Reducing Data Center Energy Consumption

A summary of strategies used by CERN, the world's largest physics laboratory

White Paper

Intel® Xeon® Processor

Data Center Optimization

To deploy massive new computing resources without exceeding the thermal limits of its 35-year-old data center, CERN is taking a comprehensive approach to improving energy efficiency. This paper outlines CERN's key strategies, including a move to the latest Intel® Xeon® processors that are helping the organization increase performance per Watt by a factor of five.

Executive Summary

"Multi-core processors based on the Intel® Core™ microarchitecture deliver about five times more compute power per Watt than single-core processors based on the earlier Intel NetBurst® microarchitecture."

– CERN[1]

Improving data center energy efficiency is becoming a fundamental requirement for most organizations, not only to contain operating costs, but also to support growth, extend the life of existing facilities, protect the environment, and address increasing regulatory requirements. Electricity costs are rising fast. Most businesses already spend about half as much for the electricity to power and cool their infrastructure as they do for the hardware itself, and this percentage can be expected to increase.

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This white paper outlines the energy-saving strategies developed by CERN openlab[2] and used by CERN, the world's largest physics laboratory, as it deploys massive new computing resources to support the most powerful particle accelerator ever built. It describes how CERN is increasing the total performance capacity of its 35-year-old data center up to five times by moving from older servers based on single-core processors to newer servers based on the latest 45nm Intel® Xeon® processors, which have four cores per processor. According to CERN, this move is increasing the useful life of its data center by about two years.

Upgrading to more energy-efficient servers is one component of a comprehensive approach that includes additional server optimizations, an improved server tendering processes, a more efficient data center layout, consolidation through virtualization, and software optimizations that allow existing systems to perform faster and more efficiently.

CERN's efforts will not make its energy challenges disappear, but they are helping the organization dramatically expand its computing capabilities without major upgrades to its facility and without disrupting existing operations. For organizations looking to reduce their operating costs and avoid expensive data center retrofits, CERN's practical, real-world approach provides an excellent model.

Rising Energy Costs and Aging Data Centers

"Going green is about more than just 'political correctness'; it also can have a tremendous, positive effect on business pressures to lower the overall cost of computing."
– Gartner[3]

Data center power and cooling are becoming major challenges for most organizations. Since 2002, electricity costs have risen by about 5.5 percent annually, and organizations are now spending approximately $0.50 on power and cooling for every dollar they spend on hardware.[4] According to Gartner, that ratio can be expected to grow substantially over the next few years.[5] Energy costs will become an increasingly significant component of IT budgets, and an increasingly tough challenge for organizations as they work to grow their computing capabilities and contain costs.

In many cases, this challenge is compounded by the design constraints of existing data centers. Most facilities today are several decades old and many are already running at or near thermal capacity. Unless energy efficiency is dramatically improved, organizations will be unable to expand their computing infrastructure without the expense and disruption of upgrading their data center, building a new one, or migrating to a co-location facility.

Few businesses experience these challenges more acutely than CERN, the world's largest physics laboratory. CERN is in the process of deploying the Large Hadron Collider (LHC), a high-energy particle accelerator that measures an incredible 27 kilometers in circumference and will be used to extend our fundamental understanding of the universe. The computing requirements for the LHC are no less massive than the accelerator itself. When fully operational, LHC experiments will create 10-15 petabytes of data per year that have to be stored permanently.

One of CERN's biggest challenges in deploying the LHC is their 35-year-old data center. This facility was constructed in 1972 to host mainframe systems, and was later retrofitted to host large numbers of distributed computers. Until recently, it housed about 1,100 single- and dual-core processor-based servers, with a total thermal load of 1.5 MW. With the addition of another 1,300 Intel Xeon processor-based systems, all with quad-core processors, consumption is expected to rise to 2.0 MW. Similar increases will be needed annually, and this is rapidly pushing the facility toward its limit of 2.5 MW.

To defer the need for a costly new facility – and to maximize research progress per dollar spent – the CERN IT organization has been focused for several years on maximizing total performance per Watt for its computing infrastructure. The lessons learned by CERN engineers have value for all organizations looking for ways to grow their computing solutions, reduce their costs and extend the life of existing facilities.

Consume Less to Maximize Savings

There are two basic approaches to increasing data center energy efficiency: reducing energy consumption and improving cooling efficiency. In most cases, it is more effective and less costly to reduce consumption. This approach delivers savings both directly, through lower consumption, and indirectly, by generating less heat and therefore reducing the load on the cooling infrastructure. As CERN notes with respect to its own environment, "...one Watt saved on power consumption translates into a total saving of two Watts."

In addition, significant improvements in cooling efficiency typically require major infrastructure investments, while consumption can be reduced incrementally throughout the facility, on a system-by-system basis. Though organizations should look closely at all strategies that help to increase overall energy efficiency, it makes good sense to focus first and foremost on reducing consumption.

Optimizing Data Center Performance/Watt

This section outlines the key strategies CERN is using to optimize energy efficiency in its data center. Like many other organizations, CERN has found that its return on investment (ROI) is generally highest for energy-saving strategies that reduce consumption rather than for those that increase cooling efficiency (see the sidebar, Consume Less to Maximize Savings).

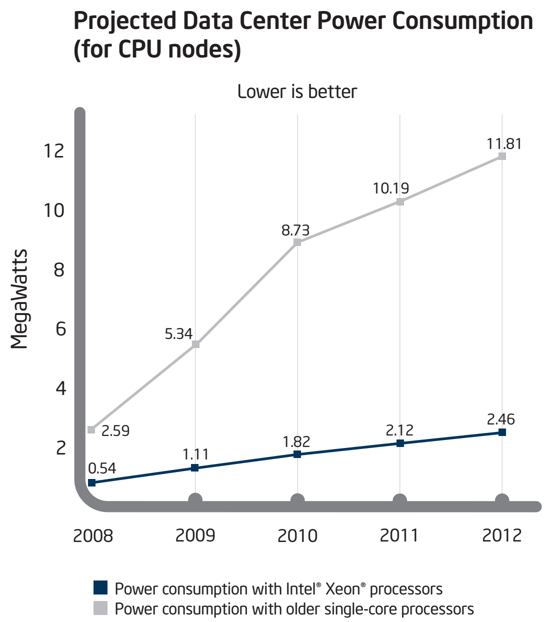

Figure 1. Based on CERN's projections, the organization could reduce total power consumption almost five times by using the latest Intel® Xeon® processor-based servers (based on the Intel® Core™ microarchitecture), rather than older single-core Intel Xeon processor-based servers (based on the Intel NetBurst® microarchitecture).

Moving to the Latest Intel® Xeon® Processor-based Servers

The most potent strategy CERN has found for increasing energy efficiency is to replace its older servers based on single-core processors with the most recent Intel Xeon processor-based systems, which have four cores per processor. According to CERN scientists, "This is enabling CERN to provide five times more compute power within the same data centre power envelope."[6] (See Figure 1.) The savings in data center space are even greater – about 7.8 times based on the number of required servers (Figure 2 on page 5).

According to CERN, this move alone has already increased the useful life of its data center by about two years, enabling the organization to avoid the cost and disruption of adding a new facility. Many organizations can realize similar value by replacing older servers with more powerful and energy-efficient systems. Those that are constrained by power and thermal barriers can increase their computing capacity up to five times without increasing energy consumption. Those that are constrained by space limitations can increase their computing capacity nearly eight times without expanding their data center footprint. In both cases, upgrading older servers may help to extend the useful life of existing facilities by a number of years, delivering millions of dollars in capital and operational savings.

There are two primary reasons that the latest Intel Xeon processors provide such significant gains. The first is that a processor with multiple execution cores can perform far more work than a single-core processor, while consuming about the same amount of energy and taking up the same amount of space. This is because each individual core can be run at a lower frequency. A small reduction in frequency causes a small reduction in the amount of work performed, but a relatively large drop in the amount of energy consumed. As a result, more cores running at lower frequencies can deliver substantial gains in total performance per Watt.

The second reason for these gains is that the Intel® Core™ microarchitecture (used in Intel's latest multi-core processors) is much more efficient than the earlier Intel NetBurst® microarchtiecture. In fact, CERN found that its SPECint/(Watt*GHz) measurements were 5.7 times higher for processors based on the Intel Core microarchitecture. That means every processor core is delivering substantially more useful work per clock cycle.

The latest Intel Xeon processors also incorporate a number of advanced energy-saving technologies.

- Intel's industry-leading 45nm process technology improves energy efficiency at the most fundamental level, by reducing the amount of energy required per transistor.
- Intel® Intelligent Power Capability adds to these advantages, by powering up only those components of the processor that are needed to process a given workload.

Altogether, these performance and energy-efficiency enhancements enable IT organizations to pack far more computing power into their existing facilities. For CERN, this means being able to increase the total computing performance of their existing data center by a factor of five, with no increase in power and cooling requirements when moving to Intel Xeon processor-based systems. Most organizations can expect to realize comparable gains.[7]

Intel is strongly focused on increasing performance per Watt in next-generation Intel® processor-based servers. Future processors will include more execution cores, as well as additional microarchitecture improvements. The Intel® Xeon® processor 7400[Δ] series (code-name Dunnington) will be available in the second half of 2008. Dunnington will be followed by another Intel Xeon processor (code name Nehalem) that will be offered in 4- and ultimately 8-core versions. Nehalem will include the new Intel® QuickPath interconnect technology, which will offer extremely high server bandwidth.[8] CERN has high hopes for these new processors and believes Nehalem may help them extend the life of their data center by an additional six months.

Intel is also developing more energy-efficient chipset and memory technologies that will further increase server energy efficiency. To view the latest energy-efficiency benchmarks for Intel Xeon processor-based servers, visit the Intel Web site at www.intel.com/performance/server/xeon/ppw.htm.

Configuring Servers for Overall Energy Savings

In configuring its servers for maximum energy efficiency, CERN looks at a number of other factors.

- **Choosing the Best TDP** – Intel Xeon processors are available running at various clock frequencies. The higher the frequency, the higher the processor's Thermal Design Power (TDP). Processors with a high TDP deliver higher performance, but also consume more energy. Since CERN is more concerned with performance per Watt than with absolute performance per server, processors with a lower TDP sometimes deliver better overall value, and are selected accordingly. (In computing environments where absolute performance is more important, processors with a higher TDP should be used. An example would be a real-time business environment in which fast individual transactions are critical for delivering the best possible user experience.)
- **Using Energy-Efficient Power Supplies and Fans** – Though energy-efficient power supplies and fans cost more, they reduce overall server energy consumption and can provide lower TCO over the life of the system. In general, larger fans and power supplies are more energy efficient. That's one reason blade servers tend to deliver better performance per Watt than comparable tower or rack-mount servers. They typically have just a few large fans and power supplies to support multiple servers.
- **Optimizing the Server Acquisition Process** – To ensure that energy efficiency is taken into account in every new server purchase, CERN integrates performance per Watt metrics into its acquisition process. Performance is measured using the industry-standard SPECint benchmark. Power consumption is measured at the primary AC circuit, so the result reflects the energy consumption for the entire system. CERN's testers make the power measurement twice: first when the system is idle, and then under load. They weight the results based on 80 percent utilization, which is typical in CERN's data center. The resulting performance per Watt measurements are used when projecting total lifecycle costs for each system. CERN uses these measurements not only to determine the most energy- and cost-efficient servers, but also to help determine when older servers should be replaced (see the sidebar, Optimizing Server Refresh Cycles on page 6).

Projections of Data Center Requirements

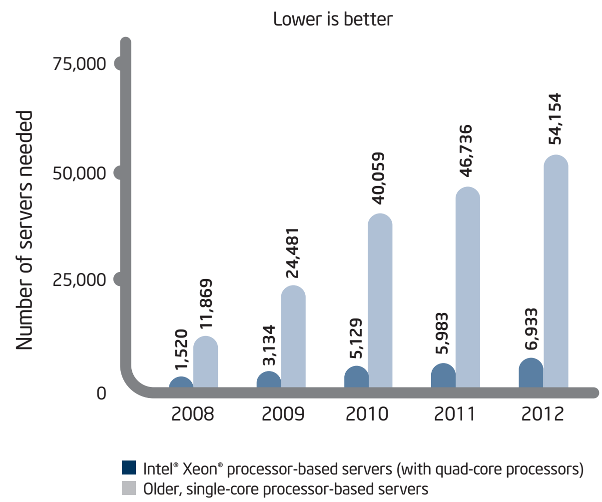

Figure 2. According to CERN engineers, the use of Intel® Xeon® processors reduces the total number of servers they need by nearly a factor of eight.

Every organization has unique workloads that stress server resources in different ways, so CERN recommends using benchmarks or internal tests that reflect specific workload requirements. It is also important to weight idle and loaded energy consumption based on typical utilization rates in the target environment.

Organizations without the resources to perform internal tests might want to consider using the new SPECpower benchmark. This new industry-standard benchmark measures system-level performance for a typical Java workload (using SPECjbb) and provides a score that represents energy efficiency across all operating conditions. It can help organizations compare server energy efficiency using consistent and reliable metrics. Information and results for a variety of servers are available on the SPEC Web site at www.spec.org/power_ssj2008.

Optimizing Server Refresh Cycles

"Develop a change-management program to move to more energy-efficient hardware – typically every three to five years to manage the energy cost increase."
– Gartner[13]

CERN purchases new servers with a 3-year warranty, and, in the past, has found that time frame to be appropriate for maximizing value. However, with the increasing importance of energy efficiency on data center costs and longevity, CERN is reevaluating its server lifecycle practices, and finding that faster refresh rates may be in order for some servers.

Many other organizations are doing the same. To quantify the potential benefits in a typical data center environment, Intel engineers conducted an independent study to determine the impact of replacing 126 Intel® Xeon® processor-based servers (6 racks) purchased in 2004 with 17 of today's 45nm Intel Xeon processor-based servers. The new quad-core processor-based servers would deliver the same performance capacity with:

- An 83 percent reduction in floor space
- An 87 percent reduction in energy cost (approximately $53,000 in savings, depending on utility rates)
- Full payback on the new servers in less than two years

Optimizing Data Center Layout

Like many organizations, CERN arranges the servers in its data center front-to-front and back-to-back, to create hot and cold aisles. Cooling air is channeled into the cold aisles and hot air is exhausted into the hot aisles. This approach reduces hot and cold air mixing, which is one of the major sources of cooling inefficiency. CERN also encloses its cold aisles, which eliminates another source of hot and cold air mixing. Cooling efficiency can be further improved by actively extracting heat from hot aisles, but this technique is not practical in CERN's retrofitted data center.

A comprehensive approach to optimizing cooling efficiency would include using airflow and heat distribution simulations to identify and remediate inefficiencies. This can be an important strategy for organizations with relatively stable computing environments. However, the CERN data center houses an exceptionally heterogeneous computing environment and equipment is being added and replaced at a high rate. Because of this constant change, no solution would remain optimal for long and it would be difficult, if not impossible, to achieve meaningful returns on the time and effort required.

Using Virtualization to Increase Utilization

CERN's primary workloads are designed to be distributed very efficiently across multiple servers, multiple processors and multiple cores. As a result, server utilization is typically between 70-80 percent, and will move toward 85-90 percent when the Large Hadron Collider is fully operational.

With utilization so high, virtualization is not appropriate for CERN's primary workloads. It would introduce performance overhead without delivering any real benefit. However, CERN does use virtualization to consolidate smaller and infrequently used applications, which reduces the number of servers required for these secondary workloads.

According to CERN, "Potential energy-savings from virtualization may be much greater for organizations with lower average utilization rates."

To put the energy-saving potential of virtualization in perspective:

- Typical server utilization is about 5-15 percent for organizations that use a one-application-per-server deployment model.[9]
- Server utilization with virtualization is typically 30-60 percent (depending on IT preferences), for about a factor-of-five gain.
- As discussed earlier, the latest Intel Xeon processor-based servers provide an additional five times boost in energy efficiency compared with older servers based on single-core processors. (They provide a two times boost in energy efficiency versus servers based on earlier Intel Xeon processors[10] with two cores per processor.)
- For many organizations, the combination of energy-efficient servers and better utilization can therefore provide energy-efficiency gains of up to 25 times and higher, while also reducing data center footprints and providing a more flexible and manageable infrastructure (see the sidebar, Virtualization and Consolidation in Action on page 7).

Intel Xeon processors with four cores are ideal for virtualization. They include integrated support for Intel® Virtualization technology, which reduces the need for compute-intensive software translations between the guest and host operating systems. With their greater processing capacity and superior virtualization effi-ciency, they can increase virtualization performance by as much as 2.5 times compared with typical dual-core systems.[11]

Optimizing Software

"Selecting proper software technologies can be at least as important as choosing optimal hardware."
– CERN[12]

Software is as important as hardware in increasing performance per Watt in the data center. The great majority of today's software code was written when energy consumption was not a concern for developers. Major gains can be realized by optimizing existing code so it accomplishes more work in fewer clock cycles and makes better use of underlying hardware capabilities.

Additional gains will come from new features in operating systems, utilities and management applications that enable organizations to monitor and dynamically manage power consumption more effectively, not only for individual components and systems, but for whole data centers. In an ideal future scenario, only necessary software components will be running at any given time, and they will be running on the most energy-efficient systems available.

CERN mentions three key software strategies that can deliver substantial value today:

- **Dynamic Control of Processor Frequency –** The latest Intel Xeon processors support a low-power C1 Enhanced Core State that reduces power consumption to as low as 16 Watts when the processor is idle. They also support Demand Based Switching, which dynamically throttles down processor frequency for light workloads. Both of these technologies are supported by most server vendors in their system BIOS, but they must be turned on during server deployment. CERN does not use these technologies, since its utilization rates are so high, but recognizes the potential benefits for other organizations.
- **Using Optimizing Compilers –** Optimizing compilers increase application performance by optimizing software code to take better advantage of the underlying processor architecture. CERN reports that one internal study demonstrated SPECint/Watt gains as high as 65 percent when using an Intel® Compiler with profile-guided optimization. For information about these and other Intel software development tools, visit the Intel® Software Network, at www.intel.com/cd/software/products/asmo-na/eng/index.htm.
- **Software Threading for Multi-core Platforms –** Multi-threading takes sequential software code and converts it into multiple "threads" that can run simultaneously on multiple processors or multiple cores. It can substantially improve performance for a single application running on a multi-core processor-based server. CERN is currently working with Intel to evaluate the benefits of multi-threading, and to more fully understand the impact on software development, since multi-threading requires advanced techniques. For more information about multi-threading, and about Intel® Performance Libraries, which are already highly threaded and optimized, visit the Intel® Software Network, at http://software-community.intel.com/communities/multicore.

Energy-conserving software strategies are evolving rapidly, and Intel is working with leading vendors and IT organizations to accelerate this evolution and to help coordinate hardware and software advances. For the latest information, tools and tips on optimizing energy efficiency via software innovation in Linux* environments, visit www.lesswatts.org.

Virtualization and Consolidation in Action

Though virtualization has limited utility in CERN's highly utilized server infrastructure, it can provide major benefits in many corporate IT environments. As one example, GAZ Group, Russia's largest automotive manufacturer, was looking to increase performance and accelerate response times for its core business applications – but expanding the hardware infrastructure was not possible due to space constraints and excessive cooling costs. To meet the challenge, GAZ turned to virtualization software running on the latest Intel® Xeon® processor-based servers. Though earlier virtualization attempts on dual-core processor-based servers had failed to meet requirements, the quad-core processor-based servers enabled:

- **A 10:1 consolidation ratio,** with a simultaneous reduction in CPU utilization from 100 percent to about 25 percent.
- **Better response times.**
- **Lower energy costs** and room to grow with existing systems in existing facilities.

Read the full case study at **www.intel.com/cd/business/enterprise/emea/eng/casestudies/389397.htm**.

Conclusion

Rising electricity costs and aging data centers are causing many businesses to take a very serious look at the energy efficiency of their computing infrastructure. With its enormous computing needs and 35-year-old data center, CERN has been dealing with this challenge for several years, and is taking a comprehensive approach to achieving the highest possible performance per Watt. Most notably, CERN has replaced older servers based on single-core processors with newer servers based on the latest 45nm Intel Xeon processors, which have four cores per processor. The organization estimates this strategy has added about two years to the life of its data center, and believes future multi-core Intel processors could increase that by another six months.

CERN has also made changes to its tendering process, its data center layout, its power and cooling strategies and its software development techniques. All of these changes are focused on getting more total performance while consuming less total energy. Altogether, these strategies provide an excellent starting point for businesses who are look for ways to reduce their own data center costs and prolong the useful life of their facilities.

For More Information

About CERN's energy-saving strategies: Read the CERN openlabs white paper, *Strategies for Increasing Data Centre Power Efficiency* http://openlab-mu-internal.web.cern.ch/openlab-mu-internal/Documents/2_Technical_Documents/Technicall_Reports/2008/AH-SJ_The%20approach%20to%20energy%20efficient%20computing%20at%20CERN%20final.pdf.

About CERN openlab: http://openlab-mu-internal.web.cern.ch/openlab-mu-internal/.

About reducing energy consumption in Linux environments: www.lesswatts.org.

About broader efforts to reduce computer energy consumption: www.climatesaverscomputing.org.

About Intel® Xeon® processor-based servers: www.intel.com/products/processor/xeon5000/index.htm.

About software optimization: Visit the Intel® Software Network at http://softwarecommunity.intel.com/isn/home/default.aspx and the Parallel Programming Research Community at www.parallel-programming.org/about.php.

[Δ] Intel processor numbers are not a measure of performance. Processor numbers differentiate features within each processor family, not across different processor families. See www.intel.com/products/processor_number for details.

[1] Strategies for increasing data centre power efficiency: An overview of CERN's approach to energy-efficient computing, by Dr. Andreas Hirstius, Sverre Jarp and Andrzej Nowak, CERN openlab, January 17, 2008.

[2] CERN openlab is a collaboration between CERN and industrial partners to study and develop data-intensive solutions to be used by the worldwide community of scientists working at the next-generation Large Hadron Collider. For more information, visit: http://proj-openlab-datagrid-public.web.cern.ch/proj-openlab-datagrid-public/

[3] Source: Data Center Conference: Day 4 Highlights the 'Greening' of Data Centers, by John R. Phelps and Mike Chuba, November 30, 2007, Gartner, Inc., ID Number: G00153658.

[4] The 5.5 percent rise is an average, based on a standard Compound Annual Growth Rate (CAGR) calculation. Source: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html.

[5] According to Gartner, "During the next five years, most enterprise data centers will spend as much on energy (power and cooling) as they will on hardware infrastructure (0.6 probability)." Source: Eight Critical Forces Shape Enterprise Data Center Strategies, Part Two, by Rakesh Kumar, June 19, 2007, Gartner, Inc., ID Number: G00148349.

[6] This factor-of-five improvement is based on CERN's own SPECint/Watt measurements. Source for quote: Strategies for increasing data centre power efficiency: An overview of CERN's approach to energy-efficient computing, by Dr. Andreas Hirstius, Sverre Jarp and Andrzej Nowak, CERN openlab, January 17, 2008. http://openlab-mu-internal.web.cern.ch/openlab-mu-internal/Documents/2_Technical_Documents/Technicall_Reports/2008/AH-SJ_The%20approach%20to%20energy%20efficient%20computing%20at%20CERN%20final.pdf.

[7] Actual benefits will depend on each organization's computing environment, including their facility, systems, workloads and policies.

[8] See the Intel press release at: www.intel.com/pressroom/archive/releases/20080317fact.htm.

[9] Eighty-two percent of installed resources (server, storage and network) have only 10 percent utilization. Source: IMEX 2008.

[10] For more information, visit the Intel Web site at: http://www.intel.com/performance/server/xeon/summary.htm?iid=products_xeon5000+body_performance.

[11] For more information, and a TCO calculator that can help you estimate the benefits of virtualization in your environment, visit the Intel Web site at: http://www.intel.com/business/technologies/virtualization.htm.

[12] Strategies for increasing data centre power efficiency: An overview of CERN's approach to energy-efficient computing, by Dr. Andreas Hirstius, Sverre Jarp and Andrzej Nowak, CERN openlab, January 17, 2008.

[13] Data Center Power and Cooling Scenario Through 2015, by Rakesh Kumar, March 14, 2007, Gartner, Inc., ID Number: G00146042.

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