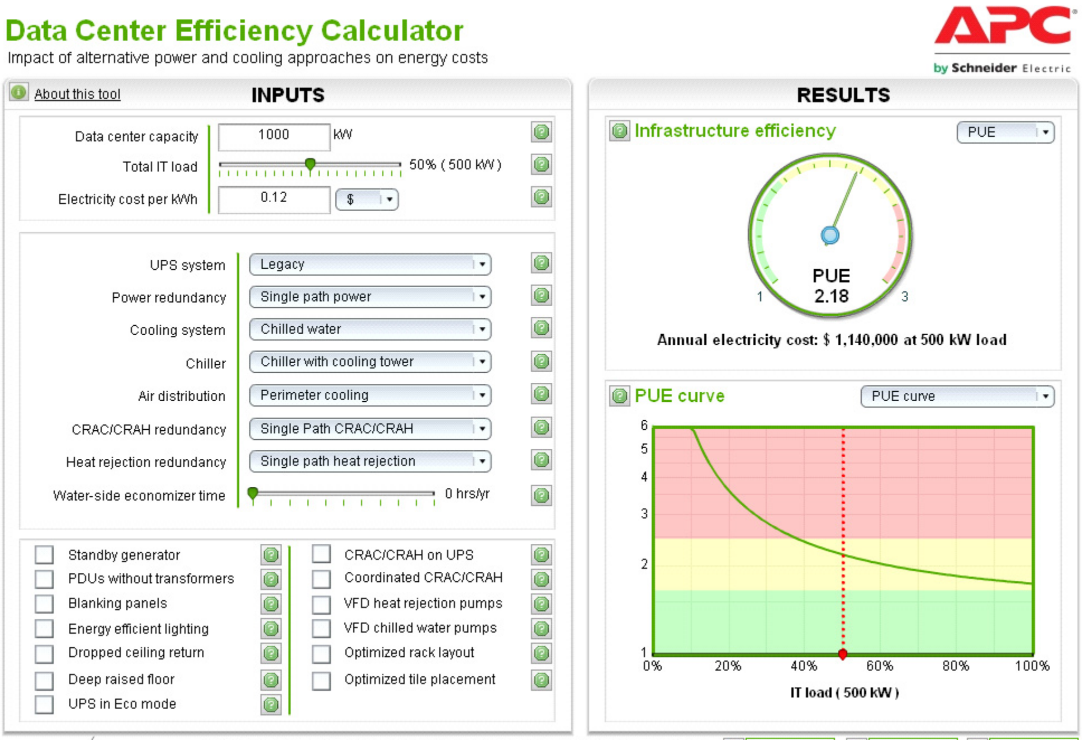
The good news on the physical infrastructure side of data center energy consumption, however, is that innovative best practices, utilization of measurement tools, and deployment of modern technology solutions can reduce the data center electric bill by 20-50%[3]. This white paper will discuss the key steps that need to be undertaken in order to achieve the goal of improved data center efficiency.

How an efficiency assessment can help

The first time the efficiency of a data center is measured it should be part of an overall efficiency assessment by experts. In addition to making an efficiency measurement, a data center efficiency assessment typically provides an analysis of the as-built configuration and recommendations regarding efficiency improvement. Ideally, an assessment should provide a mathematical model of the data center as one of its deliverables. A proper assessment can produce the following outputs:

- Identification of problem areas
- Recommendations for quick, inexpensive fixes
- Recommendations for organizing a long term energy efficiency strategy

Various tools, such as the APC by Schneider Electric Data Center Efficiency Calculator (see **Figure 2**), are available for use on the APC web site (go to http://tools.apc.com). These tools are useful for calculation of data center efficiency and carbon footprint rough estimates.



Data Center Efficiency Calculator
Impact of alternative power and cooling approaches on energy costs

INPUTS

Data center capacity: 1000 kW
Total IT load: 50% (500 kW)
Electricity cost per kWh: 0.12 $

UPS system: Legacy
Power redundancy: Single path power
Cooling system: Chilled water
Chiller: Chiller with cooling tower
Air distribution: Perimeter cooling
CRAC/CRAH redundancy: Single Path CRAC/CRAH
Heat rejection redundancy: Single path heat rejection
Water-side economizer time: 0 hrs/yr

☐ Standby generator
☐ PDUs without transformers
☐ Blanking panels
☐ Energy efficient lighting
☐ Dropped ceiling return
☐ Deep raised floor
☐ UPS in Eco mode
☐ CRAC/CRAH on UPS
☐ Coordinated CRAC/CRAH
☐ VFD heat rejection pumps
☐ VFD chilled water pumps
☐ Optimized rack layout
☐ Optimized tile placement

RESULTS

Infrastructure efficiency: PUE
PUE 2.18
Annual electricity cost: $ 1,140,000 at 500 kW load

PUE curve

Figure 2

"What if" scenarios can be generated using TradeOff Tools™

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[3] APC by Schneider Electric, White Paper 114, "Implementing Energy Efficient Data Centers", 2010

Understanding the language of data center efficiency

Data center electrical efficiency is rarely planned or managed and, as a result, most data centers waste substantial amounts of electricity. Efficiency varies widely across similar data centers, and – even more significant – the actual efficiencies of real installations are well below the practical achievable best-in-class values. In order to address this issue, users need to establish a common metric in order to compare alternative data center efficiency scenarios. This will allow specific data centers to be benchmarked against similar facilities, and to measure progress against internal or external targets.

The metric

Link to resource
White Paper 158
Guidance for Calculation of Efficiency (PUE) in Data Centers

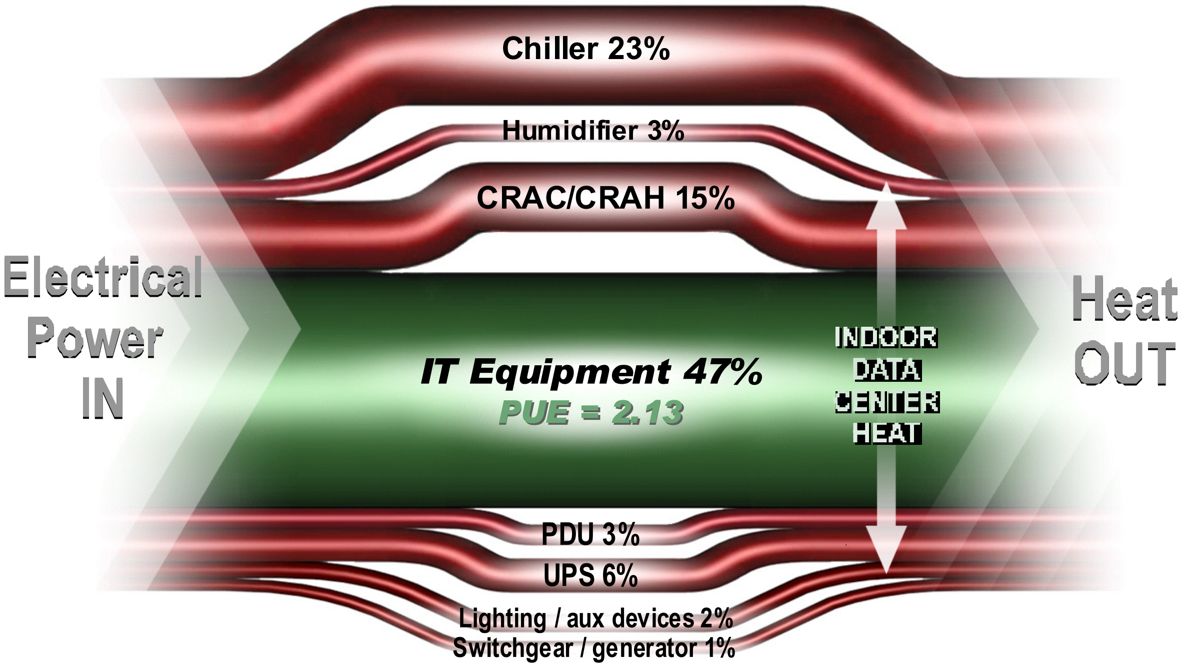
A common metric used is Power Usage Effectiveness (PUE) which is determined by dividing the total amount of power entering a data center by the amount of power that actually makes it to the data center computer equipment (servers, storage etc.) PUE is expressed as a ratio, with overall efficiency improving as the quotient decreases toward 1. For more information on PUE and efficiency metrics, refer to White Paper 158, *Guidance for Calculation of Efficiency (PUE) in Data Centers*.

Where the power goes

If the “useful” power of the data center (defined by PUE) is the power delivered to the IT loads, where does the rest of the power go? **Figure 3** shows where power flows in a sample data center. Note that virtually all the electrical power feeding the data center ultimately ends up as heat. The data center represented in **Figure 3** is 50% loaded data center, with an “N” configuration for all systems (no redundancy), a traditional uninterruptible power supplies (UPS), as opposed to a new high efficiency UPS, no economizer, perimeter cooling, poor floor layout, poor tile placement. Note that less than half the electrical power feeding this data center actually is delivered to the IT loads. The data center in this example reflects a PUE of 2.1 (47% efficient).

Figure 3

Power in, heat out



The energy consumption of a data center over a period of time is computed using the average of the data center efficiency over that period. Therefore, when we speak about data center infrastructure efficiency (PUE), we really are interested in the average efficiency over a period of time.

Link to resource
White Paper 154
Electrical Efficiency Measurement for Data Centers

PUE measured instantaneously will generally NOT be equal to the annual PUE or, for that matter, to the daily, weekly, or monthly PUE. Single measurements of data center efficiency are inherently inaccurate and should not be used as a basis for benchmarking or efficiency management. For more information on data center energy consumption, see White Paper 154, *Electrical Efficiency Measurement for Data Centers*.

Factors impacting data center efficiency measurement

Conditions in a data center change over time, and this causes the efficiency of the data center to also change over time. Several factors have a major impact on the data center's efficiency:

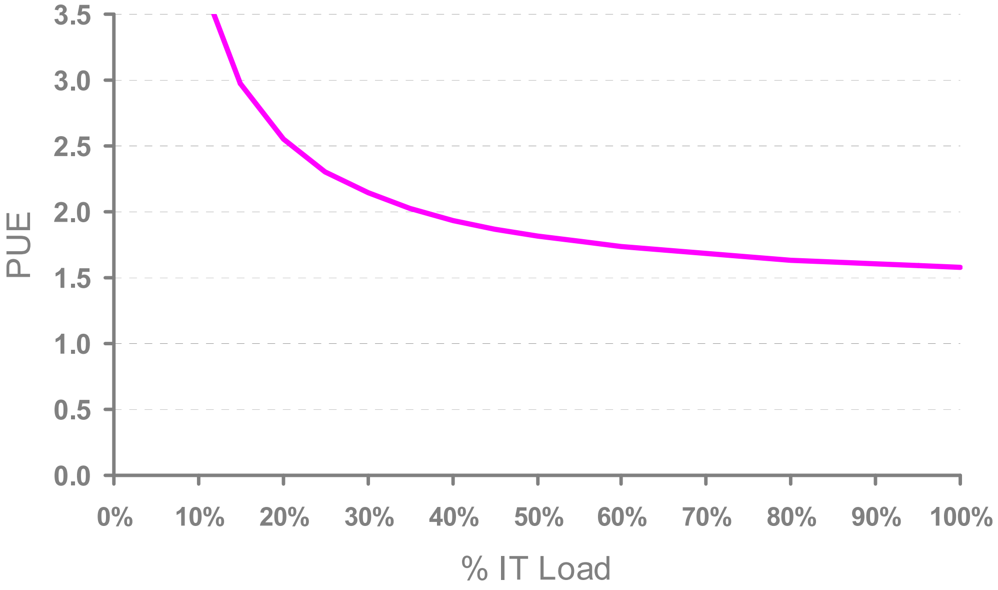
IT load

Link to resource
White Paper 113
Electrical Efficiency Modeling for Data Centers

Power management features in newer generation IT equipment can cause the IT load to vary moment-to-moment, while the removal and addition of IT equipment by the data center operator causes longer term changes in the IT load. Data centers running low loads are less efficient than data centers running high loads (see **Figure 4**). This is primarily due to fixed losses from the supporting physical infrastructure equipment (e.g., power and cooling). All power and cooling devices have electrical losses (inefficiency) dispersed as heat. A portion of this loss is fixed loss – power consumed regardless of load. At no load (idle), fixed loss is the only power consumed by the device, so 100% of the power consumed is electrical loss (heat) and the device is 0% efficient, doing no useful work. As load increases, the device's fixed loss stays the same and other losses that are tied to the amount of load on the device, collectively called proportional loss, increase in proportion to the amount of load. As load increases, fixed loss becomes a smaller and smaller portion of the total energy used, and as the load decreases, fixed loss becomes a larger portion of total energy used. For more information on physical infrastructure power losses, see Schneider Electric White Paper 113, *Electrical Efficiency Modeling for Data Centers*.

Figure 4

PUE as a function of IT load



Outdoor conditions

Outdoor conditions are another factor that varies with time and affects data center efficiency. While sunlight, humidity and wind speed can affect efficiency, the most important variable is the outdoor temperature. The efficiency of a typical data center declines as temperature increases. This is because heat rejection systems consume more power when processing the data center heat, and because outdoor heat infiltration into the data center becomes an additional heat load that must be processed.

User configuration and settings

Users take a variety of actions that affect the PUE. Users can change temperature or humidity set points, move or add vented floor tiles, or can fail to clean air filters. These effects are highly variable and depend on the exact design of the power and cooling systems. When the user changes these “settings” – for example, moves a vented floor tile, changes a filter, or changes a temperature set point – the data center design is considered to have been changed and new measurements are required.

Measuring and modeling

Numerous issues exist when attempting to generate an accurate PUE energy efficiency measurement for a data center. These include:

- Certain devices within data centers draw power, but whether their power data should be included in an efficiency calculation is unclear.
- Certain data center subsystems are not present in a given data center (e.g., outdoor lighting or network operations center (NOC)).
- Some subsystems support a mixed-use facility and are shared with other non-data-center functions (for example, cooling towers and chiller plants), so the fraction of power attributable to the data center cannot be directly measured.
- Some subsystems are impractical or costly to instrument (for example, power distribution units (PDUs) due to number of output connections).
- Some power measurement points include loads that are unrelated to a data center but these loads cannot be separated during measurement.

To overcome these problems, the following three-step approach should be implemented:

1. Categorize data center subsystems as either (a) IT load, (b) physical infrastructure, or (c) not included in the calculation.
2. If a subsystem is shared with non-data-center loads, estimate the power using a standardized methodology for that subsystem type.
3. If technical barriers to measurement exist, estimate the power using a standardized methodology for that subsystem type.

Link to resource
White Paper 158
Guidance for Calculation of Efficiency (PUE) in Data Centers

For more information on measurement of PUE, refer to White Paper 158, *Guidance for Calculation of Efficiency (PUE) in Data Centers*.

Estimate of shared resources

Some data center related devices are a resource that is shared with other entities within a given facility. For example, a data center may share a chiller plant with an office building, or the data center UPS may also provide power to a call center. Even an exact measurement of the energy use of such a shared device is unhelpful in the data center efficiency calculation, because the losses of that device associated with loads other than the data center should not be included in the PUE.

A common approach taken when a device is shared is to simply omit the device from the PUE calculations. This can result in major errors, however, especially if the device is a major energy user such as a chiller. Such an approach invalidates the PUE calculation for benchmarking purposes. A better strategy is to estimate (or indirectly measure) the fraction of the losses of the shared device that are associated with the data center, and then use these losses in the PUE calculations. This approach can yield surprisingly accurate results.

Consider the following example of a shared chiller plant:

1. Measure/estimate the thermal load on the chiller using known electrical losses of all other data center loads. Measure/estimate the chiller efficiency performance. Then use this information to calculate the electrical power the chiller uses for data center loads.
2. Measure/estimate the fractional split of the thermal load between the data center and other loads (using water temp, pressure, pump settings, etc). Measure the chiller input power, and then allocate the fraction of the chiller power to the data center according to the fractional split.
3. Shut off the non-data center loads on the chiller, and then measure the chiller to determine the chiller power associated with the data center.

These indirect measurements are made during an expert data center energy audit, but can be attempted by sophisticated data center operators. Once the technique is established for a specific data center, it is easy to re-use it over time for efficiency trending.

Estimation of devices impractical to measure

It can be complex, expensive and impractical to measure energy use of some devices. In many cases, indirect measurement and estimation of devices can allow determination of the PUE in a practical and cost-effective manner.

Consider the case of a PDU. In a partially loaded data center, the losses in PDUs can be in excess of 10% of the IT load, with a significant effect on the PUE calculation. Yet most data center operators omit PDU losses in PUE calculations because they are considered too difficult to determine. This can cause a serious error in the PUE calculation.

Fortunately, the losses in a PDU are quite deterministic, in that they can be directly calculated from the IT load if the characteristics of the PDU are provided. The losses of a PDU can therefore be estimated with a high degree of precision if the load is known in watts, amps, or VA. In fact, estimating the losses in this way is typically MORE accurate than using built-in PDU instrumentation.

Once PDU losses are estimated, they are subtracted from the UPS output metering to obtain the IT load, and they are counted as part of the physical infrastructure load in determining the PUE. This simple method improves the accuracy of the PUE calculation when compared to ignoring the PDU losses.

Data center operators need to understand that determining PUE does not require extensive, expensive instrumentation because many losses in a data center can be very effectively estimated by indirect measurement and estimation.

Integration of a mathematical model

A mathematical model is the key to creating a process and system for efficiency management. It is the model that allows understanding of the causes of inefficiency; therefore, the purpose of data center efficiency measurement is to establish the parameters of the efficiency model.

Link to resource
White Paper 154

Electrical Efficiency Measurement for Data Centers

An efficiency model for a data center can be created for an existing data center, or it can be created before a data center is even constructed, if the design and the characteristics of the power, cooling and lighting devices are known. If the model accurately represents the design, the data it provides will be similarly accurate. While the electrical performance of some types of devices, such as lighting, UPS and transformers are very consistent and predictable, many uncertainties exist regarding the as-built performance of devices, such as pumps and air conditioners that cause the model to lose accuracy. This is where measurement can help. For more information on a mathematical model for efficiency management, see White Paper 154, *Electrical Efficiency Measurement for Data Centers*.

Data center efficiency best practices

If future data centers are to be more efficient, a number of new approaches will have to be implemented. Efficiency optimization must deal with the data center system as a whole (see **Figure 5**). Attempts to optimize the individual inefficiencies will be less effective. The following system-wide practices provide a roadmap for improved data center efficiency:

- *Powering off unused equipment* - Power and cooling equipment that is not needed should not be energized.
- *Hot aisle / cold aisle arrangement* - The rows of racks should be oriented so that the fronts of the servers face each other. In addition, the backs of the rows of racks should also be facing each other. This orientation of rows creates what is known as the “hot aisle / cold aisle” approach to row layout. Such a layout, if properly organized, can greatly reduce energy losses and also prolong the life of the servers.
- *Tuning redundant systems* - Subsystems that must be used below their rated capacity (to support redundancy) should be optimized for their fractional-load efficiency, not for their full-load efficiency.
- *Capacity management tools* – These tools help to minimize ”stranded capacity” within the data center, allowing the maximum amount of IT equipment to be installed within the gross power and cooling envelope, pushing the system to the highest point on its efficiency curve. An effective capacity management system consists of the tools and rules that allow a data center to operate at a higher density and with smaller safety margins (without compromising safety). For more information on capacity management tools, see White Paper 150, *Power and Cooling Capacity Management for Data Centers*.
- *Instrumentation to monitor energy consumption* - The data center should be instrumented to identify and warn about conditions that generate sub-optimal electrical consumption, so that energy waste situations can be quickly corrected.

Link to resource
White Paper 150

Power and Cooling Capacity Management for Data Centers

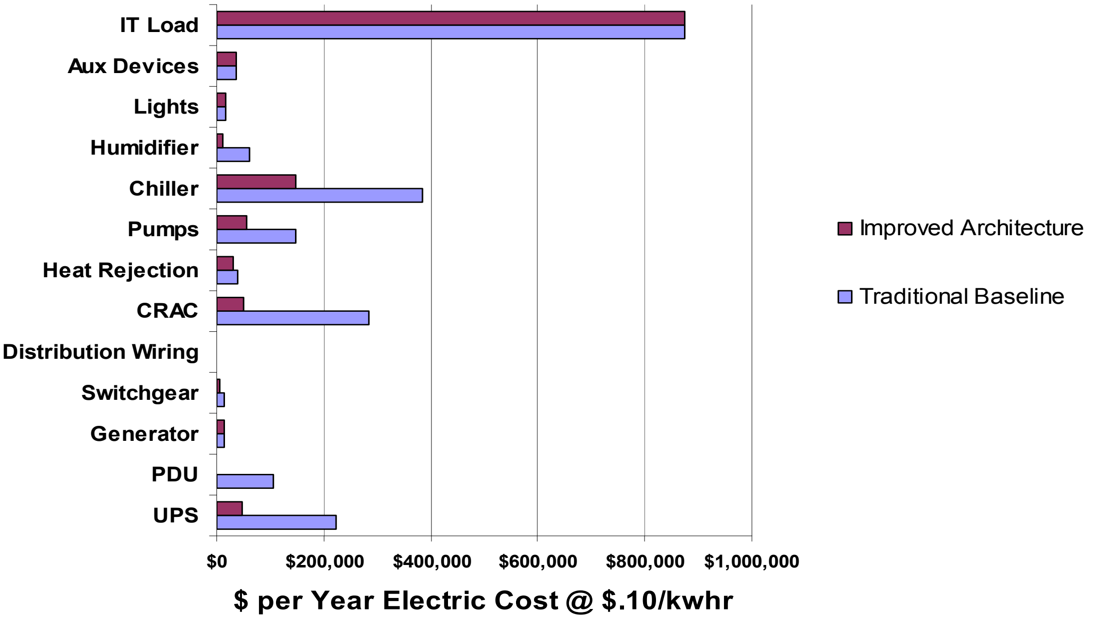


Figure 5

Cost savings of improved architecture broken down by data center subsystem

Link to resource
White Paper 129

A Scalable, Reconfigurable and Efficient Data Center Power Distribution Architecture

- *Scalable power and cooling to enable rightsizing* - The use of a scalable power and cooling solution can increase efficiency in smaller data centers or in data centers that are early in their life cycles, as well as defer capital and operating costs until needed. For more information regarding the impact of modularity and scalability, see White Paper 129, *A Scalable, Reconfigurable and Efficient Data Center Power Distribution Architecture*.

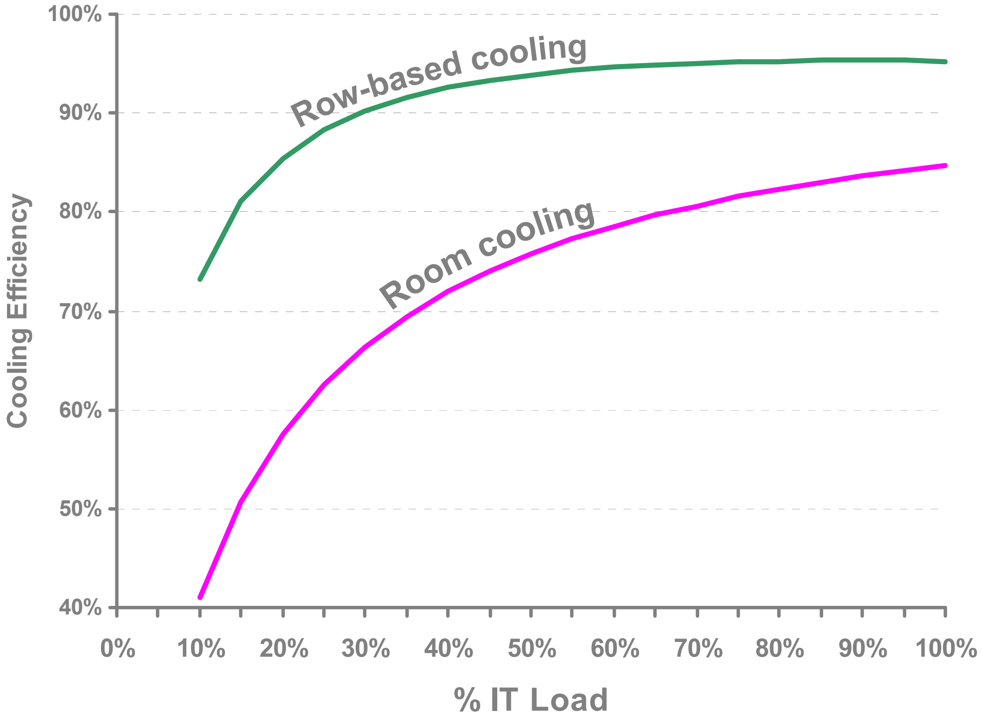
Link to resource
White Paper 126

An Improved Architecture for High Efficiency, High Density Data Centers

- *Row-based cooling* - Shortening the air flow path via row-based cooling reduces mixing of hot and cold air streams which improves the predictability of air distribution and improves the efficiency of delivering cold air to the loads that need it (refer to **Figure 6**). A typical perimeter computer room air conditioner (CRAC) unit has an efficiency of 80% at 70% IT load, which means that 20% of the input power is going to fan and humidification. By contrast, the row-based CRAC has an efficiency of 95% at 70% IT load, which means that only 5% of the input power is going to fan and humidification. For more information on the impact of row-based cooling, see White Paper 126, *An Improved Architecture for High Efficiency, High Density Data Centers*.

Figure 6

Efficiency comparison of room vs. row-based cooling



Link to resource
White Paper 128

High-Efficiency AC Power Distribution for Green Data Centers

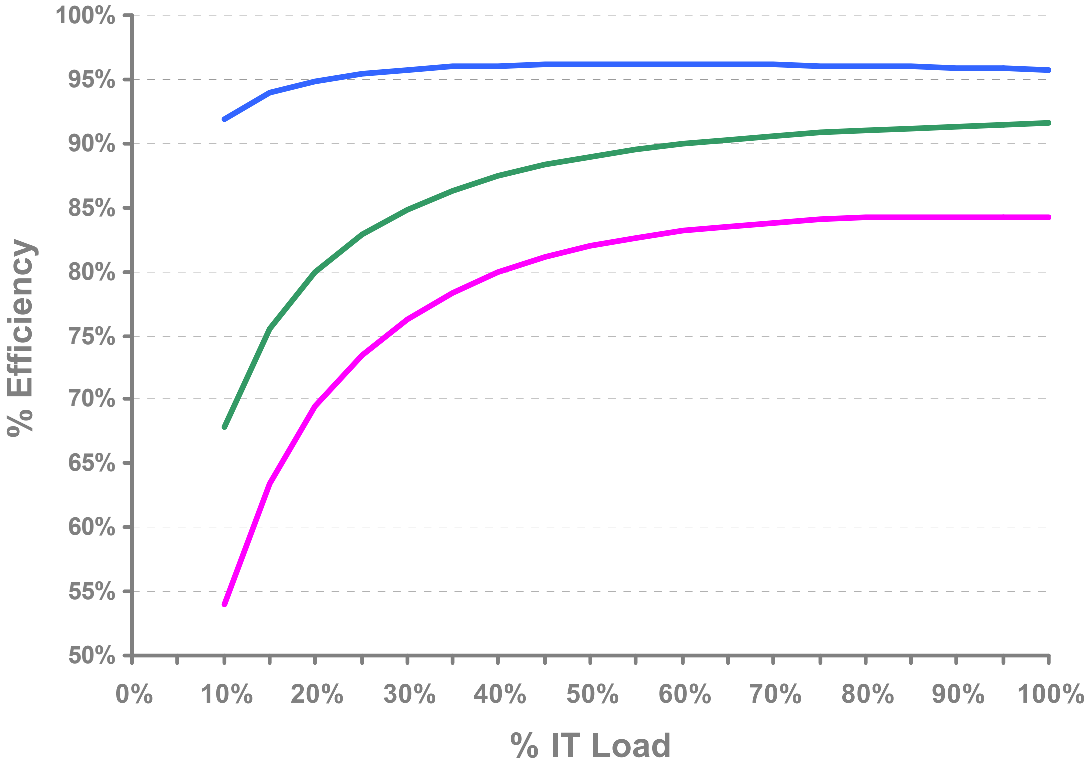
415/240 V AC power distribution – In North America, sending power to IT loads at 415/240 V AC instead of 208/120 V AC eliminates PDU transformers and their associated losses. In addition to this efficiency gain, the elimination of PDUs reduces copper costs, reduces floor loading and frees up additional space for the IT equipment footprint. For more information on higher voltage distribution, see White Paper 128, *High-Efficiency AC Power Distribution for Green Data Centers*.

“Free cooling” – This is a common term used to denote a data center operating in “economizer mode”. While not truly “free,” these technologies can be very helpful in improving data center efficiency in the appropriate geographies. Cooling economizer systems save energy by utilizing outdoor air during colder months of the year allowing mechanical cooling systems like chillers and compressors to be shut off or operated at a reduced capacity.

High-efficiency UPS - Technologies are now available that substantially increase the efficiency obtainable by UPS systems. **Figure 7** compares efficiencies of high-efficiency UPS to UPS efficiency data published by Lawrence Berkley National Labs[4]. At 30% load the newest UPS systems pick up over 10% in efficiency when compared to the average of currently installed UPS systems.

Figure 7

UPS efficiency as a function of load comparing latest generation UPS to historic published data



Variable Frequency Drives (VFD) - Many electric motor-driven devices in the data center operate at full speed even when the loads they are supporting require less capacity. Variable frequency drives (VFDs) help to match the output of the fan to the load. The speed control mechanism in these devices helps to maximize efficiency. Fan speed must be adjusted to match the IT load in real time. Both management software and wired and wireless thermal sensors can help in the regulation or control of VFD drives.

Reference designs – For facility and IT managers in federal data centers, Schneider Electric has created a series of reference design data centers. This is a series of pre-designed data centers that have been optimized to run at high efficiency utilizing existing building and IT room physical infrastructure technologies. Such designs save months in research time and have been pre-tested to perform at the targeted PUE levels.

Modular containerized solutions - Existing building structures often limit the electrical efficiencies that can be achieved through power and cooling distribution. Manufacturers can now build modular, containerized power and cooling modules that utilize standard power and cooling components and design them to a specific PUE target. Packaged, shipped and installed as a container that plugs into an existing building, these solutions can rapidly increase efficiencies within existing data centers.

Hot aisle containment - A hot-aisle containment system (HACS) allows higher work environment temperatures and increased chilled water temperatures which results in increased economizer hours and significant electrical cost savings. Cooling set points can be set higher

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[4] LBNL report on UPS efficiency: http://hightech.lbl.gov/documents/UPS/Final_UPS_Report.pdf, Figure 17, page 23. Accessed March 21, 2008.

Link to resource
White Paper 135

Hot Aisle vs. Cold Aisle Containment for Data Centers

while still maintaining a comfortable work environment temperature. Retrofitting an existing perimeter-cooled, raised floor data center with HACS can save 40% in the annual cooling system energy cost corresponding to 13% reduction in the annualized PUE. For more information on hot-aisle containment, see White Paper 135, *Hot-Aisle vs. Cold-Aisle Containment for Data Centers*.

Interior lighting with sensors - High efficiency interior lighting can cut consumption from 1.5 to 3 watts per square foot. Occupancy sensors can increase savings by turning on lights only when the physical space is occupied. Where utility rebates are available, sensors can pay for themselves in less than one year, but most pay for themselves in two to three years without rebates. Savings will vary depending on the area size, type of lighting and occupancy pattern.

Of all of the efficiency techniques available to users (refer to **Table 1** for partial list), **right-sizing** the physical infrastructure system to the load has the most impact on physical infrastructure electrical consumption. Scalable physical infrastructure solutions that can grow with IT load offer a major opportunity to reduce electrical waste and costs. Right-sizing has the potential to eliminate up to 50% of the electrical bill in real-world installations. The compelling economic advantage of right-sizing is a key reason why the industry is moving toward modular, scalable physical infrastructure solutions.

Table 1

Range of achievable electrical savings (partial list)

	Savings	Guidance	Limitations
Right-size physical infrastructure	10 – 30%	• Using a modular, scalable power and cooling architecture • Savings are greater for redundant systems	• For new designs and some expansions
More efficient air conditioner architecture	7 – 15%	• Row-oriented cooling has higher efficiency for high density (APC White Paper 130) • Shorter air paths require less fan power • CRAC supply and return temperatures are higher, increasing efficiency, capacity, and preventing dehumidification thereby greatly reducing humidification costs	• For new designs • Benefits are limited to high density designs
Economizer modes of air conditioners	4 – 15%	• Many air conditioners offer economizer options • This can offer substantial energy savings, depending on geographic location • Some data centers have air conditioners with economizer modes, but economizer operation is disabled	• For new designs • Difficult to retrofit
More efficient floor layout	5 – 12%	• Floor layout has a large effect on the efficiency of the air conditioning system • Involves hot-aisle / cold-aisle arrangement with suitable air conditioner locations (APC White Paper 122)	• For new designs • Difficult to retrofit
More efficient power equipment	4 – 10%	• New best-in-class UPS systems have 70% less losses than legacy UPS at typical loads • Light load efficiency is the key parameter, NOT the full load efficiency • Don't forget that UPS losses must be cooled, doubling their costs	• For new designs or retrofits
Coordinate air conditioners	0 – 10%	• Many data centers have multiple air conditioners that actually fight each other • One may actually heat while another cools • One may dehumidify while another humidifies • The result is gross waste • May require a professional assessment to diagnose	• For any data center with multiple air conditioners
Locate vented floor tiles correctly	1 -6%	• Many vented tiles are located incorrectly in the average data center or the wrong number are installed • Correct locations are NOT intuitively obvious • A professional assessment can ensure an optimal result • Side benefit – reduced hot spots	• Only for data centers using a raised floor • Easy, but requires expert guidance to achieve best result
Install energy efficient lighting	1 – 3%	• Turn off some or all lights based on time of day or motion • Use more efficient lighting technology • Don't forget that lighting power also must be cooled, doubling the cost • Benefit is larger on low density or partly filled data centers	• Most data centers can benefit
Install blanking panels	1 – 2%	• Decrease server inlet temperature • Also saves on energy by increasing the CRAC return air temperature • Cheap and easy with new snap-in blanking panels such as those by APC	• For any data center, old or new
Variable Frequency Drives (VFD)	1 – 10%	• Replaces fixed speed drives • Enhances performance of chillers and pumps • Appropriate controls needed to match IT load and outdoor conditions	• For data centers operated 24X7X365

Conclusion

Energy efficiency initiatives in Federal data centers can begin with assessments that can easily reveal the "low hanging fruit" when it comes to energy conservation. Techniques, such as blanking panels and hot aisle / cold aisle orientation for racks, can begin the process of improved energy efficiency.

However, the essence of improvement is accurate measurement of energy being consumed so that a baseline for improvement can be established. Data center energy efficiency models can be utilized, at a reasonable cost, to measure consumption to a surprisingly accurate degree.

Once consumption is measured, management techniques and new technologies can then be deployed which significantly reduce energy costs throughout the electrical room, mechanical room and IT room of the data center.

About the author

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Resources

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Electrical Efficiency Modeling for Data Centers
White Paper 113

Implementing Energy Efficient Data Centers
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Guideline for Specifying Data Center Criticality/Tier Levels
White Paper 122

An Improved Architecture for High-Efficiency, High-Density Data Centers
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