Designing and Building an Environmentally Responsible Data Center

A Technical Paper
in STS 402

Presented to

The Faculty of the
School of Engineering and Applied Science
University of Virginia

In Partial Fulfillment

Of the Requirements for the Degree

Bachelor of Science in Computer Engineering

By

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April 25, 2008

On my honor as a University student, on this assignment I have neither given nor received unauthorized aid as defined by the Honor Guidelines for Papers in STS courses.

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1 Introduction

A new buzz word, *"Green"*, is on everyone's tongue recently, which is the result of a growing trend all over the world. For years groups like Clean Air Watch[1] and the Sierra Club[2] have advocated a change in modern society's habits in favor of a cleaner and "*greener"* Earth. The industrial world is embracing this trend with the hybrid car. For example, even Capitol Hill is moving toward a change with U.S. House Speaker Nancy Pelosi's plan to "*green"* the Capitol complex[3].

While "Green" carries a specific connotation of minimizing energy consumption and/or carbon emissions, it also makes superb business sense in the IT community. IT systems, particularly for data centers are a significant consumer of electricity. The United States Environmental Protection Agency (EPA)[4] has stated that data centers consumed 59 billion kilowatt hours (KWh) in 2006 ($4.1 billion) of which the federal government is responsible for 10% and it is estimated to increase up to 103 billion KWh by 2011[5]. Many data center managers see the energy bill for operating the equipment and power consumption becomes a major concern for them. Servers and storage have developed into a very power-hungry element of data centers. Thus Data Center managers are beginning to embrace "Green IT" and "Green" data centers have become a significant factor in future data center design.

Procuring power efficient hardware is not just a smart business move for companies that are trying to save money, but it will soon become a mandatory shift when laws are passed to force such a change. Europe has already seen signs of this shift with the European Commission publishing the Directive 2005/32/EC on the eco-design of Energy-using Products (EuP)[6] and with the recycling regulations that are already in place.

People around the world have grown socially aware, questioning the morality of political, social and business decisions taken. Thanks to the Internet, information has become easily accessible to everyone, which has allowed people to be more aware of their surrounding. Businesses and agencies are thus under a magnifying glass and every move they make is judged by society. Therefore, they do not want to conduct business in such a manner that would reflect a bad image. Since the hot topic of today is being environmentally friendly, it is crucial that companies adopt the *"Green"* attitude.

[1] Clear Air Watch home page: http://www.cleanairwatch.org/
[2] Sierra Club home page: http://www.sierraclub.org/
[3] Effort to 'green' U.S. Capitol complicated by coal, Jim Spellman and Andrea Koppel, CNN, May 11, 2007: http://www.cnn.com/2007/POLITICS/05/10/capitol.green/index.html
[4] EPA home page: http://www.epa.gov
[5] US government plugs ways to cut data centre power needs, Patrick Thibodeau Framingham, Computer World, Monday, 28 May, 2007: http://computerworld.co.nz/news.nsf/spec/435883A59AAA52C4CC2572E600008A23
[6] Environmentally-friendly design of Energy-using Products: framework Directive for setting eco-design requirements for Energy-using Products (EuP): http://ec.europa.eu/enterprise/eco_design/index_en.htm

In the United States of America, this movement has been fueled by a society that has been advocating this movement. But soon enough government regulations in the US will be another driving force for IT companies to go *"Green"*. The European Union has already started on that track with the Restrictions on Hazardous Substances (RoHS) and Waste Electrical Equipment (WEEE) regulations. Although such regulations do not exist in the US, the Environmental Protection Agency (EPA) is working to include with the ENERGY STAR power consumption ratings hardware such as servers in its certification program[7].

As system components become faster and more effective, they also dissipate more heat. Chip manufacturers have focused their design on functionality and performance but not so much on heat efficiency. This allows more heat dissipation, while at the same time lowering the maximum acceptable temperature of operation for these chips. Such characteristics of the systems in use lead to a higher need for cooling per chip to avoid overheating and damage to the processors. The heat problem translates itself into a power and efficiency problem. These chips consume more power than their predecessors, so data center managers these days can only stack ten servers in the same rack that used to hold up to thirty servers[8]. At the same time, these devices generate more heat, which equates to higher cooling power. Cooling a data center requires sophisticated and elaborate equipment that consumes power, exacerbating the power dilemma.

With the average cost of Kilowatt-Hours (KWH) in the U.S at around $0.092 in 2007 and $0.0892 in 2006[9], running a data center can be costly. Cooling accounts for a major portion of the energy bill, second only to the cost of running the equipment itself. The lack of focus toward designing an efficient data center has resulted in the need of between 0.5 and one watt to cool one watt of equipment when ideally managers would like to achieve a 0.3:1 cooling watt to equipment watt ratio. Making cooling efficiency the major concern in the design of a data center, and purchasing energy-efficient or "*green*" hardware becomes compelling.

Data centers' energy bills are rising fast, it's becoming a budget issue for the entire company. Managers need to find a way to reduce the energy cost while maintaining their high efficiency productions that business customers require these days.

Processor chips are designed to include the maximum computing power possible in the least space possible. This results in a need for more power and dissipating more heat per unit of equipment. It turns out that this strategy is less efficient because neither data centers nor the electric utility companies are able to provide enough power to the racks housing the hardware or to generate the necessary cooling that is required to compensate for the heat produced by the servers, switches and routers present in the data center.

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[7] The Greening of IT, Christopher Mines, Frank E. Gillett, Forrester, April 19, 2007

[8] Power and Cooling Heat Up The Data Center: Maximizing Efficiency Yields Both Pragmatic And Social Benefits, Richard Fichera, Forrester, March 8, 2006

[9] Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Energy Information Administration, June 13, 2007: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html

Data center managers found out through experience that the key to efficiency was not physical space but power consumption. Unfortunately the chip manufacturing industry focuses the design mainly toward speed and not power efficiency. Throughout the years, semiconductor design has favored higher speed allowing higher leakage currents. Leakage current is wasted energy flowing through the junctions when the transistor is in the “zero state”. Estimations indicate that leakage current in high-end processors is between 18% and 20% of total power consumption[10].

Measuring the efficiency of a data center lies in measuring the ratio of systems per rack. But an average data center is equipped to handle racks powered up to 5-6 KW worth of equipment and its equivalent cooling power. With the hardware specifications discussed earlier, stacking racks to their full capacity will require them to be powered with approximately 25 to 30 KW per racks, which becomes a design issue and a critical point for vendors and data center managers[11].

The IT market is very competitive in terms of providing the best services, but what characterizes such a service is the speed and functionality of the equipment rather than the component efficiency. Power supplies are the main component that gets neglected in favor of such competitiveness. The consequences are a data center that consumes more power in power conversion and cooling than the computer systems actually need. This means that most of that power is wasted energy which we can work on saving by using energy efficient equipment[12]. There is a classic cost tradeoff between a more efficient (expensive) power supply and the cost-savings over the life cycle.

In this thesis we will present the common techniques and technologies used in today’s data centers, we will then show why they are inefficient in terms of energy consumption. Once we have determined the problem we will give solutions for deploying and operating an energy efficient data center.

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[10] Power and Cooling Heat Up The Data Center: Maximizing Efficiency Yields Both Pragmatic And Social Benefits, Richard Fichera, Forrester, March 8, 2006

[11] Power and Cooling Heat Up The Data Center: Maximizing Efficiency Yields Both Pragmatic And Social Benefits, Richard Fichera, Forrester, March 8, 2006

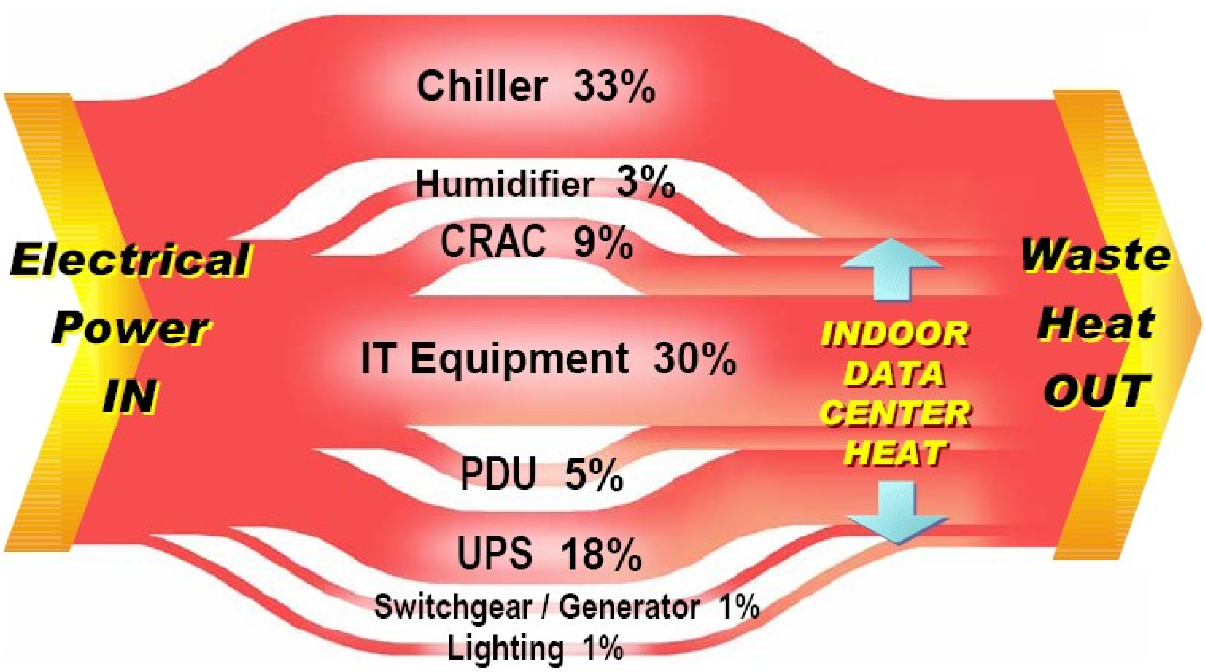
[12] The Green Grid Opportunity: Decreasing Datacenter and Other IT Energy Usage Patterns, The Green Grid, February 16, 2007: http://www.thegreengrid.org/gg_content/Green_Grid_Position_WP.pdf

2 Power

2.1 The Problem

Powering a data center is not inexpensive. With the average cost of Kilowatt-Hours (KWH) in the U.S at around $0.092 in 2007 and $0.0892 in 2006[13] and with the rising costs of gas, running a data center is costly. The United States Environmental Protection Agency (EPA)[14] stated that data centers consumed 59 billion kilowatt hours (KWh) in 2006 ($4.1 billion) and it is estimated to increase up to 103 billion KWh by 2011[15].

The first point of contact for power is with the UPS (Uninterruptible Power Supply) system followed by the power distribution units (PDU) located at various points within the data center. According to Figure 1, about 23% of energy is wasted at the PDU and UPS level, so increasing efficiency at this level is important when trying to build a "green" data center.



- **Figure 1 – Areas of Interest for Power Improvement, Source: Implementing Energy Efficient Data Centers, Neil Rasmussen, APC.**

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[13] Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Energy Information Administration, June 13, 2007: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html
[14] EPA home page: http://www.epa.gov/
[15] US government plugs ways to cut data centre power needs, Patrick Thibodeau Framingham, Computer World, Monday, 28 May, 2007: http://computerworld.co.nz/news.nsf/spec/435883A59AAA52C4CC2572E600008A23

2.2 The Solution

Right-sizing the physical infrastructure system to the load, using efficient physical infrastructure devices, and designing an energy-efficient system are all techniques to help reduce energy costs. There are fixed losses in the power and cooling systems that are present whether the IT load is present or not, and these losses are proportional to the overall power rating of the system and new best-in-class UPS systems have 70% less energy loss than legacy UPS at typical loads[16].

The following ideas are proposed to help increase the power efficiency at the level of UPS and PDU systems:

- **A modular power system that can easily grow and adapt to changing power requirements:** System requirements are difficult to predict and the majority of systems are significantly oversized. Research shows that typical data centers today are utilized to less than 50% of their infrastructure capacities. In addition, industry projections of power density requirements show power density that is increasing and unpredictable, yet new data centers must meet requirements for 10 years.
- **Pre-engineered standardized power solutions that eliminate or simplify the planning and custom engineering in order to accelerate the speed of deployment:** The planning and unique engineering involved in traditional power systems takes 6-12 months, which is too long when compared with the planning horizon of most organizations. Engineering is time-consuming, expensive, a key source of downstream quality problems, making it very difficult to expand or modify the installation later.
- **A power system with mistake-proofing features and decreased single points of failure that improves system availability:** According to the Uptime Institute, 40% of all downtime in data centers is caused by human error. In addition, traditional UPS systems placed far upstream of the IT loads result in more circuit breakers that act as single points of failure.
- **A management system that provides visibility and control of power at the rack and outlet level:** Dynamic power variations among servers and constantly changing and reconfigured loads at the rack level are causing unexpected overload conditions and overheated racks. As power densities per rack continue to rise, these problems will only get worse.
- **A power system with standardized, hot-swappable, user-serviceable modules that reduces Mean Time to Recover (MTTR):** With traditional systems, spare parts are not readily available, and diagnosis and repair are invasive. These systems can be so complex that service technicians and maintenance staff make errors and drop loads when operating and maintaining the system[17].

Many companies have developed tools to control the power in a data center. In fact power management tools have become widely available, but very rarely used in practice.

[16] Guidelines for Energy-Efficient Datacenters, the Green Grid, February 16 2007
[17] Facility Considerations for the Data Center, APC and PANDUIT and Cisco Systems

According to the chairman and chief scientist at the Rocky Mountain Institute, the electricity usage in a typical data center hardly varies but the IT load varies by more than two factors. This means that more power is consumed in a data center than needed. By employing power management tools, energy requirements for data centers can be cut by about 20%, but unfortunately this is not taken advantage of by manage data center managers[18].

One example of power management tools that is in use in several U.S. military data centers is Cassat's Collage. Some of its features include:

- **Automating Power on and power off of physical servers:** Collage directly controls server-level (and even blade-level) power controllers such as Dell ERA, Dell RAC, and HP iLO. For servers without embedded power control, Collage supports third-party Power Distribution Units such as those from APC. When a server is not assigned and/or not in use, its controller is automatically switched off. Collage automatically—or manually—discovers servers and their associated power controls that are placed in the data center.
- **Power-conscious standby infrastructure:** For servers in HA and DR pools, their associated power controllers are automatically switched off by Collage when they are idle. If/when needed, these servers are switched on and provisioned with the appropriate applications. Further, in the case of large or catastrophic failures, Collage has the capability to power on large quantities of servers in priority-based sequence.
- **Moving compute loads to least expensive power geographies ("follow-the-moon"):** With Collage, local electrical costs as well as electrical consumption-per-server can be treated as a constantly monitored Service-Level Agreement (SLA). The Collage Controller optimizes against these variables, relocating application loads onto servers in geographies where overall electrical cost-per-server is lowest.
- **Time-based compute load migration to least expensive power geographies:** With Collage, the location and instantiation of specific applications can be applied as time-based policies. Thus, on a regular basis, the Collage Controller relocates application loads onto servers in geographies where overall electrical cost-per-server is lowest.
- **Policy-based utilization of most energy-efficient equipment:** Collage can assign arbitrary factors—such as power efficiency or power cost—to physical servers in its inventory. Policies can then be assigned to individual applications, or even data-center-wide, to assign higher-efficiency servers to meet compute demands.
- **Power off servers with low-priority applications during power emergency:** Collage provides the facility to assign priority levels to applications. When a

[18] The Greening of IT, Save Energy, Save Costs and Save the environment, Computerworld Executive Briefings

trigger condition occurs, certain class(es) of applications (and associated servers) can be minimized, shut down, or rescheduled per predetermined policy.

- **Graceful IT curtailment/shutdown during unplanned environmental conditions:** The Collage controller can be instructed to gracefully shut down physical servers based on predetermined server/application priority. Simple coordination with environmental sensors/systems can determine the velocity of shut down or geographical migration. If/when ordinary conditions resume, the controller can automatically reverse the shut down and restart applications in priority order[19].

2.3 Taking it a Step Further

Most data centers rely on the local energy provider for electricity source and back it up with a big diesel generator in case of power outage. But we have seen lately that eco-friendly data center owners are changing the trend by looking for alternative energy sources. Popular energy sources include solar energy, hydraulic energy and geothermal energy. Google and Microsoft are examples of companies that are opening new data centers next to greener energy sources.

Hydro-power: Hydroelectric plants are easy to build wherever a multipurpose damn exists and the cost of running them is very low. These plants do not depend on fossil fuel so that cost is eliminated and greenhouse gas emissions will not be a concern. On the other hand hydroelectric plants may cause a disturbance in the aquatic life of the surrounding region by reducing the possible mating regions. But in general hydroelectric plants are a good way to produce predictable and stable loads of power[20] [21].

Geothermal energy: The energy harnessed from this method is clean and safe for the surrounding environment. It is also sustainable because the hot water used in the geothermal process can be re-injected into the ground to produce more steam. Geothermal energy is unaffected by weather change and can operate both day and night and it does not require any dependence on fossil fuel. Some concerns exist about injecting hot water into areas of dry rock where water has never been before and concerns about whether a specific geothermal location can undergo depletion. But overall geothermal energy has great potential. If heat recovered by ground source heat pumps is included, the non-electric generating capacity of geothermal energy is estimated at more than 100 GW (gigawatts of thermal power) and is used commercially in over 70 countries. A 2006 report by MIT, that took into account the use of Enhanced Geothermal Systems (EGS), concluded that it would be affordable to generate 100 GWe (gigawatts of electricity) or more by 2050 in the United States alone, for a maximum investment of 1 billion US dollars in research and development over 15 years[22] [23] [24].

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[19] Dynamic Server Power Management and “Green Data Centers”, Cassatt

[20] Beyond Three Gorges in China, Water Power and Damn Construction Magazine International, January 10 2007: http://www.waterpowermagazine.com/story.asp?storyCode=2041318

[21] Graham-Rowe, Duncan, Hydroelectric power's dirty secret revealed, New Scientist, February 24 2005: http://www.newscientist.com/article.ns?id=dn7046

Solar energy: Solar energy has been in use for a few years and electricity generation can be done at different levels. For small or medium-sized application, Photovoltaics (PV) is usually used. As for large-scale generation, concentrating solar thermal power plants have been more common but new multi-megawatt PV plants have been built recently. This mean of power generation is scalable which is helpful for data center managers who might want to expand in the future.

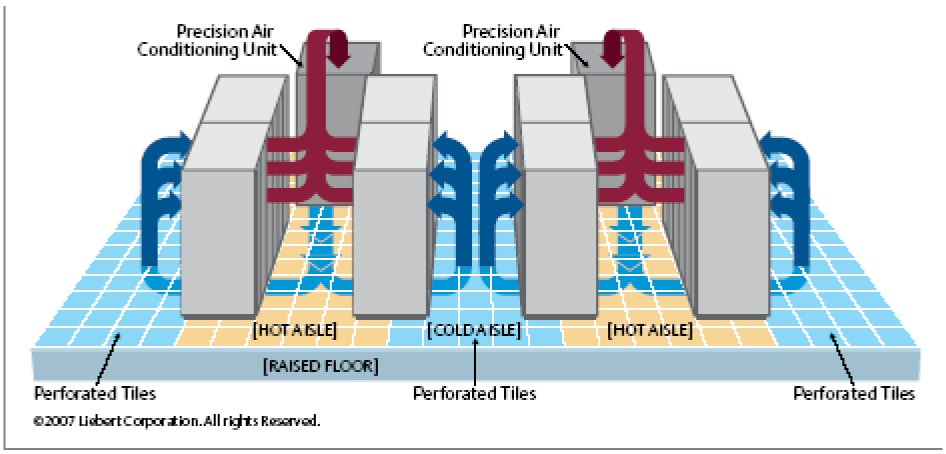
Power is an area in data center design that can be improved enormously to achieve better energy efficiency. Rightsizing, deploying modular power systems and using power management tools are a few ideas to increase power efficiency.

[22] Geothermal energy links to other alternative energy and geothermal information websites. Retrieved March 13, 2008, from http://www.solarnavigator.net/geothermal_energy.htm.
[23] Matheson, I. (2005, April 22). Kenya looks underground for power, BBC. Retrieved March 13, 2008, from http://news.bbc.co.uk/2/hi/africa/4473111.stm.
[24] The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, Massachusetts Institute of Technology, 2006

3 Cooling

3.1 The Problem

The average data center sits on a raised floor with peripheral cooling units that receive the hot air from the ceiling vents, cool it, and send it back to the racks under the raised tiles. A poorly built data center does not account for energy use and the perforated tiles are randomly placed all over the data center and most likely cable is running under the elevated tiles blocking the flow of cool air coming from the peripheral conditioning units. And most likely, servers are grouped together in one small area making it a high density surface that requires more power to cool and thus the cooling intensity in the entire data center is increased in order to cater for that particular spot. When more equipment is added, more heat is emitted so the need for additional cooling increases resulting in more power consumption to achieve the cooling level necessary to keep the room at the adequate temperature. This legacy approach has been in place for many years and looks something like figure 2. This briefly describes a very inefficient data center in terms of cooling efficiency. The problem is very important to solve and there are multiple things that can be done. Some of the solutions require a total reconstruction of the entire data center from scratch but others can be implemented without major infrastructure change, following are some ideas on both levels.



- **Figure 2 - Raised Floor Cooling, Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency, Source: Liebert**

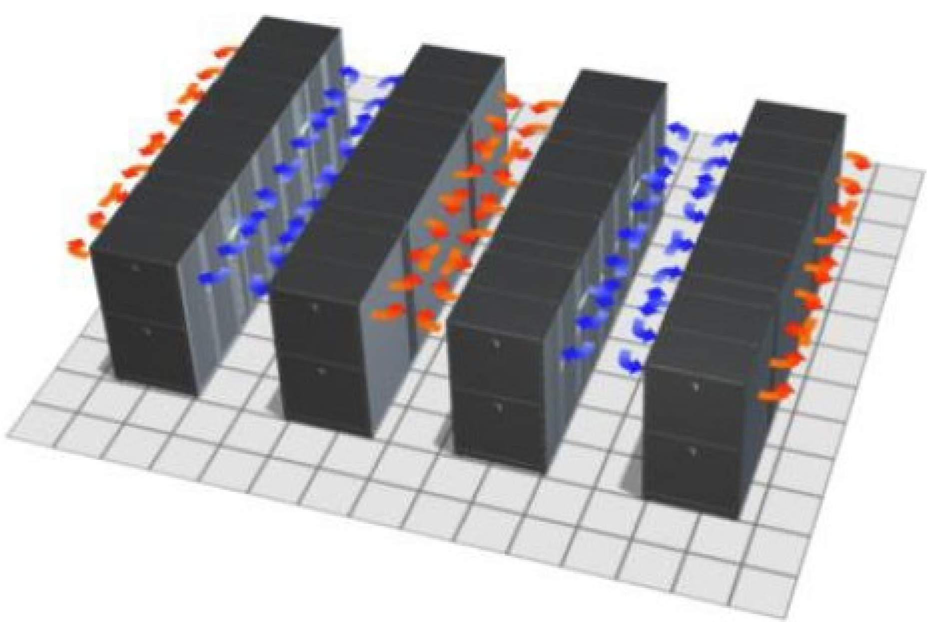
3.2 The Solution

Businesses might approach going green in different manners, some might decide to keep their current data center and apply a redesign to introduce more energy efficient features to the current design and other businesses might be looking to build a new data center from the bottom up. Cooling is an area of data centers that allows both possibilities and following are the strategies to go green for both situations.

3.2.1 Redesigning an existing data center

One simple step that can be taken to significantly improve the cooling of data centers is to cleverly position and orient racks to make cooling the hotter equipment a bit easier. This step involves a couple of tricks: hot aisle/cool aisle layout and spreading the equipment over the surface area.

Hot aisle/cool aisle: all electronic equipment is designed with a fan that takes in outside air to cool the hot chips -- for our design purposes we will call that side the front -- and an exhaust that exhausts the heat; we will call that side the back. If we face the back (the exhaust) of one server to the front (the fan) of another sever we would be pumping hot air into the box and negating the efforts of the air conditioning units who would have to work twice as hard to re-cool the air coming from the perforated tiles that got mixed with the hot air. This situation is both inefficient and also will damage the hardware. Where if we position all the equipment such that the fronts face each other and the backs face the other side we would create what is known as the hot aisle/cool aisle design shown in figure 3.

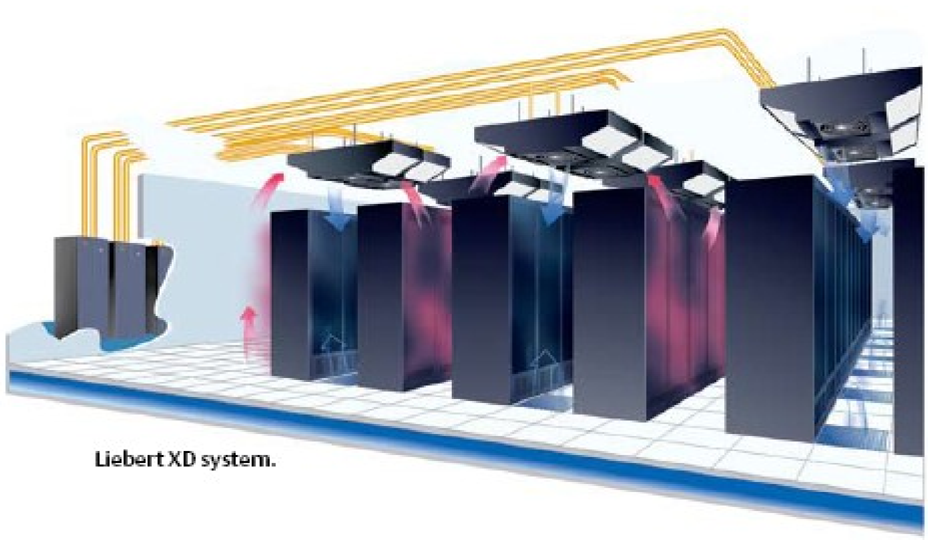


- **Figure 3 - In-Row Cooling Solution, The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers, Source: White Paper #130, Kevin Dunlap and Neil Rasmussen, APC**

This design eliminates the problem stated previously but also achieves even more cooling efficiency. The perforated tiles in the new design do not have to be spread all over the data center, in fact they can be concentrated in the cool aisles where the pump cool air sufficient just too feed the fans, decreasing the load on the peripheral cooling units as well.

To achieve these results the racks must be rearranged. If these racks stand on wheels then moving them around would not be a huge problem, otherwise a bit of manual work is in order. No matter the case, some rewiring will be necessary. This involves some tedious work but that can be easily done and the rewards and worth it.

If it is possible, we can take the effort a step further by trying to increase the efficiency of the heat elimination in the room and the cool air circulation. For that Liebert offers a system that improves on these areas. Liebert suggests placing cooling modules above the racks to complement the perforated tiles by supplying cool air to elevated servers and providing a more efficient way to eliminate the hot air and prevent it from mixing with the cool air as shown in Figure 4[25].



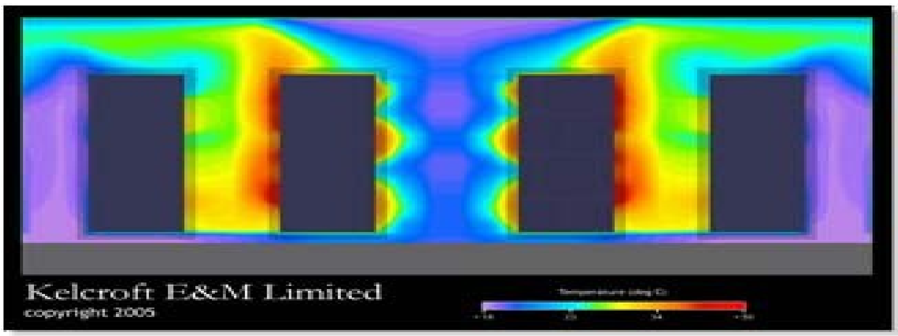
- **Figure 4 - Liebert XD System, Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency, Source: Liebert**

Spread the heat: Placing certain hardware in proximity is an error that many data center mangers commit and the reason usually is the fact that the equipment is part of the same project or performs the same task it is easy to group them together. But in fact if a server sits in one building and another sits in a second building, they could do the same operations as if they were mounted in the same rack as long as they have the proper connections. What this produces is certain areas of the data center where all the computing power is concentrated and with it is a bigger heat density, whereas on the other end of the room is a very cold spot. The effect of this situation is the requirement for the cooling units to work harder to cool the high density areas by pumping more cool

[25] Five Strategies for Cutting Data Center Energy Costs through Enhanced Cooling Efficiency, Liebert

air into the room because the system is designed to cool the entire room as a whole, and thus most of cooling power is wasted on the areas that do not have as high a heat density.

What a data center manager can do is purchase an inexpensive thermo sensor and evaluate the room housing the data center. After locating the hot spots, the manager has a better idea of the heat distribution in the room and can distribute the equipment in a way to equally spread the heat emission within the room and allowing the cooling units to perform more efficiently.



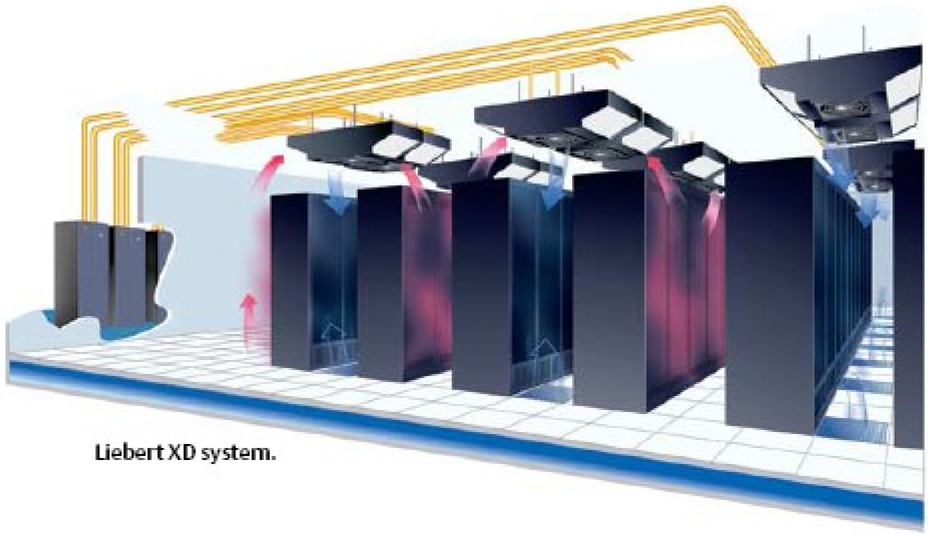
- **Figure 5 - Thermo image of a data center, Source: http://datacenter.kelcroft.com.hk/img/data_centre_design_103.jpg**

3.2.2 Building a new data center

When building a new data center it is crucial to move away from the traditional thinking and designs that have been the trend in data centers for the last several decades. The old ways worked with a technology that is outdated and replaced by new technology that is much more demanding on the cooling side because of its higher heat dissipation. This is why the entire approach of cooling a data center should be reworked to better suit the new technologies used in the IT sector. Following are a few approaches offered to help design and build a cooling efficient data center.

Replace raised tiles with in-row, in-rack cooling: One of the leading companies in data center cooling, APC, suggests that the cooling paradigm should change where the peripheral conditioning units are part of a legacy design. This concept places a conditioning unit in-row with the racks, closely coupling the cooling with the heat load. The conditioning unit captures heat directly from the hot aisle and distributes cool air back to the equipment. The benefits of this design are in its scalability and specificity. The data center cooling does not need to be designed in order to meet future needs from day one, but instead it can easily be upgraded as the need grows. The concept also provides a contained rack environment that is not affected by its surroundings, this way the cooling can be adjusted specifically for the racks it serves making it more efficient[26]. Figure 6 shows an example environment of in-row cooling.

[26] The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers, White Paper #130, Kevin Dunlap and Neil Rasmussen, APC



- **Figure 6 - Liebert XD System, Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency, Liebert**

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To achieve these results the racks must be rearranged. If these racks stand on wheels then moving them around would not be a huge problem, otherwise a bit of manual work is in order. No matter what the case is, some rewiring is necessary, which involves some tedious work but that can be easily done and the rewards and worth it.

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Proper sealing of the Data Center environment: Cooling efficiency is reduced because of loss through building material such as tiles and walls and doors which can also increase humidity in the data center. Humidity can damage computer chips and increase chances of error in hardware. Thus building a well contained room becomes vital to maintaining an efficient data center. Such a thing can be achieved by using a vapor seal to isolate the data center atmosphere. This method is both important and non-costly[28].

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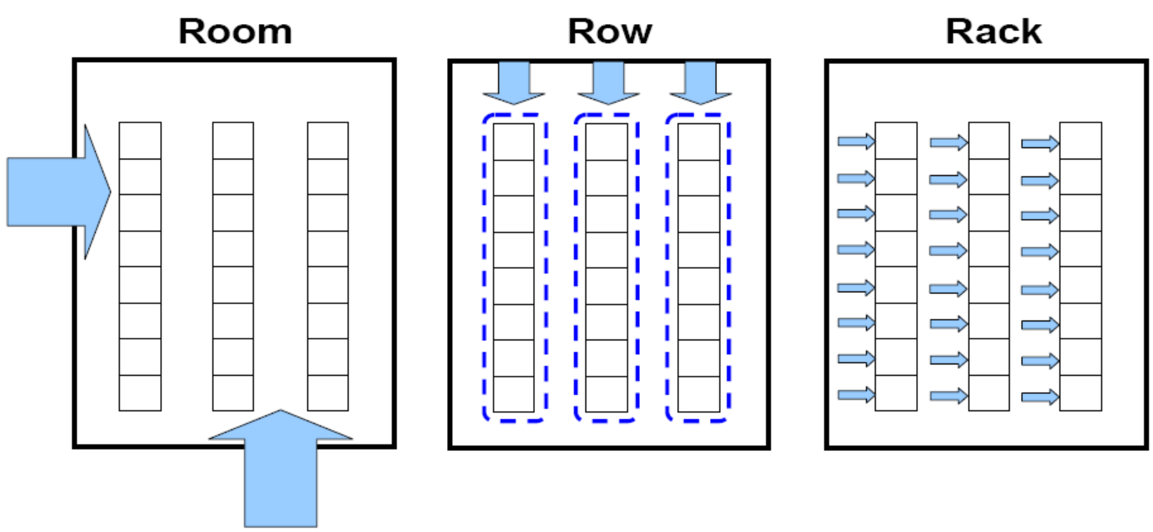
[27] Five Strategies for Cutting Data Center Energy Costs through Enhanced Cooling Efficiency, Liebert
[28] Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency, Liebert

Cooling efficient locations: The location chosen to build the data center in plays a big role in achieving energy efficiency. A location known for its cold weather can help increase cooling efficiency through the use of economizers to capitalize on the outside atmosphere to help cool the data center. This supplements the existing cooling system with one that provides "free cooling" through natural conditions[29].

Room, row, rack cooling architectures: As loads are becoming denser it is becoming harder to cool the equipment using just room based cooling architectures with peripheral units pumping the air to the entire room. Cooling has to adopt with the high heat emitted by the computer chips and certain areas in the data center might be denser than others because of utilization of blade server or multi-core servers so it is important to employ additional cooling that focuses on these dense areas. To do so managers can utilize techniques to adopt the in row cooling strategy which focuses on cooling each row separately or fore extremely dense spots, in rack cooling can be adopted to supplement the existing cooling architecture deployed in the room[30]. Figure 7 illustrates the three architectures discussed.



- **Figure 7 - Floor plans showing the basic concept of room, row, and rack-oriented cooling architecture. The Advantages of Row and Rack - Oriented Cooling Architectures for Data Centers, Source: APC**

Cooling has proved to be one of the areas where most advances have occurred. The thought process and designs around cooling are changing allowing major improvements toward energy efficiency in the data center.

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[29] Five Strategies for Cutting Data Center Energy Costs Through Enhanced Cooling Efficiency, Liebert
[30] The Advantages of Row and Rack – Oriented Cooling Architectures for Data Centers, APC

4 Equipment

4.1 The Problem

A data center is comprised of IT equipment consisting of one or more network routers, servers, storage equipment and security systems. All this hardware consumes tremendous amounts of power which the majority of it is emitted as wasted heat. Until recently, most of the designs and architectures of these technologies have focused on ways to increase the computing power of the hardware which came at the cost of an increase in power consumption. But now that the entire industry is concerned with energy efficiency, many innovations have been developed to deal with this issue and figure out ways to increase the computing power of the hardware without increasing the power consumption or even achieving a reduction in energy use.

Choosing the right racks and setting in place the appropriate cooling provides the hardware with the best environment possible in order for it to run optimally. The hardware is what it comes down to, why we talk about data centers and data center designs, but it is also where the problem resides. Servers draw power and convert that energy into an application process. Unfortunately most servers do not run at full capacity and most of the energy drawn is wasted. The wasted energy is transformed into heat that needs to be cooled. Improving on server power utilization becomes extremely beneficial in building a green data center. Many obstacles lie in front of achieving this goal, most of them result from the physical characteristics of the hardware components of the boxes in use.

4.2 The Solution

4.2.1 Power Supplies

The most modern computer power supplies typically have an average efficiency—in terms of the portion of the incoming energy that actually reaches the device—of only 50 percent at lighter loads and 67 percent for heavier loads. Most PC motherboards convert the different voltages of electricity coming out of the power supply to meet the varying needs of computer components. Manufacturers, therefore, must engineer power supplies to support multiple voltages, rather than optimize them to output just one voltage. This creates power-use inefficiencies. The solution to this problem comes from creating a simple standard in which the power supplies only have to convert the input AC electricity to 12 volts and the motherboard will then use its transformers to convert the 12 volts to whichever voltage is required by the different systems. This solution works assuming that the transformers found on the motherboards are optimized and more efficient than the power supplies. It is estimated that if the power supplies need to output only a single 12 volts current then the conversion process may be completed at up to 92 percent efficiency[31] [32]. The 80 PLUS® program[33] is a program dedicated to the development of energy efficient power supplies. This program works in parallel with the ENERGY STAR program of the Environmental Protection Agency (EPA) to rate and certify power supply products and manufacturers[34]. This provides a good guidance for data center managers who are looking to purchase new equipment.

4.2.2 Multi-Core Processors

In the last couple of years we have witnessed the surge of multi-core processors. These processors have both the advantage of a better computing power and better energy consumption. One way to make use of this new technology is to:

- Replace each dual processor server in a data center with a single processor, dual core server.
- Use a dual processor server or a single processor dual core server to replace 2 or more old single processor, single core servers
- Use a dual processor dual core server in place of a 4 single processor, single core servers.[35]

Multi-core processors present the advantage of resource sharing which leads to a higher efficiency of use of these resources. A multi-core processor shares power supplies and memory and other components of a server which means that less energy is required to powered the system. Multi-core processor servers also provide the opportunity for businesses to use tools that will help with the power efficiency such as virtualization which is discussed in this section[36].

4.2.3 Blade Servers

Blade servers are an example of new designs being employed to resolve certain issues with legacy servers. Blade servers take advantage of shared resources in order to cut down on components that are housed in a single blade. Things like storage and power supply can be shared by multiple servers, so in a blade server environment those components become shared resources and a cluster of blades would require only one instance of those resources. This achieves a reduction in space, which means a more efficient use of the data center footprint. It also achieves a more efficient use of these resources and in the case of components such as storage only one piece of hardware needs to be powered, thus requiring less power. Blade server advocates claim that this solution is a greener one, but many are still skeptical stating that the high density blade servers would collectively produce more heat that is concentrated in one area of the data

[31] Powering Down the Computing Infrastructure, George Lawton, IEEE, February 2007
[32] Google Wants Energy-Efficient Hardware, September 26 2006, http://googlesystem.blogspot.com/2006/09/google-wants-energy-efficient-hardware.html
[33] 80 Plus home page: http://80plus.org
[34] 80 PLUS® Certified Power Supplies and Manufacturers, http://80plus.org/manu/psu_80plus/psu_join.php
[35] Implementing Energy Efficient Data Centers, Neil Rasmussen, APC, 2006
[36] Intel® Multi-Core Processors, Making the Move to Quad-Core and Beyond, R.M. Ramanathan, Intel Corporation, 2006

center. This is a problem in many of the old data centers which are designed in such a way that the entire room is cooled using a peripheral cooling unit that forces cool air through raised flooring. Such a design suggests that the heat is evenly distributed around the data center, whereas blade servers contradict this assumption. Blade servers achieve higher computing capacity with less equipment, which falls under a “do more with less” paradigm that many in the industry today suggest is the future of IT. As for the cooling issue, adopting the high density rack solutions discussed in the cooling section would easily resolve the problem[37] [38]. Most manufacturers provide blade solutions, such as Dell with the PowerEdge blades, HP with the ProLiant BL blades and the Integrity BL blades, IBM with the BladeCenter HS20 Express Model and the BladeCenter HS21 Express Model, the Intel® Server Compute Blade SBXD132 and SBX82, and Sun with the Sun Blade 6000 Family and the Sun Blade 8000 Family[39] [40] [41] [42] [43].

- **Figure 8 - Sun's Blade 8000 Modular System, Source: http://www.sun.com/servers/blades/8000**

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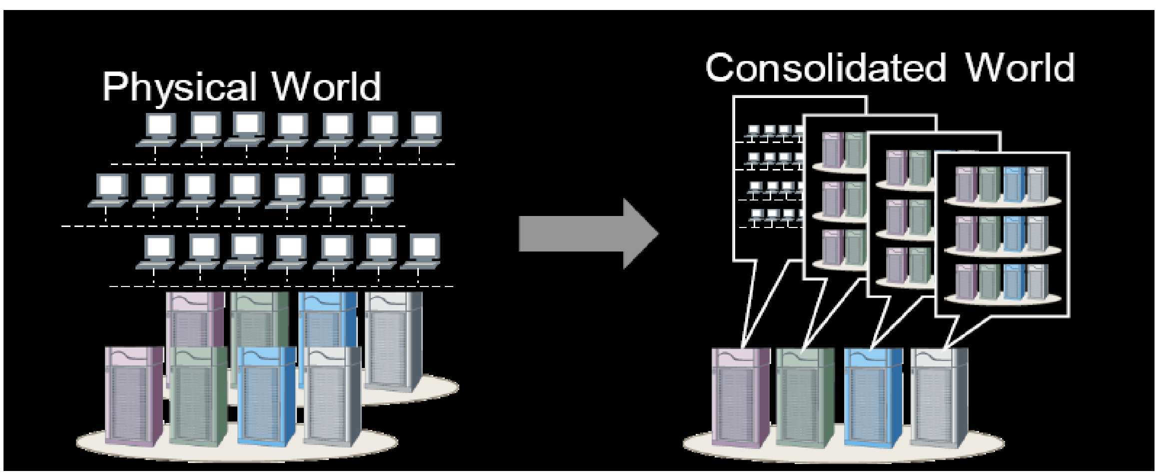
[37] Implementing Energy Efficient Data Centers, Neil Rasmussen, APC, 2006
[38] Power and Energy Management for Server Systems, Ricardo Bianchini and Ram Rajamony, IEEE, 2004
[39] Business Technology: Time To Do More With Less, Bob Evans, InformationWeek, July 15, 2002, http://www.informationweek.com/story/IWK20020712S0006
[40] Dell.com: http://www.dell.com/content/products/category.aspx/servers?~ck=anav&c=us&l=en&s=bsd&cs=04&~ck=anav
[41] HP: http://h71028.www7.hp.com/enterprise/cache/80316-0-0-0-121.html
[42] IBM: http://www-03.ibm.com/systems/express/flexible11blade.html
[43] Sun: http://www.sun.com/servers/blades/

4.2.4 Storage Equipment

Although blade servers are the major breakthrough in IT hardware, many companies are finding ways to save on energy with their various products. Storage companies are looking to consolidation as their mean of going green. EMC, Pillar, Sun and others have including energy efficiency as one of the key factors and characteristics of the products they advertise. Storage consolidation can present a data center manager with the following benefits:

- Reduce hardware costs up to 30-50%
- Reduce operations costs up to 70-80%
- Reduce total TCO (total cost of ownership) up to 30-70%
- Fully utilize server capacity
- Increase storage utilization
- Deploy new services efficiently
- Improved redundancy and high availability
- Manage computing resources strategically
- Drive higher value from IT

All these benefits come from the reduced amount of resources needed to manage because of the consolidation of the hardware which results in less power and cooling needs and a reduction in energy consumption. The main technology used for server consolidation is SANs (Storage Area Networks) and most storage companies provide their own SAN solution[44] [45].

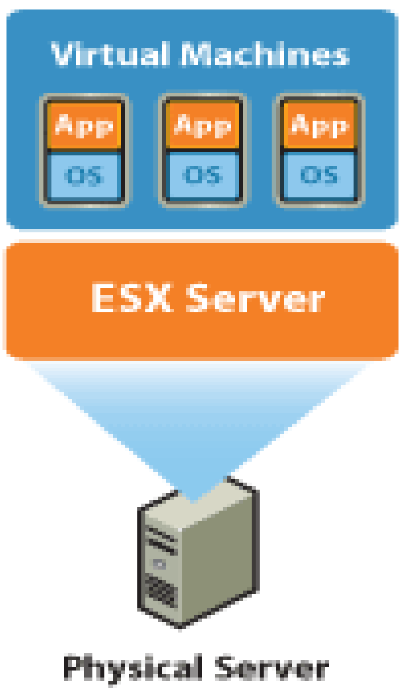


- **Figure 9 - Storage Consolidation, Source: Consolidate Storage, Simplify Your IT Environment, http://whitepapers.zdnet.com/Storage/Management/Storage+Consolidation**

[44] Storage Consolidation, Source: Consolidate Storage, Simplify Your IT Environment, Dell, http://whitepapers.zdnet.com/Storage/Management/Storage+Consolidation
[45] Storage Consolidation, Hitachi Data Systems, http://www.hds.com/solutions/mid-sized-organizations/storage-consolidation.html

4.2.5 Virtualization

Virtualization helps consolidate application workloads onto fewer, more highly utilized servers and storage devices. Reducing the number of physical servers reduces the energy requirement for those servers as well as requirements for associated cooling, uninterruptible power supplies (UPSs), and peripheral systems. In California, Pacific Gas and Electric is partnering with virtualization software leader VMware to offer electricity bill rebates to customers that apply virtualization to eliminate servers in their data centers[46]. Traditionally, companies have used one server for one task, such as e-mail or Web hosting, to simplify configuration, management, and operating-system use. Each server in a data center thus frequently sits idle and, in fact, operates at only 5 to 20 percent of its processing capacity. Nonetheless, the servers are still running and consuming about 80 percent of their peak energy-use levels. Virtualization lets a single computer run multiple operating systems or several versions of the same operating system, thereby enabling a server to run more than one task. Users could thus shut down numerous servers and thereby reduce power usage significantly[47]. VMware is the pioneering company in virtualization and provides the consumer with a wide range of products, but more companies have realized the value of this technology and have entered the market. Companies like Microsoft and other hardware manufacturers have developed their own virtualization tools to go with their lines of hardware products.



- **Figure 10 - Virtualization, Source: http://www.vmware.com/virtualization**

[46] Implementing Energy Efficient Data Centers, Neil Rasmussen, APC, 2006
[47] Powering Down the Computing Infrastructure, George Lawton, IEEE, February 2007

5 Buildings

5.1 The problem

Data centers can be hosted in the basement of a big office building or in building of their own specially constructed for the data center needs. No matter what the case is, that building is a part of the data center and if we aim to green data centers we also have to consider the buildings and include them in the design process.

Buildings have a profound effect on the environment, which is why green building practices are so important to reduce. In the United States, buildings account for:

- between 40 and 49% of total energy use
- 25% of total water consumption
- 70% of total electricity consumption
- 38% of total carbon dioxide emissions[48]

These numbers represent an area where improvements can and should be done. In this chapter we will provide guidelines of what could be done to improve the design and building process to produce green buildings and make the data center greening process complete.

5.2 The solution

The way to tackle this process is by adopting the green building process which targets the efficiency with which buildings use resources (energy, water, and materials) through better site choosing, design, construction, operation, maintenance, and removal (the complete building life cycle).

5.2.1 Site

Choosing a site to build a data center on can play a great role in achieving energy efficiency. If a company builds a data center in a hot site like the desert then the energy required for cooling grows, and if the company builds the data center in a cold site like the North Pole than a lot of energy is consumed to heat the building for the people working in it. So if the company has a choice of what site to build their data center in, that decision has to be made wisely. The site has to have a balance that meets the cooling and heating needs of the data center which will save in future energy consumption.

[48] Sustainable Buildings, Hal Levin, Building Ecology Research Group, Santa Cruz, CA, USA, June 27 2006

5.2.2 Design and Construction

The construction of a building deals with multiple aspects of that building and improvements can be done to all these areas to make them greener.

- **Foundation:** The building foundation is at the core of a safe and secure home environment for our families. As the base of all structures, foundations provide the stability needed to create a solid and healthy environment. Some builders are finding plastic to be extremely helpful in laying a foundation. Plastics comprise a wide variety of products and design solutions for the building and construction market. Coupled with other building materials, such as concrete, plastics present an array of innovative possibilities -- such as Structural Insulated Panels (SIPs) and Insulating Concrete Forms (ICFs). According to the Insulating Concrete Form Association (ICFA), homes built with SIPs (made with an expanded polystyrene (EPS) or extruded polystyrene (XPS) foam core laminated to sheets of high-strength oriented strand board), can help homeowners save hundreds of dollars each year on energy bills. In fact, because SIPS create a tighter building envelope than conventional insulation, your builder can actually reduce the size of heating and cooling equipment. That reduces costs immediately.
- **Electricity:** Although the significant role plastic plays in our high-tech world is often taken for granted, there is little debate that plastic electrical products are particularly well-suited to meet the concurrent electrical and fire safety requirements that contribute to safety in home design. Since World War II, we have depended on plastic as an insulator and as a means to help enjoy modern conveniences through electricity. With few exceptions, the electrical and communications wires behind walls, under floors, underground and on the roof, are often insulated with plastic. These wires and encasements are often made with vinyl, a naturally-fire retardant plastic. The durability of plastic electrical components helps products last a long time.
- **Plumbing:** Beyond serving as a cost-effective, efficient and durable means of meeting plumbing needs, plastics can serve as a green solution. For example, the manufacturing of PVC pipe can provide an overall savings of energy compared to alternative materials. A 1991 study by Franklin & Associates indicated that the manufacture of pressure piping used in the building, construction and transportation industries required 56,497 trillion fewer BTUs than iron and concrete/aggregate alternative pipe. Also, because PVC pipe and fittings are lighter in weight than alternative piping materials, they can save energy in transportation.
- **Flooring:** Plastic vinyl flooring is impermeable, holds up to traffic and is easy to care for and clean - helping to provide a hygienic and safe environment. That's why it's often the choice of hospitals and health care facilities. Resilient plastic - both vinyl sheet and tile - is among the most popular hard surface floorings in the United States. Durable, easy to maintain, and resistant to moisture, vinyl flooring offers the additional benefit of having no fibers to trap dust mites and other allergens. Because of its longevity, vinyl flooring does not have to be replaced as often as many other types of flooring. This durability can be a significant benefit to the environment because fewer resources end up getting used to make and

install new floors. Based on environmental and economic criteria developed by the U.S. National Institute of Standards and Technology's Building for Environment and Economic Sustainability (BEES) lifecycle assessment model, plastic vinyl composition tile outperforms linoleum and recycled-content ceramic tile. These criteria include solid waste, indoor air quality (IAQ), global warming, acid rain and natural resource depletion

- **Roofing:** According to the Spray Polyurethane Foam Alliance (SPFA), spray polyurethane foam (SPF) roofing systems are noted for their long life, renewable and energy saving characteristics, as well as their ability to help control moisture in buildings. SPF roofing systems are resistant to leaks caused by hail, wind-driven debris, and high wind blow-off. The Underwriters Laboratories conducted research on SPF roofs due to their performance during Hurricanes Allen, Hugo and Andrew. The SPF's wind uplift resistance exceeded the capacity of UL's equipment - validating SPF roofing systems' excellent wind up-lift resistance. Furthermore, SPF roofing systems can provide significant energy savings. SPF eliminates thermal bridging by providing a continuous layer of insulation over existing thermal bridges in the roof deck. Also, SPF roofing systems typically are coated with light colored, reflective coating, which reduces the amount of heat transported inside the building through thermal bridges. The Oak Ridge National Laboratory notes that roofing is one of the largest contributors of solid waste, as it is a building element that needs to be replaced. SPF roofing systems are often used to re-cover an existing roof, which can eliminate the need to tear off the roof completely. This then reduces the amount of construction material in landfills. SPF can also be applied to a variety of substrates and in various degrees of thickness to add slope and fill in low areas.
- **Insulation:** Insulation the building is a good way to make the heating and cooling of the building efficient. In many cases, the HVAC systems in a data center have to compensate for the changing temperature due to the change in the outside weather. So insulating the building can provide a protecting layer against the outside environmental effects.
- **Wall Coverings:** The energy required to manufacture vinyl wall coverings is only half as much as that needed to produce the same amount of an alternative wall covering. Vinyl wall coverings also offer favorable Indoor Air Quality attributes since this plastic has a relatively low potential for odors or emissions. Studies show considerably higher levels of volatile organic compounds (VOCs) from some paints than from vinyl wall coverings. Painting a room with oil and/or solvent-based paints can result in emissions of approximately nine times the amount of VOCs released by vinyl wall coverings incorporating water-based adhesives and inks.
- **Windows:** Vinyl windows are impervious to rust, rot, blistering, corrosion, flaking and infestation by termites or other insects. Today, plastic rivals traditional materials for windows and frames, providing competitive energy efficiency, aesthetics, design flexibility and cost criteria. For example, polycarbonate plastic -- the same material used in eyeglasses and known for durability and clarity -- is used in windows. Shatter-resistant and lightweight, the plastic product has low thermal conductivity, thus reducing heating and cooling

costs though still providing protection against dangerous weather. The presence of mold can have drastic affects on indoor air quality and the health of those with asthma or hypersensitivity. When plastic is used as window dressing, such as solid vinyl or vinyl-clad frames, it serves to help minimize condensation, thus aiding in the prevention of mold. A study by an internationally respected lifecycle analysis firm shows vinyl window frames require three times less energy to manufacture than aluminum window frames. Beyond that, the use of vinyl window frames has been shown to save the United States nearly 2 trillion BTUs of energy per year - enough to meet the yearly electrical needs of 18,000 single-family homes. The design of vinyl window frames further enhances energy efficiency by creating chambers in the frame that provide additional resistance to heat transfer and insulating air pockets. The energy efficiency of vinyl windows and glass doors can mean less electricity is used to heat and cool a building which can help reduce the greenhouse gas emissions associated with coal-fired power plants. In addition, the low maintenance requirements of vinyl windows and glass doors eliminate the need for paints, stains, strippers and thinners, which can negatively impact air quality.

- **Siding:** Since vinyl is significantly lighter in weight than some alternative materials, energy is saved during initial transportation. Vinyl siding and accessories are recyclable, both pre-use (e.g., manufacturing off-cuttings and construction site waste) and post-use (e.g., removal at end of useful). Vinyl siding and accessories are also durable products, offering cost savings, as well as energy savings in terms of avoiding the need to manufacture replacement parts
- **Doors:** Today there are a variety of durable and efficient plastic solutions for doors that are easy to maintain and can provide greater R-values (efficiency of insulation) than many other materials. Despite their light-weight properties, plastic doors are extremely durable. In fact, the growing use of plastic door products has validated their strength, energy-efficiency and acoustic value. Entry doors with a foam plastic core can inhibit sound and add insulation value that can help lower heating and cooling energy needs. Sealant foams also can be used to caulk around windows, doors and sill plates to seal against unwanted air infiltration[49] [50] [51] [52].

5.2.3 Operation, Maintenance and Removal

Part of being green is operating at a green level. This includes the uses of the material during the life span and as well as the end of life disposal processes. Following are things to consider along the life cycle of the materials used in green buildings:

- Evaluate and specify materials or assemblies based on life-cycle analysis tools such as eLCie, BEES and Athena.

[49] Green Building Solutions: http://www.greenbuildingsolutions.org/
[50] Building Green: http://www.buildinggreen.com/
[51] Natural Resources Defense Council: http://www.nrdc.org/
[52] U.S. Green Building Council: http://www.usgbc.org

- Create a management plan for construction waste management with the help of a consultant. Some integrated waste management companies such as Allied Waste offer services that are designed to meet LEED criteria in this area.
- Make use of preexisting building shells and other structural elements at your site, when possible.
- Set aside used materials such as hardwood flooring, high-quality brick, structural steel, plumbing fixtures and cabinetry and install them in your new space or elsewhere.
- Use materials that were harvested, extracted or recovered in the region.
- Choose remanufactured furniture, which is made from recycled parts, costs less and saves natural resources.
- Limit wood use. For items such as shelving and bookcases, consider using composites made from wheat fiber or other agricultural waste or other non-wood materials.
- Specify certified wood products. Purchase wood or wood products that are certified by the Forest Stewardship Council, indicating they originate from sustainable, well-managed forests. FSC-certified wood can be more expensive than common types of wood, but is less expensive than exotic varieties. Growing demand is driving down the price of certified wood[53].

Data center managers tend to focus on servers and cooling equipment when attempting to come up with greening strategies for their data center and ignore building materials. But in fact building are a big source of energy consumption and greenhouse gas emissions and a lot can be done in that are to improve on the energy consumption of data centers. Using recyclable materials, insulation and proper selection of the building site are ways to accomplish a green building.

[53] Natural Resources Defense Council: http://www.nrdc.org/buildinggreen/strategies/materials.asp

6 Conclusion

Through this paper we have seen that a lot goes into building a data center. It is important that companies think green from start when designing a new data center. We have seen that improvements can be made in every aspect of the process, including building material, layout design, supplying power, cooling and the equipment themselves. The table below gives a summary of improvements that can be made on each level.

Table 1 - Recommended actions for a green data center

Building a green data center has a tremendous impact on the environment which cannot be measured and also provides companies with ways to save money on wasted energy use. Currently, legacy cooling equipment consume 1 watt to cool each watt consumed by the IT equipment, but deploying state of the art cooling mechanism can reduce that to a 0.5:1 ratio and might even reach 0.3:1 in ideal cases. This suggests 50% to 70% savings on energy costs alone. As for the hardware itself, it is estimated that a current high-end processor has between 18% and 20% of its total power consumption leaked and wasted. Improvements on that end translate into another 10% reduction in energy consumption[54].

Implementing green strategies during the building process of a new data center or the redesigning process of an old one can reduce energy consumption significantly. This will

[54] Power and Cooling Heat up the Data Center, Richard Fichera, Forrester, March 8 2006

result in savings for the company itself and major positive impacts on the environment. Many ways to achieve this goal are available and have been discussed in this thesis. Some of these strategies are easy to implement and others require reasonable effort but the benefits render it worth the time and money of the company involved.