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New energy efficiency metrics for the IT industry

Rafael R. Sukhov [a]
E-mail: r.sukhov@uptimetechnology.ru

Maxim B. Amzarakov [a]
E-mail: m.amzarakov@uptimetechnology.ru

Evgeny A. Isaev [b]
E-mail: is@itaec.ru

[a] INO Uptime Technology
Address: 7, Marshala Rybalko st., Moscow 123060, Russia

[b] Institute of Mathematical Problems of Biology RAS – the Branch of Keldysh Institute of Applied Mathematics of Russian Academy of Sciences
Address: 1, Professor Vitkevich st., Pushchino 142290, Russia

Abstract

Reducing the technogenic impact of human activity on the ecology of the planet is a problem that is increasingly moving from a theoretical category into a practical one. The environmental situation is serious and requires more attention. One of the significant factors of the negative impact of humans on their environment is the emissions of harmful substances that occur during the production of electricity. The technical development of humanity and the widespread introduction of information technologies are characterized by an explosive growth in the number of electronic devices and the amount of data transmitted over information networks. This contributes to an increase in the need for computing resources for storing and processing this data, and as a result, the need for electricity is also increasing. Over the past 15–20 years, computing equipment has increased its computing power many times. The number of servers in operation is currently estimated at many millions of units, and the total energy consumption of the server park is becoming very significant in the structure of energy costs in all developed countries. In this article, we will analyze a way to reduce energy costs in the operation of servers and data centers, the application of which has a high potential for saving energy. We will give an example of a new way to evaluate the efficiency of IT equipment using a new factor – the server idle coefficient (SIC).

Keywords: energy efficiency, energy consumption, server, data center

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Introduction

The development of global (international) and regional (at the level of certain countries) social networks, Internet services, and the widespread introduction of information technologies in all sectors of the economy lead to the need to increase the efficiency of the use of computing resources. Currently, this is expressed in the consolidation of server equipment in specialized places of operation – data processing centers, which allows us to reduce costs due to the deep optimization of power supply and cooling of server equipment, as well as in the development and production of servers with improved characteristics in terms of power consumption and computing power.

Modern data centers that use innovative ways of power distribution and cooling are already approaching the theoretical limits of energy efficiency. Further technological developments in the engineering systems of data processing centers will slightly increase energy efficiency [1], while significantly increasing their cost.

On the one hand, according to the available studies [2], it can be concluded that, e.g. in the UK, approximately 10% of total electricity production is consumed by commercial and government data centers and IT systems located in them.

On the other hand, modern servers have come close to the limits of compactness and energy efficiency. The current "silicon" technological basis will not provide a significant reduction in energy consumption with comparable computing power in the near future.

And, despite the active development in recent decades of so-called "green" energy – that is, energy that uses alternative energy sources to traditional ones, operating on oil, extracted natural gas and coal, traditional energy sources during combustion emit carbon dioxide into the atmosphere, which leads to an increase of the greenhouse effect and global warming.

Currently, more than two-thirds of the energy sources in world production are traditional ones that cause significant harm to the environment (*Fig. 1*) [3].

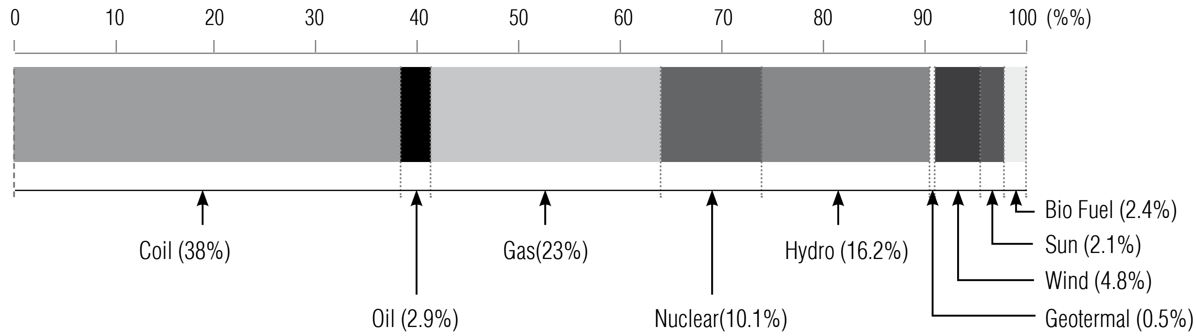

Fig. 1. Share of electricity generation by energy sources in the world.

Consolidation of IT resources improves efficiency both by optimizing maintenance costs and by reducing costs associated with power supply and subsequent additional cooling costs. The emergence of a new industry – data centers – is a logical development of the IT industry as a whole.

A modern data processing center (DPC) is a high-tech enterprise that provides continuous and reliable power supply to servers. The main resource that is managed, distributed and supplied by the data center is electricity, the efficiency of which determines the overall efficiency of the data center in particular and the IT industry as a whole.

Understanding the existing limitations pushes researchers around the world to look for new ways to reduce energy costs in the IT industry.

In the work of a data center, two of the most significant consumers of electricity can be distinguished: server equipment and auxiliary engineering systems (air conditioning, power distribution and uninterruptible power supply, etc.). For each type of consumer there are various energy efficiency metrics that, to one degree or another, make it possible to give a qualitative or quantitative assessment of each of the consumers. However, the authors of this article are not aware of a single metric that would allow both of them to be comprehensively combined and make it possible to assess the impact on the final energy efficiency of the data center operation.

That is why it becomes important to create a single metric that would allow us to evaluate the efficiency of using electricity in a data center when performing calculations, regardless of which processor the server uses, or what cooling technologies are used in the data center [1, 2].

However, the task of measuring server energy efficiency is not as simple as it seems at first glance.

1. Current energy efficiency indicators

The efficiency of a data center, in terms of energy costs for maintaining the operation of server equipment, is evaluated by using the power usage effectiveness (PUE) coefficient [4]. This coefficient appeared in 2007 and has firmly entered the everyday life of specialists. It allows you to instantly assess the energy efficiency of a data center as an object of engineering infrastructure.

PUE is calculated as the ratio of the total data center energy consumption (including all energy costs, both IT and support costs) to the energy costs of the data center server equipment, i.e. PUE shows how much electricity the data center consumes to ensure that the server equipment works properly:

$$\mathrm{PUE} = \frac{P_{total}}{P_{IT}}, \text{ where} \quad (1)$$

P_{total} – the total amount of energy consumed by the data center;

P_{IT} – the amount of energy consumed by all IT equipment in the data center in the same time.

According to the Uptime Institute data, the PUE coefficient decreased sharply from 2006 to 2013 [5], however, after 2013, the PUE coefficient remains approximately at the same level (*Fig. 2*) and fluctuates at the level of 1.5–1.7.

Each watt of electricity consumed by the server is associated with energy costs for its “delivery”: transmission, conversion, cooling, lighting, etc. Currently, this additional cost required to keep the server up and running is 0.5 to 0.8 watts for every watt the server consumes.

In the professional environment such an effect is called a cascading effect (*Fig. 3*).

At the moment, it is not expected that the energy efficiency of the data center can be significantly improved. Individual data center projects show phenomenally low PUE values of 1.06–1.1. However, it should be noted that

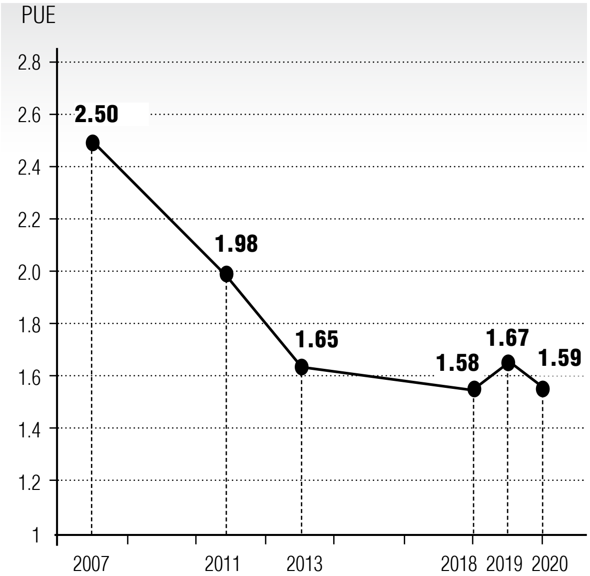

Fig. 2. Decrease in the dynamics of improving the energy efficiency of data centers [5].

such values are achieved under very limited conditions, while using harsh, complex and interdependent operating conditions of engineering systems [6] and IT equipment. In most cases they are difficult to achieve or practically unrealizable [7].

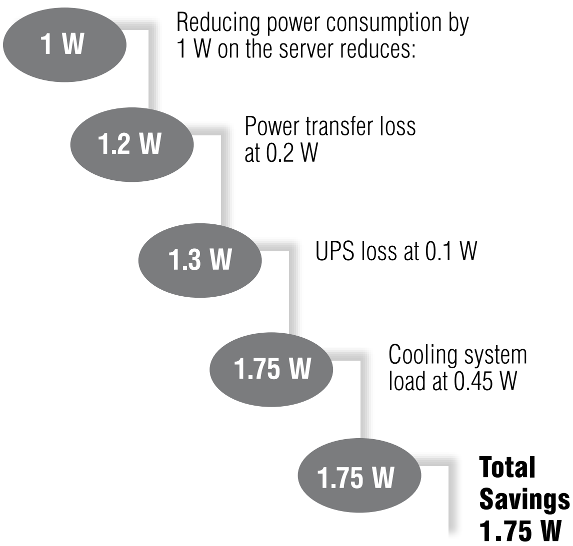

Fig. 3. Cascading effect.

Another component of energy costs, which has a high weight in total energy consumption, lies directly in the IT equipment.

Almost since the advent of the first computers, there has been a relentless struggle to reduce the size and power consumption of computers. And in this area amazing results have been achieved. For example, you can look at the results achieved by AMD [8]. Over the past six years, AMD has improved the power efficiency of its mobile processors by 31.7x (*Fig. 4*).

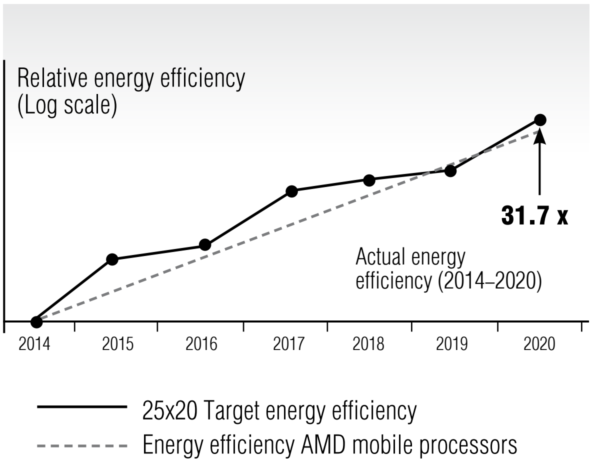

Fig. 4. Increasing the energy efficiency of mobile processors [8].

We observe an interesting effect here. In the last 15–20 years, the average power consumption of the processor itself and the computer (server) as a whole has been decreasing insignificantly, and the processor performance, i.e., computer (server) is growing significantly. Formally speaking, the computer processor becomes much more energy efficient, because the performance of one operation requires significantly less energy than was required before.

And, arguing in this vein, it can be assumed that in this case, the overall energy consumption of the IT industry and the data center industry should be reduced, which is a favorable factor for reducing resource consumption.

However, this does not happen. The main reason, in our opinion, lies in the fact that all the increase in processor performance is "spent" on meeting the needs of society in the best possible way, for example, making video content of better quality, delivering this content to the user more quickly, generating new content, attracting new users, creating new IT services that are increasingly using neural networks, built in their turn also on server clusters, etc.

So far, we do not see that there is any limit to this "arms race," but at the same time, can we find ways to reduce energy consumption which will be less dependent on the above-mentioned drivers that generate demand for IT services?

2. Energy management

Based on the data given in the article [1], we can take as a basis the energy distribution in the average server, shown in *Table 1.*

The table shows that the main consumer is the server processor – this is almost 64% of the total server power consumption. At the same time, it is also known that, on average, depending on the nature of the calculations performed, server processors are busy with useful work from 2 to 30 percent of the time [9, 10]. From this, we can conclude that while the processor consumes a significant part of the energy in the server, in fact the processor most of the time does not perform useful work.

For server manufacturers and other participants in the IT industry, this fact is not a secret, and in order to minimize energy losses during server downtime, as well as to reduce the risk of processor overheating and the occurrence of negative effects in semiconductors (tunnel effect), they have been building special server management systems into server management systems for a long time: algorithms and methods for managing energy saving which allow you to flexibly configure the operation of all elements of the server (processor, RAM, permanent memory, video card, etc.) and thereby reduce unproductive losses of the server as a whole. Research in the direction of how to make server energy management systems more efficient is ongoing.

Examples of such studies include:

- Berkeley laboratory study: Comparing server energy use and efficiency using small sample sizes (comparison of energy consumption and efficiency of servers on the example of servers of typical sizes of small format) [11];

Table 1.

Distribution of energy costs in the server

Component	Consumption, W	Consumption, %
Processor	115	63.89%
RAM	15	8.33%
Hard disks	2	13.33%
Network communication	5	2.78%
Cooling	8.87	4.93%
Power supply	11.13	6.18%
Other energy costs	1	0.56%

- Report at the international conference on high-performance computing, data transfer, storage and analysis: Energy-aware data transfer algorithms (energy-saving data transfer algorithms) [12];
- Report at the 9th International Conference on Applied Energy: Development of a simple power consumption model of information technology (IT) equipment for building simulation (development of a simple power consumption model of information technology (IT) equipment for building simulation) [13].

And in the future, we will see new generations of servers and telecommunications equipment which, thanks to technologies created on the basis of such research, will have better characteristics than today.

As the main areas that would improve energy efficiency, the following can be distinguished:

- measurement of energy consumption;
- control of energy consumption;
- energy management.

3. New trends in efficiency

As we noted earlier, the energy efficiency of a server depends on how much it is loaded with useful work, performing calculations.

There are many different metrics for measuring the energy efficiency of computing. The simplest metric is the measurement of the amount of energy expended to produce a floating-point calculation [14].

For personal computers, the SPEC metric is widespread [15]. This calculates the amount of energy spent on performing typical actions on a computer running different operating systems.

Energy Star (an organization under the Environmental Protection Agency EPA, USA) has developed a whole program for measuring efficiency – SERT [16], including the measurement of power consumption in the production of various operations.

SUN Microsystems proposed the SWAP (space, wattage and performance) metric [17].

However, all the metrics mentioned above have one common drawback, namely, the need to determine the performance of the server. For the SWAP metric, useful work is determined directly by indicating the complex actions performed. For the SPEC metric, performance is determined by the performance of known programs. For SERT, this is the performance of specialized software execution.

And these restrictions significantly narrow the possibilities of using such metrics, which in their turn does not make it possible to extend this or that technique to all types and types of servers and computing.

But on the part of society, represented by the state, there is a serious request for the search and implementation of new mechanisms and technologies that allow additional energy savings when using servers.

And in this sense, the state performs a very important function, namely, it sets rules and standards, sets metrics, or boundary values, the achievement of which becomes mandatory, thereby stimulating the industries involved in the search for new solutions and their implementation in technologies and equipment.

A widespread example of energy efficiency improvement in the world is the introduction of energy efficiency classes in industrial and household electrical equipment, as well as the establishment of control dates when restrictions begin to operate, or a complete ban on the circulation of equipment with low energy efficiency indicators, as introduced in Russia in the form of a state industry standard (GOST) [18], or on the example of the provisions of the EU Commission [2, 19].

Another illustrative example of the implementation of an energy efficiency program is the LEAP program (Lower Energy Acceleration Program) – the program for the development of lower energy consumption [20]. This program is an initiative run by the Dutch government and is part of such an EU program. Within the framework of this program, studies are carried out aimed at finding areas where significant improvements are possible in terms of energy efficiency.

In particular, the report prepared by Certios and WCoolIT by order of the Netherlands Enterprise Agency (Netherlands Industrial Agency) is very interesting. The report is called "LEAP Track 1 "Powermanagement" Pilot analysis" – LEAP Stage 1 Pilot analysis of energy saving [9].

Before proceeding directly to such metric as the server idle coefficient (SIC), it will be useful to describe the criteria used in calculating the metric.

The authors of the SIC metric do not claim to define performance or useful work. However, the operation of any computing device is characterized by the performance of "parasitic calculations" (for the processor – the NOOP instruction). From the authors' point of view, any computational action is useful, regardless of what kind of calculation is performed and how "useful" it is to the consumer. Nevertheless, most of the time, the processor does not perform computational operations, but is in standby mode, in which the NOOP instruction is executed. The energy expended to perform this operation is considered a direct waste.

The idea of the study was to try to understand how efficiently the processor time is used, how much they affect the energy savings implemented in the hardware of servers or operating systems, the ability to manage energy savings, and also whether it is possible to present the actual energy efficiency of the server in an equally understandable way for all kinds.

For the study, statistics were taken from a pool of servers operating with a real load and different profiles of the load itself. We tested all the main power saving modes built into servers and some operating systems in various load modes.

The data obtained was analyzed and presented in a very visual way, demonstrating the real situation with the energy consumption of these servers. *Figure 5* shows the dependence of energy consumption depending on the load on the server. An example of server operation with power management enabled is given. The direct dependence of power consumption on processor load is clearly visible. We also see that this server has explicit maximums and minimums of the payload on the processor associated with the specifics of the applications running on this server.

The energy efficiency assessment was performed using a methodology to measure server processor uptime and idle time, which correlated with energy monitoring data at these points in time.

In this case, the SIC coefficient was proposed as the final server efficiency coefficient – the server idle coefficient.

$$\text{SIC} = \frac{E_{total}}{E_{total} - E_{idle}}, \quad (2)$$

$$\text{SIC\%} = 100\% \cdot \frac{E_{total}}{E_{idle}}, \quad (3)$$

where

E_{total} – total energy consumed by the server;

E_{idle} – energy consumed by the server during idle time.

Indicator (2) is interpreted by analogy with the PUE coefficient, i.e., the closer the value is to one, the more energy the server spends on useful work out of the total amount of energy spent.

The indicator (3) is the percentage of power consumption when the server was idle to the total amount of power spent. That is, the closer this indicator is to 100%, the less time this server performs useful work.

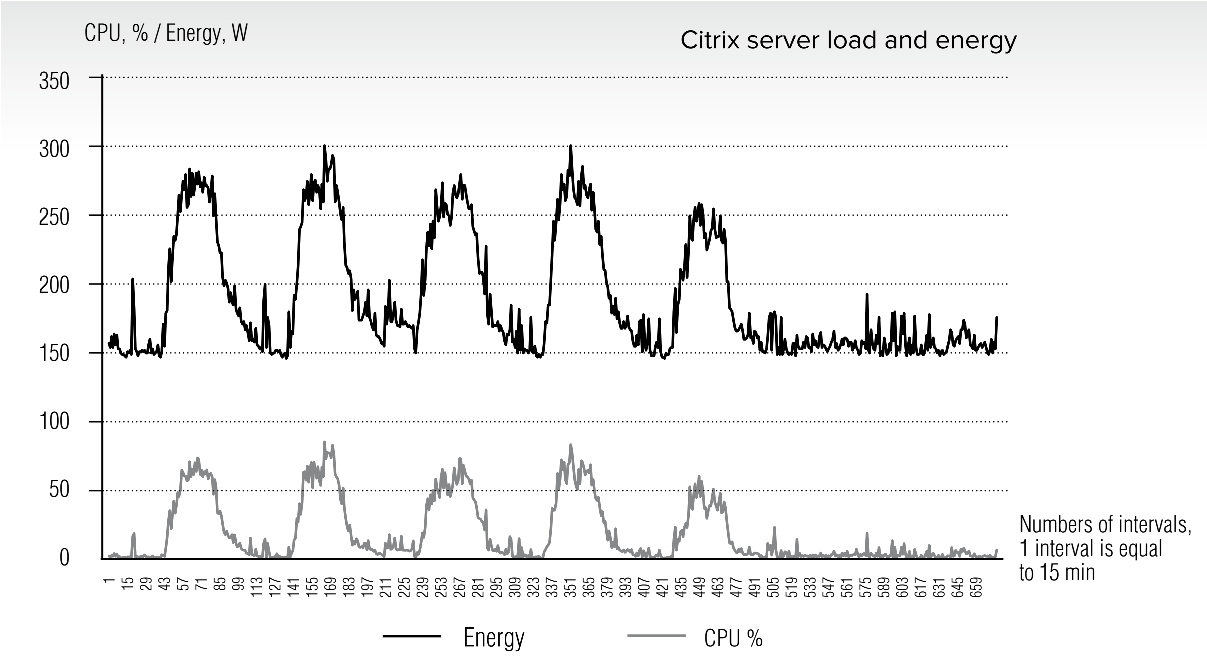

Fig. 5. Graphs of the dependence of the consumed energy of the processor on the load [9].

The study noted that:

- SIC % indicators in different groups of servers varied from 34% to 91%;
- there is a gap in the knowledge of the technical staff responsible for the operation of servers about the role of virtualization in power supply management;
- there are still strong prejudices regarding a significant decrease in the performance of systems configured to use dynamic power saving modes;
- most server cluster operators do not have any clear rules and policies regarding server power management. And where these policies exist, they most often override in favor of maximum server performance.

The obtained research data show a very high potential for reducing inefficient energy consumption.

As a practical example, we can analyze the data presented in *Fig. 6*.

Graphs of *Fig. 6* shows data on the server processor load and its power consumption in two operating modes: the upper graph is the high-performance mode; the lower graph is the power saving mode under the control of the server operating system.

The received data was processed and presented in the total values of the energy consumed in different modes and the SIC was calculated for the power saving mode enabled:

- total energy consumption for the period: 24.5 kW;
- total energy spent during idle periods: 8.43 kW;
- Average CPU idle time: 60.4%.

Using formulas (2, 3), the SIC coefficient is calculated as a percentage and as a ratio of the amount of total energy spent to the energy spent on computing needs:

$$SIC\% = 8.43/24.4 = 34.4\%;$$

$$SIC = 1.5;$$

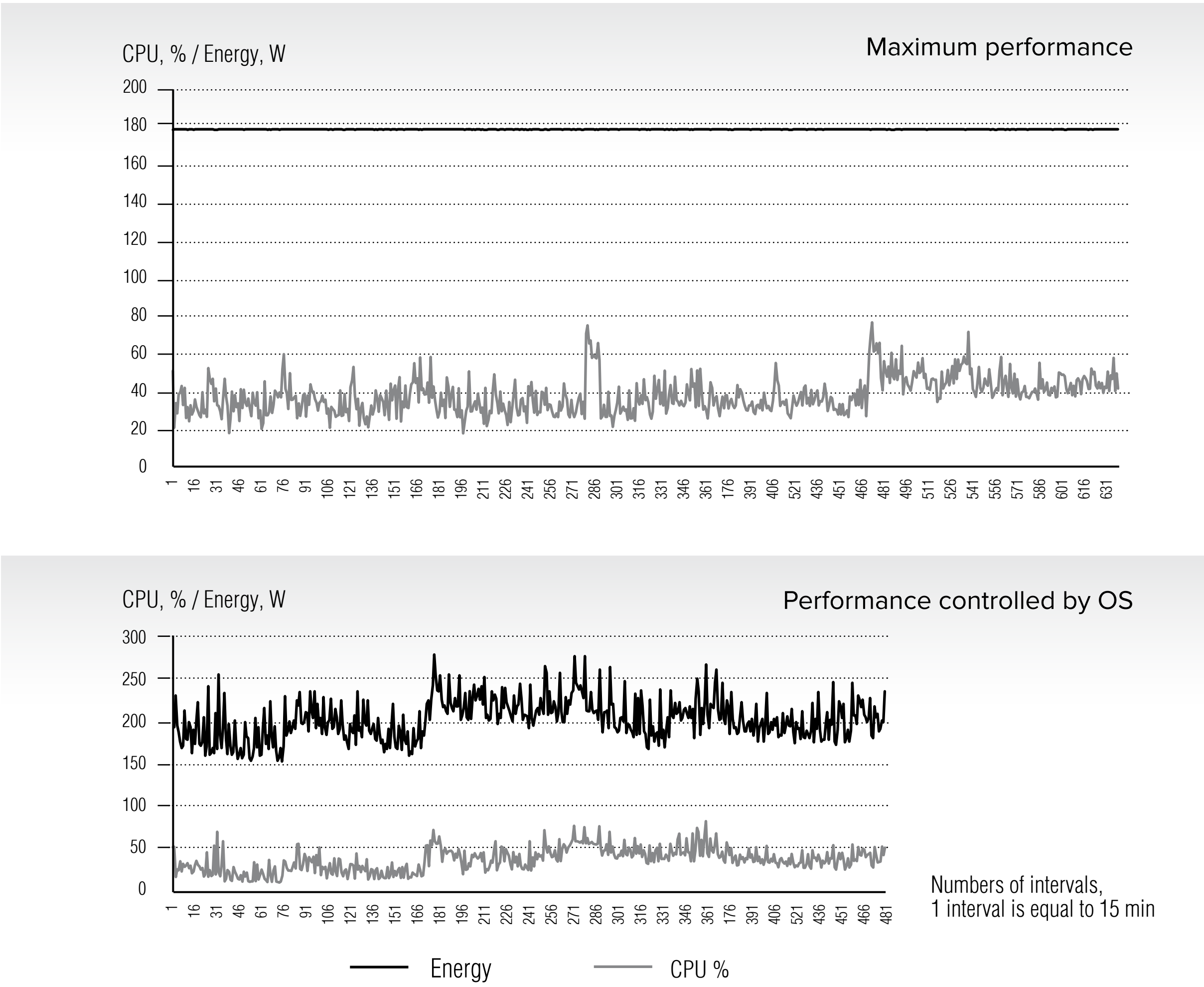

Fig. 6. Server load and different power saving modes [9].

and in power saving off mode:

- SIC% = CPU idle time % = 60.4%
- SIC = 2.53.

Thus, the SIC coefficient gives a visual representation of the efficiency of the server.

This approach seems to be interesting and promising, as it allows you to evaluate the efficiency of server hardware without reference to its real energy consumption parameters. This makes it possible to evaluate the effectiveness of the complex: server – software – clustering – dynamic load management.

The development of this approach will certainly require a deeper study and the development of a unified methodology and data extraction mechanisms for the evaluation and subsequent interpretation of the data obtained.

4. Evaluation of the practical benefits of using the server downtime factor

Improving the idle factor value is possible in two ways. The first direction is to improve the scheduling of instruction execution by the operating system and software. That is possible, for example, due to better distribution of calculations between servers. The aim to increase the useful time of computing power is the task for developers of information systems and software.

The second direction – reducing the power consumption of server equipment in the absence of calculations – is a task for developers of processors and server equipment.

It can be argued that the widespread introduction of the SIC metric makes it possible to create a single basic environment for a comparable and reliable assessment of the efficiency of modern servers, which, in combination with government regulation, will give a great incentive to software developers to increase the payload of computer processors and to equipment developers to increase the energy efficiency of their devices.

The SIC coefficient also makes it possible to apply new methods for the practical implementation of energy efficiency programs in data centers with minimal investment costs for the implementation of such practices.

Switching to server power monitoring using the SIC coefficient allows you to perform these procedures in real time, without spending resources on costly and time-consuming measurements of the PUE coefficient or its derivatives.

Automated SIC background calculation on each server and aggregation into a single analysis system can make it possible to almost instantly identify server hardware that is being used inefficiently.

Based on the cautious estimates of the authors of the study [9] in the possibility of energy savings of at least 10% for highly loaded servers when switching to dynamic server power management, we estimate the amount of potential energy savings for a small typical data center with the following characteristics:

Total number of servers in operation: 2 000 pcs.;

Average power consumption per server: 200 W;

Influence of cascade effect (PUE coefficient) data center: 1.7.

Suppose that, as a result of controlling the SIC coefficient, we managed to reduce the power consumption of one server by 10% on average, we will get:

$$P_{savings} = 200\ (\mathrm{W}) \cdot 10\% = 20\ (\mathrm{W}) \text{ – for one server;}$$

Taking into account the total number of servers, equal to 2000, we get:

$$P_{total\ savings\ IT} = 20\ (\mathrm{W}) \cdot 2000 = 40\ (\mathrm{kW}) \text{ – for total IT load,}$$

Thus, we see that the seemingly insignificant 20 W savings in power consumption per server on the scale of our example, in the amount of 2000 servers, allow us to obtain a total reduction in electrical power consumption in the amount of 40 kW.

Taking into account the PUE coefficient, we get:

$$P_{total\ savings} = 40\ (\mathrm{kW}) \cdot 1.7 = 68\ (\mathrm{kW}) \text{ – for data center,}$$

Reducing the power consumption of auxiliary engineering systems necessary for the normal functioning of the servers adds another 28 kW of electrical energy to the overall savings.

Below we will move from consumed electricity measured in kW·h to consumed electricity measured in kW·h and calculate the amount of electrical energy savings per month:

$$P_{total\ savings} = 68\ (\mathrm{kW}) \cdot 720\ (\text{hours}) = 48\,960\ (\mathrm{kW{\cdot}h}),$$

where 720 hours – is the average number of hours per month.

Next, we calculate the amount of electricity savings per year:

$$P_{total\ savings} = 68\ (\text{kW}) \cdot 8640\ (\text{hours}) = 587\ 250\ (\text{kW·h}),$$

where 8 640 hours – is the average number of hours per year.

If we assume that in Moscow the cost of one kWh of electricity in 2021 is 7.11 rubles, then for the year we will get a total savings in cash:

$$S_{total\ savings} = 587\ 250\ (\text{kW·h}) \cdot 7.11\ (\text{rub.}) = 4175\ (\text{mln rub.}).$$

The given example of a data center, in comparison with the giants of the industry, has a small capacity, about 700 kW, but this example clearly shows what potential there is in reducing the overall energy consumption of data centers and the IT industry.

Conclusion

This article discusses the issue of the main trends in the field of increasing the efficiency of using electricity in the operation of server clusters and systems.

The energy efficiency of the calculations performed at the level of individual devices, based on the number of operations per unit of power, and the reduction in operational losses of engineering systems of data centers [21] are the main driver for improving the energy efficiency of the IT industry as a whole.

It is shown that a 10% reduction in energy consumption on servers reduces the required power from 700 to 632 kW and provides significant savings in the cost of paying for consumed electricity.

It is necessary to pay close attention to new ways of improving the energy efficiency of the IT industry, namely of changing approaches to managing server systems. Combining single devices – servers into clusters and systems with simultaneous management of processor capacity loading, as well as dynamic management of the power supply of server elements, in addition to the main ways to increase energy efficiency, provides another powerful tool for management and control.

The introduction into practice of new methods for evaluating the efficiency of server hardware, such as the server idle coefficient (SIC), can give a qualitatively new assessment of the efficiency of calculations, regardless of how energy-efficient the server processor is by itself. ■

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About authors

Rafael R. Sukhov

Financial manager, INO Uptime Technology, 7, Marshala Rybalko st., Moscow 123060, Russia;

E-mail: r.sukhov@uptimetechnology.ru

ORCID: 0000-0002-8124-137X

Maxim B. Amzarakov

Director, INO Uptime Technology, 7, Marshala Rybalko st., Moscow 123060, Russia;

E-mail: m.amzarakov@uptimetechnology.ru

ORCID: 0000-0001-6229-8592

Evgeny A. Isaev

Cand. Sci. (Tech.);

Senior Research Fellow, Institute of Mathematical Problems of Biology RAS – the Branch of Keldysh Institute of Applied Mathematics of Russian Academy of Sciences, 1, Professor Vitkevich st., Pushchino 142290, Russia;

E-mail: is@itaec.ru

ORCID: 0000-0002-3703-447X