Erick Butler POLETTO
Ricardo Alexandre FIORELLI

Data Center Energy Efficiency: Analysis and Test of Energy Consumption Benchmark Tools

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Erick Butler POLETTO
Ricardo Alexandre FIORELLI

Efficienza Energetica dei Data Center: Analisi e Verifica dei Tool di Benchmark dei Consumi

Tesi di Laurea

Orientator: Prof.ssa Chiara FRANCALANCI

Laurea Specialistica in Ingegneria Informatica
Dipartimento di Elettronica ed Informazione (DEI)
Politecnico di Milano

Milan – IT

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Acknowledgements

"It's the only home we know. Yet everyday, we take the earth for granted.
Everytime we leave the lights on, we are doing the earth harm.
When we forget to turn off our computers, energy is also wasted.
But together we can help make the world a greener place, one simple act at a time.
Because when it comes to the environment, small changes can make a world of difference.", ***The "Power To Change" manifest***

Questions and Doubts

In order not to have any text not related to the thesis in the middle of the text and maybe, in the final version nobody sees it, I created this file, like that, we can put some information here and delete it in the last version. Of course, these are not the only issues related to the thesis, but it is better to have a centralized way to do that.

The questions are:

Section 3.4.2 or Appendix D.1 Do we need to insert all tables here, in appendix, or where do we need to insert the tables? Or just the database schema? These tables were taken from the SANDRA Access file.

Glossary of Abrevitations

x	x
CIO	Chief Information Officer
CPU	Central Processing Unit
DDR	Double-Data Rate
HVAC	
HDD	Hard-disk Drive
ICT	Information and Communcation Technology
LTO	Linear Tape-Open
MFD	Multi Function Devices
MPN	Manufacturer Part Number
OS	Operational System
PC	Personal Computer
PDU	
PSU	Power Supply Unit
RAID	
ROI	Return on Investment
ROM	Read-Only Memory
SaaS	Software as a Service
SDRAM	Synchronous Dynamic Random Access Memory
SAN	Storage-Area Networks
TOC	Total Cost of Ownership
VM	Virtual Machine
VPN	Virtual Private Network
x	x

Abstract

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1 Introduction

Purpose of the study.

1.1 Motivation

1.2 Definition of the problem

1.3 Solution Strategy

1.4 Structure

This document is structured as follows:

- Chapter 1 is the introduction;
- Chapter 2 is the state of the art, giving relevant information presenting the major ideas of the work;
- Chapter 3 is the Methodology, where the problem is engineered, the justification and discussion of the method;
- Chapter 4 is the Analysis and Results part, it is stated how the problem is solved and
- Conclusion is the part where

2 State of the Art

2.1 Green ICT or Green Computing

Green ICT, which is a new term originated from "Green Computing", is the exploitation of a combination of techniques and approaches in ICT towards the end of achieving a more energy efficient use of computer related resources. In other words, it is the research and development of techniques and software that monitor the energy spent by servers, computers, printers and all information and communication equipment to the end of making a responsible use of these resources in terms of energy consumption. In order to achieve this objective, it is imperative to analyse the information about the ICT components among workstations, servers, networks, cooling and many others. The analysis of the information provided by these measures is made through a set of tools, which will be explained in the chapter 3.

The steps that have to be taken in order to apply a green strategy are first to analyse where in the data center the more energy is being wasted ("Assessment"), and then to act with correction and prevention interventions ("Action Plan"). For instance: when buying a new piece of equipment, it should be determined how much energy each of the available options spend and opt for those which consume less energy. Moreover, energy-efficient architectures such as thin clients, virtualization and power management policies should be considered in higher decisional levels. The direct benefits from green ICT strategies range from the direct reduction of electricity bills and costs related to cooling to the reduction of the space required by a datacenter.

The ICT energy consumption has become a critical issue for IT organizations nowadays, where it can provide substantial cost reductions in datacenters and compliance with environmental policies. In the United States alone, data centers consumed $4.5 billion worth of electricity in 2006. Industry analyst Gartner (KUMAR, February 2007) estimates that over the next 5 years, most enterprises will spend as much energy as they spend on hardware infrastructure, power and air conditioning. Furthermore, It is also important to consider that there are some indirect objectives concerning green computing, such as reduction of carbon footprint and disposal of hazard elements to the environment.

2.1.1 Strategies for Applying a Green Solution

According to NTT Communications[1], there are two main approaches for applying a green solution.

Green of ICT concentrates on the operation of the ICT equipment and information system. The objective of the method is to reduce the environmental through power savings and recycling.

- **Data Center** Centralizing the information in a Data Center, with consolidated data, thereby reducing power consumption whereas improve the efficiency regarding cost, operation adn maintenance.
- **Hosting** It is a enterprise related solution including virtualization, by optimally allocating the resources.

Green by ICT concentrates on the energy efficiency reached by the use of ICT operations. The objective is to reduce logistics and transport movements through ICT. Also, reducing material consumption.

- **Communitation** reduces the energy consumed with transportation, by utilizing VOIP solutions with video-conference
- **Remote Data Access** reduction of travel and material consumption by having, for example, mobile terminals or VPNs, where the employees can have acces to work information wherever. In addition, the service should provide secure and reliable remote access enabling the use of multiple devices.

In the next sections there is the explanation of all the approaches and categories for applying a green solution.

2.2 Computer Energy Management Categories

In terms of hardware and equipment, the main measures to be taken towards a Green ICT environment can be grouped in the following categories:

[1] `http://www.ntt.com/business_e/feature/green_ict.html`

- Workstation Configuration;
- Policies / Tools / Labels;
- Thin client architectures;
- Servers and Virtualization;
- Data Storage;
- Power Architectures;
- Data Center Infrastructure.

For each of those categories there are several types of information that are relevant to the evaluation of the current situation of power consumption. For each category there will be a corresponding description along with a number of possible interventions, either purely conceptual or available in the market.In some cases a numerical analysis will also be provided. This information will allow the creation of a methodology to identify critical consumption issues where an investment in green ICT would bring the greater savings.

2.2.1 Machine Configuration

This category represents the components used in a certain machine configuration. The component's performance and power consumption can be obtained from several sources, such as the manufacturer specifications, benchmarks and also direct measurements in the case of power consumption. The following are the dimensions that influence the final power consumption of a machine.

Single-core / Multi-core Processors Processors in general affect the overall power consumption of the computer by means of the workload that is required by it. For example, if the computer is in idle (without any processes running) the energy consumed is less than if the computer stays in full workload, but the idle state does not mean anything to the efficiency, because it is needed a high workload (about 70%) to have the best workload/power consumption ratio.

RAM Memory There are several types and dimensions of memories that should be analyzed, for instance the difference in operation in 2.5V in DDR SDRAM, when compared 3.3V in SDRAM significantly reduce the power consumption. When compating

DDR and DDR2, The Table 1 compares the difference in power consumption of DDR and DDR2 under various circumstances and it shows that the power consumed by RAM, even on maximum workload (+4.5W), does not have much effect on the overall computer consumption (220W).

RAM Type	Size	Load	+12V1	+5V	+3.3V	Rise from Baseline
PC3200 DDR	512 MB	Idle	0.5A	0.6A	3.0A	n/a
		Memtest86	No Change	No Change	+0.7A	+2.3W
	1 GB	Idle	No Change	No Change	+0.6A	+2.0W
		Memtest86	No Change	No Change	+1.0A	+3.3W
533 MHz DDR2	512 MB	Idle	0.5A	3.6A	0.5A	n/a
		Memtest86	No Change	+0.4A	No Change	+2.0W
	1 GB	Idle	No Change	No Change	No Change	No Change
		Memtest86	No Change	+0.9A	No Change	+4.5W

Table 1: Power Consumption: RAM

Hard Drives and Mass Memory Power consumption in this case is affected mainly by design of the hard drive's spindle motor and the number and size of the spindle platters and, also,other components such as the actuator and controller board. Also, solid-state and flash drives reduce significantly the power consumed by the component, Figure 1 shows this difference.

Chassis Concerning power supply, fans or other PC components not belonging to the main parts, it is necessary to require quality other than price. Heating and cooling are really where the power consumption goes. Most computers only make up a fairly small percentage of your electrical bill. One should never underestimate the efficiency of the power supply, because most low quality ones are only about 45-55% efficient, whereas it is possible to achieve more than 80%.

Monitor Type As shown by Table 2[2], flat panel liquid crystal display (LCD) monitors power consumption equals to half the power of conventional CRT monitors. LCD monitors also dissipate less heat, which helps to reduce air conditioning costs. Another interesting point is that either LCD or CRT monitors consume the same amount of energy with or without screensavers. As LCD monitors do not consume much energy when turned off, that would be the best solution for idle computers.

[2] `http://michaelbluejay.com/electricity/computers.html`

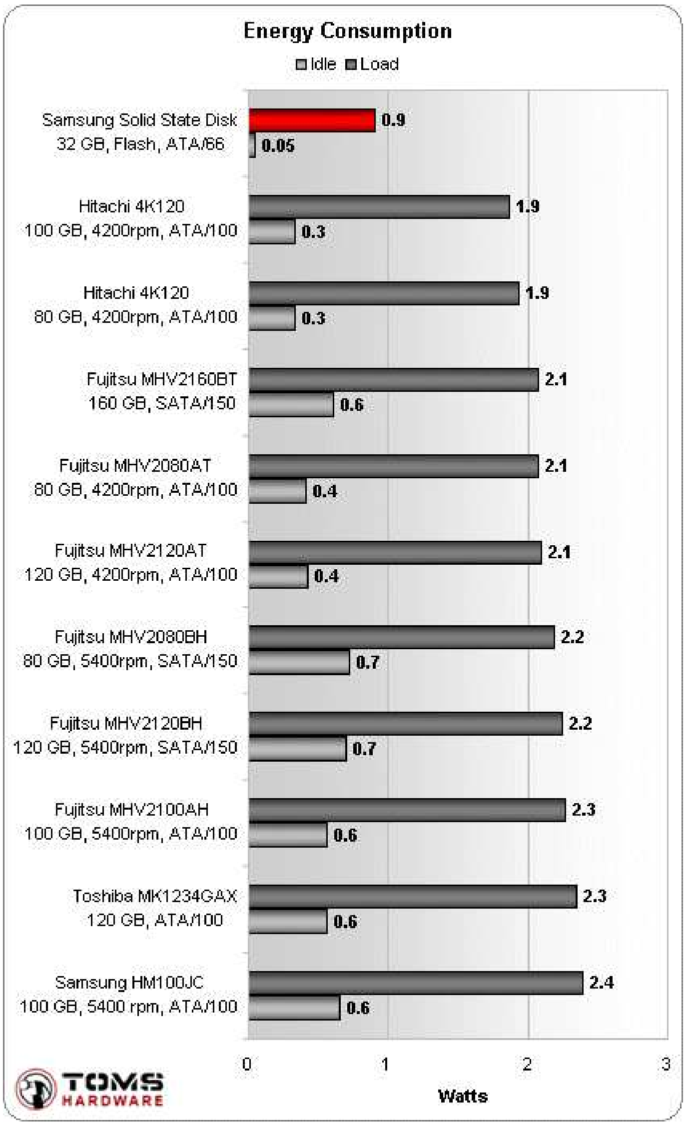

Figure 1: Power Consumption for Hard-drives

Monitors	
Typical 17" CRT	80 watts
Typical 17" LCD	35 watts
Apple MS 17" CRT[a]	63 watts
Apple MS 17" CRT[b]	54 watts
Screen saver[c]	same as above
Sleeping monitor[d]	0-15 watts
Monitor turned off at switch	0-10 watts

[a] mostly white (blank IE window)

[b] mostly black (black Windows desktop with just a few icons)

[c] any image on screen

[d] dark screen

Table 2: Energy used by Monitors

2.2.2 Policies / Tools / Labels

The amount of saved energy depends also on policies that regard technology acquisition and IT management, which may be enforced by a variety of specialized tools. Examples of policies that regard equipment acquisition are: the acquisition of new computers or components labeled as green by the manufacturer, purchase of computers with multi-core processors and even to discourage the purchase of specific kinds of hardware such as dual or large monitors and graphic cards. Another kind of policy relates to the management of the machines. One example of the latter is to turn off workstations or servers if they are going to be unused for a long time. This kind of measure is particularly efficient as a computer in idle mode uses 20 to 50 times the power of a computer in standby mode[3].

Computers	
Desktop Computer	60-250 watts
On screen Saver[a]	60-250 watts
Sleep / Standby	1-6 watts
Laptop	15-45 watts

[a] no difference

Table 3: Energy used by a standard computer

The tools that automate these methods have as their main feature the possibility to let computers in a network in standby mode or even to turn them off after a long period of no utilization. In addition, the shared usage of networked pieces of hardware can be an effective way to achieve energy savings. Networked systems allow several nearby users to share a single printer, which generally generates savings in both equipment cost and energy if compared with each computer having a dedicated printer. Above that, choosing multifunction devices (MFD) that encapsulates in one machine the functionality of many others. In addition to saving space and materials, these multifunctionals save energy if compared to several different machines working in parallel. The Table 4[4] describes the power consumption in standby mode that an energy-efficient networked printer should have in relation to the printer type and to the number of pages it prints per minute.

One last kind of policy is to favor the acquisition of eco-labeled products. An eco-label is given to products that comply with some energy efficiency specifications. The most famous of these labels is the ENERGY STAR®, which is an energy efficiency program sponsored by the U.S. Environmental Protection Agency. For example, An ENERGY STAR® qualified computer is possible to use up to 70% less electricity than computers

[3] `http://www.cosn.org/Initiatives/GreenComputing/EnergyUse/tabid/4515/Default.aspx`
[4] `http://www1.eere.energy.gov/femp/procurement/eep_printer.html`

Efficiency Recommendation		
Printer Speed	Recommended “Sleep” Mode[a]	
	Laser B/W + All Ink jet[b]	Laser Color[c]
≥10 pages/min	10 watts or less	35 watts or less
11-20 pages/min	20 watts or less	45 watts or less
21-30 pages/min	30 watts or less	70 watts or less
31-44 pages/min	40 watts or less	70 watts or less
>44 pages/min	75 watts or less	70 watts or less

[a] “Sleep” mode is a low-power standby condition, it restores automatically with a print request.

[b] Includes both black-ink and color ink jets, and printer/fax combinations.

[c] Also includes LED and thermal transfer color printers.

Table 4: Energy Recommendation to an Energy-Efficient Printer

without enabled power management features.

2.2.3 Thin Client Architectures

According to *Wikipedia*, in 2009, “a thin client is a client computer or client software in client-server architecture networks which depends primarily on the central server for processing activities, and mainly focuses on conveying input and output between the user and the remote server”. This is very well connected to both ideas of cloud computing and Green ICT and it is possible to subdivide in three categories for comparison against standard the PC architecture: Performance, Power Consumption and Hardware Savings and they are going to be exploited in the following subsections.

PC vs. Thin Client: Performance

In order to analyze and give a comparison base of the performance between standard PCs and two types of thin clients, a set of tests were executed. The variable that was the number of active clients on a network, each running the same typical office applications tasks. The following client platforms were considered in this study:

- PC: OptiPlex 210L PCs, basic managed PC desktops running Windows XP Professional;
- Sun thin client: Sun Ray 2 running Sun Ray proprietary software;
- Wyse thin client: Wyse Winterm 5150SE, Linux-based thin clients running Wyse Linux V6.

Each network used a standard file server, an HP ProLiant DL360 3.4MHz with and Intel Xeon processor and Microsoft Server 2003 Enterprise Edition. For test reasons, all the files that were manipulated by the PC were stored at the server. The tests are listed below:

- Calculating subtotal in Microsoft Office Excel 2003 (Figure 2 and Table 5)
- Compressing a PDF within Adobe Acrobat 7.0 Standard (Figure 3 and Table 6)

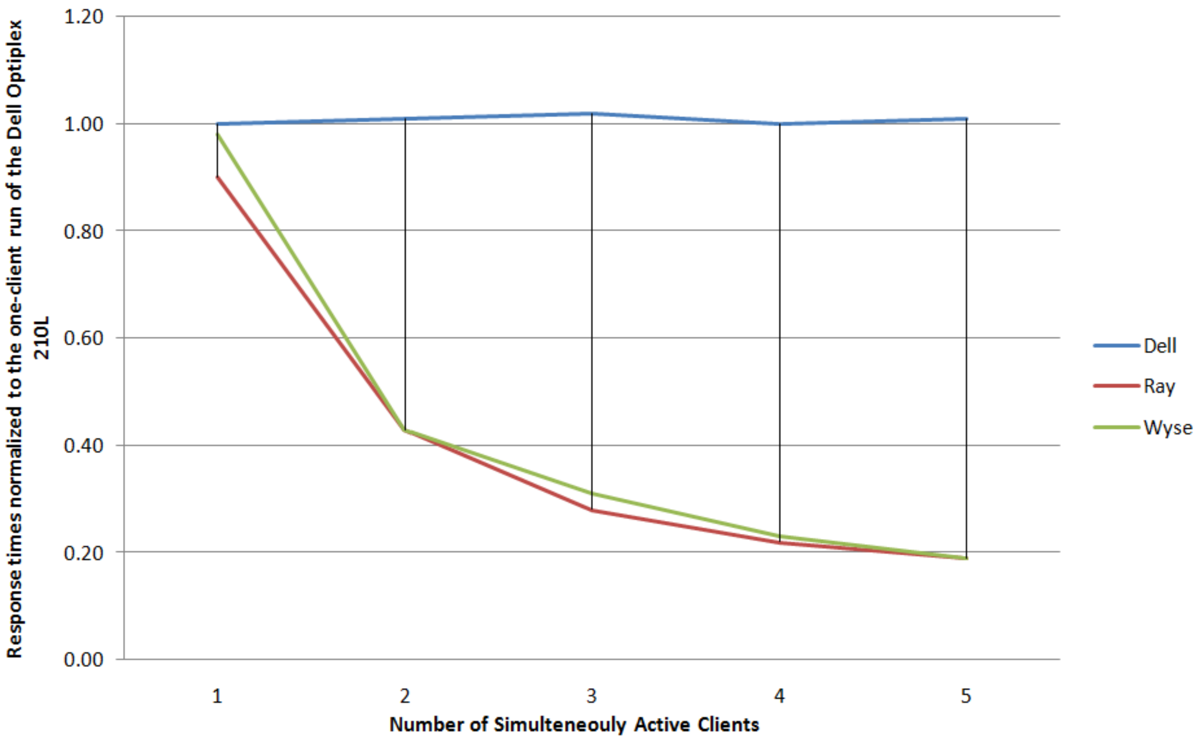

Figure 2: Normalized Excel Subtotals Task Response Times

Performance Results				Comparative Rating		
PC solution	Thin-client solutions		Number of	PC solution	Thin-client solutions	
Dell OptiPlex 210L	Sun Ray 2	Wyse Winterm 5150SE	concurrent active clients	Dell OptiPlex 210L	Sun Ray 2	Wyse Winterm 5150SE
12.9	13.2	13.1	1	1.00	0.90	0.98
12.8	30.2	29.7	2	1.01	0.43	0.43
12.7	45.5	41.9	3	1.02	0.28	0.31
12.9	58.3	57.3	4	1.00	0.22	0.23
12.8	68.1	67.9	5	1.01	0.19	0.19

Table 5: Performance Results for Excel Subtotals Calculation

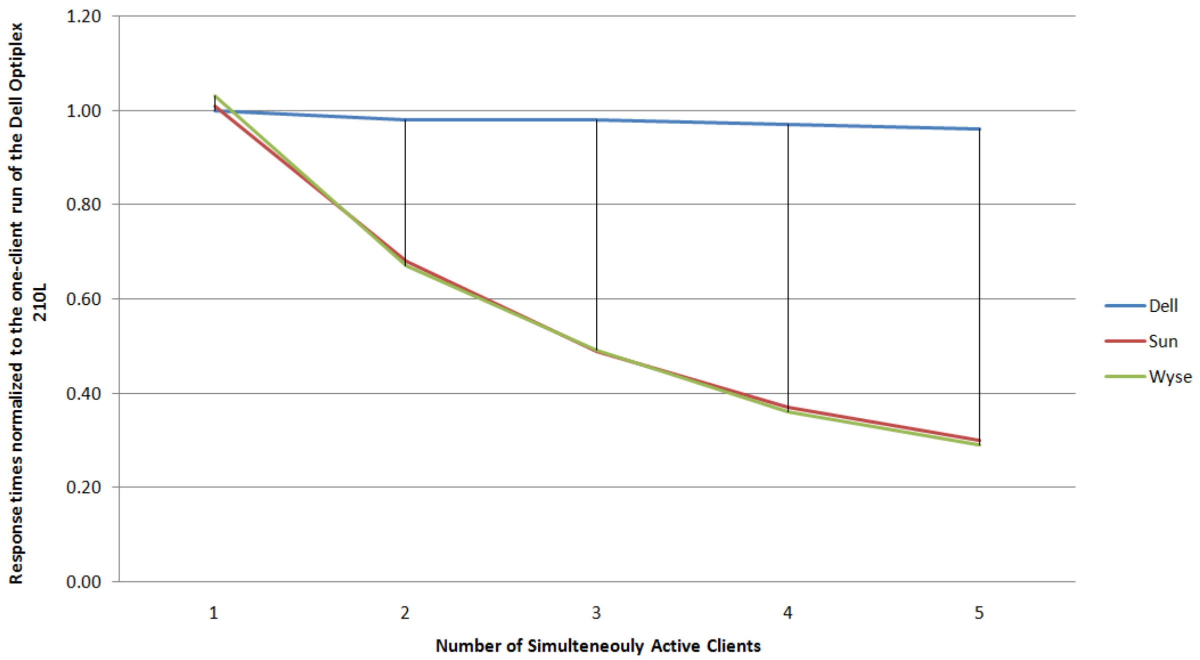

Figure 3: Normalized PDF Subtotals Task Response Times

Performance Results				Comparative Rating		
PC solution	Thin-client solutions		Number of	PC solution	Thin-client solutions	
Dell OptiPlex 210L	Sun Ray 2	Wyse Winterm 5150SE	concurrent active clients	Dell OptiPlex 210L	Sun Ray 2	Wyse Winterm 5150SE
16.1	16.0	15.6	1	1.00	1.01	1.03
16.4	23.8	24	2	0.98	0.68	0.67
16.5	33.0	33.1	3	0.98	0.49	0.49
16.6	43.7	44.3	4	0.97	0.37	0.36
16.7	54.0	55.1	5	0.96	0.30	0.29

Table 6: Performance Results for PDF Compression Subtotals Calculation

PC vs. Thin Client: Power Consumption

Supposing 30 thin users share a 400W server, the total power consumption will be 1300W - a yearly cost of €640.00. 30 PCs would consume 10000W instead - a yearly cost of €4900.00 (assuming the MWh cost is €80.00). The Table 7 shows the power consumption of thin-client and PC.

Hardware Savings

Savings on client hardware The economy brought by the substitution of PCs with thin clients was estimated around US$ 208 per PC per year. The estimative considered the average prices of a PC, an adequate thin client and the PC upgrade costs every 3

	Thin Client	**PC**
Weight	2.2 - 7.7 lbs	22 - 33 lbs
Volume	1.5 - 3 dm^3	30 - 35 dm^3
Packing material	2.2 - 4.4 lbs	3 - 5 kg
Power consumption(including monitor)	20 - 50 watt	300 - 400 watt
Heat rejection	5 - 35 watt	85 - 115 watt
Noise level	0 dbA	50 - 60 dbA

Table 7: PC and thin client power consumption

years. If energy consumption is considered, the savings will be even greater.

The following considerations were taken:

- Thin client cost: US$250.00 x PC cost: US$750.00;
- PC needs to be upgraded every 3 years and thin clients need to be replaced every 6 years.

Therefore, in a 6-year period US$1500.00 will be spent on a PC against US$250.00 that will be spent on a thin client.

Extra server hardware costs Considering that:

- On average 30 users will need a dual processor server with 4 GB of RAM and SCSI hard disks;
- A brand new server should cost around US$4,500.00 and will depreciate on average in 3 years.

For 60 users, the thin client solution should out-price the PC one by US$11,300.00 per year, excluding the administration costs of both solutions.

2.2.4 Servers and Virtualization

Rack vs. Blade

According to Goldworm(GOLDWORM, 2007), Blade servers are a package of "ultra-high density components including servers, storage, and communications interfaces in a pre-wired chassis with shared components such as power, cooling, and networking. In contrast to the conventional *horizontal* positioning within a rack (rack mounted servers), blades servers are typically (though not always) installed *vertically* in a blade chassis, like books in a bookshelf". This disposition of the blade servers along with their reduced dimension provide a high server density and thus of performance. For example, 60 blade servers such as the one depicted in Figure 4 can fit in the same physical space as 42 rack-mounted servers. A blade enclosure, which can hold from 8 to 24 (REHN, 2008) blade servers, provides common services such as power supply, cooling and networking thus eliminating redundancies in each individual blade server. A standard rack can accommodate more than 250 blade servers against approximately 42 standard servers. In

(a) IBM LS20 **(b)** Sun 6000 Series Blade Enclosure **(c)** HP Intros Rack

Figure 4: Examples of Blade Servers

the Table 8, a comparison is made between IBM HS21 blades and x3550 rack servers. The blades and rack servers have comparable performance.

- 2.0 GHz intel quad core;
- 8 GB DDR2 memory;
- Both in standard configuration, with no HDDs;
- Space saving and efficiency - packing more computer power in a significantly smaller area;
- Consolidation of servers to improve and centralize management as well as utilization;

(a) Chenbro 5U RM51924 **(b)** Rack Server

Figure 5: Examples of Rack Servers

- Return on investment (ROI) and improved total cost of ownership (TOC) through increased hardware utilization and reduced operating expenses;
- More energy efficient, due to existence of centralized power supply, cooling and networking.

IBM server model	**Base Power Consumption**	**kWh consumed over 5 years**	**Total cost ($0.03/kWh) over 5 years**
BC-H Chassis, no blades	0.510 kWh	22,350	$670.50
BC-H HS21 blade	0.318 kWh	13,936	$418.08
x3550 server	0.373 kWh	16,346	$490.39
x3650 server	0.455 kWh	19,940	$598.20
BC-H chassis with 14 HS21 blades	4.962 kWh	217,455	$6,523.65
14 x3550 servers	5.222 kWh	228,849	$6,865.46
14 x3650 servers	6.370 kWh	279,259	$8,374.80

Table 8: Power consumption for several servers, excluding cooling and redundancy

According to the figures, the choice of using a blade server provides roughly 5% power saving over a similar rack-mount configuration. The main benefit brought by the use of blade servers, however, is the processing density, as a rack filled with blade servers may carry up to 50% more servers than one with rackable servers. Other benefits are that blade servers are easier to service and reduce the number of power cables needed from as much as 80% (HENDERSON, 2007).

In conclusion, blade servers do not provide much in terms of power saving but it greatly reduces the amount of space used in datacenters. However, the high power density might prove to be a problem to server farms in terms of overheating. Solutions to this problem are described in the section of Data Center Infrastructure.

Virtualization

The overall goal of virtualization is to create a logical abstraction of physical assets. It allows multiple "virtual" servers to run on one physical server, thereby consolidating many physical servers into one. *Wikipedia*, in 2009, defines virtualization as the following: "Virtualization is the process of presenting a logical grouping or subset of computing resources so that they can be accessed in ways that give benefits over the original configuration. This new virtual *view* of the resources is not restricted by the implementation, geographic location or the physical configuration of underlying resources.". Virtualization can improve efficiency and availability of resources and applications in the organization and according to *Vmware*, the choice of virtualized servers over the standard nonvirtualized configuration makes possible to save 50-70% overall IT costs. Apart from the reduction of costs, virtualization may free up IT resources, provide better infrastructure optimization and utilization, increase availability and improve desktop management.

Besides that, virtualization has made positive improvements to the environment issue. Gartner (STAMFORD, October 2007) estimates that 1.2 million workloads run in virtual machines, which represents an annual aggregate power savings of about 8.5 billion kWh - more electricity than is consumed annually in all of New England for heating, ventilation and cooling. While this is a good start, there are plenty of opportunities for saving even more energy and money. Analyst firm IDC (IDC, February 2007) states that the un-utilized server capacity equates to approximately:

- in term of equipment and energy costs : US$140 billion annually
- in terms of hardware costs : 3 years supply of hardware
- in terms of computing power : more than 20 million servers

At the annual production rate of 4 tons of carbon dioxide (CO_2) per server, these un-utilized servers produce a total of more than 80 million tons of CO_2 per year. This is more than is emitted from the country of Thailand and more than half of all countries in South America. From the organizational point of view these data suggests that virtualization is a good improvement to the data center, saving not only space provided to the servers but also saving energy by reducing the idle time of the servers and augmenting their workload.

It is also important to state that, by providing a virtualized solution, the number and variety of available applications can be increased.

There are two kinds of virtualization that may be used in a data center: storage and computing virtualization. Storage-area networks (SAN) may be implemented to present several different physical storage racks as a single virtual storage pool (ANTONOPOULOS, September 2005). On the other hand, computing virtualization can be implemented in two ways. The first case is when a single physical server can offer multiple virtual servers, each with its own OS. Another option is to consolidate multiple physical servers into a cluster that acts as a single server. There are cross-platform server virtualization softwares available which allows data center managers to cluster and partition servers.

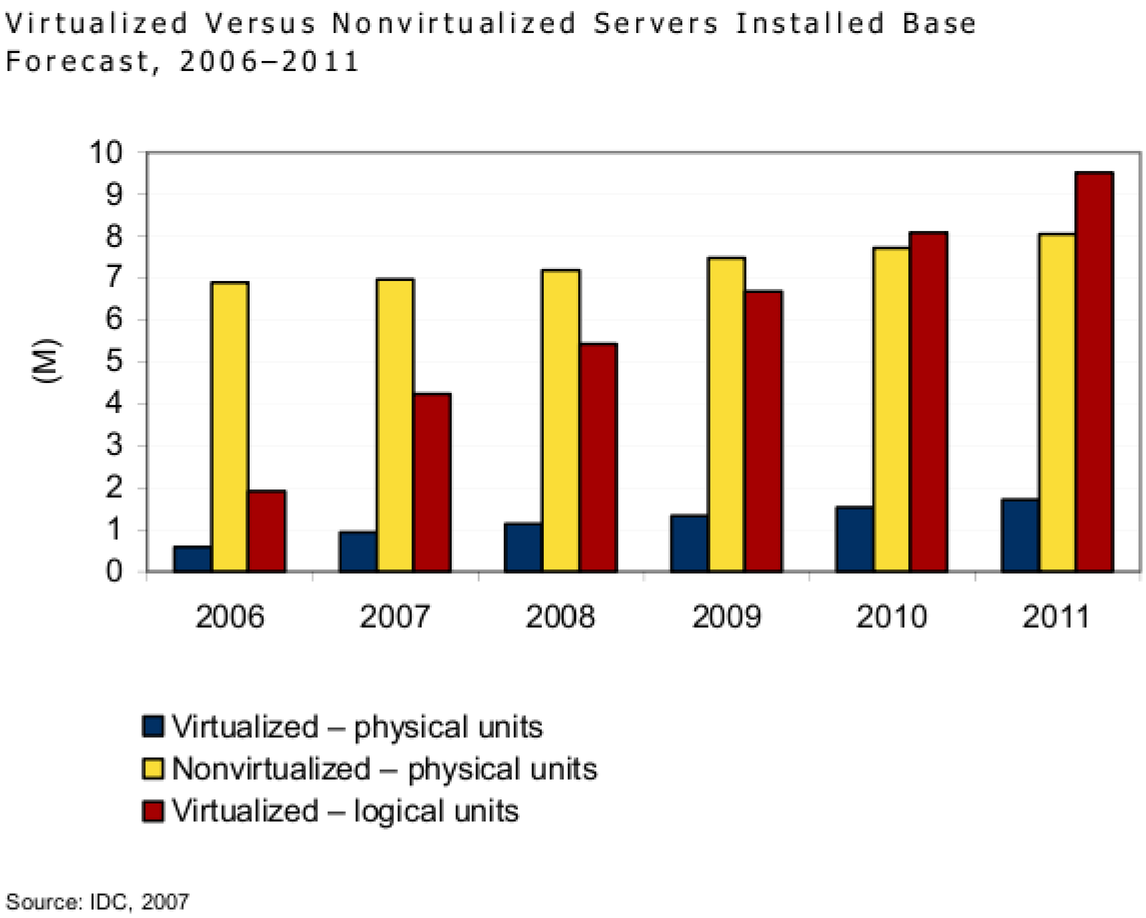

Figure 6: Installed Base of Virtualized and Non-Virtualized Servers

According to the Figure 6 there is a trend indicating an increasing number of virtualized units over time along a forecast that by the end of 2009 the number of virtualized servers will be greater than non-virtualized ones. Logical units represent virtualized storage while physical units represent the use of non-virtualized storage. As shown in the Figure 7, virtualization tools such as VMware allow one physical server to act as a number of logical servers. VMware also provides a benchmark tool called VMmark[5] along with a set of test results in (MAKHIJA, September 2006) for a configuration that includes a mail server, a java server, a standby server, a web server, a database server and a file server.

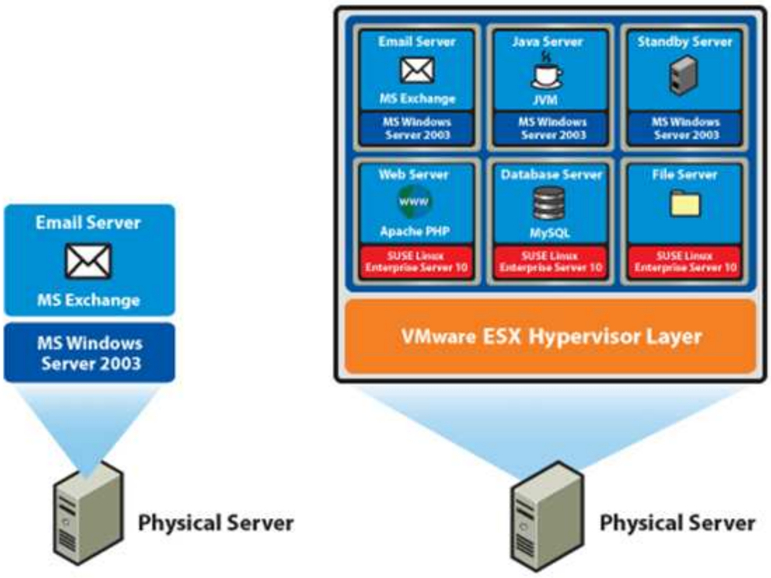

Figure 7: Illustration of Virtualization Applied to a Physical Server

Coming along with the virtualization trend are high-throughput and eco-responsible processors such as the Sun's UltraSPARC T1 processor (HETHERINGTON, December 2005), which support up to 128 virtualized systems in a single server and gives one of the best performance per watt of the available processors. As shown in the Table 9[6], with relation to the UltraSPARC CPU the only comparable performance was met by the POWER5+ processor, which in average dissipates 4.5 times as much as the earlier.

2.2.5 Data Storage

There are currently three main technologies to store data: hard disks, tape drives and flash-based storage. This session will cover the first two, as they are the predominant technologies in datacenters. At the end of the session a comparison will be made between hard and tape drives.

[5] http://www.vmware.com/products/vmmark/
[6] http://www.anandtech.com/cpuchipsets/showdoc.aspx?i=2657&p=4

System	CPU	Power Dissipation CPUs (Estimated)	Number of cores	Number of Active Threads	Score (bops)	Score (%)
Sun Fire T2000	1x 1.2GHz UltraSPARC T1	72-79 W	8	32	63.378	160%
Sun Fire X4200	2x 2.4GHz DC Opteron	150-180 W	4	4	45.124	114%
IBM p5 550	2x 1.9GHz POWER5+	320-360 W	4	8	61.789	156%
IBM 346 xSeries	2x 2.8GHz DC Xeon	270-300 W	4	8	39.585	100%

Table 9: Performance and Power Dissipation for Several Processors by the Specjbb2005 Java Benchmark

Tape Drives

A tape drive is a data storage device that reads and writes data stored on a magnetic tape. Its main use is as archival storage of data stored in hard drives. It is typically used for archival storage of data stored on hard drives. Tape media generally has a favorable unit cost, long archival stability and low energy consumption per MB of data stored to compensate for their slow seek times. Despite the slow seek time, tape drives can stream data to tape as quickly as hard drives. For example, modern LTO drives can reach continuous data transfer rates of up to 80MB/s, which is as fast as most 10,000rpm hard disks, according to *Wikipedia, 2008*. Tape drives can range in capacity from a few megabytes to hundreds of gigabytes. Data can be compressed as to maximize the capacity usage. In this case the compression rate is of usually 2:1. A set of tables related to tape drives can be found in Appendix B

Disk Arrays

Disk array refers to a linked group of one or more physical independent hard disks constituting a larger, high-performance system. They are usually implemented using RAID technology, which can provide component redundancy and high throughputs.

Comparison between Tape Drives and Disk Arrays

Supposing a 995 TB database consisting of:

- Storage base (frequently used data)

- Backup cache (13 weeks)
- Backup archive (1 year backup)

A solution consisting exclusively of disk arrays would require four 32-drawer disk array systems of 245 TB each. In order to ensure reliability and recoverability, a RAID5 format with two RAID5 arrays assigned to each drawer has been assumed. The total equipment cost is estimated on US$10.57M (REINE, October 2008) and according to the table 10 the disk array solution consumes 98KWh per TB per year. With a native capacity of 800GB

Power	Processor Chassis	Standby Power Supply	Per SATA Drawer	Number of SATA Drawers	Total Array Power	Power Per Day	Annual Power	Annual Cost US$0.12/kWh
Typical	430 W/h	34 W/h	325 W/h	32	11 kW/h	264 kWh	96,360 kWh	11,563
Maximum	800 W/h	300 W/h	425 W/h	32	15 kW/h	360 kWh	131,400 kWh	15,768

Table 10: Tape Drive Power Costs

and throughput of 120 MB/sec, an LTO 4 drive has a compressed capability to write at 240 MB/sec, or 864 GB/hour. Supposing the same database is to be entirely stored at this drive, the equipment cost would be of US$233,878.00 with an annual energy cost of US$599.00.The tape solution will consume 1150 kWh in 1 year or 1,16kWh per TB per year. In overall, for the 995 TB database the following conclusions can be drawn:

N^o of frames acquired	N^o of drives acquired	Library acquisition cost	Frame acquisition cost	Cartridge cost	Drive acquisition cost	Space cost	Energy cost	Total cost
1	2	76,000	30,000	82,278	45,600	68,850	599	303,327

Table 11: Disk Array Power Costs

- Disk arrays consume 84 times as much as tape drives, per TB stored
- The disk array solution costs 35 times as much as the tape drive solution

Although the cost difference between of both solutions may be high, performance should be also considered in the comparison. In that case, an adequate proportion between disk array and tape storage must be drawn according to the frequency of backup access.

2.2.6 Power Architectures

Conventional AC Architecture

In this configuration (Figure 8) the following transformations take place:

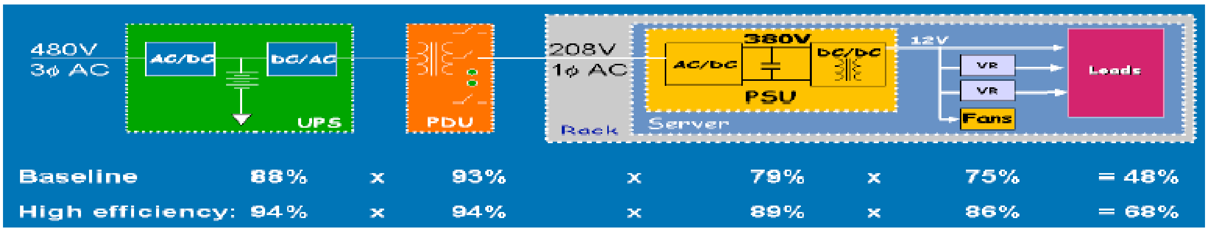

Figure 8: Conventional AC architecture efficiency

- PDU steps down the voltage from 480VAC to 208VAC;
- Power Supply Unit (PSU) converts 208VAC to 380VDC;
- Final component distribution at 12VDC.

The efficiency is measured for both conventional (baseline) and high efficiency (best-in-class) equipments. The difference in efficiency between the two equipment choices is of 20%.

Rack-Level DC Architecture

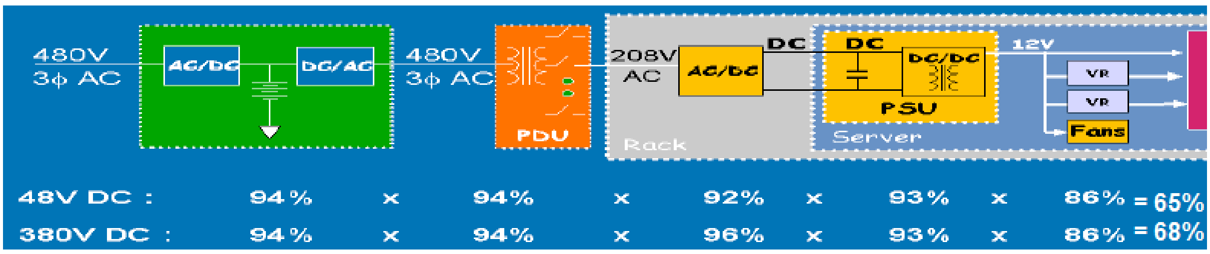

Figure 9: Rack-level DC architecture efficiency

On Figure 9, it is possible to see that, after the PDU, an 208VAC to 48VDC/380VDC conversion is made in the rack. PSU and PDU are considered to be best-in-class, with high efficiency.

Facility-level DC Architecture

In this configuration (Figure 10), the DC-AC conversion in the UPS and the AC-DC conversion in the power supply are removed. It can be noted that the 480VAC-380VDC conversion in the UPS is more efficient than the 480VAC-48VDC conversion.

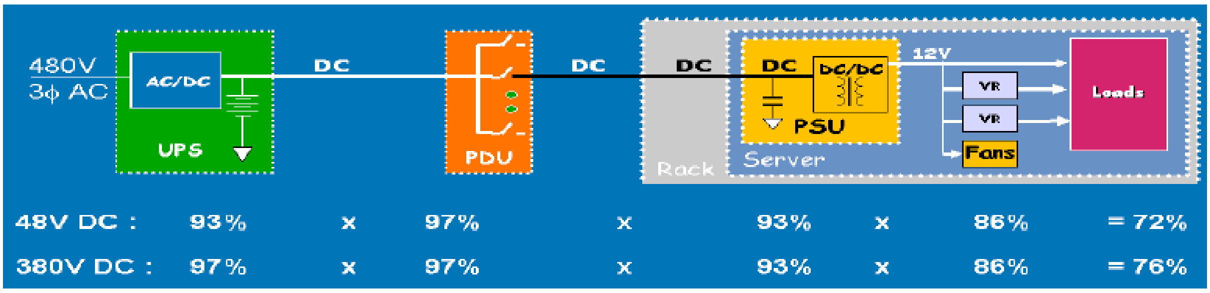

Figure 10: Facility-level DC architecture efficiency

2.2.7 Data Center Infrastructure

Water Cooling

The reasonable limit of rack power and cooling capacity for a conventional forced-air (HVAC) cooled data center is 8 kW per rack. For power densities approaching 15 kW per rack, the layout of the computing rooms and cooling facilities must be determined using specialized software (such as HP Static Smart Cooling). For racks requiring more than 15 kW, the latest cooling techniques use water (Figure 11) (HP, April 2007).

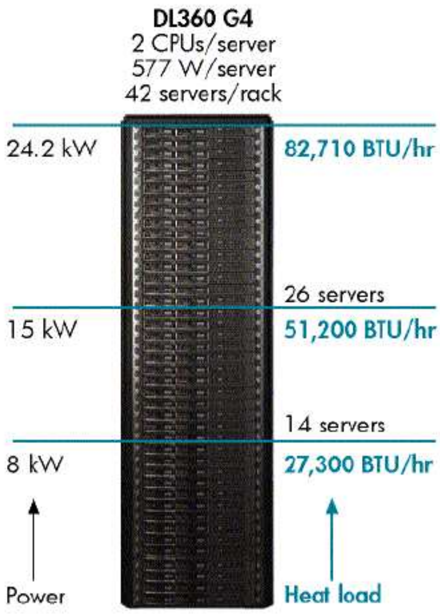

Figure 11: Power Consumption per Number of Servers in the Rack

As shown in the figure 12, the use of water cooling reduces in 50% the equipment footprint, allowing greater server density. A 35 kW heat load dispersed among 4 racks could be concentrated in one single rack.

With relation to maintenance costs, The annual cost for water cooling and air cooling

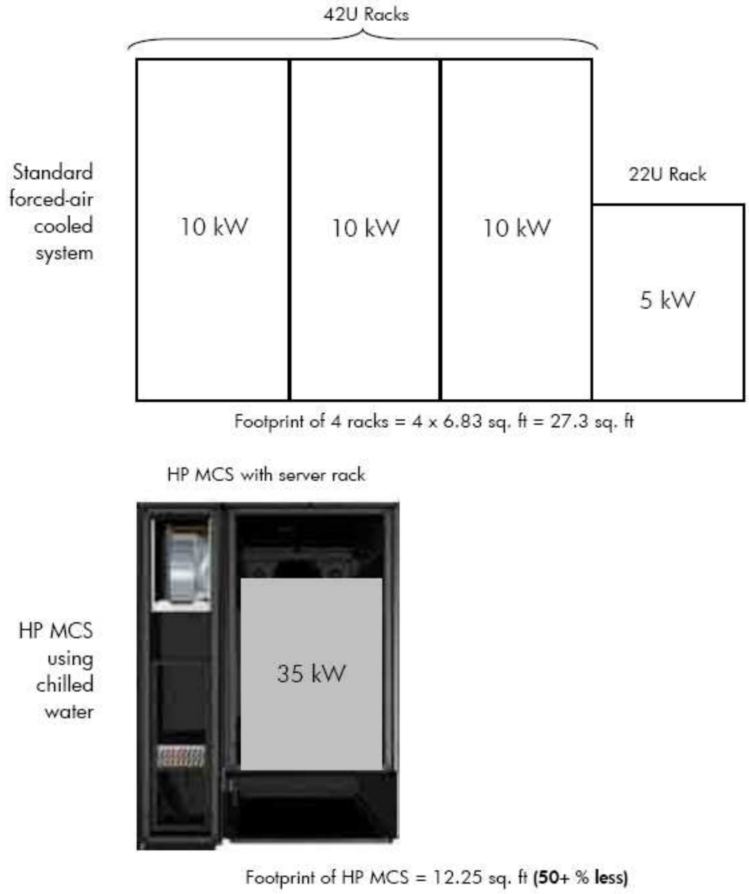

Figure 12: Footprint Reduction for a 35 kW Heat Load

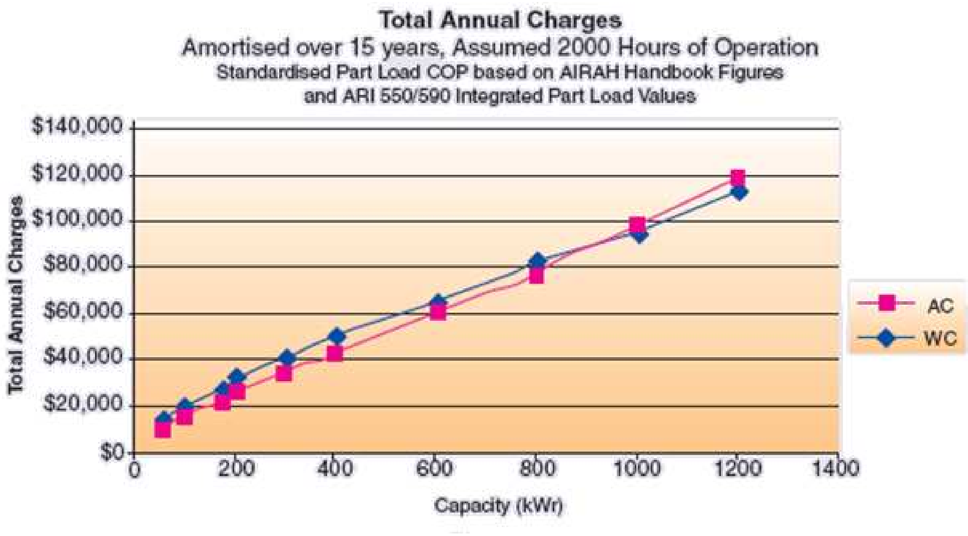

Figure 13: Economic Cross-over of Annualized Charges Air-cooled to Water-cooled for 2000 Hours of Operations (in US $)

(including charges, maintenance, equipment) do not differ by a large amount as seen in Table 12 and Figure 13. In this way, the main benefit brought by water cooling is the

LIFE CYCLE COSTING - TOTAL ANNUAL CHARGES METHOD - TI AE 140									
Generic Comparison 600 kWr @ 3000 hrs		Option A - Water Cooled With Cooling Tower				Option B - Packaged Air Cooled Plant			
ITEM	Design Years = n	Full Life Cost	Annual Charge Factor	Present Value (1)	Equiv. Annual Charge	Full Life Cost	Annual Charge Factor	Present Value (1)	Equiv. Annual Charge
CAPITAL COSTS									
A - Provision of New Water Cooled Chiller	15	$189,750	0.15		$29,362		0.15		
B - Cost of Air Cooled Packaged Plant.	15		0.15			$159,500	0.15		$24,681
Dosing Set c/w dual biocide and inhibitor pumps	15	$2,750	0.15		$426		0.15		
Water Meter Monitoring	15	$250	0.15		$39		0.15		
Chemical Spill control	15	$50	0.15		$8		0.15		
Cleaning Access to cooling Tower to facility RMP and OH&S requirements	15	$10,000	0.15		$1,547		0.15		
			0.15				0.15		
SUB TOTAL					$31,382				$24,681
RUNNING COSTS		Cost/a				Cost/a			
Water Supply Cost for Options A	15	$2,479	0.15	7.28	$2,792		0.15	7.28	
Water Sewerage Discharge Cost for Options A.	15	$150	0.15	7.28	$169		0.15	7.28	
Annual maintenance Chemical Dosing and Cleaning for Option A	15	$2,022	0.15	7.28	$2,277		0.15	7.28	
Annual Registration Charge and RMP Review for Option A	15	$500	0.15	7.28	$563		0.15	7.28	
A - Estimated Power Cost - for Options A.	15	$36,264	0.15	7.28	$40,837		0.15	7.28	
B - Power Cost - Air Cooled Chiller.	15		0.15	7.28		$45,664	0.15	7.28	$51,423
	15		0.15	7.28			0.15	7.28	
SUB TOTAL					$46,638				$51,423
MAINTENANCE AND REPLACMENT COSTS		Cost.				Cost.			
Option A Compressor and Chiller Component Replacement.	7.5		0.22				0.22		
Option B Fan Motor Replacement	7.5		0.22			$5,000	0.22		$1,083
		Cost/a				Cost/a			
A - General Maintenance Costs for Option A.	15	$1,500	0.15	7.28	$1,689		0.15	7.28	
B - General Maintenance Costs for Option B.	15		0.15	7.28		$500	0.15	7.28	$563
	15		0.15	7.28			0.15	7.28	
	15		0.15	7.28			0.15	7.28	
SUB TOTAL					$1,689				$1,646
SALVAGE VALUE									
A - Scrap Value of Cooling Tower System	15	-$500	0.15	0.16	-$12		0.15	0.16	
B - Scrap Value of Air Cooled Packaged Plant	15		0.15	0.16		-$500	0.15	0.16	-$12
	15		0.15	0.16			0.15	0.16	
SUB TOTAL					-$12				-$12
TOTAL ANNUAL CHARGES					$79,696				$77,738

ASSUMPTIONS
Escalation = e 2.0%
Discount Rate = r 13.0%

NOTES
(1) Present Value (Escalating Annuity) for Running Costs and Maintenance.
Present Value (Single Sum) for Salvage Value and Replacement Costs.

Table 12: Life Cycle Costs of Water-cooled and Air-cooled Solutions

footprint reduction which can increase the server density in a data center.

3 Methodology

This chapter will describe the steps taken to the end of constructing the components database and of validating the data contained in it. These can be shortly described as follows:

Phase 0: Project definition - As this work is part of a project aimed to create a methodology to implement a Green ICT strategy, this first phase consisted of the definition of the logical components of this project and of how the current work would collaborate to it.

Phase 1: Analysis of Benchmarking Softwares - A number of existing softwares were analysed and those that have proven to be more adequate were selected. A list of the analysed softwares can be found in Appendix C.

Phase 2: Catalog - The tools were used to obtain information about computer components that were later used to create a component database.

Phase 3: Database design and construction - The database schema was designed and data began to be inserted into the relations.

Phase 4: Analysis - The validity of the stored data was tested with the help of direct measurements.

3.1 Overview

The main and broader objective of the research that is being conducted is to develop a methodology to implement a green ICT strategy. Namely, the methodology would provide a set of tools to guide the hardware acquisition process in an organization either in terms of workstations or of datacenter equipment. The present work will contribute to this research by providing a component database with information related to hardware components, which will be used as one of the inputs of the methodology. This work was conducted in order to determine how much energy a computer's components, for instance, CPU[1], Memory and Hard Drives spend and also how much they would affect the cost of acquisition of new computers as a whole. This is calculable with information such as component performance, power consumption and price. The analysis was carried out with the help of specialized softwares that will be described in the following sections and also with analytical measures made with an energy measurement device. In the end the benchmarking measures obtained from these softwares were compared with both the measures obtained from the device and with information provided by the component datasheets. With the benchmarking software, more than 1000 components were categorized in a database, whose schema can be found in Figure 16. Firstly, the SiSoft Sandra's database 3.3.1 was used to collect the components and separate them by categories, along with their benchmark related data. Secondly, WebSPHINX 3.3.3 was used to create a collection of components and their respective MPNs. In the end, an energy measurement device 3.3.2 was used for the comparison and validation of the results given by the other benchmarks and acquisition of new data. Finally, these data were all linked in a database for later comparison.

3.2 Research Design

The experimental method of research was used in this study. Figure 14 draws the steps of the method. To define the experimental type of research, Bryman (BRYMAN, 1989) states that "the experimental design (...) allows the causal hypothesis that underpins the question to be examined", which means that this method is a systematic and scientific approach to research in which the researcher manipulates one or more variables, controlling and measuring any changes in other variables. The emphasis given is on the results and analysis of the benchmarks provided and their measures. It allows to verify the thesis on which this work is based by making use of empirical methods which in the case relates to the benchmarks used.

The present study is meant to identify the power consumption of the computer components and to evaluate the accuracy of the obtained data through direct measurements. The quantitative method (direct measurements and benchmarking), other than the qualitative method, was employed in order to identify the more energy efficient components that may be used in green datacenters. Among all components, the ones included in

[1]Central Processing Unit

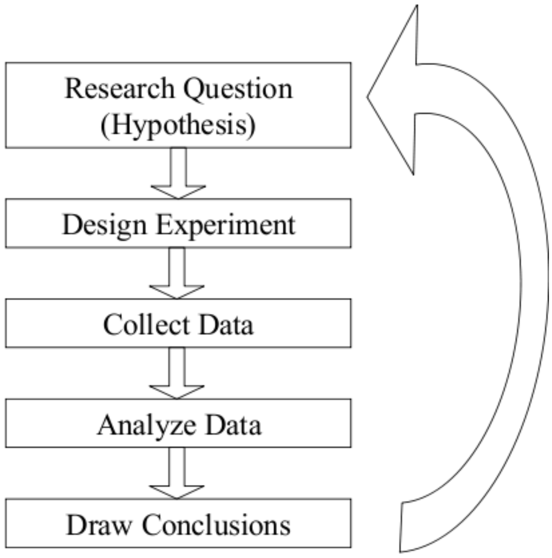

Figure 14: The Experimental Design Process

the measurements are: Chipsets, Memory, Data Storage, Processor and the chassis (fan, power supply, etc). The choice of analysing each component separately and also the whole computer power consumption was made in order to evaluate the behaviour of a machine configuration where a number of components have to interact and confront it to the expected behaviour of each component.

In order to obtain relevant data, three analysis' methods were used: empirical, benchmarking and research. For the empirical method, it was used an energy measurement device (section 3.3.2) that connected the electrical plug to the computer, and the measure was written in a spreadsheet 14. While doing this, the benchmarking tool (section 3.3.1) was performed in the host computer in order to acquire measures in a set of different situations. The last method, the research, carried with the use of a web crawler called WebSPHINX, provided information about the price and the MPN of each component in the database. As each component has a unique MPN this made possible to uniquely identify each one of them, enabling thus the use of a normalized database over the identified components.

In a later stage, all the data acquired by the measurement approaches was separated by categories and components. The database generated is described and furtherly explained in the section 3.4.

3.3 Energy Management and Benchmarking Tools

In order to obtain relevant information about the data required for making the comparison between the components, some energy management and benchmarking tools were used.

The softwares that used were selected over the other available ones for their superior evaluation on the following criteria:

Size of Database The database of components used by the software, in order to get a good result, should be considerably large;

Characteristics of Benchmarks The benchmarks provided by the software should provide information about the energy consumed for each component;

Number of Benchmarks The software should have a good variety of benchmarks;

Quality of Benchmarks Although the number of benchmarks should be sufficient in number, the quality, precision and relevancy were also important in the decision method;

Ease of Use In the sense that the software should provide an ambient of work that is both intuitive and user-friendly;

The acquisition of data was made analysing the results of these benchmarks, making use of their database and system measurement capabilities.

3.3.1 SiSoftware SANDRA

SiSoftware Sandra[2] is an information and diagnostic utility. It provides most of the information one need to know about their hardware, software and other devices whether hardware or software. SANDRA was the main software utilized to benchmark the data in this thesis work. It contains a vast database of components associated with both benchmark results and manufacturer specifications.

This software gives the possibility of benchmarking computer devices at several levels of operation. For example, it can benchmark a processor and show its performance over several operational levels, from power saving to full workload. Moreover, it may monitor

[2] The **S**ystem **AN**alyser, **D**iagnostic and **R**eporting **A**ssistant

the performance in several levels, from the overall performance of a system to the performance of its components, including CPU, memory, hard disks, CD/DVD ROM, network adapters, etc. For that reason, it is considered one of the most complete benchmarking tools available. Besides the benchmarking, Sandra also provides hardware specifications for components such as the Motherboard, processor, disks, printers, etc. One last resource is the benchmarking of software performance, which is provided for key softwares (web browsers, e-mail program, etc.), OS information, processes, memory usage and more.

The detailed list of modules utilized by SiSoftware Sandra can be found in Appendix A.

Furthermore, SiSoftware Sandra provides a catalogue of pricing, which, in addition to the power consumption and other important characteristics, enables the user to choose the best combination (which means the maximum performance/power ratio) of devices can be chosen to the server.

3.3.2 Energy Measurement Instrument

Figure 15: Energy Measurement Instrument

The device, which can be seen on Figure 15, was used for comparing and validating the results of the benchmarks given by Sandra. After the result of the benchmark was obtained from the SiSoftware Sandra, this equipment that was connected to the computer read how much energy it was consuming. The data from both sources were inserted in the database.

3.3.3 WebSPHINX - A Personal, Customized Web Crawler

WebSPHINX[3] is a Java class library used for web crawling. It provides a way to browse and process web pages automatically.

This piece of software was used to determine the componentÂ´s MPN code and also to create the pricing list, used in the database described in 4.1.

The target website used to obtain the information[4] provided a specific search engine for each kind of component. The searches for each one of those used a base URL concatenated with a page number and the result pages were standardised and presented a list of components of a specific category (i.e. hard drives or processors) along their MPN number and suggested price. This made possible the automation of the search and the subsequent filtering of the desired information. The individual components along with their MPN codes were inserted in the Device relation in the database while the pricing data were used in the Price relation.

3.3.4 CPU-Z

CPU-Z detects information about the CPU, RAM Memory, motherboard, chip-set and more. That program was used to complete the database with missing information about the components.

This software extracts system information such as name, number of cores, cache size and clock frequency for processors; mainboard model and chipset and size, bandwidth and type for main memory. This information is particularly useful when SiSoftware Sandra cannot identify a component or individuate its power consumption. The data obtained with the use of CPU-Z is confronted with the power consumption of similar components to obtain an estimate of the desired value.

3.4 Data Processing and Analysis

3.4.1 Measures

For each computer in which this method of data acquisition was performed the results were inserted in the tables 13 and 14. The Table 13 was obtained by running SANDRA

[3]Website-Specific Processors for HTML Information Extraction
[4]http://www.sisoftware.net/

benchmarks where the first column "Processor Benchmark" represents the results from the "Processor Arithmetic" benchmark, where the energy spent by the processor is displayed in the results. Afterwards, the "Cache & Memory" benchmark was executed and its estimate of the power consumption of processor, chipset and memory was inserted in the table.

Similarly, for the measurement device (table 14) the power consumption was measured in three situations: firstly, with the computer in idle state (monitor on, with no user processes running). Secondly, with the same configuration but with the monitor powered off. Lastly, the power consumption was measured with the processor fully stressed, i.e. while running SANDRA performance benchmarks. One limitation we had while taking measures is that it was only possible to obtain data from notebooks. In this way the difference between the measures with the monitor turned on or off should provide the monitor power, which is not considered by the Sandra benchmarks.

In order illustrate an example of the acquired data, only a few measures are displayed in the tables. The full version is evinced in Appendix E.

Computer Model	Processor Benchmark (W)	Cache & Memory Benchmark (W)
HPdv3500el (13.3")	19.69	26.69
HPdv6580el (15.4")	32.01	40.06
Compaq-nx9420 (17.0")	26.93	36.16
Acer Aspire 4720z (15.0")	19.78	34.57
Acer Aspire 5930G (15.4")	25.13	32.13

Table 13: SANDRA Table Analysis

Computer Model	Idle with Monitor On (W)	Idle with Monitor Off (W)	Estimated Monitor Power (W)	Processor Fully Stressed (W)
HPdv3500el (13.3")	28.57	25.19	3.38	35.64
HPdv6580el (15.4")	62.18	57.14	5.04	85.27
Compaq-nx9420 (17.0")	78.89	74.65	4.24	79.64
Acer Aspire 4720z (15.0")	44.57	39.88	4.69	67.28
Acer Aspire 5930G (15.4")	44.48	39.56	4.92	62.83

Table 14: Energy Measurement Device Table Analysis

3.4.2 Components Database

The Sisoftware SANDRA has a database with the results of all benchmarks for a considerable number of components making it proper for component comparison in terms of performance and energy efficiency. The data from this database was extracted to fit the database described in Appendix D.1.

The only issue related to the SANDRA database is the that components are not treated uniquely and each benchmark has its own list of components. For example, a benchmark of cryptography for the processor provides just the processor family "Intel Core 2 Duo T8400" while other relations may store a specific processor model, such as "Intel Core Duo T2300 (DC, 1.66GHz, 2MB L2)". As the database cannot be normalized in this way, it was necessary to provide an unique code for each component.

In Sisoftware website there exists a list of components and their suggested price. This list has a web-based version and also can be accessed inside the software, which besides the price provides all the information present in the linked inside the software for each component that is being analysed. An information from the website that has proven to be useful is the MPN code, that, like the ISBN for books, is unique for each component. Therefore, in order to create a unique relation with all the components that would be referred by the benchmark relations it was necessary to obtain these MPNs and assign them to the components and afterwards link them to the specific benchmarks. An example of the table generated with WebSPHINX for processors are shown in Table 15.

Processors	**MPN**
AMD Phenom II X4 940 Quad Core Processor	HDZ940XCGIBOX
Intel Core 2 Duo E8400 Dual Core Processor	BX80570E8400
AMD Athlon 64 X2 Dual Core Processor	AD775ZWCGHBOX
AMD Phenom II X3 720 Triple Core Processor	HDZ720WFGIBOX
Intel Core 2 Q9550 Quad Core Processor	BX80569Q9550

Table 15: Example of Table Generated by WebSPHINX

3.4.3 Manufacturer Specifications

The last set of information that was required by the final evaluation were the manufacturer specifications. These data were obtained by searching for each analysed computer model in the manufacturer site and looking for its components. As the more power-consuming components in a computer (excluding power supply components) are the processor, mainboard and memory, these were identified in the manufacturer site. After identifying the processor, mainboard and memory used in each computer, their specifications were used to validate the informations obtained by the benchmarks.

4 Analysis and Results

4.1 Analysis

4.1.1 Overview

4.2 Results

4.2.1 Benchmark Results

Conclusions

Perspectives and Future Developments

Suggestions for future developments, there are

-
-
-
-
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APPENDIX A – List of SiSoftware Sandra Modules

Here is the list of principal modules used in this research work.

•System Summary

•Mainboard/Chipset/System Monitors Info

•CPU/BIOS Info

•APM & ACPI (Advanced Power Management) Info

•PCI(e), AGP, CardBus, PCMCIA bus and devices Info

•Video Information (monitor, card, video bios, caps, etc.)

•OpenGL Information

•Keyboard Info

•Windows Memory Info

•Windows Info

•Font (Raster, Vector, TrueType, OpenType) Information

•Modem/ISDN TA Information

•Network Information*

•IP Network Information*

•WinSock & Internet Security Information

•Drives Information (Removable Hard Disks, CD-ROM/DVD, RamDrives, etc.)

- •Ports (Serial/Parallel) Info
- •Remote Access Service Connections (Dial-Up, Internet)*
- •OLE objects/servers Info*
- •Processes (Tasks) & Threads Info
- •Modules (DLL, DRV) Info
- •Services & Device Drivers (SYS) Info*
- •SCSI, SAS Information*
- •ATA, ATAPI, SATA, RAID Information
- •Data Sources Information*
- •CMOS/RTC Information*
- •Smart Card & SIM Card Information*

List of Benchmarks

- •Arithmetic Benchmark (including SSE2, SSSE3)
- •Multi-Media Benchmark
- •Multi-Core Efficiency Benchmark
- •Power Management Efficiency Benchmark
- •File System (Removable, Hard Disks, Network, RamDrives) Benchmark
- •Removable Storage/Flash Benchmark
- •CD-ROM/DVD Benchmark
- •Memory Bandwidth Benchmark
- •Cache & Memory Bandwidth Benchmark
- •Network/LAN Bandwidth Benchmark
- •Internet/ISP Connection Benchmark
- •Internet/ISP Peerage Benchmark

Applications and Usage

- •Hardware Interrupts Usage*
- •DMA Channel Usage*
- •I/O Ports Usage*
- •Memory Range Usage*
- •Plug & Play Enumerator*
- •Hardware registry settings
- •Environment settings
- •Registered File Types
- •Key Applications* (web-browser, e-mail, news, anti-virus, firewall, etc.)
- •Installed Applications*
- •Installed Programs*
- •Start Menu Applications*
- •Installed Web Packages* (ActiveX, Java classes)
- •System Event Logs*

* Commercial version only

APPENDIX B – Comparison Tape Drives

SDLT & DLT Tape Drives	Native Capacity & Transfer Rate	Compressed Capacity & Transfer Rate
DLT-S4	800GB at 60MB/s	1600GB at 320MB/s
SDLT 600	300GB at 36MB/s	600GB at 72MB/s
SDLT 320	160GB at 16MB/s	320GB at 32MB/s
SDLT 220	110GB at 11MB/s	220GB at 22MB/s
DLT 8000	40GB at 6MB/s	80GB at 12MB/s
DLT V4	160GB at 10MB/s	320GB at 20MB/s
DLT1	40GB at 3MB/s	80GB at 12MB/s
DLT-VS160	80GB at 8MB/s	160GB at 16MB/s
DLT-VS80	40GB at 3MB/s	80GB at 6MB/s
DLT 7000	35GB at 5MB/s	70GB at 10MB/s
DLT 4000	20GB at 1.5MB/s	40GB at 3MB/s
DLT 2000XT	15GB at 1.25MB/s	30GB at 2.5MB/s

Table 16: Comparison Between SDLT and DLT Tape Drives Capacities and Transfer Rates

Product	Capacity, native (uncompressed)	Average file access time (first file)	Data transfer rate, native (uncompressed)
T-Series			
T9840A	20 GB	8 sec	10 MB/sec
T9840B	20 GB	8 sec	19 MB/sec
T9840C	40 GB	8 sec	30 MB/sec
T9940A	60 GB	41 sec	10 MB/sec
T9940B	200 GB	41 sec	30 MB/sec
LTO Ultrium			
LTO Gen 1	100 GB	86-96 sec	15-16 MB/sec
LTO Gen 2	200 GB	64-75 sec	32-35 MB/sec
LTO Gen 3	400 GB	72 sec	80 MB/sec
SDLT			
SDLT 320	160 GB	82 sec	16 MB/sec
SDLT 600	300 GB	79 sec	36 MB/sec

Table 17: Access times for several tape drives

SDLT & DLT Tape Drives	Native Capacity & Transfer Rate	Compressed Capacity & Transfer Rate
LTO-4	800GB at 120MB/s (864GB per hour)	1.6TB at 240MB/s
HP Ultrium 1760	800GB	1.6TB at 576GB/hr
HP Ultrium 1840	800GB at 120MB/s	1.6TB at 240MB/s
HP Ultrium 960	400GB at 80MB/s	800GB at 160MB/s
HP Ultrium 460	200GB at 30MB/s	400GB at 60MB/s
HP Ultrium 230	100GB at 15MB/s	200GB at 30MB/s
IBM LTO-4	800GB at 120MB/s	1.6TB at 240MB/s
IBM LTO-3	400GB at 80MB/s	800GB at 160MB/s
IBM LTO-2	200GB at 35MB/s	400GB at 70MB/s
IBM LTO-1	100GB at 15MB/s	200GB at 30MB/s
Quantum LTO3	400GB at 245GB/hr	800GB at 490GB/hr
Quantum LTO3 HH	400GB at 68MB/s	800GB at 90MB/s
Quantum LTO2	200GB at 123GB/hr	400GB at 245GB/hr
Quantum LTO2HH	200GB at 94GB/hr	400GB at 144GB/hr
Tandberg Data LTO4 FH	800GB at 120MB/s	1.6TB at 240MB/s
Tandberg Data LTO3 FH	400GB at 80MB/s	800GB at 160MB/s
Tandberg Data LTO3 HH	400GB at 60MB/s	800GB at 120MB/s
Tandberg Data LTO2 HH	200GB at 24MB/s	400GB at 48MB/s
Tandberg Data LTO1 HH	100GB at 16MB/s	200GB at 32MB/s
Certance LTO-1	100GB at 960MB/min	200GB at 1920MB/min

Table 18: Comparison Between LTO Tape Drives Capacities and Transfer Rates

APPENDIX C – List of Other Energy Management Tools

C.1 Power To Change

Power To Change is a widget for desktops that measures how much energy was saved when the computer is turned-off. With this application installed, when the machine is turned on, the user can receive information about how much energy and carbon footprint it was saved while it was turned off, and also, compare with global results and others. The widget can be downloaded from `http://www.hp.com/powertochange`.

C.2 PlateSpin - Recon

This software did not compose the ones used for doing this thesis. Yet, it is important to notice this, because it is almost the same of Sandra, but it provides a more incisive work on Data Centers in general. It provides workload profiling, analysis and planning of complex server consolidation, disaster recovery, capacity planning, asset management and green data center initiatives. It also provides forecasting for optimizing the data center by collecting hardware, software and services inventory for all server workloads. Furthermore, it results an statistics work for the server workloads running on data center and how their resources are being used.

C.3 APC Virtualization Energy Cost Calculation

`http://www.techworld.com/green-it/news/index.cfm?RSS&NewsID=116650`

APPENDIX D – Database of Components

D.1 SANDRA Benchmark Table Schema

ID	**Number**	**Component ID**
OsType	Text	Architecture type (x86 or x64)
Platform	Text	Platform type (Desktop/Mobile/Server)
System Name	Text	CPU Model
Speed (MHz)	Number	CPU Speed
Power (.01W)	Number	CPU Power
CPU Type	Text	CPU Family
No of Core Units	Number	Number of CPU cores
FSB Speed (MHz)	Number	Bus Speed Obs: set as 0 for all records
Aggregate Performance (MOPS)	Number	Average between performance in dhrystone and whetstone benchmarks
Dhrystone int ALU value (MIPS)	Number	Dhrystone performance
Type of dhrystone	Text	Type of dhrystone benchmark (.NET)
Whetstone float FPU value (MFLOPS)	Number	Whetstone performance
Type of whetstone	Text	Type of whetstone benchmark (.NET)

Table 19: RefDNetAA: .NET Arithmetic Benchmark on several CPUs

D.2 Database Schema

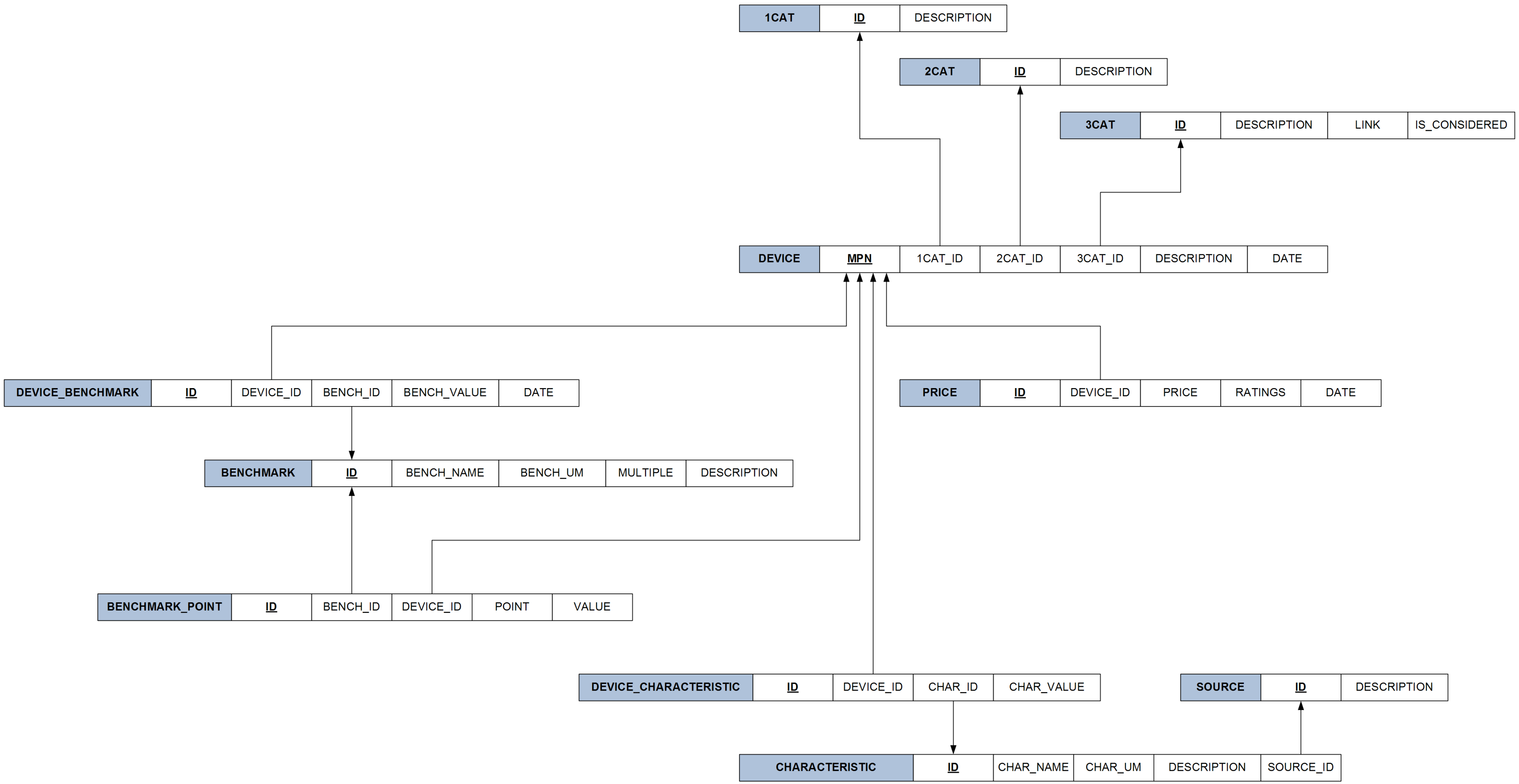

Figure 16: Database Schema

APPENDIX E – Measures

E.1 Measurement Tables

E.2 Characteristics of Measured Computers

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