Energy efficiency insight into small and medium data centres: A comparative analysis based on a survey

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Abstract

Data centres are the backbone of a growing number of activities in modern economies. However, the large increase in digital content, big data, e-commerce, and Internet traffic is also making data centres one of the fastest-growing users of electricity and such consumption is expected to vastly increase in the next decade. The total energy consumption of data centres corresponds to almost 1.5 % of the global electricity consumption, and had an average annual growth rate of 4.3 %. Therefore, it is very important to increase the energy efficiency in data centres with actions such as power usage management, server consolidation, energy efficient components and systems.

Small and medium data centres account for more than 50 % of the total electricity consumption in this sector. In fact, surveys indicate that this data centre profile waste more energy than larger facilities. Nevertheless, existing studies tend to be focused on the energy related issues for large data centres rather than small and medium data centres. In order to analyse and propose changes to this current perspective, a survey was designed to provide insight into the current reality in terms of energy efficiency actions in small and medium data centres in Brazil the USA, and Portugal. The survey was sent to key decision makers with technical responsibilities for these data centres.

This paper aims to present best energy efficiency practices, using two surveys from literature as relevant source of data and results to compare with the conducted survey, analysing the main opportunities and challenges in small and medium data centres energy efficiency. It highlights that while data centres are recognized as a central part of organizations' energy efficiency strategies, many are improving energy efficiency rather slowly compared with the metrics, evidences, and case studies published by academia and industry.

Introduction

The popularization of Internet and the importance that Information and Communication Technology (ICT) has in contemporary society is changing the way in which computing resources are traditionally provisioned and allocated, by establishing a model in which the computing infrastructure itself is provided as a service to its users. In a not very distant past, data were generated and communicated primarily among ICT systems – albeit of diminishing size. Nowadays, data-producing systems will increasingly involve small, low-power sensors and actuators embedded in the physical world – a network of cyber-physical systems, also referred to as the Internet of Things (SIA 2015). Following the same conceptual perspective, it is important to highlight that the set of solutions proposed in the context of ICT in order to reduce the environmental impacts has been called Green ICT (Craig-Wood et al. 2010), (Uddin and Rahman 2012).

Data centres are nowadays the backbone of the modern economy, having different profiles, from the server rooms that power small-to medium-sized organizations, to the enterprise data centres that support large corporations and the server farms that run cloud computing services hosted by major market players. However, the increase in demand of computing resources, such as digital content, big data, e-commerce, and Internet traffic has brought an inevitable growth in the energy consumption associated with these infrastructures, making Data Centres one of the fastest-growing users of electricity (Josh and Delforge 2014).

In this context, energy efficiency of data centres has reached a key importance in recent years due to its high economic, environmental, and performance impact. Some data centres may consume as much energy as 25,000 households, and their operating environments may consume up to 100 to 200 times as much electricity as a standard office space (Shuja et al. 2012). Furthermore, the energy costs of powering a typical data centre doubles every five years (Buyya et al. 2013). Therefore, with such a steep increase in electricity use and rising electricity costs, power bills have become a significant expense for today's data centres (Gao et al. 2013) and in some cases power costs may exceed the cost of purchasing hardware (Dayarathna et al. 2016).

Data centre energy usage may create several environmental problems as the following statistics demonstrate: The total energy consumption of data centres in 2012 was about 270 TWh, which corresponded to about 1.5% of the global electricity consumption, and has an approximate annual growth rate of 4.3 % in the period (Van Heddeghem et al. 2014). In 2005, the total data centre power consumption was 1 % of the total U.S. power consumption, and created as much emissions as a mid-sized nation like Argentina (Mathew et al. 2012). Just in 2013, U.S. data centres consumed about 91 TWh and such consumption is projected to increase to roughly 140 TWh by 2020, costing nearly 12,4 billion euro annually in electricity bills and emitting nearly 150 million metric tons of carbon pollution per year. Moreover, if worldwide data centres were a country, they would be the globe's 12th largest consumer of electricity, ranking somewhere between Spain and Italy (Josh and Delforge 2014).

For these reasons, data centre energy efficiency is now considered as an essential concern for some data centre operators, ahead of the traditional considerations of availability and security. Finally, in terms of performance, even when running in the idle mode servers consume a significant amount of energy; the more work a server performs, the more energy efficient it is. The average server operates at no more than 12 to 18 percent of its capacity while still drawing 30 to 60 % of maximum power. Even sitting virtually idle, servers draw power 24/7, which adds up to a substantial amount of energy use (Josh and Delforge 2014). Thus, large savings can be made by turning off these servers or increasing the effectiveness of the relationship between performance and work. This and other measures such as workload consolidation need to be implemented to reduce data centre electricity usage. At the same time, these power saving techniques reduce system performance, pointing to a complex balance between energy savings and high performance, according to Dayarathna et al. 2016.

Therefore, for all the elements previously described, an understanding of data centre energy use and energy efficiency options, as well as of the metrics used to characterize data centre energy performance are fundamental to address this large load in the most sustainable way (Masanet et al. 2011). The purpose of this paper is to present an insight on the energy efficiency perspective of small and medium data centres, based on the results of two surveys from the literature undertaken in North America and Europe and the one carried out in the context of this work, with the main participation occurring in Brazil, with some additional U.S. and Portugal representatives, where important surveys and discussions have already taken place. The remainder of the paper is structured as follows. Section 2 presents a data centres energy efficiency outlook addressing this issue considering the different realities based on their size. Section 3 addresses two previous surveys carried out in the U.S. and European context, as well as our own survey, which was designed to provide insight into the current reality in terms of energy efficiency actions in small and medium data centres in the USA, Brazil and Portugal. The final section summarises the paper and presents its conclusions.

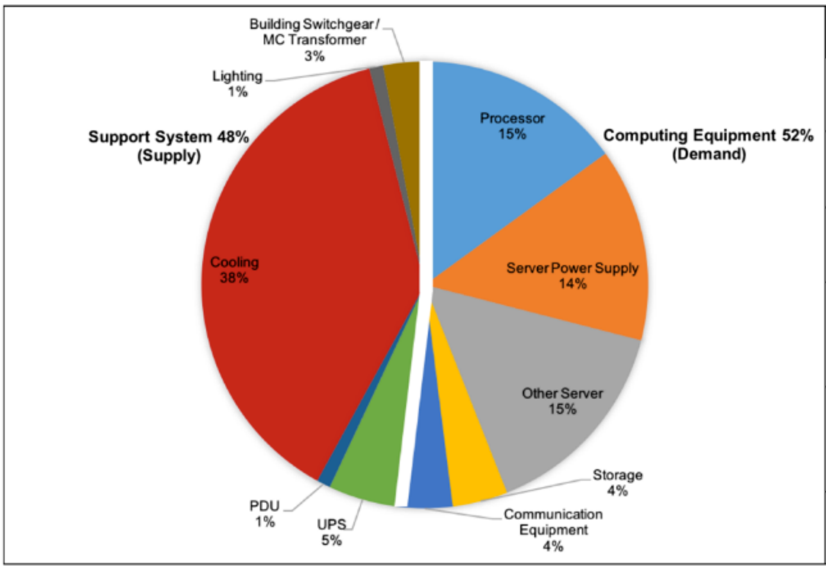
A data centre energy efficiency perspective

Jiang et al. (2015) globally conceptualize a datacentre as a facility used to house enterprise's ICT equipment such as servers, telecommunications, and storage systems, including supporting infrastructures of high quality power delivery and cooling systems. Data centres can have different profiles, ranging from the server rooms that power small-to medium-sized organizations, to the enterprise data centres that support large corporations and the server farms that run cloud computing services hosted by major market players. As stated in Ghatikar G. et al. (2010), data centres can include more than 100,000 hardware devices and their electrical load can range from about 1 kW to about 100 MW. Figure 1 shows the power draw of the different components of a typical 465 m² data centre.

On one hand, existing studies tend to be focused on the energy related issues, i.e. power usage management, server consolidation, load management or demand response programs, for large data centres rather than small, medium and data centres, which in the US account for nearly 50 % of the total electricity consumption, as shown in Figure 2 (Josh and Delforge 2014). However, on the other hand, many organizations, such as laboratories, research institutes, universities, industries and enterprises have multiple small and medium data centres scattered around its facilities wasting more energy than larger facilities in macroeconomic terms. In fact, up to 76 % of these small and medium facilities are actually oversized and therefore inefficient, whereby up to 58 % of energy is wasted in unnecessary and inefficient components such as chips, slots and fans (Delforge 2014), (Bennett and Delforge 2012).

An additional issue is that the power and energy consumption of small profile data centres is a low proportion of that of the whole facility. According to Tang et al. 2014 the capacity of the school where the test site took place was about 1,880 kW and the average power demand of the small data centres in this school was about 300 kW, which corresponds to roughly 16 % of the total. In the scope of this paper, the data centre energy consumption from different faculties and departments in University of Coimbra were monitored, the average consumption was found to be about 14 % of the whole buildings' consumption. The fact that the data centre energy use is a relatively minor part of that of the whole site may mean that it is paid relatively little attention when it comes to considering how to increase energy efficiency. This may prove an additional barrier to change.

There has been significant progress in data centre energy efficiency over the past decade, with server farms operated by companies such as Google, Facebook, eBay, Microsoft and Apple leading the way, motivated by cost, publicity, and pressure from



Category	Power Draw
Computing	588 kW
Lighting	10 kW
UPS and distribution losses	72 kW
Cooling power draw for computing and UPS losses	429 kW
Building switchgear/MV Transformer/other losses	28 kW
Total	1,127 kW

Figure 1. Analysis of a typical 465 m² data center (Emerson 2015).

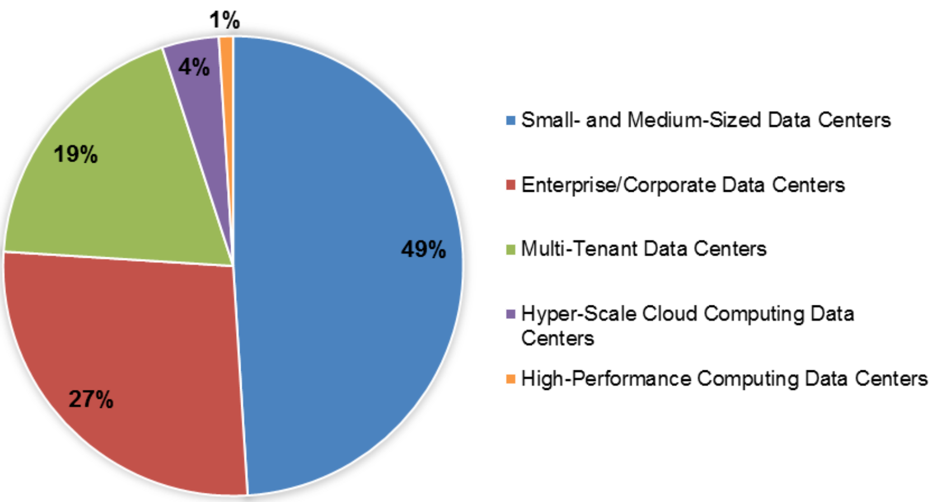


Figure 2. Estimated U.S. data centre electricity consumption by market segment (Josh and Delforge 2014).

environmental organizations, and incentivized because they own and operate their data centres. They are highly efficient due to their economies of scale, diversity, aggregation of users, flexibility of operations and focused management attention. However, an estimated 20 to 30 % of servers in even these large data centres are obsolete or unused – because projects have ended or business processes have changed – but they are still plugged in and consuming electricity every day. Operators may not realize these devices are no longer needed or may not want to decommission them and risk negative impacts on business operations.

In order to verify this reality, the approach presented in Emerson 2015 highlights the best energy efficiency practices applied to a 465 m² data centre based on real-world technologies and operating parameters, as depicted in Figure 1. Through a model, it was possible to quantify the savings in five years due to each action at the system level, as well as to assess how energy reduction in some systems affects consumption in supporting systems. The results have shown nearly 50 % reduction in data centre energy consumption without compromising performance or availability, as presented in Table 1.

However, these hyper-scale cloud computing companies, that have moved computing applications to an Internet-based platform, represent only approximately 5 % of all data centre servers. The less-visible small and medium-sized organizations lag far behind in efficiency. Therefore, there is a critical need for action, including developing utility incentive programs to reduce waste in the massive amounts of electricity used by data centres of all sizes (Delforge 2014).

Surveys

In order to test the truth of these assertions, three surveys with different foci are presented. It is important to point out that the approach used in each study differs, as well as the level of detail. The first two surveys, conducted consecutively by The Green Grid and NRDC, are utilized in this work as relevant sources of

Table 1. Benefits from efficiency improvement actions (Emerson 2015).

Efficiency Improvement Area		Savings (kW)	Estimated Cumulative Yearly Savings				
			Year 1	Year 2	Year 3	Year 4	Year 5
ICT Polices	Low-power processors	111	6	22	45	78	111
	High-efficiency power supplies	124	12	43	68	99	124
	Server power management	86	9	26	43	65	86
ICT Projects	Blade servers	7	1	7	7	7	7
	Virtualization	86	9	65	69	86	86
Best Practices	Higher voltage AC power distribution	20	0	0	20	20	20
	Cooling best practices	15	15	15	15	15	15
	Variable-capacity cooling	49	49	49	49	49	49
Infrastructure Projects	High-density supplemental cooling	72	0	57	72	72	72
	Monitoring and optimization	15	0	15	15	15	15
Total		585	100	299	402	505	585

data and results, but with different perspectives. Furthermore, the survey developed in this work was focused on aspects that were not characterized in the first two surveys, providing a broader outlook on the small and medium data centres energy efficiency context.

THE GREEN GRID SURVEY

The Green Grid questioned 150 key European ICT decision makers with data centre responsibilities in the UK, France and Germany. It was found that while the majority of organizations are facing growing pressures to improve the efficiency of their data centres, 43 % of those surveyed have no energy efficiency objectives in place as presented in Figure 3.

Key findings addressed include:

- Energy efficiency and operating costs are the most common areas of the data centre reported as requiring improvement, as can be seen in Figure 4;
- Two in five respondents reported that their data centres are expensive to run (48 %) or upgrade (41 %), demonstrating that cost is the most commonly reported impact of data centre operations;
- The difficulty in predicting future costs (43 %) and the cost of refreshing hardware (37 %) are cited as the top challenges to developing resource efficient data centres, along with the difficulty in meeting environmental targets (33 %).

Furthermore, 97 % felt that they could improve their monitoring capabilities. Some of the findings presented a positive outlook for future innovations in data centre resource efficiency, with nearly all those surveyed clearly seeing areas for improvement and 55 % stating that energy efficiency was their highest priority when making changes.

However, to match the European Commission's expectation for data centres to be at least 80 % powered by renewable energy by 2020, ICT leaders will need to commit to renovate their resource efficiency policies, since the share of renewable generation in data centres is still very low (The Green Grid 2016).

NRDC SURVEY

The other survey, carried out by NRDC (Bennett and Delforge 2012), surveyed 30 U.S. ICT managers. The focus was on virtualization and cloud computing, since they are the largest and most cost-effective savings opportunities profile in server rooms.

[Virtualization is the process of creating a software-based, or a virtual representation of a physical device, i.e., servers, storage, and networks. Server virtualization technology allows to create several Virtual Machines (VMs) with different configurations on a single physical server and, therefore, to reduce the amount of hardware in use and idle processing time, improving the utilization of resources and providing energy savings. In order to measure the adoption, or lack, of this technology in its different aspects, the penetration rate and gap are used as metrics to verify the energy efficiency technology potential in a computational environment The total amount of virtualized servers is measured by the penetration rate, whereas the penetration gap measures the percentage difference between the virtualization adoption and the penetration rate, i.e., a high penetration rate and a low penetration gap are good energy efficiency indicators considering virtualization policies.]

In this context, the questions addressed various issues related to their current server fleet, virtualization practices, cloud computing, obstacles to implementing efficiency improvements, energy use, and billing. The results from this survey compared with results from other survey of large companies' virtualization practices conducted by the market research firm (Vanson-Bourne 2011), as presented in Figure 5 have shown that:

- Small and medium-sized businesses operate servers in a variety of ownership configurations that may make efficiency upgrades challenging. For example, if the company decides which hardware to lease or purchase, but the host pays the

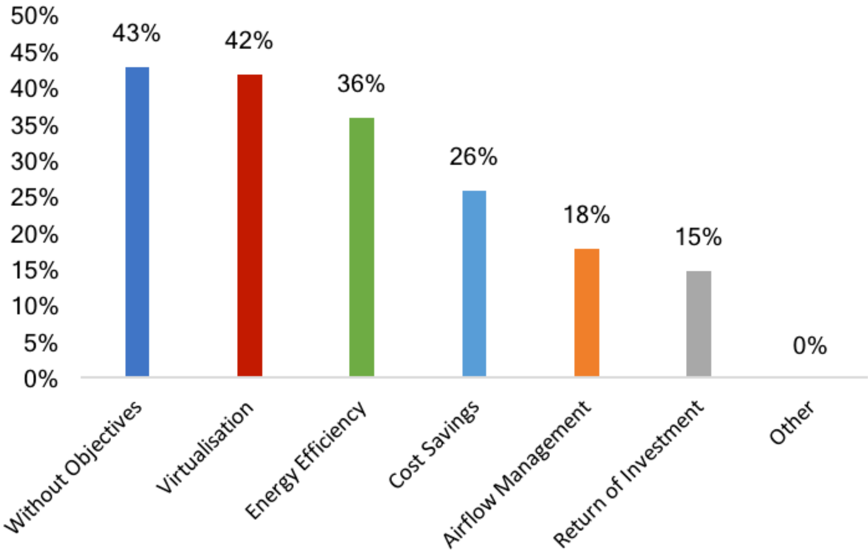


Figure 3. Organizations' energy efficiency objectives (The Green Grid 2016).

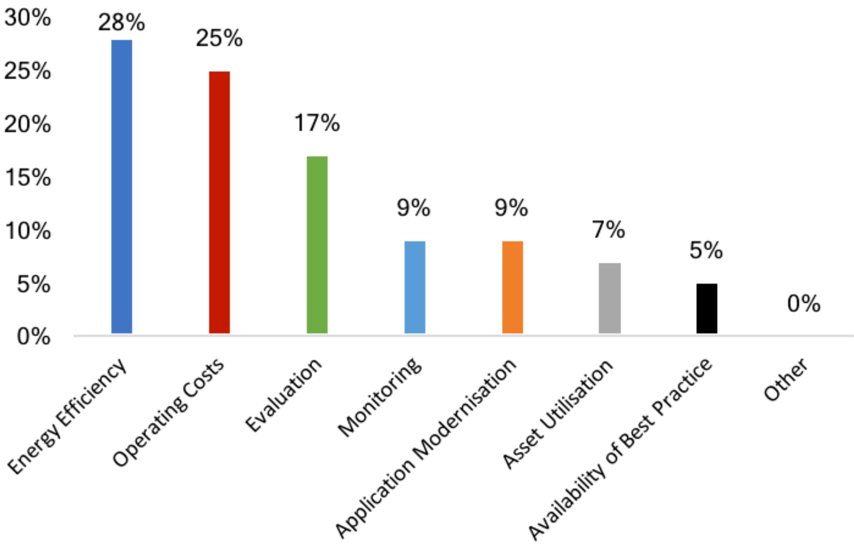


Figure 4. Areas requiring most improvement (The Green Grid 2016).

electricity bills at the off-site location, the server operator does not have a financial incentive to optimize the energy efficiency of its servers. This split-incentive situation is similar to the owner-tenant problem so common in commercial buildings.

- Indicators of virtualization adoption by smaller businesses lag behind larges ones. Most companies have tried virtualization and plan to do more in the future, but still have progress to make before achieving deep transitions to a mostly virtual server fleet. Their surveys' results revealed starkly different results, especially in the percentage of companies that have tried virtualization and the percentage that plan to use or increase virtualization in the future. Whereas 90 % of large enterprises have virtualized at least one server, only 37 % of small companies have done so. This shows that there is still a lot of education and marketing to be done in this sector.
- When virtualization is used, small organizations tend to implement it more broadly than large ones, which narrows the penetration gap to 11 %. However, there remains a large untapped virtualization opportunity in both markets and particularly in small and medium-sized organizations, where only 26 % of all server stock has been virtualized.
- Almost all large companies have used virtualization, and many say they plan to increase its use in their operations, increasing the virtualization penetration rate. In contrast, only 23 % of small companies said they plan to increase their virtualization in the next 12 months.

- Small companies have not adopted virtualization because of unaligned incentives and lack of information. Currently, 60 % of the staff that make server purchasing decisions do not have access to their company's energy bill. This is critical, as server rooms can account for anywhere from 30 to 70 % of an organization's electricity consumption (particularly in office-based organizations). Because over 90 % of organizations do not have a way of monitoring server room electrical use, this opportunity is being overlooked as a strategic way to seriously reduce overhead costs and environmental impact.
- Half of all organizations surveyed plan on a server room upgrade next year. Replacement of servers coming to the end of their warranty is the most cost-effective way to implement efficiency best-practices, since project benefits include the cost avoidance of investing in 1-for-1 server hardware and software replacement.

The barriers and opportunities highlighted by this survey were:

- Barriers to cloud use are more psychological than real;
- There is corporate inertia, with lack of attention to energy efficiency;
- Some companies are concerned about privacy;
- Companies are more aware of software costs than energy costs;
- Uncertainty about data security is the most common barrier;
- There are unaligned incentives;
- There is a lack of information;
- Technology is not the barrier to adopting energy efficient practice.

SURVEY UNDERTAKEN IN THIS WORK

The survey developed in this work aimed to analyse different contexts in different countries in order to investigate different energy efficiency patterns and actions taken by small and medium data centres actors. The 27 questions were addressed to key decision makers with technical and management responsibilities for these data centres. The survey obtained 22 responses. (Since the total population (number of data centres) is not high (at least comparing it with other types of buildings and facilities) it is normal to have the assessment based on a relatively small number, of relevant, responses. Such number is not too different from the 33 responses obtained in the survey conducted in the U.S. by NRDC). The 22 responses are distributed between the three different countries, as follows: Brazil with 13 responses, the U.S. with 5 and Portugal with 4. The response rate was 65 % in Brazil, 50 % in the U.S. and 40 % in Portugal.

The main object of analysis to identify the energy efficiency of small and medium data centres in Brazil. The U.S., was chosen as a North America representative and Portugal as the European Union representative, of regions where surveys had already been published, to provide a good comparison.

Two questions were asked to map the data centre respondent's professional role, and their institutional profile. As depicted in Figure 6, the major professional role in the responses was technical or encompassing both management and technical responsibilities. The planning/design and just the management role had 2 and 1 responses, respectively. In addition, most responses were from the educational sector, such as: universities, laboratories, or companies related to this type of activity in the different participants' countries. There were the same number of responses from business, electricity and electoral justice government sector, contrasting with only one from healthcare sector.

Respondents were asked about the size of their data centres based on floor area. Floor area was chosen because many servers are expected to be located in server closets and server rooms, which have different technology characteristics – and, hence, different efficiency opportunities – than larger data centres. It also facilitates the characterization of electricity costs and potential cost savings, since small and medium data centres are the objects of this work. This criterion enables the analysis of energy demand in five data centre space types: server closets, server rooms, localized data centres, mid-tier data centres, and enterprise-class data centres. The characteristics and technology assumptions associated with these data centre space types are summarized in Table 2.

The distribution of size of data centre collected by this survey are presented in Figure 7. This shows that 65 % of those surveyed operated a small data centre, with 32 % a medium. Just one response came from the operator of an enterprise class data centre. Howsoever, it is important to highlight that this survey was directed to just the small and medium-sized centres operators and managers.

Thereafter, a set of questions was asked in order to find out the level of energy efficiency of the servers, such as:

- How many servers does the data centre have?
- How many legacy servers are there?
- What is the number of servers with some energy efficiency label?
- How many Dynamic Voltage and Frequency Scaling (DVFS)-enabled servers does the data centre have?

[DVFS strategies modify frequency according to the variations on the utilization performed by dynamic workload (Arroba et al. 2015). These policies help to dynamically reduce the consumption of resources as dynamic power is frequency-dependent. DVFS has been traditionally applied to decrease the power consumption of underutilized resources. DVFS is by far the most commonly used technique at the architectural-level, as well as one of the currently most efficient methods to achieve energy savings. This technique scales power according to the workload in a system by reducing both operating voltage and frequency. Reducing the operating frequency and voltage slows the switching activity, achieving energy savings but also decreasing the system performance. DVFS implementation on the CPU results in an almost linear relationship between power and frequency, taking into account that the set of states of frequency and voltage of the CPU is limited. Up to 34 % energy savings in dynamic consumption can be reached just by applying this technique on a server CPU, as presented in Le Sueur and Heiser 2010.]

The average obtained proportion, considering the order of questions, was 10-3-8-2, i.e., for each set of 10 servers, 3 are

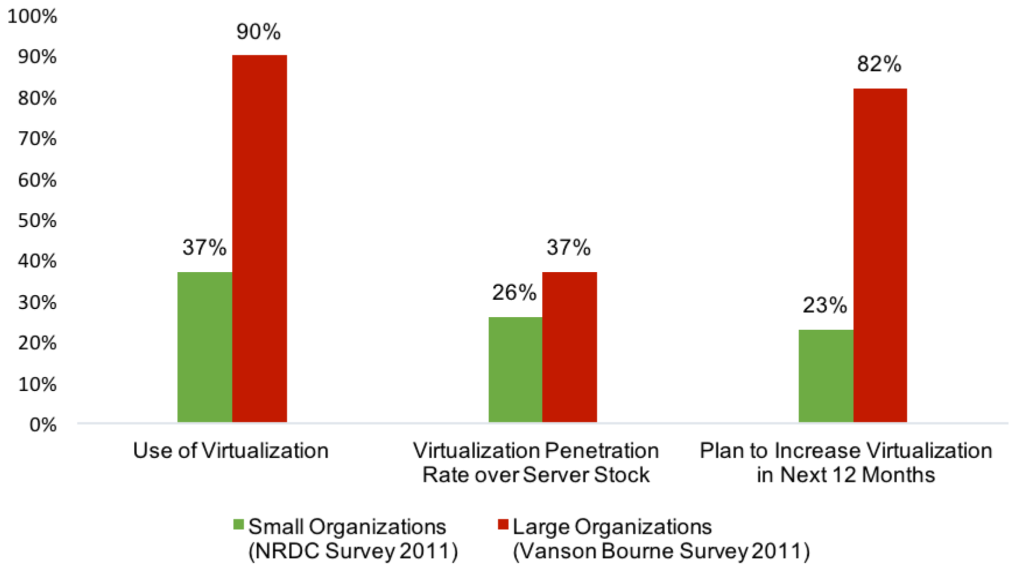


Figure 5. Comparative survey results (Bennett and Delforge 2012).

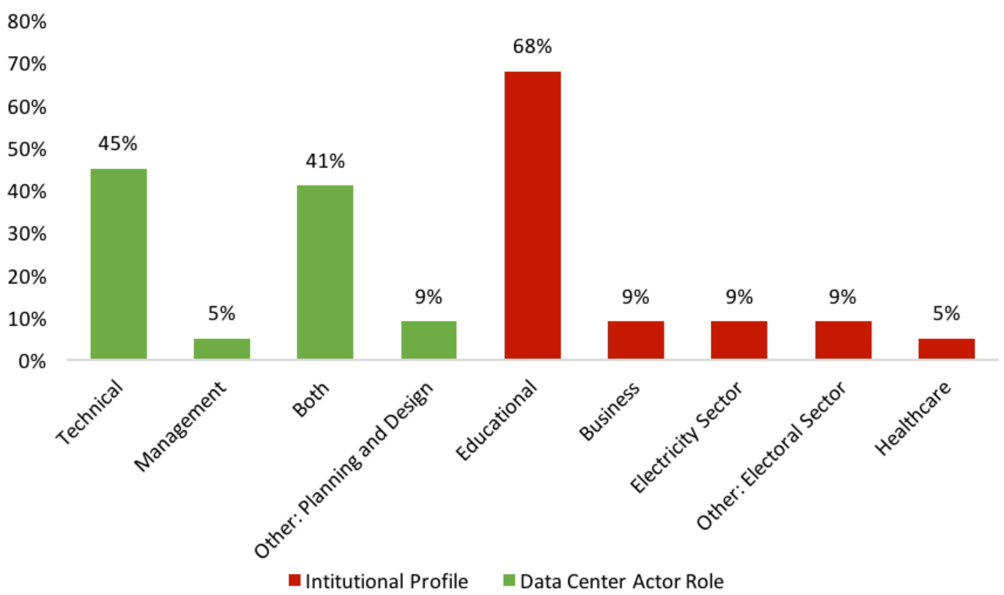


Figure 6. Institutional profile and data centre actor role.

legacy, 8 have some energy efficiency label and only two have DVFS enabled.

In order to verify energy efficiency actions at the storage devices level the following questions were asked:

- How many storages appliances does the data centre have?
- What is the maximum storage capacity?
- What is the current raw storage?
- How many storage appliances with energy efficiency label does the data centre have?

The average proportion was 1-1, i.e., all the actors who have storage appliances in its facilities have already acquired them with some energy efficiency label. However, the average proportion to those data centres which do not have storages appliances in their facilities was 10-3, i.e., for each 10 data centres, nearly 3 of them do not have storage appliances.

A set of questions was asked on cooling solutions: which are the most popular solutions in this data centre profile, the amount of equipment in the facility, and their joint power consumption. 15 out of 22 (69 %) of participants have answered these questions with the following outcome:

- Split: 55 %
- Hot and Cold Aisle: 45 %
- Chillers: 27 %

Table 2. Typical characteristics of data centre space types (Masanet et al. 2011).

Space type	Typical size (m^2)	Typical ICT device characteristics	Typical infrastructure system characteristics
Server closet	<19	1–2 servers No external storage	Typically conditioned through an office heating, ventilation, and air conditioning (HVAC) system. Environmental conditions are not as tightly maintained as for other data centre types. HVAC energy efficiency associated with server closets is probably similar to the efficiency of office HVAC systems.
Server room	<47	A few to dozens of servers No external storage	Typically conditioned through an office HVAC system, with additional cooling capacity, probably in the form of a split system specifically designed to condition the room. The cooling system and power backup equipment are typically of average or low efficiency because there is no economy of scale to make efficient systems more first-cost competitive.
Localized data centre	<93	Dozens to hundreds of servers Moderate external storage	Typically use under-floor or overhead air distribution systems and a few in-room air conditioning (AC) units. AC units in localized data centres are more likely to be air cooled and have constant-speed fans and are thus relatively low efficiency. Operational staff is likely to be minimal, which makes it likely that equipment orientation and airflow management are not optimized. Air temperature and humidity are tightly monitored. However, power and cooling redundancy may reduce overall system efficiency.
Mid-tier data centre	<465	Hundreds of servers Extensive external storage	Typically use under-floor air distribution and in-room AC units. The larger size of the centre relative to those listed above increases the probability that efficient cooling, e.g., a central chilled water plant and central air handling units with variable speed fans, is used. Staff at this size data centre may be aware of equipment orientation and airflow management best practices. However, power and cooling redundancy may reduce overall system efficiency.
Enterprise -class data centre	>465	Hundreds to thousands of servers Extensive external storage	The most efficient equipment is expected to be found in these large data centres. Along with efficient cooling, these data centres may have energy management systems. Equipment orientation and airflow management best practices are most likely implemented. However, enterprise-class data centres are designed with maximum redundancy, which can reduce the benefits gained from the operational and technological efficiency measures.

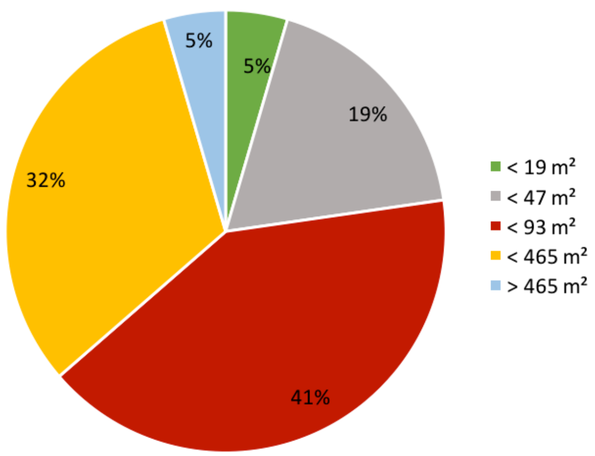


Figure 7. Data centre size distribution.

- High Precision: 18 %
- In Row: 18 %
- Free cooling: 10 %
- Rack Air Distribution: 0 %
- Perimetral: 0 %
- Other: 0 %

The participants were able to choose more than one solution and split cooling is the most used solution in small and medium-sized data centre profiles, followed by hot and cold aisle, whereas solutions such as free cooling tends to be adopted in larger spaces.

The rest of the questions sought to assess, through a yes or no methodology, if servers, storage appliances and network devices have energy monitoring. Respondents were also asked about the adoption of simple measures, such as the use of metrics like Power Usage Effectiveness (PUE), the annual calculation of data centre energy consumption and the knowledge of the electric load diagram. [PUE is defined by the ratio between the total data centre energy use and the ICT device energy use – it is a common metric that accounts for the electricity use of infrastructure equipment.]

Figure 8 presents the responses. The results are alarming from the energy efficiency point of view as the energy consumption of most of the servers, storage appliances and network devices are not monitored. A higher proportion did not calculate annual energy consumption. Moreover, 14 % of respondents were unaware of metrics such as PUE and 18 % did not know if there was an electrical load diagram in the facility.

The answers to the questions on monitoring actions can be used to calculate a propensity for energy efficiency actions by country, as shown in Figure 9. For the overall number of answers, the average data centre actors most effectively participating in energy efficiency actions are 4 out of 5 for the U.S., 2 out of 4 for Portugal and 3 out of 13 for Brazil.

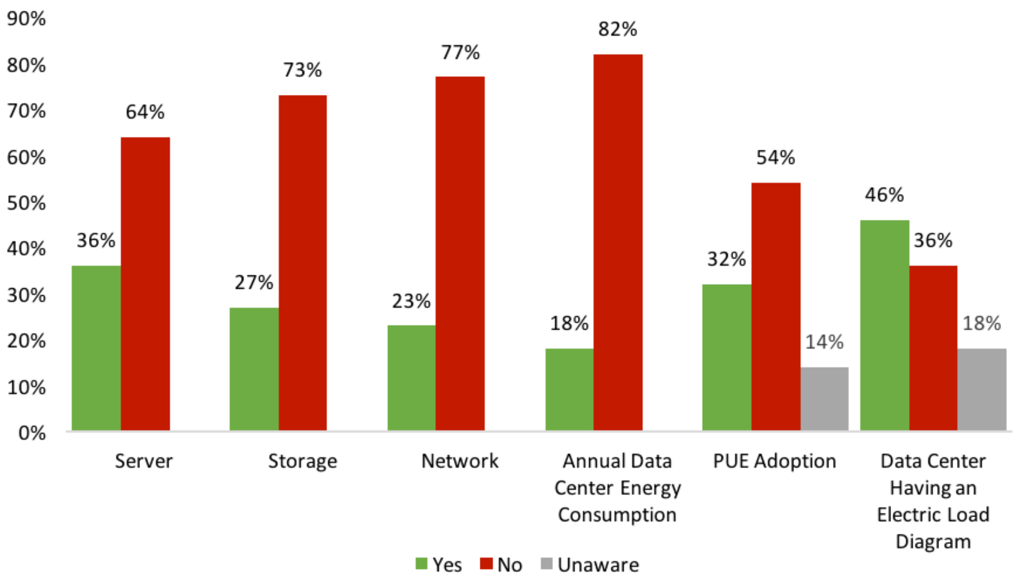


Figure 8. Energy efficiency monitoring actions.

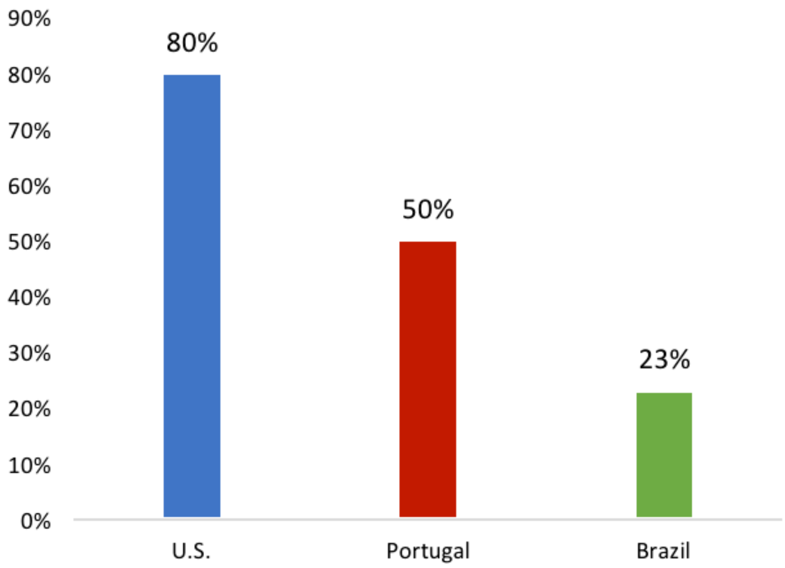


Figure 9. Energy efficiency action tendency.

The answer to the last two survey questions can be used as indicators to establish a correlation with the low index of actions in energy efficiency by the majority of those surveyed, where nearly 73 % answered that another sector is responsible for managing the overall data centre energy consumption and nearly 91 % answered that payment of energy bill is the responsibility of the institution that owns the data centre the and not the data centre itself.

Conclusions

This paper presented an insight on the energy efficiency perspective based on three surveys which assessed the importance of energy use to operators of small and medium data centres. This shows that, even though there have been major advances in energy efficiency for large data centres over the last decade, with nearly 52 % savings, in small and medium data centres the reality is greatly different – 43 % have no energy efficiency objectives in place. Furthermore, the survey conducted in this work highlighted alarming statistics, where 64 %, 73 % and 77 % of surveyed participants do not monitor servers', storages appliances' and network devices' energy use, respectively.

It is important to note that lack of accurate information and corporate misalignment are the main causes of slow deployment of energy efficiency in this sector. Thus, the policy recommendation is that it is essential to treat small and medium data centres as an individual market case, which requires attention, specific incentives and policies to address their particularities. Innovative possibilities include making joint energy analysis of multiples data centres at the same time and proposing an aggregator to mediate operations between data centres and utilities.

It is a desirable goal to achieve a trade-off between the maximum performance of data centres and the minimum environmental impact by considering various aspects such as cost, and energy consumption as constraints. Therefore, it could be concluded that further studies are necessary to develop additional strategies for data centres. These could include more case studies, simulation and evaluation to allow small and medium data centre operators to learn from each other., With the building pace and scale of data centres greatly increasing, various energy-saving technologies should be integrated into data centres to better improve resource utilization and reduce energy consumption, and achieve green data centres.

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