Crossing the Great Divide in Going Green:
Challenges and Best Practices in Next Generation IT Equipment

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Abstract

Computing technologies are becoming increasingly powerful and power hungry. While the enhanced capabilities of new server, storage and networking equipment deliver bottom line results, new equipment can stress both the data centers’ power and cooling infrastructure and utility companies. This creates a range of demands on data center operations:

- Data centers may not be able accommodate new equipment due to power and cooling capacity limitations or space.
- Data centers may have hot spots that cause reliability issues.
- Data center power and cooling costs are increasing.
- Companies may have made commitments to reduce their carbon footprints, but increasing data center power demands make it difficult to achieve these goals.

With each new generation, IT equipment requires more power and cooling per unit of space. At the same time, this equipment generally delivers more computing power, capacity and information management potential per unit of applied energy.

New information management solutions that are properly configured and utilized can help the enterprise and Small to Medium Businesses (SMBs) do more with less equipment, reclaiming power and cooling capacity for data center operations.

Seeing the big picture, defining best practices and adopting a holistic approach to next generation information and power management technologies are some of the challenges that we face. Virtualization, consolidation and new storage technologies are just some of the methods we can use to improve data center efficiency. Most would agree that we need to address the “divide” of power and cooling requirements and the need for information management growth.

This article will define best practices and offer solutions for crossing the “Great Green Divide.”
**Introduction**

Power plants burning fossil fuels generate over 70% of the electricity consumed in the United States. Coal, the least environmentally friendly fossil fuel, generates 50% of the electricity consumed in the United States. [1]. In contrast to our goal of “going green,” coal-fired power plants’ contribution to electricity production will likely increase to 57% by 2030. Fossil fuel power plants account for almost 40% of the total CO₂ produced in the U.S., and coal-fired power plants are responsible for nearly 80% of that amount. The increased concentration of CO₂ in the atmosphere increases the earth’s greenhouse effect and accelerates global climate changes.

As shown in Figure 1 - Data Center Challenges, it is apparent, based on feedback from data center administrators, that power and cooling are the biggest challenges facing IT Data Centers [12]. In the IT community, our attempts to increase cooling efficiency and to optimize IT equipment, as they relate to power consumption, have never been more important!

![Figure 1 - Data Center Challenges](image-url)
"The Great Divide" – Definitions and Challenges

**Increasing Energy and Infrastructure Costs**

Since equipment density and energy prices are consistently rising, we can attribute as much as 40% of the total data center operating costs to energy [1]. For example, worldwide electricity used by servers doubled between 2000 and 2005. Most of this increase was due to growth in the number of servers; a small percentage was due to increased power use per server.

We can estimate the annual energy cost for a server based on its rated power and the price of electricity ($0.11 per kW-hr in some parts of the U.S., for example) as follows:

**Equation 1 – Annual Power Cost**

\[
\text{(Annual Power Cost)} = 8760 \text{ hrs/yr} \times \$0.11/\text{kW} \times (\text{IT Equipment Power in kW})
\]

In addition to increasing energy costs, infrastructure costs are also growing significantly. Data centers are mission-critical, requiring year-round monitoring and maintenance of redundant power and cooling equipment. To quantify this cost, the Uptime Institute, a respected provider of educational and consulting services for Facilities and Information Technology organizations interested in maximizing data center productivity, introduced a simplified data center infrastructure cost (IC) equation. It sums the cost of raw computer room space ($/ft²) and the cost of the power and cooling resources ($/kW). We obtain the value of the $/kW component in the equation from one of four functionality ratings, Tier I to Tier IV. The highest rating, Tier IV, represents a fault-tolerant (mission-critical) data center. Here is the IC equation at Tier IV:

**Equation 2 – Infrastructure Cost**

\[
(\text{Infrastructure Cost}) = (\text{Total Power} \times \$22,000/\text{kW}) + (\text{Area} \times \$220/\text{ft²}, \text{or} \$2,400/\text{m²})
\]

We can amortize the result derived from this equation by dividing it by the life span of the data center, typically 10 to 15 years, to estimate the annual infrastructure cost. The IC equation is useful, but only provides a rough estimate of infrastructure costs.
By using these two equations, we can demonstrate that the total infrastructure and energy expenditure can be more costly than the IT equipment acquisition costs. Such findings have caused a paradigm shift away from strategies that focus on driving down the cost of IT equipment as a primary means to control data center costs. Instead, driving down energy and infrastructure expenses have become the primary concern.

A typical data center power consumption profile is shown below in Figure 2 – Power Consumption in the Data Center [3]. Cooling is the overwhelming power consumer; then the data center equipment itself and finally, power conversion. Given this allocation of power consumption, increased cooling efficiencies may have the biggest initial short-term benefit. Given this power allocation mix, we can agree that the greatest opportunity to reduce the carbon footprint lies in providing new processes and technologies for reducing data center equipment power consumption and cooling.

![Data Center Power Consumption](image)

**Figure 2 – Power Consumption in the Data Center**
Characterizing Cost, Performance, and Energy Efficiency

To characterize cost, performance and energy efficiency, we can use this framework for understanding direction and focus in “cracking this going green nut.”

![Diagram showing the influence of contribution vs. physical size with levels from Transistor to Atmosphere](image-url)

Figure 3 - Green Technology Contribution and Opportunities
As illustrated in Figure 3 - Green Technology Contribution and Opportunities, there are various levels of physical and technological constructs within the data center. Each level is inter-related; and each chain element has inter-related physical, mechanical and electrical attributes. For example, the transistor, the fundamental electrical building block that has links to most, if not all data center technology equipment, contributes to the data center’s overall power and cooling requirements. Continuing up the physical chain, each level: chip, module, card, draw/enclosure and rack, all offer there specific influence of contribution supporting ‘green’ opportunities.

One way to reduce power and cooling (P&C) costs is to offer an optimized semiconductor device or chip that utilizes multiple core CPU’s and shares Memory Management Units (MMUs) with a more dense design. Selecting lower voltage levels and smaller geometries that continue in line with “Moore’s Law” (Semiconductor performance doubles every 18 months) reduces P&C costs.

At the module, card, draw/enclosure element levels, advances in packaging, and thermal heat transfer technologies via air and liquid continue to offer opportunities for optimized P&C. In addition, at the top of the element stack, opportunities to consolidate blades and optimize utilization of various thermal transfer solutions such as segregation of cool source and hot return systems continue to accelerate enhanced P&C efficiency.

In addition to the physical or ‘hardware’ related opportunities, the “software” influence, the inelegance integrated into this hardware stack, is also an extremely important contributor to the overall “Going Green story.” Advances in P&C management, consolidation through single-instance storage, data de-duplication, operating system virtualization, and power management software as well as application integration into the aforementioned technology can and will have a major impact on P&C. The “software influence” technology will be utilized in the data center and in every part of the IT infrastructure. This is also true in the consumer and end-user electronics space, especially as it relates to virtualization of the desktop..

The physical mapping of the element stack shown in Figure 3 will be an important theme going forward in this article describing our “green” opportunity.
Rising Computing Demand

Data centers are vital to the world's economy. They provide mission-critical IT services including computing, networking, and data storage for major organizations, corporations and governments. The demand for IT business support continues to grow along with the need for increased connectivity and on-demand access to digital information and media. The good news is that IT data equipment continues to evolve in accordance with Moore’s Law as a function of performance per watt which has approximately doubled every two years since 1999[1]. Business application demand is increasing as well as the associated data, resulting in a continuous need for more storage, servers and infrastructure. Consequently, data centers must continue to scale their infrastructure and bring new data centers online to meet the computing demand.

Why it all matters

Building green data centers and retrofitting existing data centers with green features is increasingly on CIO’s top ten initiatives in 2008. Interest will only increase because data centers continue to increase their use of electricity. In fact, the Environmental Protection Agency (EPA) recently asserted in a report to Congress that usage more than doubled between 2000 and 2006.

The EPA estimates that the nation’s IT equipment and data centers consumed about 61 billion kilo-watt-hours (kWh) of electricity in 2006 at a total electricity cost of about $4.5 billion. This is more than the electricity consumed by all the nation's color televisions and is similar to the amount of electricity consumed by 5.8 million U.S. households [1].

The EPA estimates that national energy consumption by data centers could nearly double again between 2006 and 2011, reaching more than 100 billion kilowatt hours and costing $7.4 billion annually. In the future, the most energy-efficient data centers are going to be the most cost-effective, and will therefore support the most successful businesses [1].

Wall Street is paying close attention to the construction of green data centers. "The financing of green buildings is preferred in the financial markets with better interest rates because the likelihood of a green building holding its value over the next 30 years is much higher."[13]
What does “Going Green” mean? - Understanding the challenges

“Going Green,” simply stated, is reducing the data centers’ carbon footprint. One way to measure a particular data center is demonstrated in Equation 3 – Data Center Efficiency (DCE), below [6]. This is the indicator ratio of an IT data center’s energy efficiency.

**Equation 3 – Data Center Efficiency**

\[
\text{DCE} = \frac{\text{ITEquipmentPower}}{\text{TotalFacilityPower}}
\]

IT equipment includes servers, disk and tape storage, networking switches, routers and printers. The total facility power includes power conversion and cooling infrastructure. For example, let us consider that the sum of all IT equipment energy usage results in 1,500 kilowatt hours (kWh) per month. The total facility power, including UPS, energy switching, power conversion and filtering, cooling and associated infrastructure costs (See Figure 6 - Data Center Delivery Factor and Coefficient of Energy Efficiency, shown on page 21,) as well as IT equipment resulted in 3,500 kWh. Using our equation, the DCE would be:

**Equation 4 – Data Center Efficiency Example**

\[
\text{DCE} = \frac{1,500\text{kWh}}{3,500\text{kWh}} = 0.43 = 43\%
\]

The DCE indicates that IT equipment accounts for about 43% of the energy consumed by this data center, while cooling, power conversion and power conditioning represents 57% of the electrical energy consumed.

The Power User Effectiveness (PUE), as shown in Equation 5 – Power User Effectiveness, is the inverse of the DCE. It illustrates the ratio of total energy consumed by the data center to the energy used to operate IT equipment.

**Equation 5 – Power User Effectiveness**

\[
\text{PowerUserEffectiveness}(PUE) = \frac{1}{\text{DCE}} = \frac{\text{TotalFacilityPower}}{\text{ITEquipmentPower}}
\]
The PUE is the total facility power divided by the IT equipment energy consumption. Using the above scenario, PUE = 2.333 (3,500 / 1,500), meaning that a storage unit requiring 100 watts of power would actually require (2.333 * 100) 233.3 watts of power to accommodate both direct power and cooling costs.

Similarly, a storage system that required 1,500 kWh of energy to power would require (1,500*2.333) = 3,499.5 kWh power to include cooling.

Equation 6 – Data Center Performance Efficiency (DCPE), is another meaningful metric. It considers how much useful and effective work the IT equipment and data center performs and compares it to energy consumption. DCPE compares useful work to total facility power. An example involves some number of transactions processed using servers, networks and storage divided by the energy consumed by the data center to power and cool the equipment. A relatively straightforward implementation of DCPE is illustrated in:

\[
DCPE = \frac{UsefulWork}{TotalFacilityPower(ForExampleIOPSPerWattOfEnergyUsed)}
\]

Equation 9 – IO’s per Second as a Function of Energy Used

This demonstrates an IOP’s (Input/Output per second) per watt measurement based on how many IOP’s can be performed (regardless of size or type, such as reads or writes) per unit of energy (in this case, watts).

\[
DCE = \frac{ITEquipmentEnergy}{TotalFacilityPower} = \frac{1}{PUE}
\]
Equation 8 – Power Usage Efficiency

\[ PUE = \frac{TotalFacilityEnergy}{ITEquipmentEnergy} \]

Equation 9 – IO’s per Second as a Function of Energy Used

\[ IOPSPerWatt = \frac{NumberIOPS(OrBandwidth)}{EnergyUsedByTheStorageSystem} \]

These numbers and metrics focus on the larger impact of a piece of IT equipment based on its cost and energy consumption, factoring in cooling and other hosting or site environmental costs. Naturally, energy costs and carbon offsets vary by geography and region along with the type of electrical power used (coal, natural gas, nuclear, wind, thermo, solar, etc.). We must keep this in perspective as part of the big picture.

**Increasing Power Density**

The need to maximize the use of data center floor space and to extend the life of data centers has resulted in an increase in IT equipment, specifically servers or servers’ density. As a result, rack power density (kW/rack) is up more than 500% in the past 10 years [5]. The growth in rack power density and the associated heat load are outpacing conventional thermal management techniques that were designed for previous generations of IT equipment.

To achieve thermal management targets, some organizations partially populate the racks up to a maximum heat load of 5 - 6 kW. This results in under-utilization. Therefore, we need new techniques to attain high power density. One technique is to isolate high-density equipment and improve the efficiency of nearby cooling resources, rather than limit rack utilization.

Equipment power density predictions, such as those published by ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) [13], have been helpful to understand rack power requirements for high-density deployments in new and existing data centers. These power density projections and relationships target facilities supporting Internet and financial services
and high performance computing applications, such as graphics-rendering farms, grid computing, transaction processing, etc.
**Conventional Thermal Management Techniques**

Conventional thermal management techniques are less efficient for cooling high-density heat loads in mixed-density environments. One reason is that traditional computer room air handlers / air conditioners (CRAH/CRACs) using raised floor plenums are typically controlled by return air inlet temperature sensors that provide an overall indication of the heat dissipated in the room. This is highlighted in Figure 4 – Conventional Cooling Diagram.

In reality, the airflow patterns in many data centers promote the mixing of warm return air with a sourced cool air supply that can cause cooler air to be circulated back to the CRAH/CRACs. This decreases the sensible cooling capacity and the overall system efficiency. The result is that cooled air is not utilized. The power cost for moving air is appreciable and this situation is inefficient. Additionally, warmer air is re-circulated through computer equipment, creating hot spots. The CRAH/CRAC return air sensor does not sense the hot spots that are typically set at 68°F to 72°F (20°C to 22°C). Traditional computer room airflow management techniques are effective for power densities less than 5 kW/rack, while high-density equipment can push power density well above 15 kW/rack [5]. New techniques are required to manage these higher densities.

![Figure 4 – Conventional Cooling Diagram](image)
Optional Cooling Technologies

There are several optional data center cooling technologies on the market that place additional burdens, such as increased power usage and inflexibility, on the infrastructure. These technologies include:

- Passive cooling
- Active cooling
- Vertical cooling

Passive cooling technologies include airflow containment devices that create physical barriers between cold air supplies and warm air return streams. Although these devices can be effective, they only address half of the problem and they can cause other issues related to turbulence and airflow imbalances. Some containment devices, such as fully enclosed rack systems, place operational limits on the IT equipment inside them, and on the facilities to stay within their designed capacity limits. In instances where air is ducted from the bottom to the top of the rack, as shown in Figure 4 – Conventional Cooling Diagram, very high fan power may be required to move enough air through the narrow cross-section and long length of the rack. If these types of fully-enclosed rack systems fail, the enclosed devices do not have adequate airflow to cool themselves, resulting in over-heated systems and eventual failure.

Active cooling technologies include fan-powered devices designed to pull additional cool supply air into high-density areas or to push warm return air to the air handlers. These devices treat only half of the problem and should be used carefully as they can, as discussed previously, cause additional issues related to turbulence and airflow imbalances. Similarly, if an active cooling device fails, associated IT equipment operation is compromised and there is a risk of over-heating. Another serious drawback is that active cooling devices significantly increase energy use and add parasitic heat to the overall system through the fans themselves.

Other cooling systems dramatically change airflow patterns, thus requiring the creation of special areas in the data center. Some of these systems create vertical airflow, forcing air through an upright stack of heat-producing devices. These vertical cooling systems require careful planning to ensure that they do not disrupt the rest of the environment. For example, vertical cooling systems move extremely large volumes of air at high velocities. Such high-velocity airflow can cause problems by robbing nearby systems of needed supply air. Regarding
exhaust air, high-velocity airflow can contribute to turbulence and recirculation in the surrounding area. As with the active cooling systems mentioned above, high-velocity fans generate additional heat that must be removed, and thus increase power use.

Gaining energy efficiency through cooling technologies is a common goal for all data centers. The industry’s challenge is to determine the best indicators, or metrics, for measuring efficiency. Some metrics measure the overall efficiency of the data center infrastructure, while others measure the efficiency of specific components or subsystems. A best practice for IT organizations is to have a clear set of benchmark metrics, allowing IT and facility management to compare cost, performance, and energy efficiency.

The following best practice metrics are outlined: Cooling Total Cost of Ownership (CTCO), Coefficient of Performance of the Power Efficiency Stack, Delivery Factor and Coefficient of Energy Efficiency.

**Cooling Total Cost of Ownership (TCO)**

Data center organizations are trying to lower TCO through consolidation and better utilization of resources. TCO, as it relates to cooling, includes the cost of facility space as well as capital and maintenance costs for power and cooling resources.

The interdependence of these variables requires a holistic (end-to-end) cost model that follows the flow of energy from heat generation at the chip core, through transistor technology, chip package, module, and card to heat dissipation at the cooling tower as shown previously in Figure 2.

Until approximately 2005, adequate floor space to accommodate rapid growth was the major problem plaguing data centers (IT and facilities organizations). With solutions now available, energy costs and the inability of data center infrastructures to accommodate new high-density computing platforms are the main problems. Higher rack densities have caused power and cooling costs to surpass the IT equipment and facility space costs.
In the past, IT tended to focus on equipment and facility departments tended to focus on the plant infrastructure. Now, both IT and Facilities need to view the data center holistically and collaborate to focus on lowering the total cost of ownership (TCO).

IT and Facilities must adopt a new paradigm to maximize the energy efficiency of components, systems, and the infrastructure while controlling energy usage. Organizations need to use energy-efficient technologies for cooling newer, high-density server, storage and network infrastructure platforms. They must also bridge the green gap between existing operating practices and recommended "best practices" for new computing platforms.

The demand for IT services and support will continue to increase. Improving power and cooling infrastructure efficiency is a business best strategy to manage this growth. It is imperative to understand the challenges and abandon out-dated technologies that ignore energy efficiency. Familiarity with new technologies to improve performance and energy efficiency, and adopting strategies and best practices for high-density IT equipment are the keys to bridging the gap.

Continue to next page
Coefficient of Performance of the Power Efficiency Stack

Figure 5 – Power efficiency hierarchy of energy transfer in a typical air-cooled data center from chip to cooling tower

As shown in the cooling flow system in, the chip-to-ambient model traces the energy flow path from chips, systems (servers, storage, network infrastructure and enclosures), racks, air distribution and chilled water systems, to the cooling tower.

Work (energy), defined as “W” in the diagram, is introduced at each stage to transfer heat to a fluid stream (air or liquid). For example, at the chip level, a Blade Server’s fan blows air across the heat sink, and the warmer air is exhausted in the back of the rack.

Flow (air mixing) and thermodynamic irreversibility introduce Inefficiencies at each stage of the energy path. Heat transfer “Q” is involved in each level of the power efficiency hierarchy in this energy transfer stack. For example, the exhaust airstreams from IT equipment undergo mixing and other thermodynamic processes in the rack before ejection into the aisle where further mixing occurs. These air streams (or a subset) make it back to the CRAH/CRAC units to transfer heat to the chilled water or refrigerant. Mechanical efficiency of air handling devices at each stage also contributes to irreversibilities and inefficiencies. The mechanical efficiency of air handling
devices, including the fans in the IT equipment, the CRAH/CRAC unit blowers, and the cooling
tower blowers, can be as low as 65% [8]. The movement of air is costly.

We can apply a dimensionless thermodynamic metric to track performance at each stage of the
energy flow path. This is known as the Coefficient of Performance (COP). COP is the heat
extracted, or dissipated, divided by the work supplied to the device. The COP of each device can
be combined into an aggregate COP of the Power Efficiency Stack (COP$_G$). Data center COP is
defined as the ratio of the total heat load dissipated to the power consumed by the cooling system:

\[
\text{Equation 10 – Coefficient Of Performance} \]  

\[
COP_g = \frac{\text{Total Heat Dissipation}}{(\text{Air Flow Work} + \text{Thermal Dynamic Work of Cooling System})} 
\]

\[
COP_g = \frac{\text{Heat Extracted By Air Conditioners}}{\text{Net Work Input}} 
\]

We can track performance using instrumentation sensors for each component along the energy
flow path using the COP$_G$ formulation. Using a monitoring network that monitors the heat load
and work done by any component in the cooling system in real time is a best practice. The COP$_G$
metric could be used as the basis to operate the data center in a variety of modes, and it could
even be used to compare data centers. It can also be used in the TCO model described earlier for
capturing the recurring costs related to data center cooling.

**Delivery Factor and Coefficient of Energy Efficiency**

While TCO and COP$_G$ are useful metrics to understand data center infrastructure, the "field"
metrics introduced in the following section help us to understand overall data center efficiency.
The “Delivery Factor” is the total power delivered to the facility divided by the net power going
directly to the IT equipment as shown in Equation 11 – Delivery Factor, below. An organization
can use the Delivery Factor to benchmark its data center operations against the industry. It also
offers a simple means to determine compliance with governmental energy policies.

The Coefficient of Energy Efficiency (CEE) is an alternative. It is the inverse of Delivery Factor,
which is represented as a percentage as shown in Equation 12- Coefficient of Energy Efficiency
(CEE), below. For example, the CEE of a non-optimized data center may be 60%, while an
optimized data center could have a CEE of 75%.
Figure 6 - Data Center Delivery Factor and Coefficient of Energy Efficiency

Equation 11 – Delivery Factor

\[ \text{DeliveryFactor}(\text{AtThePowerGrid}) = \frac{\text{DataCenterLoad(Environmental + Power)}}{\text{ITLoad}} \]

Equation 12 – Coefficient of Energy Efficiency (CEE)

\[ \text{Coefficient of Energy Efficiency (CEE)} = \frac{1}{\text{DeliveryFactor}} \times 100\% \]

Industry leaders are also using Power Use Efficiency (PUE) and Data Center Efficiency (DCE) which are equivalent to Delivery Factor and CEE, respectively.

Eighty-five percent of data centers consume 2 kW for each kW consumed by IT equipment, as shown in Figure 6 - Data Center Delivery Factor and Coefficient of Energy Efficiency, above [1]. This results in a PUE of 3 or more. The figure shows that cooling resources consume most of the non-IT power, and only a small portion goes to power conditioning/conversion. Data centers with a PUE of 3 or greater typically have a grossly over-provisioned cooling system. Over-provisioning results in a higher TCO since it increases capital and recurring expenses, and decreases utilization and efficiency. A best practice is to minimize over-provisioning which will be discussed in more detail in the next few sections. A PUE of 3.0 yields a DCE of 33%,
meaning that IT equipment consumes 67% of energy, and cooling and electrical conversion consume only one-third of facility power.

Since cooling and data center equipment efficiencies are the major contributing factors, as defined in Figure 2 on page 7, we will discuss each technology opportunity. As shown in Figure 7 - Going Green Technology Opportunity Mapping, we can map each opportunity by the physical data center’s tier. From the transistor through the outlying power grid, each level and associated technological innovation offers alternatives that can and will influence the others. Achieving the goals of a high reduction in power and increased efficiency is the focus of this holistic approach.
There are clear best practices for data center and IT equipment designers that, when combined as outlined in Figure 7 – Going Green Technology Opportunity Mapping, will produce dramatic results. Among the industry best practices specific to data center power and cooling:

- Reduce cooling demand
- Use free (outdoor air) or ambient cooling
- Use cabinet blanking panels
- Avoid over-cooling and over-provisioning
- Segregate hot air/ cold air
- Use fluid dynamics modeling to prevent under- or over-provisioning of cooling
- Minimize distance of cooling airflow
- Utilize new cooling technologies
- Use data center thermal recovery
- Utilize cogeneration and tri-generation
- Utilize efficient methods of power conversion
- Minimize provisioning of UPS systems
- Adopt singular power conversion

**Best Practice - Reduce cooling demand**

The first and primary task of a data center manager is to reduce the equipment's heat output. This will reduce the cooling requirement by using energy-efficient equipment and driving up utilization intelligently.

**Best Practice - Use outdoor air for cooling**

We must reduce the temperature by means other than air conditioning units; for example, by fully utilizing the cooling power of outside air.
The optimal data center temperature is 68-72 degrees Fahrenheit. In many areas of the United States and Europe, it is cooler outside the data center than inside for a substantial portion of the year. Data centers are largely secure and sealed environments. This poses a challenge. One method is to use a heat exchange to use outside air to cool inside air. This can be very power-efficient, especially when the air outside is much cooler. Data center facility managers are now considering outside air as an option due to increasing energy demands. In fact, some corporations are considering relocating data centers to colder areas.

Designing equipment that operates at a higher ambient temperature is another option. Although semiconductor and system manufactures are considering this, it would produce only incremental improvements.

**Best Practice - Use cabinet blanking panels**

Using cabinet blanking panels can prevent warm air from being sucked back into cooled areas of the data center. APC, which has produced several studies in this area, reports that poor design routinely doubles consumption of power for air conditioning.

**Best Practice - Avoid over-cooling and over-provisioning**

Over-provisioning of cooling systems is a common problem. Most data centers have 2.6 times more cooling than they need. However, 10% suffer from hot spots. It is common to install more air conditioning to address data center hot spots while systems in other areas of the data center are running inefficiently and are over-cooled. As a result, up to 72% of cooling is not utilized by computer equipment at all.

**Best Practice – Segregate hot air/cold air**

Mixing cool and warm air with too few thermostats controlling the temperature is another inefficient practice that we typically see in office environments. A best practice is to set the cold inlet air at a low temperature, such as 25 degrees Celsius, and target the hottest areas. The warm exhaust air should be kept separate and driven directly back to the chillers.
**Best Practice – Use fluid dynamics modeling to prevent under- or over-provisioning of cooling**

A Best Practice is to utilize liquid cooling in a large static data center as close to the lowest levels as shown in Figure 7- Going Green Technology Opportunity Mapping. Data center liquid cooling is not a new technology; it has had a long history. IBM Mainframes have used it for many years. The liquid may be Freon, water, or a glycol antifreeze mix. In reality, all cooling is liquid cooling. It is just a question of where the liquid is.

Mainframes had a specific problem where the density of heat was so great that they could not get it out with air. Air has limitations: it carries much less heat than liquid does for the same volume. Liquid has 3,500 times the capacity of air for the removal of heat [3].

At some point, air will not be sufficient to cool the hardware particularly as computers, storage and network equipment get smaller and their density goes up. This equipment will have to be cooled directly with liquid. That is what happened in mainframes many years ago.

The reason that we have been trending toward air for the last 10 to 20 years is a reversal of the power density equation that changed the power densities and the power consumption of the cores and actually fell from the mainframe days. So why did data centers switch to forced-air-cooling? It came down to cost and availability. The great advantage of air-cooling is that everyone has air. If a server uses air-cooling, it can be set up and left alone and it will take care of itself. Using air is easier than using liquid.

If every server used water, it would be useless until a water pipe was installed. Air-cooling advantages are huge in comparison because we can place the server anywhere. Every few feet we have an electrical outlet; every few feet we have an air duct. Generally, air is everywhere, but unfortunately, that is not true for water or liquid cooling availability in today’s data centers.

The density problem has returned. Conventional data centers, which have been constructed the same way for 30 years, are big rooms with raised floors that run out of capability at around 5 kW per rack over a sustained area. Ten years ago, no racks took over 5 kW, but now a completely loaded blade server rack from any vender can draw 25 kW. The industry did not anticipate this
level of power density. Today, the problem is that conventional architectures for air-cooling are being overrun by power densities.

Corporate applications are moving to blades. There are performance advantages: ease of deployment, ease of provisioning, and others. However, there is an incompatibility between blade servers and conventionally designed data centers.

There are two solutions: Redesign servers and other IT equipment and put water pipes on them because water handles more cooling density. That is what the mainframes did. There is a great deal of discussion about that because there is a history of using this approach. This solution is acceptable in scenarios where a data center has row after row of identical blade servers in a large, fixed installation. However, direct water-cooling may not be the optimum solution in a dynamic, constantly changing data center based on evolving business needs.

Planning a structured cooling system is difficult. Not everything is physically the same size or has the same power and cooling requirements, as would multiple servers in a data center. There are routers, patch panels, storage and other IT equipment that have dissimilar physical and electrical requirements. Again, we face major challenges in planning water piping in a dynamic heterogeneous situation of various equipment types.

Another Best Practice is to utilize air-cooling in dynamic data centers as close to the lowest levels as shown in Figure 7- Going Green Technology Opportunity Mapping. Air-cooling can work to much higher than 5 kW per rack. In most cases, racks can go to 25 kW.

**Best Practice – Minimize distance of cooling airflow**

The floor is the challenge in terms of air-cooling. The problem is getting the air through tiles. Its velocity must be very high in order to move 25kW of forced-air through tile. In addition, it is very inefficient to push air over a great distance. It takes a tremendous amount of air handling /blowing power to move air at the required rate. It is not uncommon to find the fan consuming more power than the servers in data centers.
**Best Practice – Utilize new cooling technologies**

New forms of cooling for servers, storage systems and network infrastructure IT equipment are on the horizon. Nano-coolers use thin-film, wafer-scale chip technology to build solid-state 'refrigeration devices’. New cooling systems use powerful pulses of air to target cooling, resulting in reduced power use. Systems using hundreds of multiple sensors that feed information back to a management system for controlling temperature and airflow will also be available.

Absorption chillers are yet another innovative technology. They use dissipated energy in warm air to provide some cooling. This technology is well understood; however, a substantial amount of waste heat is required and is only available in large data centers.

**Best Practice – Use data center thermal recovery**

This technology allows the reuse of warm air for other applications, such as central heating. Until today, this practice has been used primarily in large data centers. The efficiency of this secondary energy source is based on the large amount of power consumed.

**Best Practice - Utilize cogeneration and tri-generation**

Cogeneration, or combined heat and power (CHP), means that one local generator produces both heat and power. In many situations, 60% of energy generated by fuel at a power plant is lost in the generation and transmission processes. Cogeneration is a technology that offers great efficiency since it reuses heat and very little power is lost in transmission. Tri-generation, or combined heat cooling and power (CHCP), uses absorption chiller technologies to further use the heat to generate cooling. CHP and CHCP do not necessarily use green or renewable energy sources.

**Best Practice – Utilize efficient methods of power conversion**

Between 10% and 20% of power use in data centers is attributed to power distribution, including AC/DC conversion, transformation, uninterruptible power supplies and backup generation. In effect, 10-20% is wasted. The goal is to reduce this waste to 5% or less. The main areas of consumption are in the UPS and the requirement to repeatedly convert AC power to DC.
**Best Practice - Minimize provisioning of UPS systems**

UPS systems must be provisioned properly. UPS’s are usually over-provisioned because an interruption can occur at any time. Reducing and smoothing the overall IT load is a best practice. This should lead to lower UPS requirements and to less over-provisioning. The best way to improve UPS energy use is to improve efficiency at different workloads.

**Best Practice - Adopt singular power conversion**

Depending on the equipment and architecture, 2-5% of all power used in the data center can be lost in the process of AC/DC conversion. This is a relatively a small percentage, but can be significant in a large data center.

The grid supplies power in the form of AC, but almost all the internal components use DC power supplies. (Usually, power has to be stepped down as well, which contributes to the loss.) This conversion is done for each piece of equipment, each of which may require different voltages. This results in a greater aggregate loss.

A best practice is to convert the power once, as it comes into the data center or into the rack. This practice would eliminate substantial power loss and reduce the number of DC converters and heat output incurred by this multiple conversion process. These best practices can produce 20-40% less heat and improve system reliability.
Semiconductor Technology

The role of the processor in reducing IT's use of power is vital, since so many chips are used in so many different systems and subsystems. Because demand for processing power and storage is anticipated to rise strongly in the foreseeable future, incremental improvements in end-user power consumption will have a large, aggregated impact. Innovations in fabrication, the use of multi-core processors, and improvements in throughput or clock speeds have all resulted in greater performance jumps than in energy use. Best Practices in chip-level energy use follow.

Best Practice - Use dual-core and multi-core processors

Utilizing multi-core processors contributes to energy efficiency. Since two or more processors with a single memory controller are consolidated onto one chip, this architecture reduces power consumption significantly. The increased density also reduces the need for more servers and eliminates some of the need for additional cooling as processing capacity increases. A dual-core processor will consume 60-80% of the energy of two similar single processors.

Best Practice - Use core speed mitigation

Chip or semiconductor developers have found that by throttling back core speeds in a multi-core design they still see significant advances in terms of overall performance compared to a system with multiple (and more powerful) single-core processors. These throttled-back multimodes require less power than the single-processor implementation. Dynamically throttling back the clock speed, on-board power management, reducing power leakage through advanced process technology and as mentioned previously, decreasing external memory controller requirements, all contribute to power efficiency.
**Virtualization**

Best Practice - Utilize virtualization

This technology is arguably the most powerful in terms of reducing or controlling IT equipment power use due to the elimination of (physical) servers or the reduction of the requirement to install new servers. Beyond reducing power and going green, virtualization's ability to cut energy costs significantly increases ROI (Return on Investment).

Example:

- Power Per = 200-400 watts.
- Energy Savings given typical energy costs = $380/year (includes cooling, UPS, etc. @$0.07 per kWh)
- Energy Cost over three years = approx. $1,000.

In a data center with 1,000 servers where 1/3 are removed, an annual savings of $125,400 a year is possible. Best Practices in data center virtualization allow better utilization from shared workloads with better use of multi-core processors, improved management and performance monitoring as well as rapid provisioning, enhanced disaster recovery/resilience and easier and less disruptive hardware and operating system upgrades.

Virtualization's importance is magnified because so many data center power issues are related to rapid server proliferation. Virtualization can dramatically stop or slow this growth. Virtualization can also smooth and balance variable or unpredictable workloads, reducing over-provisioning and reducing the need for power. It also addresses other issues that occur due to the inefficiency of electrical equipment at low workloads.

The scope for server elimination depends on the roles and configurations of the servers. Most estimates put Windows server utilization at around 10-15% and UNIX utilization at 25-30%. A target of 50% utilization after virtualization can halve the number of servers required, with consequent savings in energy use [2]. It is important to note that exact
savings figures will depend on the efficiency of the remaining servers under the increased load, and the resulting changes in required cooling and power supplies.

Many organizations are seeking energy efficiency and taking measures to reduce the size and impact of their carbon footprint. Virtualization is a best practice that can help organizations realize these aspirations.

The market leader in server visualization demonstrates this best practice. The VMware infrastructure enables us to reduce the number of servers required to run applications. This is achieved through increasing utilization rates and server consolidation as shown in Figure 8 – Consolidation of Servers Example - VMware. This figure highlights the fact that multiple operating systems and associated applications can run on a single physical hardware platform by utilizing VMware’s hyper visor, ESX Server, as the core element. As a result, less energy is consumed, reducing power consumption and saving money!

Since most servers are running at 5-15% of their capacity, data centers have the opportunity to consolidate workloads and power from underutilized hardware. Virtualization is the technology that separates application workloads from the server hardware, enabling many application workloads to securely and safely run on a single server.
Virtualization is a mature and mainstream technology, and more than 40% of American enterprises have already implemented it in production environments to reduce costs and increase agility. A typical consolidation ratio is 8:1, meaning that the workloads of eight physical servers can be consolidated onto a single system. The virtualization layer adds only a small overhead, often a few percent of utilization, to share the available processing cycles across the eight virtual machine workloads. For example, a rack containing 20 dual-processor 1U servers supporting 20 workloads at 5-15% average utilization can leverage virtualization to support 320 virtual machine workloads (8 virtual machines x 40 processors) at 80% average utilization.

**Best Practice - Free up excess servers that can be powered off**

We can achieve immediate energy cost savings by reducing the number of running systems. For example, reducing data center energy costs through virtualization with a VMware Infrastructure is a typical implementation strategy. ESX Server hosts provide the foundation for server consolidation by enabling underutilized physical servers to be encapsulated and consolidated into virtual machines that are then re-deployed safely and securely alongside other virtual machines in a high utilization environment. This allows hardware from underutilized servers to be re-deployed for other purposes (for example, servers can become offsite failover servers or ESX Server hosts) or removed to free up data center space and reduce power and cooling costs.

In addition, VMware’s product, Virtual Center, provides distributed services and management, enabling us to group many ESX Server hosts into a cluster and manage them as though they were a single computer. This increases manageability, flexibility and efficiency. Virtual Center can easily manage distributed services for hundreds of ESX Server hosts running thousands of virtual machines.

**Best Practice – Utilize virtual machine management**

Using VMware technology, IT staff can have full access to virtual machine management through a single remote access client, and they can create web-based bookmarks to securely provide end users with remote access to virtual machine servers as needed. The resulting requirement for fewer keyboard/video/mouse connections further reduces hardware, maintenance and energy costs.
Best Practice - Use virtualization to move server environments between physical machines non-disruptively.

VMware’s DRS leverages a service called VMotion that continuously optimizes workloads to best match computing resource supply to computing resource demand. VMware’s VMotion is a powerful service that enables a running virtual machine to be relocated to a different ESX Server host seamlessly and with zero downtime. VMware’s product, DRS, uses a global resource scheduler within Virtual Center to coordinate with the local resource scheduler on ESX Servers thus determining the best fit for a workload based on the computing resources available in the cluster. In addition, VMware’s Distributed Resource Scheduler automatically powers off servers whose resources are not immediately required and returns power to these servers when the demand for compute resources increases again.

If an ESX Server needs to be powered down for maintenance, its virtual machines can be automatically transferred to other hosts in the cluster with zero downtime. Similarly, a cluster of ten ESX servers running at 40% utilization during a slow period can have five servers powered off to raise utilization on the remaining servers to 80% and reduce server energy costs by half. As another benefit, VMware DRS can enable dramatic performance improvements by allowing virtual machine workloads to take advantage of increased headroom and idle cycles they would otherwise not have access to in a one server/one workload scenario. For example, a workload that would have been sized for a single CPU server can take advantage of VMware’s Virtual SMP (Symmetric Multiprocessing) to access two or four processors in a multi-core or multi-processor x86 server.

VMware’s Virtual Networking reduces network traffic and network equipment. VMware’s Virtual Networking enables virtual machines to communicate with each other through virtual switches without a packet of data ever reaching the physical network. This reduces network bandwidth, potentially reduces the amount of network traffic, and minimizes aggregate traffic. We can construct high performing network architectures virtually between high traffic virtual machine servers without adding any load to the physical network. This reduction in network traffic often translates into a reduced demand for networking switches and other network infrastructure equipment.
Best Practice - Reduce test and development hardware

The VMware Infrastructure reduces the need for dedicated development and testing hardware. As virtual machines are able to perfectly replicate an environment between development, testing and production, they have long been used to support software development, testing and support. VMware Infrastructure directly reduces the need for additional, dedicated development and testing hardware, directly reducing hardware, power, cooling and space requirements. Overall, data center virtualization improves not just server workload power consumption, but also alleviates server space, cooling, provisioning, workload optimization, high availability and backup challenges.

Servers

Servers are the biggest aggregate consumers of power in the data center. A single low-end Intel/AMD server consumes about 200 watts, and a midrange server consumes around 400 watts. Combined in racks and blade systems, 5-12 kW server configurations are not uncommon. A high-end mainframe might use 5-6kW. Meanwhile, the number of servers is proliferating rapidly — from six million globally in 1997 to 35 million in 2010, according to estimates.

Power and cooling problems are severely hindering the roll out of blade servers, since most data centers struggle to cool fully loaded blade servers. Even in space-constrained data centers, it is common for rack and blade servers to run one-half or two-thirds empty to ensure sufficient power availability and cooling. Innovation to reduce power consumption by servers includes:

Best Practice – Implement laptop-style power management

Most server innovation focuses on using low-power components, standby modes, and scaled back performance when utilization is low. These are all technologies that were first adopted for laptops, which have a much better energy footprint than equivalently powered PCs or servers.
Server vendors are working on smart designs that can scale back power use based on the workload, as well as the availability of cooling. This may be accomplished by changing the voltage and frequency at a microelectronic level, or by better understanding the workload.

**Best Practice – Utilize task-based power management**

Task-based power management involves using operating system software or system-level firmware to track a variety of processes that a given machine is carrying out. If a process is completed, and no other process requires that resource, it is powered down after a pre-defined period.

Another best practice at the server level is for the OS or application to reduce the number of disk accesses. This can be done by analyzing the workload and powering disks down more quickly using power management techniques; or by making more use of cache memory and permanent flash memory.

**Storage**

Storage is estimated to account for anywhere from 20% to 40% of the total IT load (excluding infrastructure) of data center power use. As in other areas, there is clearly an opportunity to reduce storage’s energy footprint. The average disk drive uses about 15-30 watts of power and may use 30 watts of cooling, but the number of drives in a rack and the number of shared components varies widely. Like servers and PCs, low utilization is an issue; most disks are filled to 20-25% capacity. Duplicated data means that true utilization may be far lower.

**Best Practice - Reduce and manage the amount stored**

Reduce energy by reducing amount of data that is stored, at least in online systems. Using information lifecycle management and tiered storage is a best practice as well as archiving, single instancing data, and data duplication.
New data types, new applications and legislative requirements will continue to increase data storage needs in the future. However, utilizing the best practice strategies we have outlined will help dramatically. Data de-duplication is one emerging technology that has a role in reducing storage. Storing data only once has the potential to curb the rapid escalation of storage requirements.

**Best Practice - Utilize low-power components/linear power scaling or FLASH disks**

A number of techniques can be applied to reduce power consumption in a storage system. Disk drive technology is developing low spin disks, which can be slowed or stopped to reduce power consumption when not in use. Caching techniques that reduce disk accesses, and the use of 2.5-inch rather than 3.5-inch formats can reduce voltage requirements from 12 volts to 6 volts. An industry-wide move toward higher-capacity Serial ATA (SATA) drives and 2.5-inch disks is under way, which some claim will lead to better energy performance.

For more information on FLASH technology comparisons, please see section “**Best Practice – Utilize low power flash technologies.**”

**Best Practice – Utilize low power flash technologies**

A best practice is to utilize FLASH storage as applicable to the Data Center Tiered Storage requirements. Low power technologies are starting to enter the data center. With the advent of Solid State Disks (SSDs), this enabling semiconductor technology can and will have a major impact on power efficiencies.

For example, an SSD system can be based on double data rate (DDR) DRAM technology and integrated with battery backup. It requires a Fiber Channel (FC) interface consistent with conventional hard drives. This SSD technology has been available for years and has established itself in a niche market that serves large processing-intensive government projects and companies involved in high-volume, high-speed/low-latency transactions such as stock trading systems.

Organizations have used SSD for some time as large cache to boost performance by pulling data from what amounts to memory, rather than from a much slower spinning disk. The SSD
industry regularly takes advantage of the falling prices of memory and storage. This allows organizations like International Securities Exchange, Inc. (ISE), which require high performance transaction processing, to purchase 128GB of SSD storage at a price that is high but justifiable. However, even SSD proponents admit that DRAM-based SSD systems are far too expensive for use in terabyte-sized systems [1].

There are other SSD options. The rapid rise of NAND flash-memory technology promises to make SSD a viable storage option in the mainstream corporate IT storage environment. Because flash is nonvolatile, it is suitable for long-term data storage. In addition, systems built on flash technology track an entirely different price curve because they do not have to integrate the power protection and battery backup required by volatile DRAM-based SSD.

The solid-state disk (SSD) market is rapidly evolving into an alphabet soup of acronyms as companies try to find a nonvolatile storage technology. There are many technologies offering this type of functionality. They include:

- Ferroelectric memories
- Magnetic memories
- Phase-change memory
- Polymer memories
- Nanotechnology memories
- Resistively change memory
- Micromechanical probe memories
- One-time programmable ROM memories

All of these technologies deliver the high performance of double data rate (DDR) with the low cost of hard disk drives, but without the inherent reliability issues that result from multiple write problems of flash.
In addition to NOR and NAND these include:

- Phase change RAM (PC-RAM)
- Magneto resistive Random Access Memory (MRAM)
- Spin-transfer torque RAM (STT-RAM)
- Ferroelectric RAM (FE RAM)
- Nitride read-only memory (NROM)

The problem with these technologies is that they are still in development and will not be available for some time to support large-scale storage production use. As flash storage becomes more feasible in terms of density based on Moore's Law and the SSD industry's improving economy of scale, even companies that do not calculate their competitive advantage in microseconds may turn to SSD in the not-so-distant future. The advantages of NAND flash storage in terms of high performance, low energy usage and reliability may eventually offset SSD's high cost per gigabyte.

Disk drive vendors find themselves considering SSD as a potential competitor. Fundamental technology changes are in store for HDD as the industry struggles to increase aerial density (the amount of data that can be packed onto the disk) beyond what can be achieved with the latest perpendicular disk technology.

**Flash Advantages**

Flash is nonvolatile storage, which means that data remains even if power is lost. Everybody has seen flash, especially NAND flash. It is the storage behind Apple's iPod nano and is widely used in portable USB storage devices. Although flash storage comes in NOR and NAND flavors, our focus will be on the NAND version of flash. The terms NOR and NAND refer to the logical electronic gates (OR and AND) that make up the memory chip. NOR means not OR and NAND means not AND. NOR is too costly and too slow at writing. NOR is not considered a viable enterprise storage technology.

High performance, reliability, low power consumption and small size are the main advantages of flash storage. Flash-drive performance is 1,000 times better than hard disk. Flash's sturdiness gives the technology another advantage over HDD. The big appeal of SSD, both flash and DRAM, is extremely high performance.
Another appealing aspect of flash storage is its lower power consumption and low heat. Power, heat and cooling have become huge issues and flash SSD can cut reduce power usage in the data center. Flash memory has no moving parts, requires negligible amounts of power for reads, and writes (in the area of 10 mill amperes (mA).

**Flash Disadvantages**

Flash SSD does have its drawbacks, beginning with its high price. Flash proponents cite a current price of $10/GB[6]. The $10/GB price is deceiving, as it is the raw cost of low-quality flash chips to the OEM. IT organizations will likely want higher quality flash systems delivered by OEMs, and these systems currently run about $60/GB or more. How much of a premium are IT managers willing to pay for the advantages of flash storage?

Another drawback is long-term reliability, or the inability to write to a memory cell. Flash SSD may be nonvolatile, but individual flash-memory cells have a limited usage life. If you can avoid writing to a particular cell for days or weeks, you can stretch the life of the cell. A flash cell has a write-cycle life of 100,000 writes. For a high-volume transactional system, users will exceed this write limit threshold quickly.

Flash SSD systems try to overcome this problem by integrating “wear-leveling” algorithms into the controllers. These algorithms spread the writes across different cells so no cell is written to excessively. By combining wear-leveling with RAID-like striping, designs can establish an effective life of a flash SSD system beyond 100,000 writes.

Flash is delivered in two formats: single-level cell (SLC) and multi-level cell (MLC). The wear-out and cost problem may be partly addressed through a combination of SLC and MLC flash. MLC, which layers more data on each cell, is more cost effective than SLC. OEMs can use this technology to add capacity to SSD systems. However, MLC has a much shorter life than SLC. Because it is the write process and not the read process that shortens cell life, the challenge for OEMs becomes “trying to figure what portion needs to be read-only and make that portion out of MLC” [1]. OEMs will be required to build intelligence into the controller to direct predominantly read-only data to the MLC cells in a SLC/ MLC SSD storage device. In addition to write wear-out, there is another concern with writes; NAND flash has a slower write speed.
Best practice - Utilize SSD technology in applications that write once or a reduced number of times

Wear-out problems suggest flash SSD is best suited for applications that write once or occasionally but read many times. As shown in “Table 1 – Storage Technology Comparison”, below, Flash and DDR or SDRAM have significant latency and random IO advantages compared to typical hard disk drives [1]. These advantages have a cost.

<table>
<thead>
<tr>
<th>Latency</th>
<th>DDR (SDRAM)</th>
<th>Flash</th>
<th>Hard Disk Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reads: 0.02 milliseconds</td>
<td>Reads: 0.2 milliseconds</td>
<td>Reads: 4 milliseconds</td>
</tr>
<tr>
<td></td>
<td>Writes: 0.02 milliseconds</td>
<td>Writes: 4 milliseconds to 5 milliseconds</td>
<td>Writes: 4 milliseconds</td>
</tr>
<tr>
<td>Random IO/Sec</td>
<td>Reads: 400,000 Writes: 400,000</td>
<td>Reads: 5,000 to 50,000 Writes: 50 to 1,000</td>
<td>Reads: 150 to 300 Writes: 150 to 300</td>
</tr>
<tr>
<td>Price</td>
<td>$600/GB to $800/GB</td>
<td>$25/GB to $250/GB</td>
<td>$0.50/GB to $6/GB</td>
</tr>
</tbody>
</table>

Best Practice states that the primary use cases for Solid State Drives (SSD) Flash drives on Storage systems will be:

- Algorithmic trading
- Currency exchange and arbitrage
- Trade optimization
- Real-time data/feed processing
- Contextual Web advertising
- Real-time transaction systems
- Mainframe TPF (transaction processing facility)
- Large-scale Microsoft Exchange systems
- Data modeling
In terms of storage workloads, Best Practices advise that the most benefit that can be attained from SSD (Solid State Drives) Flash drives are OLTP applications that include Oracle and DB2 databases, Exchange collaboration server, and SAP R/3. In contrast, storage workloads that will benefit least from Flash drives on storage platforms are workloads such as Decision Support Systems (DSS) or streaming media with large amounts of sequential reads and writes. They will derive limited benefit from Flash drives.

Typical performance numbers for Flash drives on main stream storage systems such as EMC’s Symmetrix®, would be that Flash drives would provide up to 30 times random read miss (rpm) I/O per second (IOPS) for a single RAID 5 (7+1) Group as compared to a 15K Fiber Channel disk. Average response times of around one millisecond are possible with rpm workloads or with mixed (read + write) workloads [11].

This, in conjunction of the fact that Flash drives draw much less power than traditional spinning disks, is a major advantage. For example, in terms of power reduction, it takes 30 - 15K rpm Fiber Channel disks to equal the same level of performance as a single Flash drive in an OLTP read-intense environment. This benefit translates into a 98% reduction in energy consumption.
New technology provides us with expanding opportunities to become more “green.” By applying best practices, data centers can accommodate new equipment and meet power and cooling capacity requirements.

The requirement to reduce carbon footprints is rising on corporate and government agendas. Power demands mount in parallel. Properly configured and utilized information management solutions will reclaim power and cooling capacity for data center operations while simultaneously reducing environmental impacts.

The big picture has been illustrated, best practices defined and a holistic approach to next generation technologies described. With these tools, we can confidently move forward in this quest to cross the “Great Green Divide.”
## Appendix A – Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCE</td>
<td>Data Center Efficiency = IT equipment / Total facility power</td>
<td>Shows a ratio of how well a data center is consuming power</td>
</tr>
<tr>
<td>DCPE</td>
<td>Data Center Performance Efficiency = Effective IT workload / total facility power</td>
<td>Shows how effectively a data center is consuming power to produce a given level of service or work such as energy per transaction or energy per business function performed</td>
</tr>
<tr>
<td>PUE</td>
<td>Power usage effectiveness = Total facility power / IT equipment power</td>
<td>Inverse of DCE</td>
</tr>
<tr>
<td>Kilowatts (kw)</td>
<td>Watts / 1,000</td>
<td>One thousand watts</td>
</tr>
<tr>
<td>Annual kWh</td>
<td>kWh x 24 x 365</td>
<td>kWh used in on year</td>
</tr>
<tr>
<td>Megawatts (mw)</td>
<td>kW / 1,000</td>
<td>One thousand kW</td>
</tr>
<tr>
<td>BTU/hour</td>
<td>watts x 3.413</td>
<td>Heat generated in an hour from using energy in British Thermal Units. 12,000 BTU/hour can equate to 1 Ton of cooling.</td>
</tr>
<tr>
<td>kWh</td>
<td>1,000 watt hours</td>
<td>The number of watts used in one hour</td>
</tr>
<tr>
<td>Watts</td>
<td>Amps x Volts (e.g. 12 amps * 12 volts = 144 watts)</td>
<td>Unit of electrical energy power</td>
</tr>
<tr>
<td>Watts</td>
<td>BTU/hour x 0.293</td>
<td>Convert BTU/hr to watts</td>
</tr>
<tr>
<td></td>
<td>Watts / Amps (e.g. 144 watts / 12 amps = 12 volts)</td>
<td>The amount of force on electrons</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Volts</td>
<td></td>
<td>The flow rate of electricity</td>
</tr>
<tr>
<td>Amps</td>
<td>Watts / Volts (e.g. 144 watts / 12 volts = 12 amps)</td>
<td>Sometimes power expressed in Volt-Amperes</td>
</tr>
<tr>
<td>Volt-Amperes (VA)</td>
<td>Volts x Amps</td>
<td>Number of kilovolt-amperes</td>
</tr>
<tr>
<td>kVA</td>
<td>Volts x Amp / 1000</td>
<td>Power factor is the efficiency of a piece of equipments' use of power</td>
</tr>
<tr>
<td>kW</td>
<td>kVA x power-factor</td>
<td>Kilovolt-Amperes</td>
</tr>
<tr>
<td>kVA</td>
<td>kW / power-factor</td>
<td>EIA metric describing height of equipment in racks</td>
</tr>
<tr>
<td>U</td>
<td>1U = 1.75”</td>
<td></td>
</tr>
<tr>
<td>Activity / Watt</td>
<td>Amount of work accomplished per unit of energy consumed. This could be IOPS, Transactions or Bandwidth per watt.</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>IOPS / Watt</td>
<td>Number of I/O operations (or transactions) / energy (watts)</td>
<td></td>
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<td>Indicator of how much work, and how efficient energy is being used to accomplish useful work. This metric applies to active workloads or actively used and frequently accessed storage and data. Examples would be IOPS per watt, Bandwidth per watt, Transactions per watt, Users or streams per watt. Activity per watt should also be used in conjunction with another metric such as how much capacity is supported per watt and total watts consumed for a representative picture.</td>
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<td>Indicator of how effectively energy is being used to perform a given amount of work. The work could be I/Os, transactions, throughput or other indicator of application activity. For example SPC-1 / Watt, SPEC / Watt, TPC / Watt, transaction / watt, IOP / Watt.</td>
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<tr>
<td>Metric</td>
<td>Description</td>
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| Bandwidth / Watt| GBPS or TBPS or PBPS / Watt Amount of data transferred or moved per second and energy used. Often confused with Capacity per watt.  
This indicates how much data is moved or accessed per second or time interval per unit of energy consumed. This is often confused with capacity per watt given that both bandwidth and capacity reference GByte, TByte, PByte. |
| Capacity / Watt | GB or TB or PB (storage capacity space / watt)  
Indicator of how much capacity (space) or bandwidth supported in a given configuration or footprint per watt of energy. For inactive data or off-line and archive data, capacity per watt can be an effective measurement gauge. However, for active workloads and applications activity per watt also needs to be looked at to get a representative indicator of how energy is being used |
| Mhz / Watt      | Processor performance / energy (watts)  
Indicator of how effectively energy is being used by a CPU or processor.                                                                                                                               |
| Carbon Credit   | Carbon offset credit  
Offset credits that can be bought and sold to offset your CO₂ emissions                                                                                                                                  |
| CO₂ Emission    | Average 1.341 lbs per kWh of electricity generated  
The amount of average carbon dioxide (CO₂) emissions from generating an average kWh of electricity                                                                                               |
Appendix B – References

[2] Virtualization 3: Managing the virtual revolution, November 2007, the 451 Group
[5] Datacom Equipment power trends and cooling applications, Association of heating, refrigeration and air conditioning engineers, Atlanta, Ga, 2005
Author's Biography

Paul Brant is a Senior Technology Consultant at EMC in the Global Technology Solutions Group located in New York City. He has over 25 years experience in semiconductor, hardware, software design and IT solutions in various roles including engineering, marketing and technical sales. He also holds a number of patents in the data communication and semiconductor fields. Paul Brant has Bachelors and Masters degree in Electrical Engineering as well as a Masters in Business Administration.