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Green Cloud Environmental Infrastructure

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Abstract

We are in an era of considering environmental resource constraints along with more IT goals. Environmental impact and power consumption are becoming crucial architectural systemic quality metrics. Saving energy is a much more complex architectural problem, requiring a coordinated array of tactics, from architectural power management capacity planning techniques to optimizing operational processes and facilities design. This paper concentrates on how cloud computing provide some interesting architectural constructs, some great potential from a monetary aspect, and a very real option to provide a more environmentally friendly computing platform. This paper also deals with the definition of reduced energy consumption which is influenced by reduced greenhouse gas emissions and reduced operational costs for the data center and business.

Keywords: Green computing, cloud, environment, virtualization, Green broker , middleware

1. Introduction

Today there are lot of Web applications involving millions of e-commerce transactions and millions of web queries. This ever increasing demand is handled through large-scale data centers which involves of thousands of servers with other infrastructure such as cooling, storage and network systems. This is called cloud computing where computing is delivered as utility on a pay as we use basis. The concept of cloud computing has changed the ownership based approach to subscription oriented approach. Cloud computing is a great market opportunity. The global IT cloud services spending are estimated to increase by 27% [1]. More and more companies are going to promote their data centers. They require high energy usage for its operation.[3]. According to a report published by the European Union, a decrease in emission volume of 15%–30% is required before year 2020 to keep the global temperature increase below 2^0C.

Thus energy consumption and carbon emission by cloud infrastructures has become a key environmental concern. Cloud computing can make traditional data centers more energy efficient by using technologies such as virtualization and workload consolidation. A recent research by Accenture [4] shows that moving business applications to Cloud can reduce carbon footprint of organizations. According to the report, small businesses saw the most dramatic reduction in emissions – up to 90 percent while using Cloud resources. Large corporations can save at least 30-60 percent in carbon emissions using Cloud applications, and mid-size businesses can save 60-90 percent.

Contrary the Cloud solutions have increased the problem of carbon emissions and global warming[5]. Even the most efficiently built data center with the highest utilization rates will only increase rather eliminating the problem of Carbon di oxide emissions.

Table 1. Comparison of Significant Cloud Data Centers [5]

Cloud Datacenters	Location	Estimated Power Usage Effectiveness	% of Dirty Energy Generation	% of Renewable Electricity
Google	Lenoir	1.21	50.5% Coal, 38.7% Nuclear	3.8%
Apple	Apple NC		50.5% Coal, 38.7% Nuclear	3.8%
Microsoft	Chicago IL	1.22	72.8% Coal, 22.3% Nuclear	1.1%
Yahoo	La Vista NE	1.16	73.1% Coal, 14.6% Nuclear	7%

Hence, energy-efficient solutions are required to minimize the impact of Cloud computing on the environment. In order to design such solutions, deep analysis of Cloud is required with respect to their power efficiency as in Figure 1.

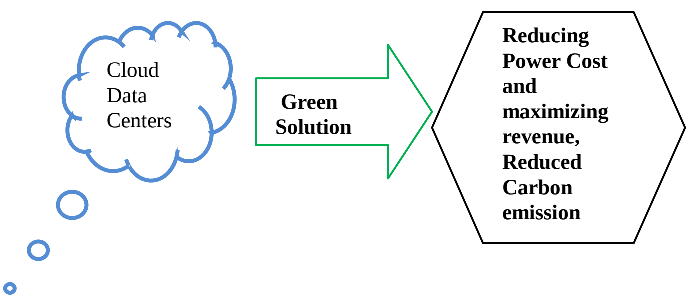


Figure 1. Cloud and Environmental Sustainability

2. Cloud Computing and Energy Usage

An end user can use Cloud services such as SaaS, PaaS and IaaS over Internet. User data pass from his own device through an Internet service provider's router, which in turn connects to a Gateway router within a Cloud datacenter. Within datacenters, data goes through a local area network and are processed on virtual machines, hosting Cloud services, which may access storage servers. Each of these computing and network devices that are directly accessed to serve Cloud users contribute to energy consumption. In addition, within a Cloud datacenter, there are many other devices, such as cooling and electrical devices, that consume power. These devices even though do not directly help in providing Cloud service, are the major contributors to the power consumption of a Cloud datacenter. In the following section, we discuss in detail the energy consumption of these devices and applications as in Figure 2.

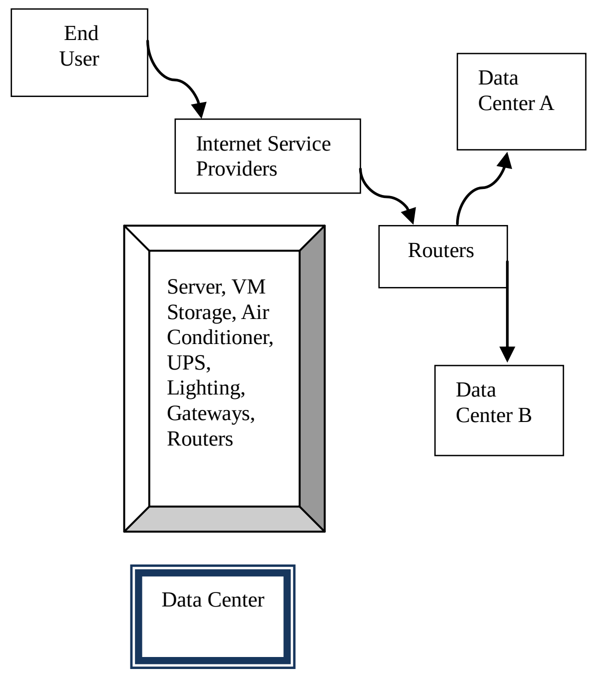


Figure 2. Cloud Usage Mode

2.1 User Cloud Software Applications

The Cloud computing can be used for running applications owned by individual user or offered by the Cloud provider using SaaS. Energy consumption is directly proportional to the application's profile. If the application consumes more memory and CPU requirement the energy consumption is more.

2.2 SaaS, PaaS,IaaS stack level

The Cloud software stack leads to an extra overhead in execution of end user applications. For instance, it is well known that a physical server has higher performance efficiency than a virtual machine and IaaS providers offer generally access to a virtual machine to its end users [6]. Monitoring and accounting needs some energy power. To avoid loss of data Cloud providers had to provide data replicas across datacenters.

2.3 Network Devices

In Cloud computing, the user data travels through many devices before it reaches datacenter.

In general, the user computer is connected to Ethernet switch of his/her ISP where traffic is aggregated. The BNG (Broadband Network Gateway) network performs traffic management and authentication functions on the packets received by Ethernet switches. These BNG routers connect to other Internet routers through provider's edge routers. The core network is further comprised of many large routers. Each of these devices consumes power according to the traffic volume. According to the study conducted by Tucker [7], public Cloud is estimated to consume about 2.7 J/b in transmission and switching in comparison to 0.46J/b for a private Cloud. They found out that power consumption in transport represents a significant proportion of the total power consumption for Cloud storage services at medium and high usage rates. Even typical network usage can result in three to four times more energy consumption in public Cloud storage than one's own storage infrastructure. Therefore, with the growth of Cloud computing usage, it is expected that energy efficiency of switches and routers will play a very significant role in what since they need to provide capacity of hundreds of terabits of bandwidth.

2.4 Datacenter

The Cloud datacenters are quite different from traditional hosting facilities. A cloud datacenter could comprise of many hundreds or thousands of networked computers with their corresponding storage and networking subsystems, power distribution and conditioning equipment, and cooling infrastructures. Due to large number of equipments, datacenters can consume massive energy consumption and emit large amount of carbon. According to 2007 report on computing datacenters by US Environmental Protection Agency (EPA), the datacenters in US consumed about 1.5% of total energy, which costs about $4.5 billon. This high usage also translates to very high carbon emissions which was estimated to be about 80-116 Metric Megatons each year. Table 2 lists equipments typically used in datacenters with their contribution to energy consumption. It can be clearly observed that servers and storage systems are not the only infrastructure that consumes energy in the datacenter. In reality, the cooling equipments consume equivalent amount of energy as the IT systems themselves. Ranganathan [8] suggests that for every dollar spent on electricity costs in large-scale datacenters another dollar is spent on cooling.

Table 2. Percent of Power Consumption by Each Datacenter Device

Cooling device (Chiller, Computer Room Air Conditioning (CRAC))	33%+9%
IT Equipment	30%
Electrical Equipments (UPS, Power) Distribution Units (PDUs), lighting)	28 %

Further energy consumption occurs due to lighting, loss in the power distribution, and other electrical equipment such as UPS. In other words, the majority of power usage within a datacenter is used for other purposes than actual IT services. Thus, to achieve the maximum efficiency in power consumption and CO2 emissions, each of these devices need to be designed and used efficiently while ensuring that their carbon footprint is reduced. A key factor in achieving the reduction in power consumption of a datacenter is to calculate how much energy is consumed in cooling and other overheads. Standard metrics are emerging such as Power Usage Effectiveness (PUE) [9] which can be used to benchmark how much energy is being usefully deployed versus how much is spent on overhead. The PUE of a datacenter is defined as the ratio of the total power consumption of a facility (data or switching center) to the total power consumption of IT equipment (servers, storage, routers, etc.). PUE varies from datacenters depending on the place where datacenter is located and devices used in its construction. Research from the Lawrence Berkley National Labs [10] shows that 22 datacenters measured in 2008 have PUE Values in the range 1.3 to 3.0. PUE of datacenter can be useful in measuring power efficiency of datacenters and thus provide a motivation to improve its efficiency.

3. Features of Cloud Enabling Green Computing

The technology "Virtualization" which allows significant improvement in energy efficiency of Cloud providers by leveraging the economies of scale associated with large number of organizations sharing the same infrastructure. Virtualization is the process of presenting a logical grouping or subset of computing resources so that they can be accessed in ways that give benefits over the original configuration [11]. By consolidation of underutilized servers in the form of multiple virtual machines sharing same physical server at higher utilization, companies can gain high savings in the form of space, management, and energy. According to Accenture Report [4], there are following four key factors that have enabled the Cloud computing to lower energy usage and carbon emissions from ICT. Due to these Cloud features, organizations can reduce carbon emissions by atleast 30% per user by moving their applications to the Cloud. These savings are driven by the high efficiency of large scale Cloud data centers.

1. Dynamic Provisioning: In traditional setting, datacenters and private infrastructure used to be maintained to fulfill worst case demand. Thus, IT companies end up deploying far more infrastructure than needed. There are various reasons for such over-provisioning: a) it is very difficult to predict the demand at a time; this is particularly true for Web applications and b) to guarantee availability of services and to maintain certain level of service quality to end users. One example of a Web service facing these problems is a Website for the Australian Open Tennis Championship [21]. The Australian Open Website each year receives a significant spike in traffic during the tournament period. The increase in traffic can amount to over 100 times its typical volume (22 million visits in a couple of weeks) [21]. To handle such peak load during short period in a year, running hundreds of server throughout the year is not really energy efficient. Thus, the infrastructure provisioned with a conservative approach results in unutilized resources. Such scenarios can be readily managed by Cloud infrastructure. The virtual machines in a Cloud infrastructure can be live migrated to another host in case user application requires more resources. Cloud providers monitor and predict the demand and thus allocate resources according to demand. Those applications that require less number of resources can be consolidated on the same server. Thus, datacenters always maintain the active servers according to current demand, which results in low energy consumption than the conservative approach of over-provisioning.

2. Multi-tenancy: Using multi-tenancy approach, Cloud computing infrastructure reduces overall energy usage and associated carbon emissions. The SaaS providers serve multiple companies on same infrastructure and software. This approach is obviously more energy efficient than multiple copies of software installed on different infrastructure. Furthermore, businesses have highly variable demand patterns in general, and hence multi-tenancy on the same server allows the flattening of the overall peak demand which can minimize the need for extra infrastructure. The smaller fluctuation in demand results in better prediction and results in greater energy savings.

3. Server Utilization: In general, on-premise infrastructure run with very low utilization, sometimes it goes down up to 5 to 10 percent of average utilization. Using virtualization technologies, multiple applications can be hosted and executed on the same server in isolation, thus lead to utilization levels up to 70%. Thus, it dramatically reduces the number of active servers. Even though high utilization of servers results in more power consumption, server running at higher utilization can process more workload with similar power usage.

4. Datacenter Efficiency: As already discussed, the power efficiency of datacenters has major impact on the total energy usage of Cloud computing. By using the most energy efficient technologies, Cloud providers can significantly improve the PUE of their datacenters. Today's state-of-the-art datacenter designs for large Cloud service providers can achieve PUE levels as low as 1.1 to 1.2, which is about 40% more power efficiency than the traditional datacenters. The server design in the form of modular containers, water or air based cooling, or advanced power management through power supply optimization, are all approaches that have significantly improved PUE in datacenters. In addition, Cloud computing allows services to be moved between multiple datacenter which are running with better PUE values. This is achieved by using high speed network, virtualized services and measurement, and monitoring and accounting of datacenter.

4. Towards Energy Efficiency of Cloud computing: State-of-the-Art

4.1 Applications

SaaS model has changed the way applications and software are distributed and used. More and more companies are switching to SaaS Clouds to minimize their IT cost. Thus, it has become very important to address the energy efficiency at application level itself. The applications consume different amount of energy on heterogeneous devices.

As these tasks have the same purpose on each device, the results show that the implementation of the task and the system upon which it is performed can have a dramatic impact on efficiency. Therefore, to achieve energy efficiency at application level, SaaS providers should pay attention in deploying software on right kind of infrastructure which can execute the software most efficiently. This necessitates the research and analysis of trade-off between performance and energy consumption due to execution of software on multiple platforms and hardware. In addition, the energy consumption at the compiler level and code level should be considered by software developers in the design of their future application implementations using various energy-efficient techniques proposed in the literature.

4.2 Virtualization

Abdelsalam et al. [12] proposed a power efficient technique to improve the management of Cloud computing environments. They formulated the management problem in the form of an optimization model aiming at minimization of the total energy consumption of the Cloud, taking SLAs into account. The current issue of under utilization and over-provisioning of servers was highlighted by Ranganathan et al. [13]. They present a peak power budget management solution to avoid excessive over-provisioning considering DVS and memory/disk scaling.In addition, there are works on improving the energy efficiency of storage systems. Kaushik et al. [14] presented an energy conserving self-adaptive Commodity Green Cloud storage called Lightning. The Lightning file system divides the Storage servers into Cold and Hot logical zones using data classification. These servers are then switched to inactive states for energy saving. Verma et al [15] proposed an optimization for storage virtualization called Sample-Replicate-Consoidate Mapping (SRCMAP) which enables the energy proportionality for dynamic I/O workloads by consolidating the cumulative workload on a subset of physical volumes proportional to the I/O workload intensity. Gurumurthi et al. [16] proposed intra-disk parallelism on high capacity drives to improve disk bandwidth without increasing power consumption. Soror et al. [34] addressed the problem of optimizing the performance of database management systems by controlling the configurations of the virtual machines in which they run.

4.3 Datacenter cooling

The datacenters are being constructed in such a way that electricity can be generated using renewable sources such as sun and wind. Currently the datacenter location is decided based on their geographical features; climate, fibre-optic connectivity and access to a plentiful supply of affordable energy. In datacenter cooling, two types of approaches are used: air and water based cooling systems. In both approaches, it is necessary that they directly cool the hot equipment rather than entire room area. Thus newer energy efficient cooling systems are proposed based on liquid cooling, nano fluid-cooling systems, and in-server, in-rack, and in-row cooling by companies such as SprayCool.

5.Green Cloud Architecture

In the Green Cloud architecture, users submit their Cloud service requests through a new middleware Green Broker that manages the selection of the greenest Cloud provider to serve the user‟s request. A user service request can be of three types i.e., software, platform or infrastructure. The Cloud providers can register their services in the form of " green offers‟ to a public directory which is accessed by Green Broker. The green offers consist of green services, pricing and time when it should be accessed for least carbon emission. Green Broker gets the current status of energy parameters for using various Cloud services from Carbon Emission Directory. The Carbon Emission Directory maintains all the data related to energy efficiency of Cloud service. This data may include PUE and cooling efficiency of Cloud datacenter which is providing the service, the network cost and carbon emission rate of electricity, Green Broker calculates the carbon emission of all the Cloud providers who are offering the requested Cloud service. Then, it selects the set of services that will result in least carbon emission and buy these services on behalf users.

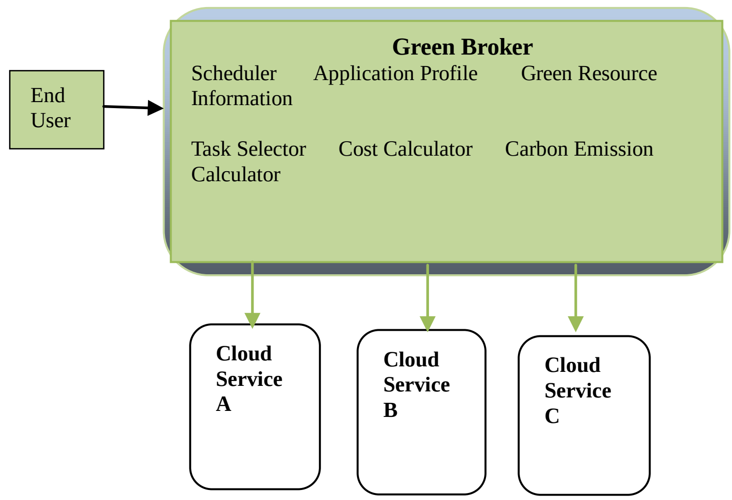
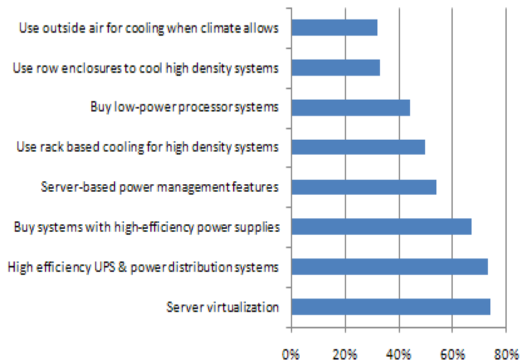


Figure 3. Green Cloud Architecture

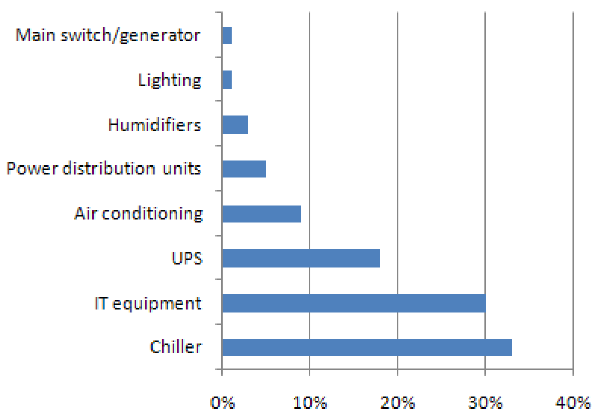
6. Conclusions and Suggestions for Green IT

A sampling of suggestions which maximize energy efficiency and minimize environmental impact are as follows-

The below green initiatives were sourced from an Infoworld research project and illustrate the most common green savings projects.



Prediction of exactly where power is consumed and realize the trends of where power consumption is changing. Then calculation of the financial cost for each material power consuming device should be performed. IT equipment generally should not consume most of the data center energy. The below graph of an APC study illustrates typical data center power allocation.



Decommission, consolidate or just turn off mystery servers. Sun systems research suggests that between 8% and 10% of all running servers have no identifiable function. It is a fact that the power to run a server costs more over its lifetime than the purchase cost of the server. Performing a data center reconnaissance to hunt down equipment without purpose provides a big quick hit in the mission to reduce energy. If servers are discovered and cannot identify their purpose after a reasonable investigation, turn them off and should wait for the help desk call. When the help desk call does not arrive after a sustained period, then remove the server from the power grid.

Consolidate and virtualize servers for greater efficiency. Servers are not utilized to their maximum. Server virtualization allocates a single server into multiple, smaller virtual servers without multiple increments of power consumption. Leveraging unused and available processing capacity without drawing additional power results in near linear savings to the bottom line. While server virtualization provides big energy savings, it should also be complimented with IT management tools in order to ensure performance management, real-time visibility and leveling analysis across your (virtual or physical) server farm. While virtualization aids network provisioning and management in many ways (e.g. you can configure a new virtual machine (VM) in minutes instead of hours for a physical server), it also adds some new complexity as the number of virtual assets will surpass the prior number of physical assets. Managing virtual assets requires new tools and new skills and some new thinking to understand the relationships between physical and virtual assets. The learning curve is short and the tools are inexpensive, however, like data center the processes must be thought-through for omissions and implications and must then be scheduled in advance, performed according to change management and weaved into other data center SOPs (including information security, fail-over redundancy, performance, scalability, system fault tolerance, business continuity, etc.)

Consider replacing servers more than three years old with newer energy-efficient models. Also review the CPU performance-stepping technology which dynamically adjusts the processor energy consumption based on processor load.

Minimize storage equipment by using SANs and other network attached storage hardware which consolidate storage space and save power.

Storage performance should be reviewed. Energy savings opportunities are too often limited to servers. While storage systems are fewer in number they are typically growing their capacity at approximately 50% per year (source: IDC) and are among the most intense energy consumers in the data center. Storage devices are often ideal for improvement as they consume on average 13 times more power than servers and storage assets often have a low utilization (frequently less than 25%). SAN, NAS and other storage virtualization can drive use utilization rates from 25% to 50% or higher. I've also realized both energy and hardware versatility benefits from inter-operable devices such as hot-swappable disk drives, power supplies, fans and other modular components such as blades and network connectors.

Storage data reduplication strategies should be reviewed. Data reduplication reduces redundant data processed and maintained in storage assets. The benefits of removing duplicate data include improved system management, increased energy savings, better data integrity and often times an improved user experience for such user functions as data retrieval, queries and reporting. Data reduplication strategies are now advanced with new technology that creates calculated hashes for each data block so that if a duplicate hash matches that of another location the storage devices does not restore the redundant block. Duplication techniques and tools provide an added boost with virtualization. Each VM redeploys the operating system multiple times. Reduplication tools can lower storage space requirements and maximize data access to data residing in the filer's cache.

Thin storage provisions should be considered. This storage management technique limits the allocation of physical storage based on levels and/or need and then automatically adds incremental capacity only when it is actually required. This capability is often a SAN, NAS or iSCI hardware function and physically allocates disk blocks to a given application only when the blocks are actually written. This removes the installation allocation guessing game and the all too common over-allocation of storage space just in case it is needed.

IT charge-backs should be implemented. The pay-for-use process will help in improving equipment accountability and utilization. Supplemental cooling should be provided if high density equipment are provided. Many data centers are well past the cooling capacity provided with raised floors, which is typically about 4kW to 7kW per cabinet. Cabinets with blade servers are often spike above 12kW and I've seen some exceed 30 kW. These types of loads should get supplemental, localized cooling.

Data center equipment segmentation. Servers and most network appliances operate at higher ambient air temperatures than storage devices and some other equipment. Similarly, 1U servers often overheat much more quickly than 2U servers - although hardware manufacturers challenge this claim. Because storage equipment requires about 12% to 18% cooler air, isolating this equipment into a separate location permits the ambient air temperature for the rest of the data center to increase to 78 to 80 degrees F and thereby result in a substantial power savings.

Cabinet glass doors should be avoided. They look cool, however, they turn cabinets into ovens.

Proper cable management inside the cabinet and under the raised flooring will result in improved airflow and more efficient cooling– cables should be neatly arranged and stuffed.

Too much refrigeration should be avoided in the data center. Data center ambient air temperature can be as high as 78 degrees F and reduce that number operate SANs which require more cooling than the rest of the equipment.

Consider 208V/30A power to reduce energy costs. Cabinet equipment which uses higher voltage 220 instead of 110 power reduces power loss through the normal wire and transformation process which permits the equipment to operate more efficiently. Usage of blank plates in cabinets should be avoided. This simple technique prevents hot spots and hot air from blowing into cool isles.

Motion detector lights activation should be provided so that convenience is not lost and savings are gained.

Replacing multiple smaller UPSs with fewer central UPSs should be suggested. UPSs now have inverter circuitry that turns DC power from batteries into AC power for IT equipment using a base level of power irrespective of the load. For bigger UPSs, consider replacing battery UPSs with flywheels. This is a significant capital investment so for most readers this is more likely something to look for when evaluating cool facilities. Battery UPSs are high maintenance and an environmental mess. Flywheels completely replace chemical batteries by spinning a wheel which provides temporary power during lapses until generator power kicks in. Unfortunately, these devices are still quite expensive, however, they consume less floor space than batteries so they may make more sense for data centers in high dollar real estate locations.

For IT operators considering new data center construction, make sure you review things like catalytic converters on generators, alternative energy supplies such as photovoltaic electrical head pumps and water cooling technologies.Each of the above suggestions can produce measurable, material and sustained savings. Even a single change can achieve big savings. For example, a single dual-socket, quad server with sufficient memory can replace 30 older, underutilized single processor machines. The power savings are in the range of 12 to 15 kilowatts and could easily translate to cost savings of $16,000 or more annually.

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