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UKRAINIAN EXPERIENCE IN IMPLEMENTING ENERGY MANAGEMENT SYSTEMS IN THE INDUSTRIAL SECTOR

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Abstract

Research objectives. The presented research pursued the following objectives: (i) to determine the features of energy management control in technological processes at Ukrainian industrial enterprises based on the idea of sustainable development; (ii) to study the experience of Ukraine in creating a network of energy-efficient enterprises; (iii) to investigate barriers to improving the energy efficiency of industrial enterprises; (iv) to analyze the model of energy management based on ISO 50001; (v) to present the results of energy efficiency control in a coal mine at PJSC "Pavlogradvugillya".

Methodology. The research was based on exploring the academic literature, international documents, and reports, and analyzing the statistical data referring to Ukrainian energy practice.

Findings. The existing methods of energy management at industrial enterprises are not efficient and require improvements. The main functions of such management are performed by the power engineering service, which has no indispensable ramified frame to control energy consumption directly on workstations. It is possible to improve the situation in energy consumption by applying energy management systems in enterprises. To control the efficiency of processes in manufacturing divisions, the planned indicators of energy consumption are calculated and compared with the actual indicators. Comparing the planned indicators with the actual data makes it possible to conclude the energy efficiency of the divisions.

Conclusions and recommendations. Implementation of continuous control is not possible without modern information technologies that allow the monitoring of the level of energy use in real-time, detect periods of high energy consumption, and take effective management decisions to optimize energy consumption.

Introduction

The problem of high energy intensity of the country's gross domestic product is related not only to the use of energy-intensive equipment and outdated technologies but also to the lack of systematic understanding and management of the processes of use and consumption of energy resources [1]. The world-recognized way of solving such problems is the implementation of energy management systems (EnMS) that meet the international standard ISO 50001. Thousands of industrial companies in Europe use energy management systems in their enterprises. In the industrial sector, from 2018 to 2019, the largest number of ISO 50001 certificates were obtained by enterprises in the metallurgical, food, and chemical industries [2]. The leaders in ISO adoption are Germany (6,243 in 2018), Great Britain (1,153), and (in recent years) China (2,364). At the same time, the following number of certificates were issued in Ukraine (according to official ISO reviews): in 2016 - 21; in 2017–189; in 2018–21; in 2019-12 [1].

Experience shows that enterprises implementing EnMS, with minimal capital investments, receive an increase in energy efficiency within the range of 10-20% [3]. This fact forms the basis of positive forecasts regarding the prospects for the development of such systems both in the world and, in particular, in Ukraine.

The law "On energy efficiency" [4] recently adopted by the Verkhovna Rada of Ukraine repeals the law "On energy saving", focusing on ensuring the "energy efficiency" of production processes with a clear definition of the meaning of this term as a quantitative indicator of the relationship between work, services, goods or energy at the output and the specified energy at the input. Based on the content of the adopted law, it is planned to strengthen control actions by the state in the field of energy resource consumption and to implement a policy of significantly reducing energy consumption.

The effectiveness of energy consumption management processes largely depends on the implementation of the idea of sustainable development in Ukraine. An analysis of the features of the implementation of this idea in the economy of Ukraine allows us to assess the effectiveness of the steps taken. Such an analysis is carried out in subsection 1. The energy efficiency of production processes is related to the perception by the company's service personnel of problems that prevent them from reducing energy consumption. Often the views existing in the enterprise do not correspond to the real state of affairs. Subsection 2 is devoted to determining the degree of significance of the existing barriers on the way to improving the energy efficiency of one of the industrial enterprises obtained through a questionnaire. Subsection 3 analyzes the structure of the energy management system that complies with the international standard ISO 50001. The implementation of energy management systems in Ukraine had its peculiarities related to the content of consulting services provided by Western countries as part of aid and aimed at solving energy problems. Subsection 4 reveals the principles of implementation of such systems for coal mines of Ukraine and demonstrates their connection with the content of actions proposed by the ISO 50001 standard.

Concept of sustainable energy development in Ukraine

It is known that the world's population is constantly growing, and the energy needs of society are increasing accordingly. Every day, humanity needs more energy to meet its needs, and this process is progressing. The development of the industrial sector using traditional sources of energy (coal, oil, gas) is accompanied by the depletion of natural resources and the emission of greenhouse gases, as a result of which the climate on the planet is gradually changing. Industrial enterprises consume about 38% (of the total volume) of the world's final energy consumption. They are the cause of 24% of total CO_2 emissions [5]. The environmental consequences of wasteful energy consumption make us think about how efficiently and safely we use energy resources.

The concept of sustainable development, proposed by the American economist Daly German, is the basis of the EU's strategic planning principles and is defined as "development that meets the needs of the present without jeopardizing the ability of future generations to meet their own needs" [6]. In 2012, at the UN summit (Conference, Rio+20), the Sustainable Development Goals (SDGs) were formulated, one of which (Goal 12 - Responsible consumption and production) is aimed at ensuring the transition from existing to rational models of consumption of energy resources in the production process.

To adapt the Sustainable Development Goals to the national specifics of Ukraine, national consultations were held in 2016 to discuss the relevance of the goals to the conditions of Ukraine and to determine the directions of work for their integration into strategic planning. The results of the ranking of the Sustainable Development Goals in the conditions of Ukraine confirm the significance of introducing new energy-saving technologies and creating conditions for reducing the impact on the environment [7].

In November 2016, Ukraine signed the Memorandum on Strategic Partnership between Ukraine and the EU. As a result, our country became a full member of the European Energy Community. This agreement provides for the implementation of the third EU energy package, the purpose of which is to increase the efficiency of the use of energy resources, create competitive conditions for the functioning of the energy market, and promote the development of renewable energy sources. On April 22 of the same year, Ukraine signed the Paris Agreement and announced the goal of reducing the country's anthropogenic greenhouse gas emissions by 40% by 2030 (compared to the state of greenhouse gas emissions in 1990 [8]).

Analyzing the causes of the occurrence of greenhouse gases in Ukraine, it should be emphasized that the main consumer of primary energy resources in our country is industry [1]. Even though, according to official data, the level of energy intensity of Ukrainian enterprises is constantly decreasing, it still exceeds the indicators of developed countries. Thus, in 2015, the energy intensity of the products of the steel industry in Ukraine was 0.52 t per year. for 1 thousand dollars USA, when the average value in EU countries is 0.31 [9].

To characterize the efficiency of the use of energy resources in the world, an indicator called the Energy Trilemma Index is used. It takes into account three main criteria of energy efficiency, namely: energy security (reliability of energy supply to consumers), energy justice (fair access of consumers to energy resources), and environmental sustainability (which shows how energy resources affect the environment). According to official data, in 2019, according to the Energy Trilemma Index, Germany ranked 9th among 128 countries in terms of all indicators of energy efficiency. At the same time, Ukraine took 61st place in this rating, including the 7th place for energy security, 85th place for energy justice, and 65th place for environmental sustainability [9].

A significant part of the energy supply companies operating in the market of energy services in Ukraine belong to one owner. The monopoly on energy services limits the opportunities of other market participants to take an active part in the production or transmission of energy, to influence the formation of fair (competitive) prices. The lack of competition causes restrictions on the free access of enterprises to energy resources, and insufficient transparency of the activities of energy companies. This creates conditions for the distortion of a clean energy supply procedure, where one enterprise has expanded access to energy resources, while another is forced to settle for unfavorable terms of energy supply or distribution.

Tariffs for energy resources for Ukrainian industry are quite high compared to EU countries [10]. So, for example, the cost of electricity for industrial enterprises is 12 euro cents per kWh. (twice as high as the price in the Czech Republic, Slovakia, and Poland). For domestic and small non-domestic consumers, the cost of 1 kWh according to Eurostat is about 5 euro cents [11]. The increase in tariffs exacerbates the issue of ensuring the energy balance of the enterprise at acceptable prices and brings the significance of its solution to the first.

Determining the significance of barriers to increasing the energy efficiency of production processes

As part of the DAAD project *"Transition to Sustainable Consumption and Production in Industry: The Business Management Context"*, employees of the Dnipro University of Technology conducted research at one of the enterprises specializing in the production of hardware products (Dnipro, Ukraine). The purpose of the study was to identify barriers (negative factors) on the way to improving the sustainability of the production process and rational consumption of energy resources. The heads of the production divisions of the enterprise were asked to answer several questions formulated in the questionnaire and to quantitatively assess the significance of factors that affect the sustainability of the production process. Each factor was evaluated on a five-point scale (1 to 5 points). 13 respondents took part in the survey. Therefore, the maximum score for each factor is 65 points. Then the ratio of points in the answers and the maximum number of points that each factor could score in its category was determined. The results of factor ranking made it possible to obtain the necessary statistical data and build graphs based on them.

First of all, the general factors affecting sustainable production and energy consumption of the enterprise were subject to evaluation.

It turned out that from the point of view of the company's specialists, the lack of knowledge and lack of operational information regarding the conditions of sustainable consumption of energy resources and production of products are the most important factors that affect sustainability indicators (Fig. 1).

In particular, it turned out that the employees of the enterprise, including heads of departments, practically do not receive information about the content of new technologies and the existing experience of the production of similar products by other market participants (Fig. 2). There is a need to increase the awareness, first of all, of the company's management not only about problems related to production and energy consumption but also about conceptual issues of sustainable development. There is a high probability that such a situation is typical for the majority of production enterprises in Ukraine. If the enterprise intends to enter the international market, its activities must meet the requirements of ISO standards. The tasks of educators are obvious - they must ensure that students master the basics of current international standards in the field of sustainable production: energy, environmental, and social standards (ISO 9001, 14001, 4500, 50001) and, thus, contribute to the solution of the problem of staffing of enterprises. This also applies to business structures, which require educated specialists capable of solving problems specific to industrial production.

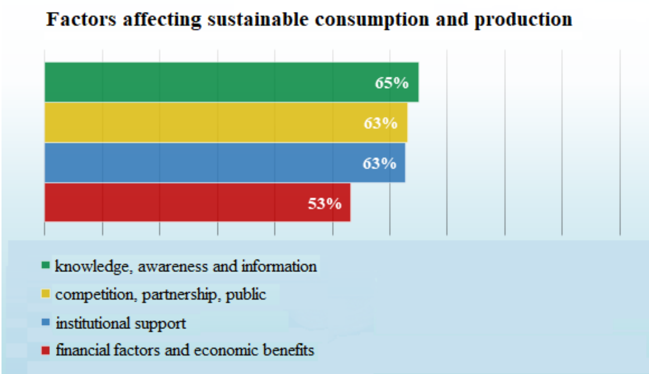

Fig. 1. Ratio of general factors influencing the sustainability production process

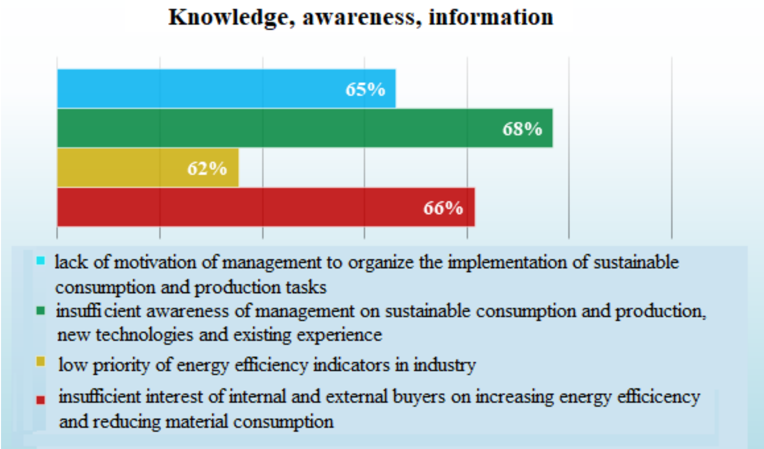

Fig. 2. Knowledge, awareness, and completeness of information as influencing factors on the stability of the production process

Another interesting result of the conducted research was that financial factors and economic benefits turned out to be the least important from the point of view of their influence on the sustainability of production (Fig. 3). This is due to limited access to cheap financial resources for the implementation of energy efficiency projects, as well as the inadequacy of investments aimed at the reorganization of the enterprise.

Despite the lack of expressed interest of enterprises in solving energy-saving tasks, we are faced with the fact that energy tariffs for industry in Ukraine are constantly increasing, and therefore the solution of these tasks is motivated by the existing tariff situation.

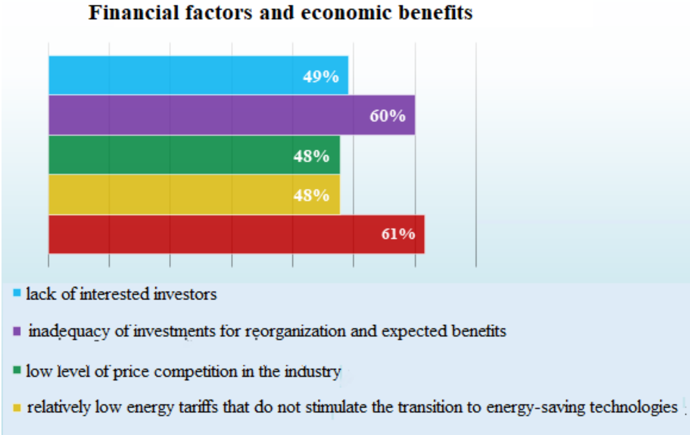

Fig. 3. Impact of financial factors and economic benefits

Energy management model based on the ISO 50001 standard

The problem of high energy intensity of the country's gross domestic product is related not only to the use of energy-intensive equipment and outdated technologies but also to the lack of systematic understanding and management of the processes of use and consumption of energy resources [1]. A recognized way to solve such problems is the implementation of energy management systems (EnMS) that meet the international standard ISO 50001. The annual number of industrial enterprises certified by the International Organization for Standardization (ISO) for compliance with international energy management standards (ISO 50001) is an indicator of the prevalence of such systems. both in the country and in the world. Today, thousands of companies in Europe use energy management systems in their enterprises. In the industrial sector, from 2018 to 2019, the largest number of ISO 50001 certificates were obtained by enterprises in the metallurgical, food, and chemical industries [2].

Practical experience shows that enterprises that implement EnMS, with minimal capital investments, during the first years receive an increase in energy efficiency within the range of 10-20% [3]. The leaders of ISO implementation are Germany (6243 in 2018), Great Britain (1153), and (in recent years) China (2364) (Fig. 4). At the same time, in Ukraine (according to official ISO reviews) the following number of certificates: in 2016 - 21; in 2017-189; in 2018-21; in 2019-12 [1], which proves the low prevalence of energy management systems in Ukraine.

Fig. 4. Worldwide issued ISO 50001 certificates
(*Source:* IEA, 2016)

What causes this situation? The fact is that the services of the enterprise, which are usually responsible for the functioning of the EnMS, do not have experience in their implementation and operation. These services are few and their duties are mainly related to solving the current tasks of operation and repair of power equipment. Solving the tasks of increasing the level of energy efficiency is not a priority action for the management and staff of the energy service, which does not contribute to reducing energy consumption.

Another significant problem of the activity of industrial enterprises is the existing organization of the order of control and management of energy use. The main functions of managing energy use at enterprises are performed by the Chief Energy Officer, which does not have an extensive structure for monitoring energy consumption directly at workplaces. The energy service, as a rule, does not have modern information support for the management process. There are no effective mechanisms capable of timely responding to wasteful use of energy, creating conditions for optimal energy consumption, and taking into account the specifics of production and output. Therefore, measures to increase the energy efficiency of production are often reduced to defining the content of annual energy consumption management programs without proper technical and economic substantiation of their components. Such a state of affairs with the energy management of Ukrainian enterprises is confirmed, in particular, by the results of surveys conducted in subsection 2, where the practical absence of important links in the structure of the management system, which ensures timely and meaningful information support for the processes of monitoring energy efficiency indicators, is monitored. The world practice of EnMS implementation testifies to their broad possibilities of combining reliable information about the available indicators of energy efficiency of production processes with optimal management solutions for the given conditions.

According to the requirements of ISO 50001, the cycle of operation of EnMS is based on a methodology known as the "cycle of continuous improvement" "Plan-Do-Check-Act" (PDCA) - "Plan-Do-Check-Act" or "Deming's cycle" and can be represented by the four stages [1].

Thus, the energy management implemented by the system is a complex of continuous processes and tools that are combined with the business processes of any organization, in particular, with the production of industrial products. It motivates her to constantly manage energy consumption and search for ways to improve energy performance. Processes and tools encompass not only procedures, equipment, and technologies but also the executors of planned actions. The effectiveness of any system (even a fully automated one) depends on the behavior of the people who created it, maintain its functioning, and improve its characteristics. Attention should be paid to the fact that the energy management system is a closed system, where planned indicators are formed and their implementation is ensured through the implementation of management actions. It is also important that the activity of the system extends to the totality of technological processes related to the production of products. It is obvious that when solving the tasks of increasing the energy efficiency of production processes, one should focus on the planning of the energy intensity indicators of technological processes and ensure their acceptable (from the point of view of energy saving) values during the production process. An important operation that ensures the operation of the energy management system is the control of the efficiency of energy use by the structural divisions of the enterprise. To control the efficiency of processes in the structural divisions, the planned indicators of energy consumption are calculated and compared with the actual indicators. Comparison of planned indicators with actual data makes it possible to conclude the efficiency of energy use by this facility.

The proposed structure of EnMS within the framework of the ISO 50001 standard does not specify the content of the listed operations (planning, improvement, evaluation, etc.). Their filling can be different and correspond to specific features of the production process. The task of specifying these components rests with the developers of the system that will function in the conditions of a specific production. The justification of the decisions taken by the developers is their novelty as scientific research.

Principles of energy efficiency control of technological processes

As an example, let's consider the particularities of the specification of solutions proposed in the creation of energy management systems for coal mines in Ukraine [12].

Electrical energy, as a rule, forms the basis of energy consumption in coal mines. As a rule, mines have commercial metering meters installed at the input of the substation, and, have technical metering meters installed to determine the energy consumption of powerful consumers. Usually, the existing level of energy consumption control is determined using Table 1. The above signs according to Table 1 correspond to the second or third level of control.

Table 1

Levels of energy efficiency control

Levels	Characteristics of the control process
1	Monthly energy bills are fixed only
2	Monthly meter readings are compared with payment invoices
3	Energy consumption in separate structural divisions of the enterprise is controlled
4	Monthly meter readings are compared with the company's output and the specific energy consumption (energy efficiency) is determined
5	Operational control of energy efficiency indicators in the Centers for Energy Accounting (CEA) is carried out

The global practice of control and management of energy use provides for the allocation of separate divisions in the production structure of the enterprise with independent control of energy consumption [12]. Such links, which are allocated in the structure of the enterprise, were named the Centers for Energy Accounting (CEA). The need to separate individual links in the structure of the enterprise is connected with the general idea of solving energy efficiency tasks directly at the places of energy consumption, involving in this process a significant number of service personnel who take a direct part in the production technology. Based on the fact that the CEA is a management object, attention should be paid to its determination procedures, providing several requirements that it must meet. It:

- the energy consumption at the center must be ***significant*** (more than 5% in the structure of electric power consumption);
- energy meter must be installed to measure the consumption of electrical energy at the CEA;
- ere must be a person responsible for energy use.

To determine the most energy-intensive consumers of energy, it is necessary to analyze the annual energy balances of an industrial enterprise, where its total costs are distributed between individual units and energy receivers. If the energy balances of the enterprise have not been drawn up, then there is a possibility of using the passport data of energy-intensive equipment for analysis. The location of the equipment on the territory of the enterprise serves as information about the possible placement of the central heating system. For example, let's analyze the energy balance (in percent) of the "Zakhidnodonbaska No. 1" coal mine. The components of this balance sheet are typical for most coal mines in Ukraine:

- mining areas	5,26
- preparatory areas	1,29
- underground transport	5,6
- air conditioning	10,88
- rise	13,32
- drainage	14,28
- ventilation	17,13
- technological surface complex	3,75
- production of compressed air	2,46
- other electrical receivers	20, 58
- lighting	0,69

- electricity losses 4,76

As you can see, there are receivers with significant amounts of energy consumption at the mine. In the first approximation, each item of significant energy consumption should correspond to a separate CEA. The extent to which such an approach to the creation of centers is possible will be shown by the results of the fulfillment of other conditions specific to the Central Economic Center. For this, it is necessary to analyze the structure of the existing electricity distribution system at the mine.

The analysis of the scheme [12] showed that the substations of the mine have feeders that supply ventilation units, compressors, skip lifts, cage lifts, as well as other objects of the technological complex of the surface. Feeders for powering underground electrical installations are also allocated. Thus, there is a correspondence between the structure of the electricity distribution scheme and the structure of the previously mentioned components of the energy balance. Such compliance is understandable since the energy balance is compiled based on the results of energy accounting at the mine's substations. It is obvious that if the named feeder cells are provided with means of energy accounting, the created centers (CEAs) will be able to control the consumption of electricity by the components of the given energy balance.

Control of electricity consumption assumes the presence of standardized values of energy consumption. It is characteristic that not all mines have standardized indicators determined for the existing conditions of coal production. An important step in normalizing the level of energy consumption in the Central Power Plant is the determination of the parameters on which this level depends. When choosing parameters, it is necessary to ensure the fulfillment of two requirements:

- the target parameters should reflect the ultimate goal of energy use in the Central Power Plant (for example, achieving a given volume of production output);
- there should be the possibility of measuring with the necessary accuracy both target and additional parameters that also affect energy consumption.

Below, as an example, there is a table of parameters (target and additional), which are often used as those that are recommended to be taken into account when determining the levels of energy consumed by installations (Table 2) [12].

Table 2

Select parameters that influence energy consumption at CEA

Electrical installation	Target parameter	Additional parameter
Powerful fans	Air volume	–
Low power fans	Work time	–
Powerful pumps	Fluid volume	–
Low power pumps	Work time	–
Conveyors	Work time	–
Compressors	Air volume	Ambient temperature
Air conditioning	Ambient temperature	Humidity
Lighting	Work time	Average daily temperature

Quite often, the indicator of the volume of production is used as the main (target) parameter. If a division of an industrial enterprise specializes in the production of several types of products, then it is desirable to control energy consumption on each technological line of the division, which is characterized by the production of a separate type. In conditions where it is problematic to select individual CEAs on this basis (for example, with relatively low energy consumption indicators of individual technological lines), it is possible to combine several lines into a CEA. To do this, it is necessary to determine a general indicator that will characterize the volume of energy consumption of the unit as a whole.

When implementing EnMS in production, attention should be paid to the motivation of direct executors of technological operations related to the production of products. It is necessary to determine the officials who will be personally responsible for the use of energy in the created central heating and cooling centers. Often, during the formation of the CEA, they face a problem when the structural division of the enterprise, based on which there is a possibility of creating a CEA, is subordinate to different persons. An example can be the equipment of a production facility, in which several workshops have a common energy distribution system. In this case, it is advisable to distribute the areas of responsibility of individual officials by installing additional energy meters. The optimal option for applying the proposed approach to determining the CEA is the presence in the management structure of the unit of officials who are responsible for the work of individual production sites.

Statistical processing of experimental data with the construction of regression models is often used for the formation of no CEAs [12]. When substantiating the list of parameters on which energy consumption depends, it is also necessary to focus on the expected type of regression dependence (single or multiple regression). Fig. 5 shows a single regression in the form of a constant value of the consumed CEA energy - E=const. In this case, energy consumption E does not depend on the volume of production P. This is observed, for example, in lighting systems of industrial premises.

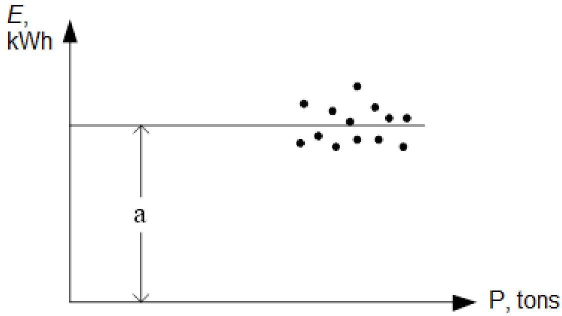

Fig. 5. Regression in the form of constant value E=const (*Source:* [12])

Nonlinear regression is usually formed in the form of a polynomial of the nth degree $E = a + вp + cp^2 +...+ dp^n$. Multiregression represents the dependence of E on several parameters $E=a+вp_1+cp_2+...+dp^n$. Its use is advisable in the case when the influence of additional parameters on energy consumption is significant. Usually, no more than three parameters (p_1, p_2, p_3) are used in such regression models.

Often in the practice of energy management, the regression dependence is represented as a straight line with a slope (linear regression). Fig. 6 shows the linear relationship between the parameters $\hat{y}$ (estimated energy consumption level) and x (output volume), which is constructed based on the results of observations.

The dependence $\hat{y}=f(x)$ is built based on the method of least squares, which ensures the minimum dispersion of S values of ui around the function $f(x)$

$$S = \sum_{i=1}^{n} \left[y_i - f(x_i) \right]^2 .$$

If, as a result of energy consumption control, the actual energy consumption exceeds the average value (based on the location of the regression line), then it can be considered that the energy consumption obtained is overestimated, and such a level of energy consumption is not legitimate (irrational use of energy). Conversely, values below the regression line indicate a rational level of energy consumption. Therefore, the regression line is the boundary separating the satisfactory results of the operation of the CEA from the unsatisfactory ones. In the case of unsatisfactory indicators, it is necessary to draw conclusions and take measures (management decisions) to reduce energy consumption within the capabilities of the current energy management system.

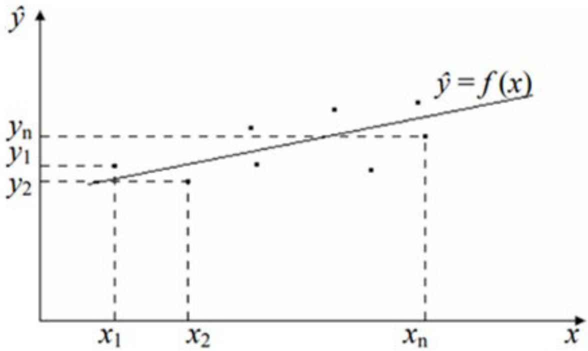

Fig. 6. Standard linear regression dependence $\hat{y} = f(x)$ (Source: [12])

Based on the results of monitoring the efficiency of energy use, reports must be drawn up in the Central Power Plant. At the same time, the availability and reliability of the received information is ensured. The results of the comparison of the actual energy consumption indicators with the planned ones can be presented in the form of graphs, tables, and diagrams. Examples of control results in the form of graphs and tables are shown in Fig. 7 and Table 3 [12].

The change in the accumulated (cumulative) amount of deviations over a certain period is of interest to the energy manager, as it allows to assess the degree of difference between the actual energy consumption indicators and the planned energy consumption during a certain period. At the same time, deviation indicators obtained during individual measurements are added. Thus, with weekly measurements, it is possible, for example, to record the result of the accumulation of energy consumption deviations for a month. This indicator can be used for the overall assessment of the efficiency of the central office during the month. The results of the control should be known to the personnel of the CEA. They are discussed by the team and analyzed to improve the situation.

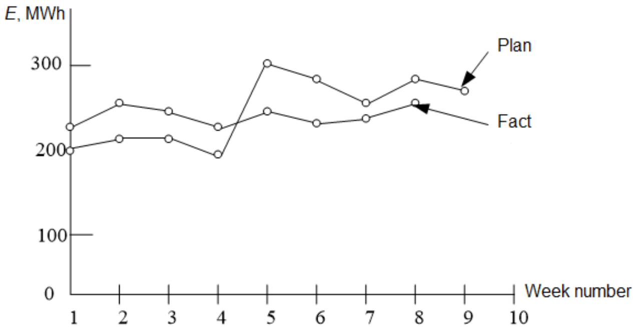

Fig. 7. Graphical appearance of energy consumption (*Source*: [12])

Table 3

Energy consumption control

Week number	Actual energy consumption, kWh	Planned indicators, kWh	Deviation, kWh	Accumulated (cumulative) sum, kWh
1	170	170	0	0
2	180	210	- 30	- 30
3	200	250	- 50	- 80
4	230	180	50	- 30
5	200	170	30	0
6	150	170	- 20	- 20

Attention should be paid to the fact that the process of controlling energy consumption in the Central Power Plant is not passive. Comparing the actual energy consumption with the planned energy consumption should lead to the implementation by the center staff of actions aimed at reducing energy consumption. This means that the location of the experimental data relative to the regression line will change, which will lead to the correction of the regression dependence (Fig. 8). Experimental data obtained in the process of controlling energy consumption can serve in the future to build the next regression dependence.

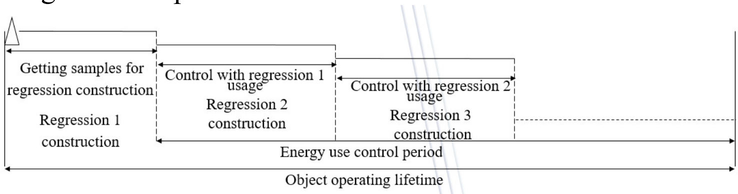

Fig. 8. Energy efficiency control process with plan indicators periodic changes (*Source*: [12])

The implementation of continuous control of energy efficiency is not possible without the introduction of modern information technologies that allow monitoring of the levels of energy use in real-time, identifying periods of increased energy consumption. The energy efficiency control system of production processes was developed by the employees of the Dnipro University of Technology and operated at the Heroes of Cosmos mine at PJSC "Pavlogradvugillya". In the chief energy department of the mine, a computer program was installed that ensured the construction of regression dependencies and the processing of the results of the comparison of actual energy consumption with planned energy consumption [13]. The initial information for the work of the energy efficiency control program was the indicators of daily electricity consumption for the technological complex of the surface of the mine, underground consumers, coal lifting, as well as for the mine as a whole. These data were obtained from the Automatic energy meter reading systems (AMR) of the mine. Every day, the mine manager entered the value of the volume of coal production into this system. Thus, the input parameters of the energy efficiency control program were linked to the corresponding values of the controlled parameters of the AMR system, which allowed to ensure their joint operation. The program was implemented in the form of spreadsheets in the Excel environment [12, 13]. Fig. 9 illustrates the regression dependence of daily electricity consumption on the daily rate of coal production. The dependence is built with confidence intervals that take into account the limited amount of statistical information obtained.

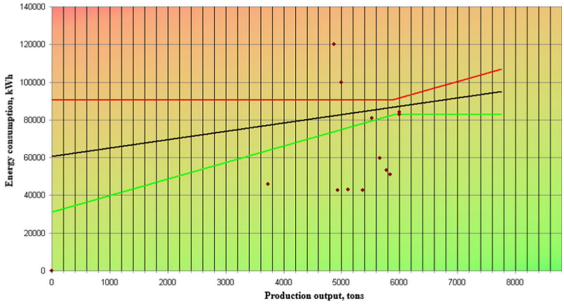

Fig. 9. Regression dependence of daily electricity consumption on the daily rate of coal production of the Heroes of Cosmos mine (*Source*: [13])

Fig. 10 illustrates the daily figures for overspending or savings of electricity. This information is subject to analysis. The causes of energy overspending should be clarified and appropriate actions should be taken to eliminate negative phenomena at workplaces.

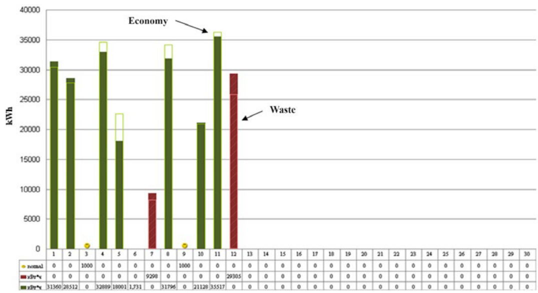

Fig. 10. Results of energy efficiency control of the Heroes of Cosmos mine (*Source*: [13])

The above-considered components of the construction and implementation of energy management systems of coal mines do not give a complete picture of the necessary actions. At the same time, when presenting the material, emphasis was placed on the presentation of fundamentally important components of the system, without which its functioning is not possible. These are positions related to the formation of planned tasks, control, and elements of energy consumption management.

Conclusions

The main scientific and practical results of the work are as follows:

1. An important component of the concept of sustainable development is the application of rational models of consumption of energy resources, which ensure an increase in the energy efficiency of production processes. Ukraine is taking active steps to improve existing energy management methods.

2. The results of a questionnaire survey of the heads of production divisions of one of the industrial enterprises of Ukraine indicate a low awareness of the team regarding energy-saving tasks and methods of solving them, which indicates the expediency of implementing an energy management system at the enterprise.

3. The existing methods of controlling and managing the energy use of industrial enterprises of Ukraine, as a rule, are ineffective and require improvement. It is possible to improve their efficiency by applying energy management systems at enterprises, which are based on the principles of personal responsibility of the heads of production units for the achieved energy efficiency indicators, and involve the wide use of computer equipment.

4. The structure of energy management systems proposed by the ISO 50001 standard reveals a general approach to building such systems. These are closed-type systems with the presence of elements of energy consumption planning, assessment of its actual level, and formation of management actions that ensure an increase in the energy efficiency of processes. Specific implementation of the actions proposed by the standard should be carried out by system developers taking into account the specifics of both individual branches of industry and implementing enterprises. The justification of the decisions taken by the developers is their novelty as scientific discoveries.

5. The considered features of the construction of energy management systems of coal mines of Ukraine. Attention is focused on the process of forming planned indicators, the order of energy consumption control, and information support of the process. The content was analyzed and the specifics of the implementation of these actions were determined in the specific conditions of the operation of coal mines.

References

1. **Chernyavskyi, A**. (2021). Guidelines for the implementation of the energy management system in accordance with the requirements of the international standard ISO 50001: 2018. Retrieved from http://www.ukriee.org.ua/wpcontent/uploads/2021/03/EnMS-Practical-Guide-2021_Ukraine_ukr.pdf.

2. Energy efficiency 2020: Fuel report (2017). Retrieved from http://www.iea.org/digital.

3. Ukraine has adopted national standards for energy audit and energy management in accordance with European norms (2016). Retrieved from http://saee.gov.ua/uk/news/1184.

4. About energy efficiency. № 1818-IX§ section I art. 5. (2021). Retrieved from https://zakon.rada.gov.ua/laws/show/1818-20#Text.

5. Digitalization and Energy: Technology Report 2017 (2017). Retrieved from http://www.iea.org/digital.

6. **Charles F. Kutscher, Jana B. Milford, Frank Kreith**. (2018) Principles of sustainable energy systems – Third edition: CRC Press Taylor & Francis, 654.

7. Sustainable Development Goals: Ukraine. National Report 2017 (2017). Retrieved from http://surl.li/hoii.

8. Climate agreement for Ukraine: Analytical note of the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine (2016). Retrieved from: http://energyreform.uacrisis.org/climate (дата звернення 26.11.2021).

9. **Palekhova, L.** (2020). Management of sustainable development: a guide to basic concepts. Tutorial. Published by Dnipro University of Technology. Retrieved from https://mk.nmu.org.ua/ua/source.

10. **Palekhova, L.** (2018) Positioning of industrial enterprises based on voluntary energy standards. NESEFF-NETZWERKTREFFEN Brandenburgische Techiche Universität Cottbus-Senftenberg. pp. 11-19.

11. Electricity prices for household consumers, first half 2020 (Eur per kWh) (2020). Retrieved from https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=File:Electricity_prices_for_household_consumers,_first_half_2020_(EUR_per_kWh).png.

12. **Pivnyak, G.G., Vypanasenko, S.I., Khovanska, O.I., Khatskevych, Yu.V., Dreshpak, N.S.** (2013). Energy management systems and their mathematical support. Tutorial. Published by National Mining University, 214.

13. **Dreshpak, N.S.** (2012). Measurement and control of the efficiency of electricity consumption by the enterprise's production units. Mining Electromechanics and Automatics №88, 139-143.

14. Implementation of the standard of energy management systems in the industry of Ukraine: UNIDO/GEF Project (2015). Retrieved from http://www.ukriee.org.ua/uk/proekt/meta-proekta.

15. Green Deal: New proposals to make sustainable products the norm and boost Europe’s resource independence. (2021) Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013.

16. Impacts of the EU’s ecodesign and energy labelling legislation on third jurisdictions (2014) Retrieved from

https://ec.europa.eu/energy/sites/ener/files/documents/201404_ieel_third_jurisdictions.pdf .
17. Topten: Best products in Europe (2021). Retrieved from https://www.topten.eu/private/page/energy-label.
18. Resource bill: Which taxes will increase and by how much (2021). Retrieved from https://www.slovoidilo.ua/2021/12/13/infografika/ekonomika/resursnyj-zakonoproyekt-yaki-podatky-zrostut-skilky.
19. ISO 50001: Benefits for manufacturers (2019). Retrieved from https://www.plantengineering.com/articles/iso-50001-benefits-for-manufacturers/.
20. European platform on Life cycle assessment (2013) Retrieved from https://eplca.jrc.ec.europa.eu/lifecycleassessment.html.
21. **Jordaan, S.** (2021). Life cycle assessment of electricity generation: A systematic review of spatiotemporal methods. Retrieved from https://www.sciencedirect.com/science/article/pii/S2666792421000500.
22. **Šerešová, M.** (2020). Life cycle performance of various energy sources used in the Czech Republic. Retrieved from https://www.mdpi.com/1996-1073/13/21/5833.
23**. Palekhova, L., & Simon, S.** (2016). Competitive advantages through the implementation of international energy management standards. Bulletin of the Dnieper State Academy of Construction and Architecture, № 3, 42-51. Retrieved from https://www.semanticscholar.org/paper/Competitiveadvantages-through-the-implementation-Paliekhova Simon/9c1febc73e964bc8b5c3b9fbabdbddb81d4484fb.
24. **Dreshpak, N.S.** (2020). Energy efficiency control systems of production processes and ways of their improvement. Electrical Engineering and Power Engineering, №1, 40-48. Retrieved from https://doi.org/10.15588/1607-6761-2020-1-5.
25. **Dreshpak, N.S., Dreshpak, O.S. & Vypanasenko, S.I.** (2021). Certain norms of energy consumption in the task of controlling the efficiency of its use. Electrical Engineering and Power Engineering, №3, 31-39. Retrieved from https://doi.org/10.15588/1607-6761-2021-3-3.
26. **Shulle, Yu. A., & Rogozyanskmiy, I. S.** (2016). The use of AMR to increase the efficiency of energy use at industrial enterprises. Information Technologies and Computer Engineering, № 1, 59-63. Retrieved from http://surl.li/gptfy.
27. Code of commercial accounting of electric energy. No311§. section I p. 1.2. (2018). Retrieved from https://zakon.rada.gov.ua/laws/show/v0311874-18#Text.