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# Measurement of Energy Performances for General-Structured Servers

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**Abstract.** Energy consumption of servers in data centers increases rapidly along with the wide application of Internet and connected devices. To improve the energy efficiency of servers, voluntary or mandatory energy efficiency programs for servers, including voluntary label program or mandatory energy performance standards have been adopted or being prepared in the US, EU and China. However, the energy performance of servers and testing methods of servers are not well defined. This paper presents matrices to measure the energy performances of general-structured servers. The impacts of various components of servers on their energy performances are also analyzed. Based on a set of normalized workload, the author proposes a standard method for testing energy efficiency of servers. Pilot tests are conducted to assess the energy performance testing methods of servers. The findings of the tests are discussed in the paper.

## 1. Introduction

The information and communication industry is one of the fastest growing industries in China in the last decade; server equipment as the basic unit of the information and communication industry also grows dramatically and rapidly, which brings huge energy consumption. According to statistics, the power consumption of the server industry is approximately equal to the power generation of the Three Gorges Hydropower Station and the damage degree of global warming from the greenhouse effect caused by the heat emitted in this server industry has accounted for 2.5% of all industrials [1]; therefore, server energy efficiency is highly concerned by server users and manufacturers. Server energy efficiency has become one of important indicators for current enterprises and data centers to choose servers [2] in order to realize green energy conservation; the research on energy conservation and energy efficiency evaluation of server products becomes increasingly more detailed. This paper studies and compares mainstream server energy efficiency testing tools at home and aboard, explores new server component efficiency evaluation technologies and testing methods, proposes the standardized load of server energy efficiency test and test requirements, and analyzes the advantages and disadvantages of the results through actual test data; and the results promote the server energy efficiency evaluation and test.

## 2. Status and evaluation level of server energy efficiency

At present, there are two main directions in the research on server energy efficiency: one is the research and development of energy conservation optimization technology of server equipment; the other is the development of accurate and intuitive energy efficiency evaluation tools of server equipment. Among them, the efficiency evaluation of server equipment does not only evaluate energy consumption of servers, but also assess whether server equipment performance is fully played or not, which contributes to the design and research on energy conservation schemes of server equipment in the aspects of hardware and software. Meanwhile, the paper specifically analyzes the energy consumption composition of server components in detail and proposes energy conservation mechanism and strategy, which are both beneficial to improve server performances.

Currently, mainstream tools for energy efficiency evaluation of server equipment are mainly developed by foreign countries, and the ways and characteristics of testing are also different. In May 2009, US Environmental Protection Agency officially issued the Energy Star Server Specification (Version 1.0) [3] and updates it year by year. Until now, the latest version of Energy Star Server Specification will be issued. The Energy Star Server Specification uses the server's idle energy consumption as the main criterion of judgment and does not consider the actual operation energy consumption of the server; therefore, it is difficult for the Energy Star Server Specification to distinguish the unit energy consumption of each module by working load but it can directly determine the level of server energy efficiency. In December 2007, Standard Performance Evaluation Corporation (SPEC) issued SPEC power_ssj 2008, the industry's first power benchmark tool for evaluating system level server equipment and computing performance. The server load generated by SPEC power_ssj2008 tool can be used to load general Java commercial applications to blade servers, tower servers, and rack servers; this tool can evaluate energy consumption of multiple load conditions of the server system from the standby mode (0%) to full load condition (100%); meanwhile, this tool can be distributed and extended, being transplanted between different system operating environments in a multithreaded manner [4,5]. Therefore, SPEC power_ssj2008 not only can be used as an indicator to compare the energy consumption and performance between different servers, but also to help improve the efficiency of the server, and is widely used in the industry. Server energy efficiency rate tool (SERT) is also a server energy efficiency testing tool developed by SPEC to test similar simplified SPEC power; SERT may also load multiple loads, compare with the results of a benchmark server test by some algorithm, and finally output server evaluation results. Furthermore, there is Green500 for ranking supercomputers in the world; Linpack benchmark test software obtains float computation results for performance judgement; and then, a power meter is used to measure energy consumption and ratios are compared; however, supercomputer serves are different from small client servers so this judgement indicator is not adopted by current compact multifunctional server. Green Grid Association established in 2007 promotes such indicators as Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE), which have been studied for many years and recognized as standards for measuring efficiency and productivity of data centers in the industry. However, Green Grid testing method is based on the overall energy consumption of data center and entire energy consumption of IT equipment and there is no dedicated energy efficiency test research at detailed levels for servers.

Server energy efficiency testing and evaluation in China is mainly based on the practices of domestic leading server manufacturers in the field of technology and products. Since 2008, with the attention of competent authorities of the Ministry of Industry and Information, political progress has been made in China’s server energy conservation and energy efficiency evaluation. In December 2009, local standard *Server Energy Efficiency Requirements and Testing Methods* was issued. In 2010, the accreditation organization issued and implemented the accreditation criteria of *Server Energy Efficiency Requirements and Testing Methods* and carried out accreditation. However, the development of server energy efficiency evaluation and testing tools is still blank. Current main standard for evaluating server energy efficiency is SERT of SPEC and the energy consumption standard is the *EnergyStar Specification* led by the US Environmental Protection Agency. China’s corresponding server performance and energy consumption evaluation is relatively backward, which mainly involves the *Server Energy Efficiency and Testing Methods* developed by Inspur Group of China; however, its requirement is only to make simple real-time measurement under specific operation state of server equipment, system load, environment and other fixed variables; therefore, it is necessary to study new energy efficiency measurement methods and put forward energy efficiency evaluation and judgement standards for server equipment and components.

## 3. Analysis of performance and energy consumption of each component of server equipment

The server is a high-performance computer in the network environment and provides corresponding services after the client in the network submits service requests. To this end, the server must be able to assume service and support services. Its high performance is mainly reflected in high speed computing power, long time reliable operation, strong external data throughput capacity, etc. The hardware structure of the server system is similar to that of common PC structure; main hardware components include central processor, memory, chip set, I/O bus, I/O equipment, power supply, and case. The server energy consumption and performance testing methods studied in the paper are suitable for server objects including tower server and rack server. This paper mainly analyzes CPU, memory, I/O equipment and other key energy consuming components.

### *3.1 Performance and Energy Consumption of CPU*

The internal structure of CPU can be divided into control unit, logic unit and memory unit; the format of control, logic, and memory units adopts binary code 0/1 to indicate instructions and data; therefore, CPU performance can be understood as the performance of data computation, which involves integer computation and float computation. According to the characteristics of integer computations, compilation, compression, video compression and conversion, XML processing and other functions are generally used as the performance indicators of integer computation of CPU; meanwhile, float computation is mainly performed through the computation of a variety of mathematical methods. The problem currently faced is how to select an effective computing method and obtain CPU performance through float and integer computation of finite shorter time.

CPU performance of server equipment is mainly reflected in the computing performance of integer and floating-point computations and shall consider the main frequency of CPU at the same time, which decides the speed indicator of data computation. In addition, CPU which requires high-speed processing shall be composed of hundreds of millions of transistors; those transistors operate and emit heat on a very small area of CPU and the temperature can reach 70°C so the huge energy consumption of them is very impressive.

### *3.2 Performance and Energy Consumption of Memory*

The memory system has been an important component of the server and is the bridge for data communication between hard disk and CPU. Because the amount of data processed by the system is quite large, almost every step of operation will have to go through the memory; therefore, it is the most frequently working part of entire system. According to research, the chip processing capacity, as predicted by Moore's law, has 80% upgraded every year but the speed of memory equipment has only 7% improvement every year; therefore, the highest processing capacity of process is not decided by the processing ability of CPU, but the memory access speed and transmission speed. Memory bandwidth is one of the important indicators; the memory not only can temporarily store CPU computing data and instructions, but also can exchange data with the hard disk and call the programs in the hard disk into the memory for computation. Typically, the time spent for data to transfer between CPU and memory is longer than that of the processor to execute functions; therefore, the memory bandwidth shall be improved to accelerate data transmission. Memory read speed is also an important indicator and refers to the minimum time of the interval required from the start of a memory computation to completion of such computation. According to the data sequence, CPU sends instructions to find hard disk data from memory, read and process the data, or writes CPU data results in the hard disk or directly outputs via the memory; the reading and writing speed of memory decides the overall operation speed of the system.

Memory frequency is an important factor affecting the performance of the memory and it directly determines the speed of the memory. The memory stores the hard disk data and transmits it to the CPU; if the memory capacity is not enough, the data transmission rate will be directly affected, resulting in time delay and waste of resources because the CPU waits for data input. Therefore, the memory capacity is one of important factors affecting the performance of the memory[6]. Balanced increase in memory frequency and memory capacity will speed up the data transmission and support CPU multithreading operation.

*3.3 Performance and Energy Consumption of I/O Equipment*

Along with the development of storage technologies, there are many types of storage devices: flash disk, disk, Solid State Disk (SSD), etc. In addition, there are still storage systems such as Network Attached Storage (NAS) and Storage Area Network (SAN). However, due to the cost factor, disk is still the storage device widely used currently. Redundant Arrays of Intensive Disks (RAID) composed of accumulative arrays is an important storage system of servers in data centers. RAID facilitates the IT staff to expand data storage and the design of scattered data arrangement, improving the security of data.

According to the working principle of disk, disk interface type and the role of disk in data cache, input and output function in the server, it can be known that I/O performance parameters include at least the number of requests per second, amount of data transmission per second, average response time, continuous disk reading and writing data and random data reading and writing, reading and writing performance of disk cache.

## 4. Design of a simplified set of standard load for evaluating energy performance of server

The server is composed of CPU chip, memory, storage system, network hardware and other components on the motherboard; each component needs to work with each other so that the performance of the server can be optimized. The storage performances of CPU, memory and hard disk shall be comprehensively considered and the weight shall not be equally shared by them. Therefore, the energy efficiency of server equipment shall be analyzed; firstly, the standard load for test shall be determined and then the weights of different components shall be determined.

*4.1 Standard Load for CPU Test*

According to the previous analysis, the computing performance indicators of the server are integer and float computation performances, while the energy consumption is the power consumption during the test period and the CPU frequency (clock frequency) is the speed indicator which determines data computing. Power (P) is an important physical parameter to describe the working characteristics of CPU. According to the formula $P=U*I$, the CPU power can be obtained by multiplication of the value of core current flowing through the processor, core voltage value and time. Because the computation of CPU performance involves the test time, the paper takes the value of CPU energy consumption as the power in order to facilitate the test and computation.

The integer computation performance of CPU is computed by compression computation, which contains two load modules, file compression and file encryption, and both uses the corrected Lempel-Ziv-Welch method (LZW). In this method, different characters are extracted from the original text file data; a compilation table is created based on these characters; the index of the characters in the compilation table is used to replace corresponding characters in the original text file data and reduce the size of original data. The compilation table is randomly and dynamically created according to the original file data; original compilation table shall be restored from complied data at the time of decoding; and decompression is the inverse process of coding. During the process, the compilation program is executed by sequence and the performance is assessed by the execution times of each second. Fixed size of array is generated at each time of execution and the array content is generated randomly.

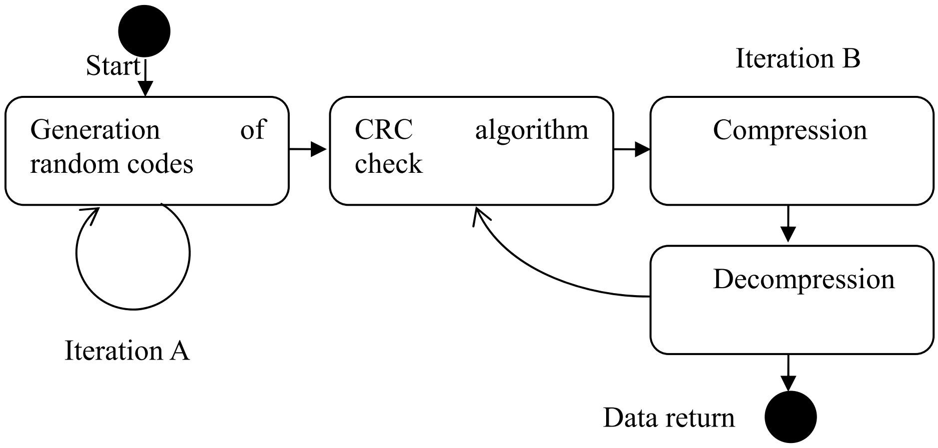



Fig1. Transaction code of LZW [7]

* See the algorithm details in the Terry Welch, IEEE Computer Periodical 17 (Issue of June 1984), Page 8-19.

Gauss elimination method module is adopted for the integer computation of CPU. The method is used to solve the linear equation group, find the rank of a matrix, and find inverse matrix of invertible square matrix. Elementary row transformation is adopted to convert the augmented matrix in the equation group into an echelon matrix; and then, the equation group corresponding to this echelon matrix is written out and back substitution is performed step by step; during the process to find the solution of equation group, the completion program is executed by sequence and the performance is assessed by the performance is assessed by the execution times of each second.

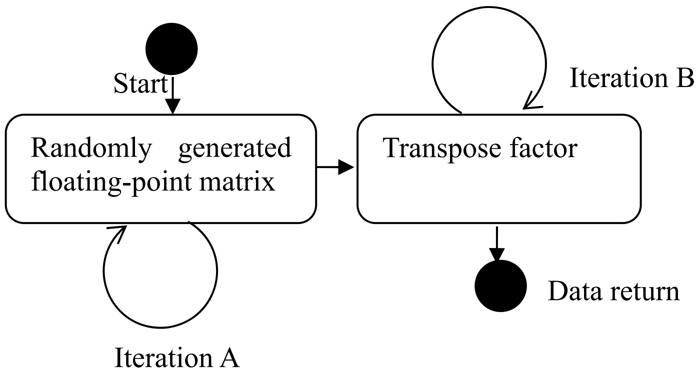



Fig2. Transaction code of Gauss elimination [7]

The computation performance indicators of the server are integer computation and float computation performances and the energy consumption is the power consumption at the time of computation; the computation of energy efficiency of CPU is

$$E_{cpu-int} = \frac{integer\ computation\ performace}{energy\ consumption}$$

$$E_{cpu-float} = \frac{float\ computation\ performace}{energy\ consumption}$$

The final computation value of energy efficiency can be obtained by the geometric mean,

$$E_{cpu} = \sqrt[2]{E_{cpu-float} * E_{cpu-int}}$$

During the test process, it is required to respectively load 25%, 50%, 75% and 100% computation load and obtain real-time loads; the computation result adopts the weighted average method to obtain the energy efficiency of computation performance.

*4.2 Standard Load of Memory Test*

The main performance indicators to investigate the server memory are reading and writing speeds. The memory bandwidth is tested by four methods, namely, Copy, Scale, Add and Triad. Copy, the simplest operation, first accesses a memory unit and reads the value in it, and then writes the value to another memory unit. Scale first reads the value in a memory unit, makes a multiplication, and then writes the results in another memory unit. Add firstly reads two values in a memory unit, makes addition computation, and then write the result in another memory unit. In this test, Triad means to combine the operations of Copy, Scale and Add.

Copy: $a(i) = b(i)$: 8-byte reading+8-byte writing, each time of 16-byte operand

Scale: $a(i) = k * b(i)$: 8-byte reading+8-byte writing, each time of 16-byte operand

Add: $a(i) = b(i) + c(i)$: 16-byte reading+8-byte writing, each time of 24-byte operand

Triad: $a(i) = b(i) + k * c(i)$: 16-byte reading+8-byte writing, each time of 24-byte operand

The test flow chart is as follows:

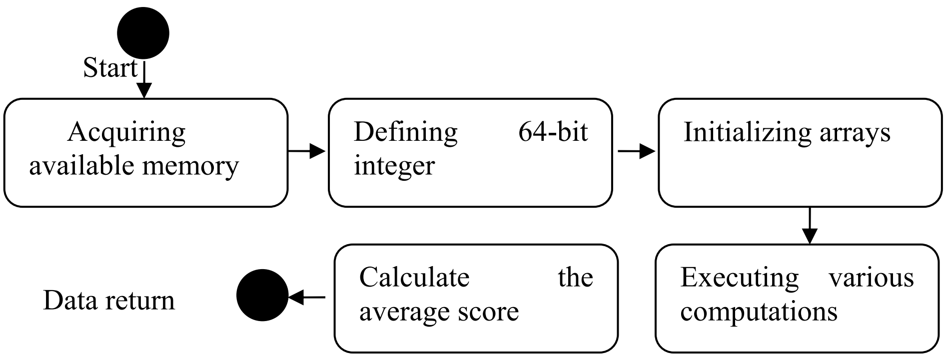



Fig3. Transaction code of memory test [7]

The computation of energy efficiency of the memory adopts

$$E_{mem-copy} = \frac{copy\ speed\ performace}{energy\ consumption}$$

$$E_{mem-scale} = \frac{scale\ speed\ performace}{energy\ consumption}$$

$$E_{mem-add} = \frac{add\ speed\ performace}{energy\ consumption}$$

$$E_{mem-triad} = \frac{triad\ speed\ performace}{energy\ consumption}$$

As for the memory, all four computation methods can reflect its energy efficiency; and their weights are the same so it is computed as per the arithmetic mean.

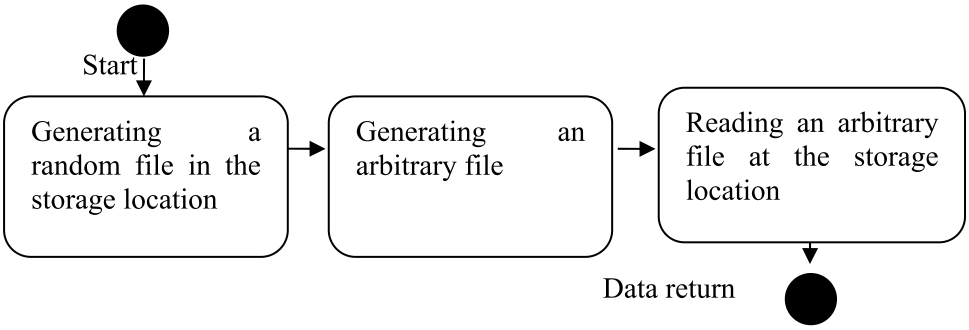
$$E_{mem} = \frac{E_{mem-copy} + E_{mem-scale} + E_{mem-add} + E_{mem-triad}}{4}$$

*4.3 Standard Load for Performance Test of Hard Disk*

The actual value of energy consumption of hard disk storage is a measure to evaluate the energy consumption of the storage system. The storage test in the research is composed of four parts, namely sequential reading, sequential writing, random writing and random reading. Each part has reading and writing computation. The I/O performance is investigated.

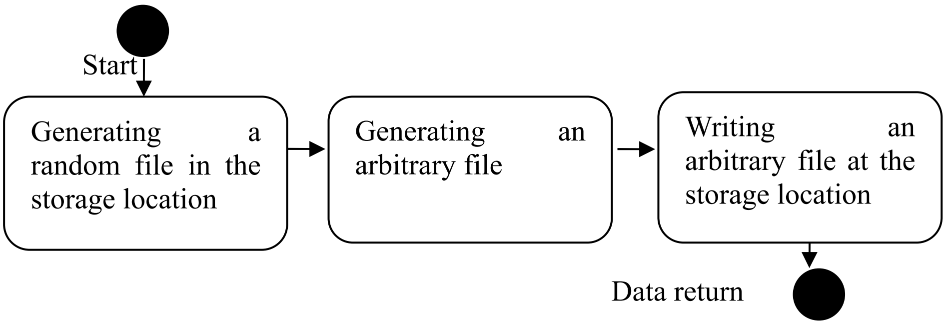
The flow chart is as follows:

**Random Reading**



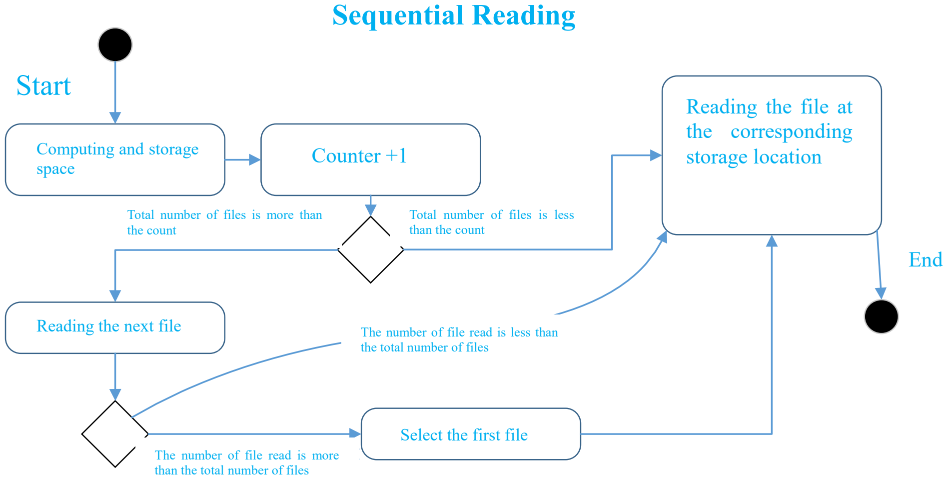

A). random reading transaction code

**Random Writing**




B). random writing transaction code

**Sequential Reading**




C). sequential reading

Fig4. Transaction code of hard disc test [7]. A). random reading transaction code; B). random writing transaction code; C). sequential reading

## 5. Conclusion

This paper provides a simplified set of standard load for evaluating energy performance of servers based on the standard test procedure developed by SPEC. It is a key component of energy efficiency test of servers in energy efficiency programs such as MEPS and labeling program. The energy consumptions of different components of sever equipment are tested to comprehensively assess the energy performance of entire server equipment, which facilitates operation and is favorable to promote the energy conservation and emission reduction of the server industry.

**Acknowledgment**
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**References**
[1]ITU -T. ICTs and Climate Change [J]. *Technology Watch Report* #3, Dec. 2007.
[2]Wu T, Liu L. X, Hu S. L. Energy Conservation Mechanism and Strategy of Servers in Green Data Centers [J]. *Microellectronics & Computer*, 2011(8): 17-22.
[3]Energy Star, *http://www.energystar.gov/*
[4]Zeng Y. Summary of Server Energy Conservation and Efficiency Evaluation Technologies, *Information Technology & Standardization*,2008(9): 7-12.
[5]SPEC power_ssj2008, *http://www.spec.org/power_ssj2008/*
[6]Matthias E., Rukun M., Wang X. R. Power Management for Main Memory with Access Latency Control [J]. *Compute Science*, 2009: 36-40
[7] Standard Performance Evaluation Corporation (SPEC), *Server Efficiency Rating Tool (SERT) Design Document* 1.0.2, 2013