Analysis of methods for assessing the energy efficiency of data centers using the power usage effectiveness method

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Abstract. The article deals with the analysis of methods for assessing the energy efficiency of data centers according to the Power Usage Effectiveness method. The demand for data centers which consumes a large amount of electricity is growing with the growth of digitalization and the accumulation of big data in the network. The energy consumption of the cooling system for the machine room accounts for a significant part of the operating costs of the building. Free cooling in a refrigeration system reduces energy consumption much more than operating systems with a vapor-compression cycle. In 2006 according to The Green Grid, the assessment method of Power Usage Effectiveness has become an international standard for measuring energy efficiency and is widely used in the design and operation of data centers. In this regard, the operation principles of free-cooling chillers are considered. The calculation example of the system payback in free-cooling is also given.

1. Introduction
Currently, the global economy makes extensive use of information and communication technologies (ICT) and related technologies for generating, transmitting, distributing, processing and storing digital data. All markets are seeing exponential growth in the volume of such data in the social sphere, in the field of education and business, with the Internet acting as the backbone transport network, and many private companies and other organizations operate their own data centers and leased facilities, acting as nodes and hubs. The generation of data and the subsequent increase in the workloads associated with the processing and storage of this data are directly related to the increase in power consumption.

The data center plays an important role in calculating, storing and managing digital information on the Internet. The expansion of the data center and, in particular, the increase in electricity consumption is an inevitable consequence of these processes, and will require an increase in electricity consumption, despite the most stringent energy efficiency strategies. This necessitates KPIs that measure resource efficiency and deliver significant emissions reductions. The data center function is focused on solving business problems by providing information services and is the operator of many processes: from ordinary correspondence in the messenger to the implementation of an online banking transaction. In the Republic of Kazakhstan, the activity of a data center is regulated by standards ST RK ANSI/TIA-942-A-2016; ST RK DSP-IS 0101_1.0.0; ST RK DSP-IS 0102_1.0.0.

Today, the main problem of energy consumption in a data center is the functioning of the ventilation and air conditioning system. Since the network and server computing equipment located in the computer...
room of the building, when processing and calculating information in the 24/7/365 mode, heats up and is a source of heat surplus. Solving the problem of reducing power consumption by refrigeration systems is very important, since according to the global industry, a rapidly growing data center will consume 4.5% of the electricity generated worldwide by 2025. For comparison, in 2010 this figure ranged from 1.1% to 1.5% (325 billion kWh).

Generation of cold, obtained in a vapor compression cycle based on the processes - compression, condensation, throttling and evaporation, is a very unprofitable measure in terms of energy consumption, since compressors in a year-round operation system consume a large amount of electricity, usually up to 37% of the total electricity consumed in a data center ... Until recently, data centers were energy-consuming facilities, since only vapor compression refrigeration systems were used to cool the turbine hall, which consume excessive amounts of electricity [1-2].

2. Objects and research methods
A computer center (data processing center) is an intelligent building that houses server and telecommunications network equipment for processing multiple digital data.

Unlike conventional server computing rooms, in the data center all service engineering systems are reserved, divided according to the degree of fault tolerance, and besides, the systems are continuously monitored to prevent emergency situations or promptly respond to them.

It should be noted that not all of the electricity consumed ensures the operation of IT equipment, for example, 50% of electricity (figure 1) is consumed by engineering infrastructures: refrigeration systems, ventilation and peripheral systems.

![Figure 1. Electricity consumption in the data center as a percentage](image)

Competent monitoring of electricity consumption in a data center can improve its efficiency. The standard metric for data center efficiency is the energy efficiency ratio (PUE) proposed by the international organization Green Grid in 2007. With the advent of the "green energy" trend in the data center industry, the Power Usage Effectiveness (PUE) has been applied to assess environmental friendliness and energy efficiency. This coefficient is the ratio of the total power consumed by the data center to the power consumed by the IT equipment. According to Green Grid, the energy utilization factor allows [1,4]:

- determine the possibility of improving the efficiency of the data center;
- compare the performance of one data center with others;
- determine the possibility of expansion and redesign of the data center in the future;
- determine the possibility of reorganizing the power supply to connect additional IT equipment;
- determine the calculated capacity values when designing a new data center.
The PUE formula is as follows:

\[ \text{PUE} = \frac{\text{Total Power Consumption of the Data Center}}{\text{Energy consumption of IT equipment}} \]  

(1)

The calculation of the PUE ratio is based on dividing the electricity consumed by the data center infrastructure as a whole by the energy consumption of IT equipment. Determining the energy efficiency of data center infrastructure will help us take the first step towards reducing overall energy consumption and energy costs. It allows you to assess the current layout of a particular data center and develop an optimal strategy for further development.

Determining the PUE provides useful information and guidance for designing efficient power and cooling architectures, deploying equipment within those architectures, and operating that equipment.

PUE helps determine:
- opportunities to improve operational efficiency in the data center;
- the efficiency of optimization of structures and processes in the data center in dynamics;
- design goals for new data centers, taking into account the full range of expected IT workloads.

It is important to note that the lower the PUE value (figure 2), the more energy efficient the data center operation is considered. The ideal ratio is close to 1.0. If the average PUE per year is, for example, 2.5 units, this means that the data center as a whole uses 2.5 times more energy than all IT equipment in general (including servers, storage systems and active network equipment) [1, 3-4].

![Figure 2. PUE value. Energy efficiency indicators](image)

Reducing PUE is mainly achieved by installing a free-cooling system. The principle of freecooling is based on air heat exchange in a heat exchanger without mixing the outside and inside air. During the summer period, water is used as a coolant; in winter, a water-glycol antifreeze solution is used. A combined version is also allowed. The use of free-cooling allows you to shift the task of heat transfer only to fans, which consume much less electricity. If these fans are equipped with energy efficient EC (Electronically Commutated) motors with variable speed, then energy costs are reduced even more.

Today, the following types of freecooling are used:
- chiller with free cooling;
- direct free cooling;
- indirect free cooling with or without adiabatic humidification of the outside air.

Chillers by installation type are:
- monoblock (figure 3 a, b);
- with a remote air condenser (figure 4 a, b);
- with a water condenser based on a dry cooler (figure 5 a, b);
- combined with free-cooling function.
Figure 3. Typical circuit solutions of a monoblock chiller: 1 - fan coil; 2 - coolant pump; 3 - evaporator; 4 - throttling device; 5 - compressor; 6 - air condenser.

Figure 4. Typical circuit solutions of a chiller with a remote air condenser: 1 - fan coil; 2 - coolant pump; 3 - evaporator; 4 - throttling device; 5 - compressor; 6 - remote air condenser.
Figure 5. Diagram of a chiller with a water condenser: 1 - fan coil; 2 - coolant pump; 3 - evaporator; 4 - compressor; 5 - water condenser; 6 - throttling device; 7 - condenser coolant pump; 8 - dry cooler.

The energy consumption for the operation of cooling systems depends on the ambient temperature. Energy consumption measurements taken during the cold season, when the air conditioning systems can be turned off and cooling is provided by the cold outside air, give a PUE value closer to unity than measurements taken during the hot season.

When the outside temperature allows the temperature of the cooling liquid to drop below the required temperature of the cooling medium, the compressor in the freon circuit is switched off and the three-way valve redirects the cooling liquid to the free-cooling heat exchanger. Thus, the cooling of the coolant in the freecooling heat exchanger occurs due to the low temperature of the outside air.

The chiller circuit has a water cooled condenser. Refrigerant condensation occurs due to the removal of liquid, which, in turn, is cooled in a dry cooler (dry cooler) and has two circuits - freon and water solution (or water-glycol antifreeze solution).

Freecooling chillers are larger, heavier and more expensive than conventional vapor compression chillers. However, the high energy efficiency of a freecooling chiller is achieved by shutting down the steam compressors during the cold season and benefits from energy savings at the end of the payback period. Since the steam compressor consumes up to 90% of the total electricity consumption of the entire system.

For chillers with a free cooling system, several operating modes can be distinguished.

One of them is the machine cooling mode. When the outside temperature does not allow the coolant temperature to drop below the required coolant temperature (t\text{coolant} > t\text{refrigerant}). In this case, natural cooling of the coolant is physically impossible. In this mode, the chiller operates like a conventional chiller with a water condenser in a freon circuit (Figure 6), a three-way valve redirects the coolant to the chiller condenser. Cooling of the refrigerant from the consumer takes place in the evaporator of the chiller, due to the removal of heat to the refrigerant. As a result, the refrigerant boils away, the refrigerant vapors are sucked into the compressor, then the compressor compresses the refrigerant vapor to high pressure and a temperature higher than the temperature of the coolant. After that, refrigerant vapors are pumped into the condenser. In the condenser, the refrigerant is condensed by transferring heat from the refrigerant to the coolant. The coolant is in turn cooled in the dry cooler by heat exchange with the ambient air. The liquid refrigerant from the condenser decreases its pressure, passing through the throttling devices and again enters the evaporator. This cooling cycle is repeated. The circulation of the coolant and the coolant is carried out using pumps.
A transient mode is a process when the outside air temperature ensures that the coolant temperature drops below the required coolant temperature \( t_{\text{cooling liquid}} < t_{\text{cooler}} \), but at the same time 100% of the cooling capacity is not yet ensured due to free cooling (figure 7).

In this case, the three-way valve is in an intermediate position. Part of the coolant is directed to the condenser to ensure the operation of the freon circuit, the other part is directed to the free cooling heat exchanger. In this mode, the coolant is cooled in two stages: first in the evaporator due to the operation of the freon circuit, and then in the free cooling heat exchanger due to heat exchange with the coolant from the dry cooler. The compressor operates in this mode, however, the power consumption is significantly reduced, since due to the operation of the freon circuit, the heat removal is reduced. Compressors stop periodically. If the chiller is multi-compressor, then some of the compressors stop, as a result of which the power consumption is reduced.
Free-Cooling occurs when the outdoor temperature drops the coolant temperature below the desired coolant temperature \( T_{\text{cool}} < T_{\text{cooling}} \). 100% cooling capacity is achieved by free cooling and the chiller compressor stops. The system goes into freecooling mode.

Cooling of the coolant occurs due to heat exchange with the coolant from the dry cooler. In this mode, the three-way valve completely redirects the coolant to the free cooling heat exchanger. The freon circuit does not work in this case. Maximum energy savings observed in freecooling mode [9-10].

3. Results of the study

At the design stage of a free cooling system in a data center, one of the main parameters for choosing an energy-efficient solution is the payback period of this project and the value of the annual energy savings. To estimate the payback period, the formula is used:

\[
\tau = \frac{C_{C1} - C_{C2}}{(N_{el1} - N_{el2}) + n \cdot T},
\]

where \( \tau \) – payback period of capital expenditures increase, years; \( T \) – annual savings on electricity, tenge; \( C_{C1} \) – capital costs for equipment without FC, tenge (KZT); \( C_{C2} \) – capital costs for equipment with FC, tenge (KZT).

The amount of annual energy savings is determined by:

\[
T = (N_{el1} - N_{el2}) \cdot n \cdot T,
\]

where \( N_{el1} \) – power consumption of equipment in machine cooling mode, kW; \( N_{el2} \) – power consumption of equipment in FC mode, kW; \( n \) – annual operating time of equipment in the FC mode, h; \( T \) – electricity tariff, tenge (KZT).

As an example, the calculation of the payback of a freecooling system for installation in a computer room (figure 8), consisting of 4 rows of 13 server racks each, 52 server racks in total, is given. The machine room is located in the city of Almaty. Each rack contains 15 servers with an average power of 400 watts. Since the heat dissipation of IT equipment is equal to its power consumption, the heat surplus of each rack is 600 W = 6 kW; then the knowledge of the total heat dissipation of the equipment will be 312 kW.

![Figure 8. General diagram of the turbine room [12].](image)

Required cooling capacity 312 kW. A monoblock chiller with and without FC system was taken as a refrigeration machine.

\( CO_1 \) → Commercial offer (229 305,00 € * 509,20 KZT = 116 762 106,00 KZT);
\( CO_2 \) → Commercial offer (174 054,00 € * 509,20 KZT = 88 628 296,80 KZT);
\( Nel.1 \) → Chiller specifications without FC (131,4 kW);
\( Nel.2 \) → Chiller Specifications with FC (12 kW).
n → The set of rules of the Republic of Kazakhstan 2.04-01-2017 "Construction climatology" (179 days / at a temperature of 0.8 °C / * 24 hours = 4296 hours) [13];
T → Average selling rate for legal entities – 20,69 KZT with VAT [14].

Dollar to tenge rate: 1USD = 509.20 KZT [15].

\[ T = (131.4 - 12) \times 4296 \times 20,69 = 10,612,778.26 \text{ KZT} \] (4)

\[ \tau = \frac{116762106.00 - 88628296.80}{(131.4-12) \times 4296 \times 20,69} \approx 2.7 \] (5)

The payback period for a monoblock chiller with free cooling for Almaty is ≈ 2.7 years.

In regions with temperate and cold climates, the availability of free-cooling helps to significantly
save the amount of electricity in the autumn-winter period. In a dry cooler, only axial fans are powered,
while in other types of refrigeration units, electricity is also required to operate the evaporator.

4. Conclusion
To improve the energy efficiency of the data center, free cooling systems should be introduced at the
design stage. When implementing, planning, building a data center to improve the PUE coefficient, one
should take into account the climatic characteristics of the environment, the possibility of using
renewable energy sources and the rejection of the energy-consuming vapor compression refrigeration
cycle in favor of more efficient cooling systems based on chiller free cooling.

Free cooling systems used in data centers are more costly to install than a vapor compression system,
but the capital investment pays off during their operation. At the same time, the development of energy
efficient technologies does not stand in one place. To achieve energy efficiency, cold seawater,
groundwater, etc. can be used as a chiller. The data center cooling system, built on free cooling, not only
works more stable, but also allows you to achieve the average annual PUE that is several times lower,
without the cost of expensive energy-efficient components (chillers, cooling towers). In this case, when
calculating the PUE, not only the ratio of the IT load is taken into account, but also the energy
consumption for the refrigeration system.

5. References
[1] Liu Y, Wei X, Xiao J, Liu Z, Xu Y and Tian Y 2020 Energy consumption and emission mitigation
prediction based on data center traffic and PUE for global data centers Global Energy
Interconnection 3(2) pp 272-282 https://doi.org/10.1016/j.gloei.2020.07.008
[2] RK ANSI/TIA-942-A-2016 Telecommunication infrastructure of data centers (ANSI/TIA-942-
A-2012 Telecommunications infrastructure standard for data centers, IDT)
[3] Lebedev N N 2018 Features of using" green "energy for dpc needs Journal of Herald of
Contemporary Research, 9.3 (24) pp 283-284
[4] PUE™: A comprehensive examination of the metric https://www.thegreengrid.org/
[5] Altoona Data Center. https://web.facebook.com/AltoonaDataCenter [date of appeal 23.10.2020]
[6] Kirillov I, Kovlenko K 2015 Effective data center about PUE and more Journal Networks and
Business 80 (1)
[7] Oganesyan E S 2014 Using PUE as an energy efficiency indicator in data centers. Journal:
Ecology of Industrial Production, pp 77-82
[8] Chillers with free cooling system and water condenser. Principle of operation. Payback period.
https://lessar.com/support/learning/
[9] Diagram of the free cooling system of a monoblock chiller. https://lessar.com
[10] How do adiabatic cooling systems work? https://www.waterchillers.com
[11] Data Center Cooling Cost Reduction - Editorial Demo’ simulation project by vaibhav_s. Public
project: https://www.simscale.com
[12] Electricity tariff for Almaty. https://esalmaty.kz/ru/business-tariffs
[13] Beauregard M A and Ayer S K 2018 Maintaining performance: Understanding the relationship between facility management and academic performance at K-12 schools in the State of Arizona *Facilities*, 36 pp 618-634 https://doi.org/10.1108/F-11-2017-0111

[14] Bieser J and Menzel K 2019 Assessing Facility Maintenance Models for Data Centres: Status and Deficits of Current Facility Management and Maintenance Concepts, *Applied Mechanics and Materials* 887, pp 255–263 https://doi.org/10.4028/www.scientific.net/AMM.887.255

[15] Braglia M, Castellano D and Gallo M 2019 A novel operational approach to equipment maintenance: TPM and RCM jointly at work, *Journal of Quality in Maintenance Engineering*, 25 (4), pp 612-634 https://doi.org/10.1108/JQME-05-2016-0018

[16] Abbas C J B Orozco A L S and Villalba L J G 2015 Monitoring of Data Centers using Wireless Sensor Networks, *Handbook on Data Centers* pp 1171–1183 doi: 10.1007/978-1-4939-2092-1_40

[17] Nor N M, Hussin M and Abdullah R 2019 Energy-saving framework for data center from reduce, reuse and recycle perspectives. *Pertanika Journal of Science & Technology* 27(3) 1259-1277

[18] ISO 26382 Cogeneration systems - Technical declarations for planning, evaluation and procurement https://www.iso.org/standard/43552.html

[19] ISO/IEC 20000-1 Information technology - Service management - Part 1: Service management system requirements https://www.iso.org/standard/70636.html

[20] IEC 62052 (series) Electricity metering equipment (AC) - General requirements, tests and test conditions.