A NEW ENVIRONMENTAL CHALLENGE: HOW TO IMPROVE DATA CENTER ENERGY EFFICIENCY

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Abstract

The introduction of Information and Communication Technology (ICT) as a common tool in almost all the companies has led to a significant increase of data centers energetic consumption. As a consequence, data centers management has become strategic from a budgetary point of view, both for costs and environmental impacts reduction and as a possibility to free up resources for other investments in the sector.
This paper faces three main subjects: an analysis of the measurement methods for data centers energy consumption and the technological options to improve their efficiency, the economic impact of those improvements and, finally, the different initiatives developed in the E.U. and the U.S. to promote green IT solutions.

Riassunto

L'introduzione dell'Information and Communication Technology (ICT) quale strumento diffuso in quasi tutte le aziende ha comportato un significativo incremento dei consumi energetici dei data center. Di conseguenza la gestione dei data center è diventata strategica in ottica di budget, tanto per la riduzione dei costi quanto per la riduzione degli impatti ambientali e come possibilità per la liberazione di risorse per altri investimenti nel settore.

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Questo lavoro affronta tre temi principali: un'analisi dei metodi di misurazione dei consumi energetici dei data center e delle opzioni tecnologiche per aumentarne l'efficienza, l'impatto economico di tali opzioni e, infine, le diverse iniziative sviluppate nell'UE e negli Stati Uniti per favorire soluzioni di IT verde.

Keywords: data center, environmental impact, energy efficiency, green IT (Information Technology)

The growing carbon footprint of ICT

The end of the twentieth century has seen the expeditious rise of ICT. The constantly growing use of these technologies has produced significant impacts. In this field, the best known categorization is the one of the three-order-effects of ICT.

The first order refers to the impacts and opportunities created by the physical existence of ICT, the infrastructure and the involved processes.

The majority of ICT's negative impacts are associated with the first order (e.g.: resources consumption and carbon emissions during manufacturing and disposal of hardware). On the other side, the second order pertains to the impacts and opportunities created by the ongoing use and application of ICT, and obviously is where most of the benefits of ICT lie (e.g.: increased efficiency, transparency, speed of transactions, rapid market-clearing and so on).

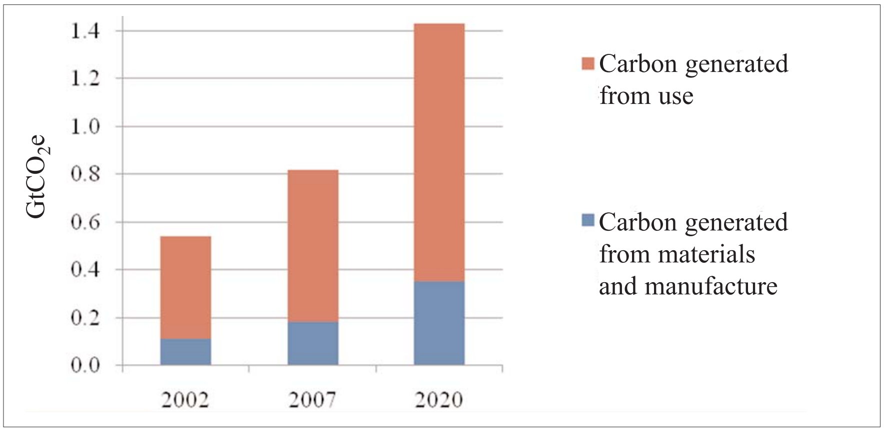
Finally, the third order is related to the impacts and opportunities created by the aggregated effects of large numbers of people using ICT over the medium to long term (1).

Both the growing volume of ICT equipment and its increased use have significant environmental implications. One part of environmental impacts derives directly from the life cycle of ICT products.

The other part originates from the use of these kind of products and services, enhancing or substituting traditional processes or creating new ones.

The negative environmental effects of growing consumption of electronic hardware are most visible in the end-of-life stage but the matter which has recently attracted the most attention from regulators, activists and corporate boards is the constantly increasing energy consumption (2).

In fact, the carbon generated from materials and manufacture is only about one quarter of the overall ICT carbon footprint[1], the rest coming from its use, as shown in Figure 1.



Note: the data about 2020 have been estimated on the basis of a "business as usual" (BAU) scenario. Source: Webb, M., & others. (2008). Smart 2020: Enabling the low carbon economy in the information age. The Climate Group. London.

Fig. 1 – The carbon footprint of ICT.

In 2007, the total footprint of the ICT sector – divided into three subsectors: personal computers (PCs) and peripherals, telecoms networks and devices and data centers – was 830 $MtCO_2e$, about 2% of the estimated total emissions from human activity released that year[2]. Although efficient technology developments will be implemented in the next years, this figure looks set to grow at 6% each year until 2020.

Even if a slow growth will continue in mature developed markets, the most significant growth is attributable to increasing demand for ICT in developing countries (5).

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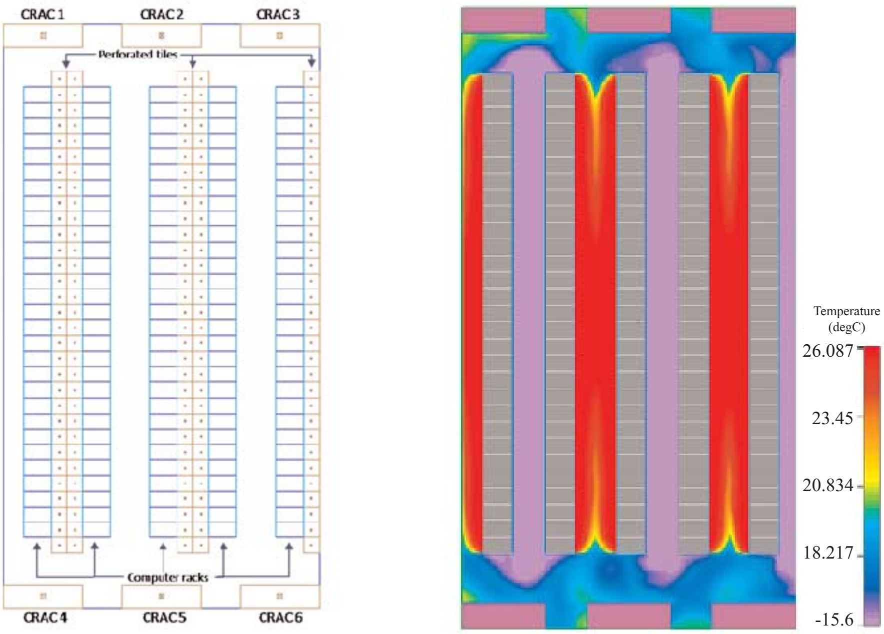
[1] A carbon footprint is "the total set of greenhouse gas (GHG) emissions caused by an organization, event or product". For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide, or its equivalent of other GHGs, emitted. The concept and name of the carbon footprint originates from the ecological footprint discussion. The carbon footprint is a subset of the ecological footprint and of the more comprehensive Life Cycle Assessment (LCA).
The ecological footprint concept and calculation method was developed as the PhD dissertation of Mathis Wackernagel, under Prof. William E. Rees at the University of British Columbia in Vancouver, Canada, from 1990-1994 (3).

[2] $MtCO_2e$ stands for millions of tonnes of carbon dioxide equivalent. A tonne of carbon dioxide equivalent (tCO_2e) is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (4).

Data centers

A data center is a facility used to house computer systems and associated components to provide information for business, government, academia and consumers around the world. It generally includes environmental controls (air conditioning, fire suppression, etc.), redundant/backup power supplies, redundant data communications connections and high security.

Most of the equipment is often in the form of servers mounted in 19 inch rack cabinets, which are usually placed in single rows forming corridors between them. These corridors can be arranged as hot aisles and cold aisles to maximize airflow efficiency (see Figure 2)(6). Data centers typically have raised flooring made up of 60 cm (2 ft) removable square tiles. The trend is towards 80–100 cm (31.5–39.4 in) void to cater for better and uniform air distribution. These provide a plenum for air to circulate below the floor, as part of the air conditioning system, as well as providing space for power cabling (7).



Source: Ferrer, E., Bonilla, C., Bash, C., & Batista, M. (2007). Data Center Thermal Zone Mapping. Hewlett-Packard Paper.

Fig. 2 - Data center layout (top view) and temperature plot from model (top view—1.65 meters from raised floor).

The environmental impact of data centers

Data centers have a variety of environmental impacts, but those relating to their electricity use are certainly the most important. Due to their enormous energy consumption, data centers have a large and growing carbon footprint.

In 2002, the global data center footprint, including equipment use and embodied carbon, was 76 $MtCO_2$ and this is expected to more than triple by 2,020 to 259 $MtCO_2$ – making it the fastest-growing contributor to the ICT sector's carbon footprint.

Including the massive web farms at online service providers, data center electricity consumption is almost 0.5% of world production (8).

Between 2000 and 2005 the amount of energy consumed by data centers around the world has more than doubled, passing from 58.5 to 122.8 TWh (Table 1) (9).

TABLE 1

ALLOCATION OF SERVER ELECTRICITY CONSUMPTION TO MAJOR WORLD REGIONS IN 2000 AND 2005

World regions	2000		2005	
	Server electricity consumption	Share of World total	Server electricity consumption	Share of World total
U.S.	23.3	39.8%	45.1	36.7%
Western Europe	15.1	25.8%	33.3	27.1%
Japan	6.7	11.5%	12.9	10.5%
Asia Pacific (ex. Japan)	5.8	9.9%	16	13.0%
Rest of World	7.6	13.0%	15.5	12.6%
World	58.5	100.0%	122.8	100.0%

Source: Koomey, J. G. (2007). Estimating regional power consumption by servers: A technical note. AMD Technical Study.

Today the electricity intensity of typical data centers is 10 to 20 times greater than that of office buildings but in some cases it may be 100 times greater, and it continues to grow rapidly.

Despite first-generation virtualization and other efficiency measures, data centers will grow faster than any other ICT technology, driven by the need for storage, computing and other information technology (IT) services (Table 2).

TABLE 2

GROWTH RATES OF ICT SUBSECTORS EMISSIONS

	2002-2007	**2007-2020**	**2002-2020**
TLC	36%	69%	131%
Data centers	67%	104%	241%
PCs, peripherals and printers	45%	80%	160%

Source: our elaborations of data from Webb, M., & others. (2008). Smart 2020: Enabling the low carbon economy in the information age. The Climate Group. London.

The increasing data center capacity demand

Demand for data center capacity is expected to grow at 10% CAGR (Compound Annual Growth Rate) over the next decade (8). The number of installed servers in the U.S. is expected to increase by 40 to 50 percent in the next four years, with sales of new servers counting about 7 million per year. If the current rates of growth continue and data center efficiencies remain the same, data center electric bills and power requirements will double in less than ten years (10). In a "business as usual" scenario the world will be using 122 million servers in 2020, up from 18 million today, which means a 17.3% per annum increase in server numbers (5).

As already mentioned (see par. 1) global ICT demand, and thus data center capacity demand, will increasingly be driven by the developing countries, especially India and China, in the next decades.

The data center industry in India is set to double its capacity in the next two years while data center capacity in India is expected to reach 4.7 million square metres by 2012 and projected to grow 31% from 2007 to 2012. The storage demand in India has grown from one PB (petabyte = 10^{15} bytes) in 2001 to more than 34 PB by 2007 (11).

Thorough growth of capacity demand is also expected in China, as the mean per annum ICT spending growth in this country from 2003 to 2008 has been of 14.2%. For India the same figure reaches 30.4%, while in the OECD countries it is only 7.3% (our elaborations on data from OECD (12)). Data center capacity demand in China is also very likely to increase because of the ever growing internet consumption in that country (13).

The energetic inefficiency of data centers

Among the various IT[3] environmental impacts, data center electricity consumption has been getting increased attention and concern from both industry leaders and public policy makers.

Business leaders are now becoming aware of the increasing costs of electricity and of the site infrastructure necessary to support each new piece of IT equipment they deploy. Moreover, both corporate leaders and policy makers are aware of the implications of the capacity limitations of national and regional power grids and of carbon emissions attributable to rapidly growing data center electricity use.

Data center expenditures' share of total corporate IT costs will grow as the number of servers, the amount of power consumed, and the unit cost of power all expand. Today largest corporations are spending between 4 and 8% of their IT budget on electricity and this share is predicted to quadruple in the near future. Without radical changes in order to improve efficiency, many companies with large data centers will face a reduction of their profitability.

The extremely low energetic efficiency of the majority of data centers is due to a number of causes that can be divided in two groups: organizational and technical. The organizational causes include the fragmentation of responsibility for data center facility management, the scarce involvement of IT executives in product strategies, and the lack of information about Total Cost of Ownership (TCO)[4].

[3] It should be noted that the terms ICT (Information and Communications Technology) and IT (Information Technology) are often used as synonyms while their definitions are rather unclear. The first term has been introduced in 1997 (14), the second back in 1958 (15). As in the acronym ICT there is a reference to telecommunication, it appeared more appropriate to use this term only in the first part of our paper, while from this point only the term IT will be used as we will be concentrating specifically on data centers.

[4] Total costs associated with the acquisition, operation, maintenance, and disposal of a product or piece of equipment (SAP, 2008).

The responsibility for data center management is often fragmented between the IT department and the corporate real estate department of an organization. Most data center managers never see the energy bill for their facilities, and their performance is not based on energy costs but on their ability to maintain data center stability and increase availability in support of rising business demand.

In this situation the people who have the competencies to solve the problem are not informed about it, not to mention being held accountable for it. It also often occurs that non-IT executives make strategic decisions requiring certain improvements in the structure of the company's data center without involving the IT specialists. Finally, lacking information about TCO of data centers makes decision making about the size of a data center more complicated than it could be.

On the technical side, data center inefficiency is due to over-sizing of the infrastructure and to use of inefficient hardware. Over-sizing is mainly caused by imprecise demand forecasting techniques and by the necessity to compensate for inefficiencies in other areas of the data center, as well as to provide an overly conservative system ready for future growth. For these reasons up to 30% of the servers housed within many data centers are functionally 'dead'. These are servers with less than 3% average daily utilization. They draw down power but serve a limited useful business purpose.

Across the data center as a whole, average daily server utilization generally tops out at a low 6%, wasting precious capital and energy. Computer utilization rates of 10 to 15 percent are not uncommon in data centers. A study by Hewlett Packard Lab of six corporate data centers found that most of their 1,000 servers were using only 10 to 25 percent of their capacity (10).

IT equipment is frequently working at less than full capacity and may remain in standby mode for much of the time. Low-load losses in power supplies and other equipment are therefore a very important part of the global IT efficiency.

Only about half of the energy used by data centers powers the servers and storage; the rest is needed to run back-up, uninterruptible power supplies (5%) and cooling systems (45%) (5).

Most of the energy that goes into servers and supplementary equipment eventually ends up as waste heat which then has to be managed by cooling systems. Generated heat must be removed from the data center to avoid damaging servers and other equipment.

Cooling systems in data centers typically account for about one-fourth to one-half or more of the electricity consumed. Indeed, cooling power requirements can (and often do) exceed the power used for the IT equipment itself.

Existing servers in data centers may have in-box power supply units that are 60 to 70 percent efficient and have significant room for improved efficiency.

Among the barriers to energy efficiency improvements, one of the most important ones has been the rapid increase in new computer applications combined with the rapidly falling cost of processing power.

Another factor that can act as a barrier to energy efficiency improvements is the pricing system for data center operations, which is sometimes based on the number of servers that are used. Consequently sellers of data center services may have little incentive to encourage efficient use of those servers through the consolidation and virtualization of applications and other efficiency improvements.

Finally, IT executives usually don't have any incentives to promote data center efficiency as, while their performance and salary increase will likely never be based on the data center's energy costs, disruption of operations resulting from attempts to institute new and untested software, hardware, or cooling innovations could very well threaten their jobs.

Proposals to stimulate data center energy efficiency

Institutions can achieve huge improvements in their data center efficiency by pulling three inter-locking levers: rationalization of demand for data center capacity, optimization of supply for data center capacity and activation of underlying organizational enablers (16).

To reduce excessive capacity demand, organizations should revisit their business policies about the necessary technical requirements of their IT based on their real needs. The reduction of infrastructure resource requirements can be achieved through tuning and re-architecture. Infrastructure asset utilization can be improved through virtualization, application stacking and server de-commissioning. This could also reduce software licensing costs, maintenance costs, and hardware replacement costs, in addition to energy costs.

Optimized supply of data center capacity requires improved forecasting and capacity management, the optimization of existing facilities, and the efficient design of new ones.

In general, ‘right-sizing’ of applications, cooling equipment, lighting, etc. probably offers the greatest number of efficiency opportunities in a data center.

Better processors efficiency can be obtained in different ways, including: ‘multi-core’ processors, low voltage processors, and smaller chips made with advanced materials. In addition to reducing the power losses in the power supplies themselves, efficiency improvements would reduce losses in distribution and cooling systems.

Another opportunity being explored is dynamically shifting load with a computer center to reduce hot spots, or shifting load from one data center to another. Although the capability to do this is driven by redundancy and reliability, the energy and demand response opportunities are significant.

As with processors, more efficient uninterruptible power supply (UPS) systems are also available.

When designing and building a new data center, energy efficiency should be kept in mind. This includes looking at the thermal properties of the building being constructed and the layout of the building for maximum cooling efficiency.

By involving the Facility Management team in the planning and layout of a data center, it can provide the tools and resources to ensure the data center will be practical to run, and as green and energy efficient as possible.

By keeping lines of communication open between the two organizations, the data center will be flexible enough to manage future changes.

The probably most cost-effective opportunity for efficiency in data centers is right-sizing the cooling equipment. The use of adaptive cooling solutions that dynamically modify data center cooling to match existing heat loads holds great promise as a power savings technology.

Most data centers are still cooled with air. Liquid cooling can be far more efficient for data centers with high power densities that need to shed large concentrations of heat.

In climates where the outside temperature is low enough, simply directing external air into the data center can save cooling costs for much of the year.

By allowing the temperature of the data center to fluctuate along a broader operating temperature range, a 24% reduction in energy consumption from cooling is possible (5).

Increased outsourcing could also have significant implications for reducing data center energy use.

On the organizational side, institutions should invest in true TCO application that incorporates full lifecycle infrastructure and data center facility cost, make technology leaders responsible and accountable for data center facilities (including decisions, capacity, cost and environmental impact), mandate data center and infrastructure involvement in early in processes of green-lighting and designing applications, and implement metrics for data center energy efficiency.

The implementation of efficiency standards and metrics for products used in data centers (be it cooling equipment, lighting, UPS or servers) and for data centers as a whole, is the basis to achieve significant improvements because what is not measured and monitored cannot be improved.

Much work has already been done in order to define and quantify data center efficiency (8,10, 17-21). As early as 2003, the Uptime Institute promulgated a research-based measurement methodology that was defined as the total utility energy required to operate a data center divided by the critical electrical load in the computer room.

In 2006 the Uptime Institute introduced the Site Infrastructure Energy Efficiency Ratio (SI-EER), which measures the number of kW needed at a data center's outside utility meter to deliver one kW of reliable power to the IT equipment inside.

The Institute also developed the Information Technology Energy Efficiency Ratio (IT-EER), which measures the computing performance of IT equipment per embedded W of power consumption.

The Power Usage Effectiveness (PUE) metric was introduced by The Green Grid in 2006. PUE is defined as the total data center electrical load divided by the IT electrical load (Figure 3) (17, 19).

IT equipment power

$$\text{PUE} = \frac{\text{Total facility power}}{\text{IT equipment power}}$$

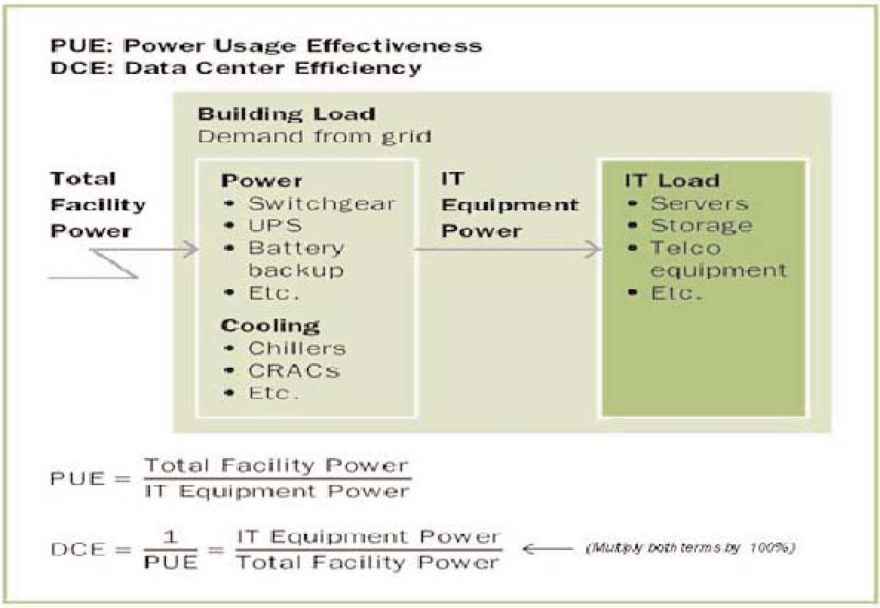


Fig. 3 – PUE and DCE - The Green Grid. (2008, April 29). A Framework for Data Center Energy Productivity - WP #13. Retrieved from http://www.thegreengrid.org/en/Global/Content/white-papers/Framework-for-Data-Center-Energy-Productivity.

The PUE can range from 1 to infinity. Ideally, a PUE value approaching 1 would indicate 100% efficiency (i.e. all power used by IT equipment only). Currently, there are no comprehensive data sets which show the true spread of the PUE for data centers. Some preliminary work indicates that many data centers may have a PUE of 3.0 or greater, but with proper design a PUE value of 1.6 should be achievable.

Measurements completed by Greenberg et al. have shown that the 22 data centers measured had PUE values in the 1.3 to 3.0 range (22). Other research indicates that PUE values of 2.0 are achievable with proper design.

For the long term, The Green Grid is working on metrics to define data center productivity. This is the natural evolution from PUE and DCiE and such a metric could be in a form that looks as follows:

$$\text{Data Center Productivity} = \frac{\text{useful work}}{\text{total facility power}}$$

While data center productivity is much more difficult to determine, members of The Green Grid feel that this is a key strategic focus for the industry.

As noted above, Data Center Productivity is simply the amount of useful work that a data center produces in relation to the amount of a consumable resource that it employs to produce this work.

Mathematically this can be expressed as:

$$DCP = \frac{\text{useful work produced}}{\text{total quantity of a resource consumed producing this work}}$$

From this parent metric an entire family of metrics can be derived based on the specific resource that is to be optimized. For example, one might be interested in the amount of work a data center produces per peak power consumed or per square foot of floor space utilized. The metrics of this family will all be designated by a name of the form Data Center (resource) Productivity with the corresponding acronym of the form DCxP.

$$DCeP = \frac{\text{useful work produced in a data center}}{\text{total energy consumed in the data center to produce that work}}$$

The Corporate Average Datacenter Efficiency (CADE) metric proposed by McKinsey to measure the individual and combined energy efficiency of data centers takes the facility efficiency and multiplies it by the IT asset efficiency. Therefore CADE represents a single, integrated metric that combines facility and IT energy efficiency levels to evaluate the total performance of data centers.

The facility efficiency is obtained by multiplying the facility energy efficiency (equivalent to the multiplicative inverse of PUE) by the facility utilization (actual IT load divided by facility capacity).

The IT asset efficiency is the mathematical product of IT utilization (i.e. the average CPU utilization) and IT energy efficiency (8).

CADE = Facility efficiency x IT asset efficiency
Facility efficiency = Facility energy efficiency x Facility utilization
IT asset efficiency = IT utilization x IT energy efficiency

Metrics and benchmarking methods are also being discussed by public policy makers, in particular within the U.S. Environmental

Protection Agency's Energy Star program (23), which is currently exploring measurement protocols and voluntary efficiency specifications for servers and possibly other data center IT and infrastructure hardware.

The EPA also proposed that separate energy meters be used to monitor large data centers in an effort to spur development of procurement standards (24).

The European Union issued a voluntary Code of Conduct in 2008 (25) prescribing energy efficiency best practices. The aim is to inform and stimulate data center operators and owners to reduce energy consumption in a cost-effective manner without hampering the mission critical function of data centers. The Code of Conduct aims to achieve this by improving understanding of energy demand within the data center, raising awareness, and recommending energy efficient best practices and targets.

The Code covers two main areas:

- IT Load – this relates to the consumption efficiency of the IT equipment in the data center and can be described as the IT work capacity available for a given IT power consumption. It is also important to consider the utilization of that capacity as part of efficiency in the data centre
- Facilities Load – this relates to the mechanical and electrical systems that support the IT electrical load such as cooling systems (chiller plant, fans, pumps) air conditioning units, UPS, PDUs etc.

However the Code of Conduct considers the data center as a complete system, trying to optimize the IT system and the infrastructure together to deliver the desired services in the most efficient manner.

The Green Grid, a global industry consortium focused on advancing energy efficiency, and the Uptime Institute have also forwarded recommendations for improved metrics, standards and technologies to reduce data center carbon emissions.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) develops standards for buildings and building systems, versions of which have been incorporated into most state and/or municipal governments' commercial codes in the United States.

A useful framework to organize different metrics for data center efficiency is the one proposed by the Uptime Institute, which groups energy and power efficiency metrics for a green data center into four broad categories, each of which is addressable by a different function within a user organization. In this way achieving data center efficiency becomes a more manageable task as it gives accountability leaders and teams a place to begin.

The four metric categories are:
- IT strategy (business requirements, systems architecture and platform selection, data topology, and network design);
- IT hardware asset utilization;
- IT energy and power efficient hardware deployment;
- site physical infrastructure overhead.

As far as public policy makers are concerned, there are more instruments that can be used to encourage the adoption of energy efficient practices in the management of data centers.

Financial incentives, tax rebates, and credits can reduce the additional cost of more efficient data center equipment, draw attention to technologies, and legitimize the technologies in the eyes of the consumer, who sees that government and/or electric utilities are essentially endorsing these technologies.

Governments spend huge sums on energy consuming products, thus offering thousands of opportunities to reduce government energy use through the purchase of energy efficient products.

Furthermore, government procurement programs are used to help raise awareness of new-to-market energy efficient products, increase comfort levels with their use, and reduce costs of manufacture through economies of scale.

Once minimum energy performance requirements are established for servers, public entities could be required to purchase only servers meeting those requirements.

Conclusions

The increasing use of IT and the consequently rising demand for data center capacity is a matter of growing importance that has recently attracted the attention of corporate leaders and policy makers.

The increasing energy costs and environmental concerns related to this issue have spurred the search for improved energetic efficiency possibilities in data centers.

The main characters of this first phase have been consultants, research institutes, and networks of businesses that operate large data centers. However the relevance of the role of public authorities is increasing, in Europe as in the United States, and this tendency will in all probability consolidate in the coming years.

Businesses will have to proceed on the path of waste reduction using all the instruments that have been illustrated (rationalization of capacity supply, utilization of highly energy efficient equipment, and elimination of organizational obstacles to efficiency) and making use of efficiency metrics to monitor their steps forward on that path.

As for policy makers, they will have to assume a major role in the promotion of virtuous conduct by private entities while also being the first to pursue energetic efficiency in their own data centers.

Similar considerations are also applicable to emerging economies, which are already experiencing a steep rise in IT usage and will witness the increasing importance of the problems related to data center energy efficiency in the future.

However businesses and policy makers of these countries will have the opportunity to make use of already proven practices and instruments to improve the energetic efficiency of their own data centers.

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