MANAGING ENERGY EFFECTIVENESS IN FINNISH DATA CENTERS

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Keywords: Data center, Energy effectiveness, Interview study.

Abstract: Energy effectiveness has become a competitive advantage for service providers managing large-scale centralized data centers. Technological solutions in this field have developed significantly in recent years, which exploitation should be supported by the organizational managament viewpoints. The goal of this study is to investigate how the companies develop their energy effectiveness and manage the functions connected with it. Based on multiple company case analysis we identified nine factors mostly influencing energy effectiveness. Derived from these findings we present finally a framework for environmental management, which can direct the organization to improve the energy effectiveness of its data center.

1 INTRODUCTION

The environmental effects of information and communication technology (ICT) have become a topic of great social significance. The electricity consumption of ICT service infrastructure is increasing and it is necessary to improve the effectiveness of the energy usage of ICT devices and infrastructure. Electricity consumption is a significant cost item for the companies in this field and the importance of managing it is enhanced as a competitive advantage.

End user companies have increasingly started to outsource their ICT infrastructure to large-scale, centralized data centers managed by a specialized service provider. This trend is further enhanced by the proliferation of cloud computing technologies, which enable placing applications in the network. Therefore, in recent years the research into electricity consumption of data centers has become especially active. In eighteen months, a server consumes electricity worth its price. This means that electricity costs can account for even a third of total cost of ownership for a data center (Belady, 2009; Brill, 2007). During the years 2000-2005, the global electricity consumption of data centers has grown on the average 17 % per year from 71 TWh to 153 TWh. Their share of total electricity consumption in the world is 0.8 %. (Koomey, 2008)

The most significant Finnish electricity consumer has traditionally been forest industry. One paper mill uses 1-2 TWh electricity per year, while the electricity consumption of all Finnish data centers is ca 1 TWh per year (Mäihäniemi, 2009). However, the structure of the industry is changing and ICT services are becoming more significant branch. Because Finland offers significant advantages as a site for data centers both for domestic and foreign companies, new data centers are being built. Google, for instance, has just decided to place its data center in Finland in a closed-down paper mill. Finland is a favorable site for data centers because the climate of Finland is cold and the country has a lot of lakes. In addition, Finland has a good electricity and communications infrastructure, skilled ICT labour, no earthquakes or tropical storms and an internationally competitive price level for electricity.

In addition to technical questions connected with energy saving it is important to have a wider understanding of the organizational viewpoints connected with their introduction and exploitation. The target of this research is to investigate how the companies develop their energy effectiveness and manage the functions connected with it. In addition, we present a framework of environmental management, which can direct the organization to continuously improve the energy effectiveness of its data center. We have limited the research to apply only to data centers, that is servers, computer network equipment, power supply and cooling systems.

Muukkonen T., Luukkainen S. and Ylä-Jääski A. (2010).
MANAGING ENERGY EFFECTIVENESS IN FINNISH DATA CENTERS.
In *Proceedings of the Multi-Conference on Innovative Developments in ICT*, pages 5-12
DOI: 10.5220/0002962200050012

2 LITERATURE REVIEW

Our literature review consists of two parts. First we study the literature on environmental management in general. Then we review the literature on managing energy effectiveness in data centers.

2.1 Environmental Management

The development and certification of environmental management systems are laborious and time consuming expensive projects. The internal motivational factors of enterprises are comprised of cost savings, the effectiveness of resource usage, productivity, the fulfillment of environmental regulation, cost reduction, environmental risk reduction and encouragement to innovate. The external motivational factors include an improved public and interest group image, positive customer feedback, strengthening of market position and adaptation to legislation. (Rohweder, 2004; Ketola, 2004)

Some research has been made into the success and profitability of environmental management systems. One of the the benefits of environmental management systems is the improvement of effectiveness due to cost savings. Additionally the operative management becomes more efficient. These systems reduce environmental risks and clarify the handling of disorders. On the other hand, there are conflicting research results of the effect of systems on image and competitiveness. The effect of the systems on the relations to the authorities is positive, because the systems increase the knowledge of the regulation. The environment generally benefits from the systems as the effectiveness improves. Because the basic principle is a continuous improvement of environmental matters, aims can be set as to long-term effects. However, the environmental management systems do not motivate companies to innovate to improve products and services, but emphasize gradual improvement. The environmental systems are mainly valid in operative management, but not in a strategic approach. In addition, their logic is based on manufacturing industry and doesn't suit the service business perfectly. (Rinnekangas, 2004a; Rohweder, 2004)

In the future the importance of the proactive environmental management will increase and the usefulness of a separate environmental organization will become questionable (Rinnekangas, 2004b). It seems to be possible that environmental management will play a more important role in every manager's work. It can be stated on the basis of literature that bringing environmental matters as part of strategic planning can yield a competitive advantage as cost savings, better corporate image, new markets and even as new business possibilities.

Energy must be dealt with similarly to other production factors from the point of view of the business strategy. The energy used by the production process of the company can be classified as a physical resource. The strategic value of the resource is defined by how much the resource affects the company's possibilities, core competence and competitive advantage. (Hitt et al., 2001)

Skilled personnel, equipment, real estate and energy are the most important production factors of the ICT companies. Energy-efficient actions are valuable for data centers valuable and they are difficult to imitate by competitors. If the company is energy efficient and has access to competitively priced electricity a permanent competitive advantage is gained. (Barney, 1991)

2.2 Energy Effectiveness in Data Centers

In this section we provide an overview of energy effectiveness research in data centers. First we, study the metrics of data center energy effectiveness. Second, we discuss what are major energy inefficiency factors in a data center. Then we analyze the current and the most common improvements in servers and data centers.

2.2.1 Energy Efficiency Metrics

The most common data center energy efficiency metric is the Power Use Effectiveness value (PUE), also known as Site Infrastructure Effectiveness Factor (SIEER). For a data center, PUE is calculated by dividing the electric power used by the whole data center with the electric power used by the ICT equipment in the data center. A PUE value of 2.0 means that site infrastructure is using the same amount of electricity as the computing equipment. The best published PUE values are about 1.3. The range between 2.0 and 2.5 is considered typical, and rates over 3.0 are considered poor. A PUE value is comparable between different data centers when it is continuously observed and presented as an annual mean value or as a graph. (Szalkus, 2008; Belady et al., 2007; McNevin, 2009)

However, a PUE value does not tell us anything about the effectiveness of the actual computing inside a data center. Several metrics, including Data Center energy Productivity (DCeP), Corporate Average Data Center Efficiency (CADE) and Computing Units per Second (CUPS) have been suggested but none have achieved the wide acceptance of the PUE. (McNevin, 2009)

2.2.2 Major Energy Inefficiencies in Data Centers

There are three major inefficiencies inside a data center. First, heat removal requires additional electric power. This inefficiency has recently become much worse because server devices require more energy and are packed more densely than ever before. The resulting hotspots put the conventional heat removal methods to their limits. Conventional air cooling methods can also suffer from multiple inefficiencies, as stated by Robert Tozer. Inefficient use of computing resources also wastes energy. A server's energy consumption remains commonly at 70 % even when the server is idle. On dedicated physical servers, total utilization can often be as low as 10 %. Roughly calculated, this means that a physical server can use as much as 86 % of the electricity to power idle use. Third energy inefficiency is the losses in electricity delivery and transformations. While losses in a single stage are minimal, total losses of consecutive transformations can be substantial. (Koomey, 2008; Flucker, 2009; Tozer, 2006)

2.2.3 Energy Efficiency Improvements in Component and System Efficiency

In recent years, the competition between processor manufacturers has changed from frequency-driven towards comparing actual capabilities, even energy efficiency. In the same time, multi-core processors have become an industry standard. Especially in servers, this has lead towards more processor cores inside a computer and thus more concentrated energy use. This has made heat removal problems both inside a server and in data centers more crucial. Most recent processors can reduce energy use by turning off processor cores when the processor is idle. (Barroso, 2005; Intel Corporation, 2009).

There have been efficiency improvements also in storage technology both on single-disk and storage system level. Major technology behind this has been the transfer form 3.5-inch hard drives to 2.5-inch hard drives. Next step is said to be the wider use of solid state drives. This will eliminate mechanical parts from hard drives and make them even more energy efficient. On storage systems, also software or algorithm based energy optimization methods have been suggested. (Sugaya, 2006; Rydning, 2009; Caulfield et al., 2009; Wang et al., 2008)

AC power sources used in desktop and server computers often have poor efficiency especially at low levels of utilization. The 80 Plus certification has improved especially desktop computer power sources. Since the technology used in server power sources is the same, the same efficiency improvements can be achieved on servers. (Calwell and Mansoor, 2005).

On the server level, the adoption of blade servers has improved energy efficiency. The idea of concentrating the power sources has made it possible to make fewer but better power sources. Current blade servers have advanced power management features to control the power used by individual blades and to turn the power sources of the blade enclosure at on optimum utilization. Blade servers have also indirect efficiency improvements since they reduce the amount of cabling needed thus enabling better airflow inside the server cabinets. (Leigh et al., 2007)

Operating system level power management is widely used on desktop systems. Since servers are supposed to answer queries rapidly almost at any hour, turning off idle servers is not very common. However, there has been research on power awareness in enterprise software and in scientific computing applications. (Rajamani and Lefurgy, 2003; Kusic et al., 2009)

2.2.4 Energy Efficiency Improvements: Virtualization

Server virtualization is a proven way to make a data center more energy efficient. By placing several operating systems on the same server, virtualization can cut down the amount of electricity needed to power idle processors. It is reported that under heavy virtualization, a physical server can have a utilization of 70 percent compared to the worst case utilizations of dedicated physical servers. Since an idle server has about 70 percent electricity demand of a fully utilized server, virtualization can cut down electricity needs significantly. (White and Abels, 2004; Crosby and Brown, 2007; Best Practices Case Studies 2007, 2007; Flucker, 2009)

In addition to energy savings server virtualization enables many operative level economical savings and enables new business opportunities. Compared to physical servers, virtual servers are more compatible, portable, manageable, deployable and customizable. With current virtualization platforms, live migration and even geographical relocation of virtual servers is possible. Server virtualization is also an important enabler of cloud computing platforms. (Crosby and Brown, 2007; Tsugawa et al., 2006; Boss et al., 2007)

2.2.5 Energy Efficiency Improvements in Data Center Infrastructure

In this section we review some aspects of data center infrastructure efficiency. Data center infrastructure efficiency is defined by how efficiently the infrastructure succeeds in provisioning electric power to the ICT equipment and in removing the heat generated by the equipment from the data center.

Data center power provisioning is built to achieve minimum service downtime, not energy efficiency. Eliminating single points of failure in each power distribution phase is done by heavily exploiting duplication of components. This leads to inefficiencies because components are not fully utilized. This can be eliminated by exploiting N+1 mode instead of current 2*N model of backup components. There are also multiple subsequent AC/DC, DC/AC and voltage transformations. As a solution, there have been some suggestions of DC based power provisioning inside data centers. While DC power provisioning is an industry standard in telecommunications, server computers and thus data centers rely on AC power provisioning. By minimizing the transformations, the power distribution chain can be improved from 77 percent to 90 percent. (Greenberg et al., 2006; Fan et al., 2007; Mäihäniemi, 2009)

Inclining energy densities and the increased heat problems inside data centers has naturally resulted in research about heat removal. Data centers have been studied by heat cameras or temperature sensors and the results have been analyzed by means of computational dynamics. The research has improved the industry standard of raised floor air cooling by separating the hot and cold airflows to cold aisles and cold aisles and by optimizing the perforation in floor tiles or enclosing the cabling under the floor to separate compartments. The knowledge about dimensioning the cooling systems is important since the CRACs are most efficient when fully utilized. By optimizing the cooling system to enable great energy densities inside a data center one will reduce ”thermal inertia” and thus making cooling emergencies more urgent to act on. (Sharma et al., 2005; Karlsson and Moshfegh, 2005; Rambo and Joshi, 2007; Hamann et al., 2008; Tozer, 2006)

In cold climates, such as in Finland, free cooling by outside air, cold water or even the rock beneath the building can be very efficient. As a further development of the idea, heat recycling can be even more efficient than free cooling. Late 2009 heat recycling was announced to be utilized in a data center opening in Helsinki, Finland. The extra heat of the data center is fed to the district heating system of Helsinki. In addition to this, district cooling system is utilized. District heating can offer economies of scale to the cooling. (Greenberg et al., 2006; Pagnamenta, 2010)

3 METHODOLOGY

The research was carried out using the multiple-case study research methodology. Multiple-case designs enhance external validity, because methods such as replication logic and pattern matching can be used to test the generalization of the results. If similar findings are observed in several cases analysed sequentially, a replication has taken place. (Yin, 2003)

Because the research area is new and because it was difficult to reach a large enough population by a quantitative questionnaire based method, we decided to gather the data by interviews. In these interviews we got widely information of 12 Finnish ICT organizations. In the interviews we investigated those organization’s attitudes to energy consumption. Key persons responsible for the data centers in various organizations were interviewed. Most of the interviewees had much knowledge about data center operations as a whole. Seven of them worked in a company offering ICT services (we call them hosting companies or hosting providers), two worked for telecommunication operators and three in other types of organizations that were managing the ICT functions internally.

The interviews were carried out as half-structured interviews, which were built on three interlinked themes. These themes were environmental and business management as well as technology aspects. A typical interview lasted about one hour.

The validity of the patterns that had been found was ensured by the pattern matching. Furthermore, the usage of multiple sources of evidence, or triangulation is hi-lighted (Yin, 2003). That is why the framework and related dimensions were integrated from a multiple data sources (literature, interviews, articles, annual reports and press releases). The limitation of the study only to Finland restricted the number of the available cases. The generalizability of the research findings is thus restricted to Finnish context and only to the hosting providers. However, there is still the possibility in further studies to test the results derived from these cases in other geographical areas and company segments.

4 RESULTS

We listened the recordings of the interviews and recognized the following themes and frequencies in the whole sample. The themes were brought up by the interviewees or inherent in multiple answers to our questions. We show here the themes that were present in at least half of the cases or at least in five of the seven hosting companies. Frequencies of the themes in interviews are presented in Table 1.

Table 1: Frequencies of the themes in interviews.

Theme	Total	Hosting
Virtualization	9	6
Buildings	8	4
Electricity Costs	8	6
Availability	7	4
Heat recycling	7	5
Billing the electricity	7	6
Airflows	6	5
Centralization	6	5
Life Cycle	5	5

4.1 Virtualization

Virtualization was mentioned in almost all of the interviews. The most significant benefit of virtualization was the improved utilization of servers, storage system and network equipment. This means savings in costs and electricity.

4.2 Buildings

Most data centers had been built in the 1980's or 1990's. While building them, there were no projections to account for the heat densities or power requirements of recent blade servers. Adding more CRACs or electricity inputs is impossible or very expensive because of the structures of the building. This theme was relevant in all the interviews, regardless of the organization type.

The following themes were present distinctively at the sample of hosting companies.

4.3 Electricity Costs

Electricity costs are significant part of service delivery. Since this is now known throughout the industry the electricity costs are also minimized by at least some of the companies. When these companies transfers the electricity savings to their prices the effective market system will force the others to optimize their electricity use.

4.4 Availability

Availability is important for hosting business. Customers trust their data and applications in the hand of the hosting companies. That is why the hosting providers use duplicated equipment to eliminate single points of failure from their systems which in turn leads to declining energy efficiency.

4.5 Heat Recycling

Almost all of the interviewed organizations have investigated the possibility of heat recycling. The problem there was that the energy providers or facility companies are only interested in investing in the heat recycling of major data centers. Some interviewees mentioned having heard about the concept of feeding the exhaust heat to the district heating system and utilizing district cooling to cool down the data center.

4.6 Billing the Electricity

At the time of the interview three of the seven hosting providers were appraising the electricity costs to a single provided service and three organizations were investigating a similar arrangement. Many interviewees thought that making the energy cost visible in customer or internal billing would guide both external and internal customers to demand more energy efficient solutions.

4.7 Airflows

Five of the seven hosting providers told that they have had airflow problems inside their data centers. Main solution to the problems had been separating the hot and the cold airflows more efficiently either by hot and cold isle method or by blocking the airflow through an empty or partly filled rack cabinet. Distributing the most heat intensive devices evenly around the data center was mentioned as a working solution.

4.8 Centralization

Five out of seven interviewees representing hosting providers introduced the theme about the efficiency of centralized service production. By consolidating service production to the data centers of hosting providers even small businesses could exploit the economies of scale. Efficiency results from following two things. First, the hosting providers are able to organize the energy issues of servers better than small businesses. Second, by consolidating the services, the equipment will run at a higher utilization rate.

4.9 Life Cycle

Server computers, storage equipment and networking equipment have a life cycle of three to five years. The whole data center lifecycle varies from five to twenty years. Hosting providers have knowledge about ICT energy issues, but this knowledge can be fully exploited only in new data center projects. The existing data centers are not utilizing all of the current best practices.

5 CONCLUSIONS

Themes presented above were all very common amongst the interviewees and their organizations. Most of the themes can be categorized as incentives or inhibitors for ICT energy efficiency. To successfully improve ICT energy efficiency an organization has to remove inhibitors and strengthen the incentives. Based on the interviews, an organization's ability to act on inhibitors and incentives is greatly affected by the life cycle of the system which carries an inhibitor or an incentive. By analyzing the incentives and inhibitors and by finding the inhibitors that can be rapidly removed the organizations could improve ICT energy efficiency more rapidly.

We suggest the following framework to improve the organizations' abilities in analyzing various incentives or inhibitors of energy efficiency improvements inside the data centers. The framework is presented in the form of a four field matrix, as represented in Figure 1. The vertical axis separates the incentives or inhibitors based on their life cycle, short being less than three years and long being over three years. The horizontal axis separates the incentives from inhibitors. The quadrant tells the user of the tool what to do about the incentive or inhibitor, whether to eliminate the inhibitor immediately, eliminate the inhibitor during renovations, periodically or continuously assess the incentive an its impact on ICT energy efficiency.

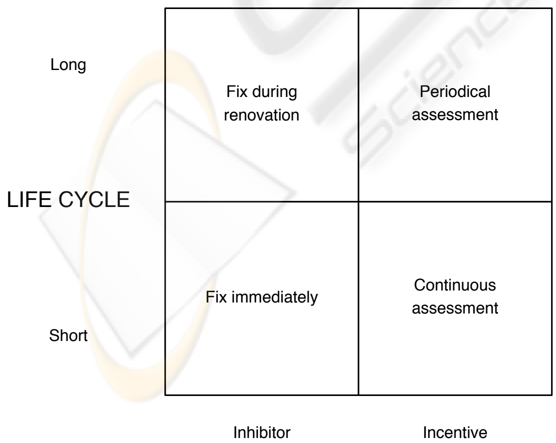

Figure 1: The framework used in reason analysis.

In Figure 2 we represent the relevant themes from the interviews using the matrix introduced above. A fast way to improve energy efficiency in different organizations is to present the energy issues as cost to the ICT management or the customers. Availability can be rethought to be provided more energy efficiently or not to be implemented in systems not really needing high availability infrastructure. Also, optimizing the airflow in the current data center can result in remarkable efficiency improvements very rapidly. Airflow planning is also an important part in building new data centers or renovating the old ones. Problems in facility infrastructure can only be attended during renovations or relocations.

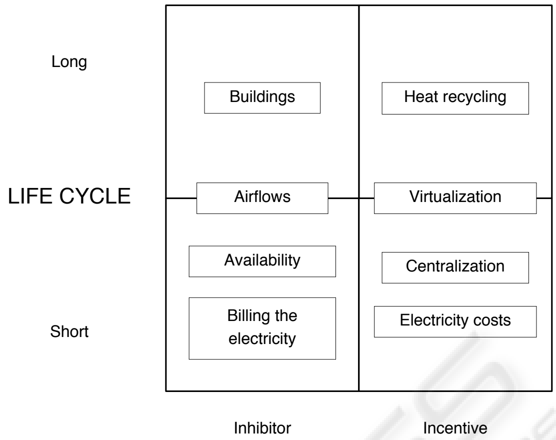

Figure 2: Themes represented by our framework.

Cost pressure caused by the industry competition is a relevant incentive driving energy efficiency amongst the hosting providers. Centralization or consolidation is a theme emphasized by the hosting providers but there is no empirical evidence supporting this result. Wide adaption of server virtualization is an important energy efficiency driver for all ICT activities in both short and long lifecycle.

6 FUTURE RESEARCH

Based on our research we suggest the following research areas. The presented framework is based on twelve interviews in one geographical area and mainly inside one industry. Generalizability of the framework requires more empirical evidence.

A thorough, holistic and comparative study about the energy efficiency differences in centralized and distributed service production would help in confirming the hypothesis of centralization's positive effect on ICT energy efficiency stated by many interviewees. Data center energy efficiency metrics should also be continuously investigated, especially the ones concentrating on efficiency of the computing.

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