ЕНЕРГЕТИЧНА ЕФЕКТИВНІСТЬ ТА ЕНЕРГОЗБЕРЕЖЕННЯ
ENERGY EFFICIENCY AND ENERGY SAVINGS

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THE METHODICAL ISSUES OF INDUSTRIAL ENERGY MONITORING SYSTEMS IMPLEMENTATION

Statistics show that energy is one of the highest operating costs in a manufacturing enterprise. So, improving energy efficiency can lead to a significant increase in profits and reduce the impact of the enterprise on the environment. To increase the performance of energy efficiency activities, it is necessary to implement an energy management system. One of the components of this system is energy monitoring, which, in turn, is based on the periodic collection and analysis of data to assess the state of the monitoring objects in terms of energy efficiency. In this paper, the role and place of energy monitoring in the energy management system of an industrial enterprise are noted. The paper proposes the concept of creating energy monitoring system in industrial companies, which is based on the combination of a monitoring system based on specific energy consumption, and usage of group energy characteristics of production facilities. Implementing such energy monitoring systems will allow to conduct operational control of energy efficiency of production facilities by creating individual systems for monitoring energy efficiency, as well as successfully carry out such monitoring at the enterprise and its subdivisions over longer periods of time using specific energy consumption indicators. It also provides general guidelines for conducting energy monitoring. These guidelines were formed based on the results of studying various methods and scientific publications in the field of energy monitoring, as well as on the basis of practical experience in the development and implementation of energy management systems. Particular attention is paid to the issues of processing and analysis of information about the objects of energy monitoring of industrial enterprises. The practical application of the concept of creating energy monitoring systems envisages gradual improvement of the existing monitoring system based on the specific energy consumption, which will be further completely replaced with individual energy efficiency monitoring systems.

Keywords: *energy baseline, energy efficiency, energy management system, energy monitoring system, specific energy consumption, specific energy consumption indicator.*

Introduction

One of the main factors that determine the production processes for a lot of industries is the cost of energy flows. It is noted that over 80% of energy needs in the industry are compensated by using fossil fuels. Cost reduction is considered as one of the critical elements in proper energy management, because energy savings reduce production costs and increase profits. Also, energy efficiency represents one of the key elements of sustainable development [1]. Energy conservation technology and facilities/equipment are only part of the approach to improve energy efficiency. Most energy efficiency in industry is achieved through changes in how energy is managed in a facility, rather than through installation of new technologies. Systematic management and the behavior approach have become the core efforts to improve energy efficiency today. That is why, organizations like the European Union (EU) have implemented several policies, strategies, and actions toward achieving a sustainable economy in fields like energy efficiency and renewable resources [2].

The modern reality of Ukraine is such that it has one of the highest specific indicators of environmental pollution and energy consumption per unit of production among the industrially developed countries of the world. So, the problem of energy saving and energy efficiency (EE) is one of the most urgent and its solution should be carried out taking into account the EU-Ukraine Association Agreement, which provides for the implementation of the requirements of Energy efficiency directive (Directive 2012/27 / EU) that established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020 [3]. In 2018, as part of the «Clean energy for all

Europeans package», the new amending Directive on Energy Efficiency (2018/2002) was agreed to update the policy framework to 2030 and beyond. According to Article 8 of this Directive requires to ensure that large enterprises carry out regular energy audits or to implement an energy / environmental management system certified by an independent body according to the relevant European or International Standards [4].

The energy management system (EnMS) suggests a lot of benefits, such as reducing energy costs and the negative impact on the environment, optimizing energy consumption, improving the corporate image of the enterprise, etc. [1]. Efficient energy management requires the identification of where energy is used, where it is wasted and where any energy saving measures will have most effect. The key feature of a successful EnMS is that it is owned and fully integrated as an embedded management process within an organization, energy management implications are considered at all stages of the development process of new projects, and that these implications are part of any change control process [5].

In Ukraine, a set of standards in the field of energy management, in addition to the harmonized international standards mentioned above, also includes the following national standards [6]:

- DSTU 4472:2005 Energy saving. Energy management systems. General requirements;
- DSTU 4715:2007 Energy saving. Energy management systems of the industrial enterprises. The structure and contents of activities according to design and introduce phases;
- DSTU 5077:2008 Energy saving. Energy management systems for the industrial enterprises. Auditing and controlling of the efficiency of functioning;
- DSTU 4713:2007 Energy saving. Energy audit of industrial enterprises. The order of carrying out of and the requirements to the organization of works.

In 2011, the International Organization for Standardization (ISO) adopted the international standard ISO 50001:2011 (E) "Energy management systems - Requirements with guidance for use" and by now we have a set of international standards ISO 50001, ISO 50002, ISO 50006, etc., which are already implemented in Ukraine [6]. These standards provide support to enterprises in all sectors regarding a more efficient energy use, through the management model that contributes to the development and implementation of the energy policy in order to achieve the objectives and action plans, taking into account legal requirements and information resulting from the analysis and management energy consumption data [1].

In 2018, the International Organization for Standardization adopted the second edition of ISO 50001, which are already harmonized in Ukraine as DSTU ISO 50001:2020. The EnMS described in this standard is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into existing organizational practices. Effective implementation of the requirements of DSTU ISO 50001:2020 provides a systematic approach to improvement of energy performance that can transform the way organizations manage energy. By integrating energy management into business practice, organizations can establish a process for continual improvement of energy performance. By improving energy performance and associated energy costs, organizations can be more competitive. In addition, implementation can lead organizations to meet overall climate change mitigation goals by reducing their energy-related greenhouse gas emissions [7].

Regardless of what standard the enterprises will be guided by when implementing EnMS for its effective functioning, it is necessary to make a periodically assessment (monitoring) of the energy performance of EnMS. Based on the monitoring results, development and implementation of a set of proactive and corrective measures to improve energy performance of EnMS should be made [6].

One of the essential conditions for achieving significant practical results in terms of energy saving is finding proper solution for quantification, monitoring and analysis of energy efficiency for different facilities (enterprises, organizations, institutions, their subdivisions, individual plants, processes, etc.).

Purpose and objectives. The purpose of the work is to increase the efficiency of energy monitoring of industrial enterprises. To achieve this goal the following tasks were solved:

- determination of the purpose and main tasks of the energy monitoring;
- formation of a complex of information and analytical tools that can be applied in practice for energy monitoring.

Material and research results

Concept of building integrated energy efficiency monitoring.

The increasing demand especially in energy intensive industrial sectors dictates the development of smart EnMS. Industrial customers need to understand their energy consumption for the purpose of reducing energy costs, improving company ecological profile, and suggestive feedback scheduling. For modern industrial company, where digitalization has turned the traditional concept of industry, energy systems should be equally sustainable, efficient and cutting edge [8].

According to works [9-11], energy monitoring is the observation, tracking, analysis and assessment of the performance of an object in the field of energy efficiency (energy management) according to a set of energy efficiency indicators. Moreover, in general, these indicators should be: specific, affordable (the calculation of the indicator should not require significant costs), easy to understand (it is necessary to understand what the given value of the indicator means), measurable, relevant (capable of accurately reflecting the process or purpose) and associated with a certain period of time.

Among the main requirements of the standard DSTU ISO 50001:2020, we can single out those that relate to the topic of this publication (see Fig. 1).

The monitoring of energy, water and gas usage by dedicated applications, allows to analyze each phase of the production process and plan potential action to improve energy efficiency useful for optimizing costs and business energy consumption. To address this issue, different industrial energy monitoring systems are developed [8]. The most popular of them are: GE Platform Advanced EMS, GE Industrial Energy Management Systems; ABB Industrial energy monitoring and reporting software; "Green Factory – Energy efficiency" software package from Festo; Advantech Factory Energy Management System; PowerMonitor 1000&5000 from Rockwell Automation; VerveTronics Imagineering's Industrial energy monitoring; Industrial IoT Platform from EPISENSOR and many others.

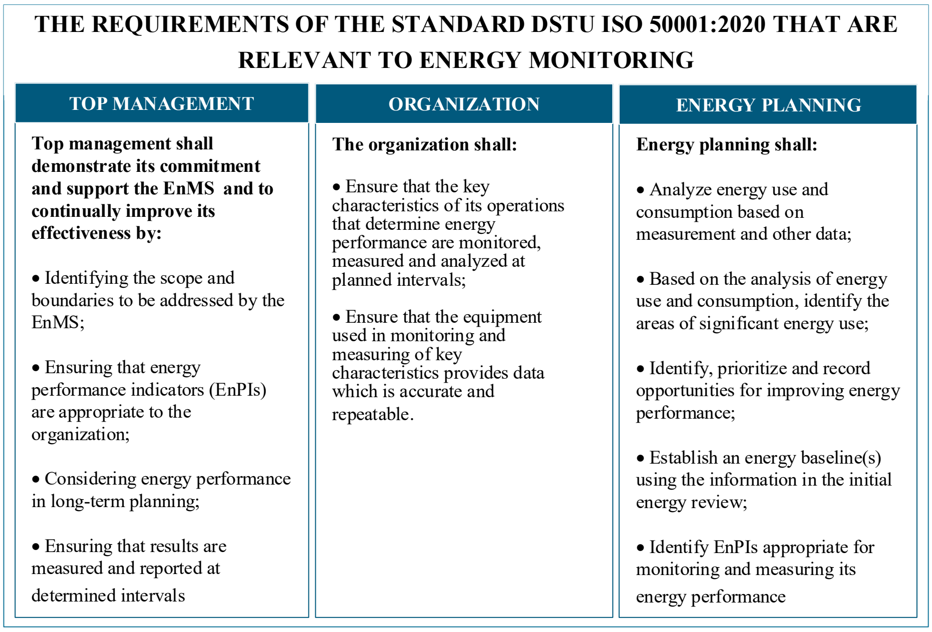

Figure 1 – The main requirements of the standard DSTU ISO 50001:2020 that relate to the topic of the publication

The main benefits of such monitoring systems are:

- reduce costs;
- improve performance;
- identify and explain excessive energy use;
- increase productivity and competitiveness;
- monitoring the consumption via Web or Phone;
- flexible reporting and alerts;
- easy reporting.

With the advantages of these devices, solutions and hardware-software integration - it's now possible to foster the development of Industry 4.0.

In general, energy monitoring can provide solutions different tasks. These tasks significantly depend on the purpose, the object and the subject of the energy monitoring. Monitoring tasks can include [9]: the monitoring of timeliness and quality of fulfillment of implementation plan of energy saving measures and energy saving programs; the monitoring of the achievement of targets energy efficiency and energy performance indicators; the monitoring of implementation of corrective and preventive actions and so on.

The process of creation and operation of an industrial energy monitoring system (IEMS) at any production facility can be presented in the form of a flowchart shown in Fig. 2.

Traditionally as energy efficiency indicators for monitoring and analysis of energy efficiency for different facilities specific fuel and energy consumption are used. However, we know that monitoring energy efficiency, in particular, electricity efficiency, on the basis of its specific costs, in line with Ukraine's current regulations, is a time-consuming process, delivering results that are not sufficiently objective and justified [12, 13]. Therefore, on the basis of determining and monitoring specific energy consumption indicators, it is mostly impossible to carry out quality and effective management of energy efficiency both at the country level, as well as at the level of individual enterprises, organizations or institutions.

On the other hand, we also know that foreign practice uses other approaches to monitoring energy efficiency, which are not based on specific energy costs. One such approach involves building and applying so-called fuel and energy efficiency monitoring systems (EMS) that have shown some positive results [14-18].

However, it should be understood that immediately giving up existing efficiency monitoring system for fuel and energy resources (FER) based on their specific costs is not feasible or appropriate. There are a number of reasons for this. One of them is that building the required amount of EMS at any production facility (at the enterprise or in its subdivision) will take considerable time. This means that the transition from one monitoring system to another can only take place gradually over a long period. And throughout this period, it is important to maintain the capability of monitoring the efficiency of FER used at both individual enterprises and at the state level.

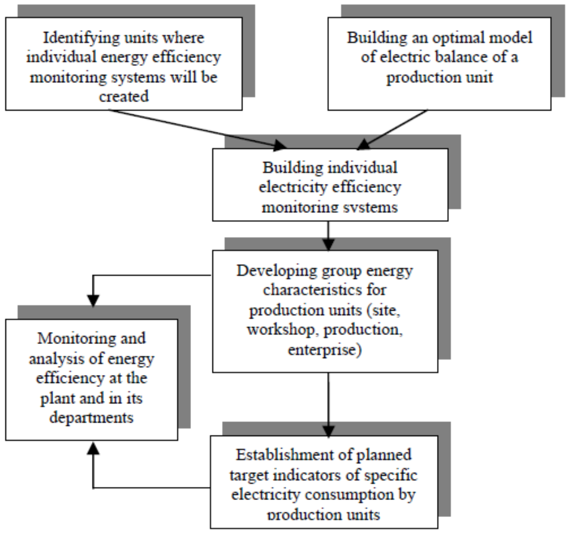

Figure 2 – The process of building and operation of IEMS

Moreover, completely abandoning the specific consumption indicators for fuel and energy in the process of monitoring their efficiency in the near future is unlikely, as, based on the international experience, building and implementing EMS directly for large production facilities is impossible [19, 20].

Therefore, research looking into improving the methods of FER efficiency monitoring systems (and this study, in particular) aims to at least partially eliminate shortcomings in monitoring based on FER specific costs, developing methods for creating and applying EMS, and thereby creating the conditions for a gradual successful transition from the existing system to more accurate and objective means of monitoring energy efficiency. Moreover, such transition should enable operational (e.g. daily, weekly) monitoring of energy efficiency.

Developing and implementation of IEMS implies that, in the beginning, determination of planned and actual specific costs (for electricity) will remain the only means for energy efficiency monitoring at the respective facility. However, instead of using computational analysis for drawing up the balance of electricity consumption at an enterprise, which is traditionally used to determine its planned specific costs, the methodology of building optimal computational models of electric power balances, proposed by the authors of this publication, will be used [21].

The very process of building an IEMS for individual energy-intensive installations, units or processes, as well as for groups of less energy-intensive equipment lies in gradually creating and implementing individual EMS.

Because any sufficiently large production facility (an enterprise or its subdivision) is a group of numerous energy consumers, it will take a long time to build all the necessary individual EMS. Therefore, at the start of the IEMS operation, it will be necessary for some time to apply both of the above approaches to energy efficiency monitoring: at the level of enterprise as a whole and its subdivisions – on the basis of specific costs of electricity, and at the level of technological facilities (individual plants, units, processes or their groups) – offering them individual EMS.

It is clear that those technological facilities that will receive individual EMS at a certain point of time, will enable operational monitoring of energy efficiency (daily, weekly, monthly, etc.).

However, as we know, individual EMS cannot be created directly for large production and economic facilities (sites, workshops, enterprises as a whole). For this reason, in the process of developing and operation of IEMS for such facilities, setting targets for specific energy consumption for traditional long-term control periods (year, quarter) will remain necessary for quite a while. However, determining target specific consumption of electricity for production and economic facilities in the IEMS can be a more justified way, different from the procedure used in existing methods of calculating the specific energy consumption in public production in Ukraine. Baseline indicators of energy consumption, established in the individual energy efficiency control monitoring systems already developed, can be used for this purpose.

Such baselines are mathematical models of energy consumption that can take into account numerous factors, such as process parameters, its conditions, and the like. Therefore, on the basis of individual baselines of energy consumption for individual plants and technological processes, much more accurate and substantiated amounts of electricity costs for the respective future period can be determined, compared to the corresponding indicators established by the traditional calculation and analytical method.

In addition, it should be noted that the baselines of energy consumption are a kind of individual energy characteristics of the respective technological facilities. Therefore, considering these baselines allows to use them as a basis for building group (cumulative) energy characteristics for individual units and the enterprise as a whole. To build such group characteristics one may apply the known step-by-step method, which involves “adding-up” individual energy characteristics of technological facilities or their groups [22].

On the basis of the group energy characteristics of production and economic facilities thus obtained, as well as the planned values of production volumes, process parameters, external conditions for these facilities, it is possible to determine the planned volumes of energy consumption for an appropriate period. At the same time, it can be stated that the planned electricity costs, determined for production and economic facilities based on their group energy characteristics, as well as the corresponding planned specific energy costs, will be more accurate and justified than the planned energy consumption figures, which are currently determined with computational analysis.

In addition, cumulative energy performance, by analogy with individual EMS, can be considered as group baselines of energy consumption for the enterprise as a whole and its subdivisions, which can also be applied for operational monitoring of electricity efficiency at these facilities.

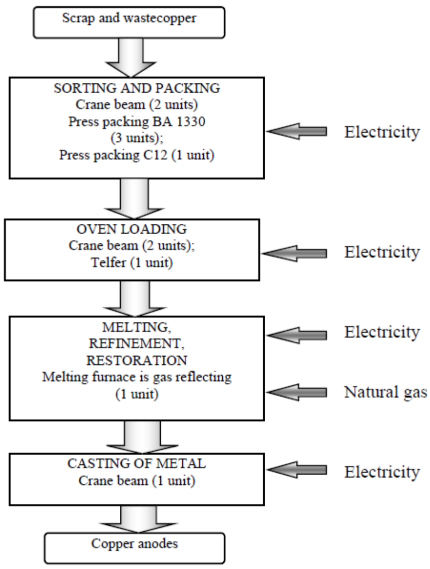

Figure 3 – Diagram of copper anode production process

Therefore, developing and implementing IEMS at industrial sites not only allows this monitoring to be operational at the level of individual units, installations or processes, but also enables, with the gradual increase in the number of individual EMSs built, improve the accuracy and validity of determining target specific costs of electricity, as well as to carry out operational monitoring of energy efficiency at the enterprise level as a whole and its subdivisions.

Thus, applying the concept of developing IEMS, as proposed by the authors of this article, will gradually improve and eventually may fully replace Ukraine’s existing insufficiently correct system of monitoring the electricity efficiency at production and economic facilities, based on the determination of its specific costs, by creating and applying individual systems for monitoring energy efficiency in production.

Moreover, in the course of such gradual replacement, energy efficiency management in public production will not be affected, as the process will be on-going.

Example of creating and applying IEMS. The process of building and implementation of IEMS can be illustrated by the example of a subdivision of the non-ferrous metallurgy plant. As an object for building an integrated system of monitoring the electricity efficiency at this plant, the department of fire refining of copper, producing the so-called copper anodes, was selected.

Fig. 3 shows a flow diagram of a copper refining process that reflects the sequence of individual operations, the relationship between them, the names and the number of units of the basic equipment where these operations are performed, as well as the energy resources consumed.

In addition, electricity is also used by various auxiliary equipment: the gas purification system, lighting systems for melting and batching stations, various lifting and transport equipment, etc.

Groups of main and auxiliary equipment of smelting and batching stations were selected for building individual systems of monitoring the electricity efficiency in this department (Table 1).

Table 1 – Individual baselines of electricity consumption and group energy characteristics

No. of the faci-lity	**Name of the facility**	**Production factor**	**Equation of the baseline of electricity consumption (original and reduced), kWh/month**
		Melting shop	
1	Gas and fume purification system	Volume of metal melting works (Q_1), t/month	$W_{1i} = 1436,401 + 50,245Q_{1i}$ $W_{1i} = 1436,401 + 55,093Q_i$
2	Lighting system of the melting shop	--------------	$W_{2i} = 4711,438$
3	Auxiliary equipment of the melting furnace	Running time of the melting furnace (Q_3), h/month	$W_{3i} = 1191,557 + 12,205Q_{3i}$ $W_{3i} = 1191,557 + 15,156Q_i$
4	Lifting and transport equipment	Running time of rail filling device (Q_4), h/month	$W_{4i} = 718,751 + 15,808Q_{4i}$ $W_{4i} = 718,751 + 3,952Q_i$
		Copper Batching Site	
5	Main process equipment	Volume of works on batch preparation (Q_5), t/month	$W_{5i} = 1962,711 + 25,7Q_{5i}$ $W_{5i} = 1962,711 + 30,998Q_i$
6	Lighting of the site	---------------	$W_{6i} = 4831,707$
Equation of the group energy characteristics of the copper fire refining department			$W_{depi} = 14852,564 + 105,199Q_i$

To obtain the data on electricity consumption by each group of equipment required to establish the respective individual baselines of energy consumption, using the method of building optimal computation models of energy balances [22], a number of balances of the department of fire refining of copper were compiled.

In the process of creating an integrated system for monitoring the electricity efficiency in the specified department, individual baselines of electricity consumption were determined for each of the groups of equipment selected as objects for building individual EMS, according to the method developed by the authors of this publication [23]. The summary of established baselines of monthly electricity consumption for the selected groups of equipment is presented in Table 1.

After establishing the above baselines of electricity consumption for each individual group of the main and auxiliary equipment of the copper fire refining department, we now may carry out an operational (monthly) monitoring of the electricity efficiency [24].

As noted above, based on known individual baselines of energy consumption using known operative step-by-step method [22] a group energy characteristic can be built to single out the fire refining of copper as a whole. It should be borne in mind that individual baselines of energy consumption are set depending on different production factors. Therefore, the equation of each individual baseline of electricity consumption must first be made uniform, that is, be brought to the form of dependence on a single factor – the output of the final (finished) products of the department (Q). The results of such an adjustment, which is carried out using appropriate coefficients, are also shown in Table 1.

In order to account for the random nature of the volumes of electricity consumption by the equipment of the specified department, corresponding confidence intervals are built with regard to the obtained group energy characteristic of the compartment (Fig. 4).

On the basis of the group energy characteristics of the compartment thus built (taking into account the confidence intervals thereto) and the plan of production of the product, specific indicators of the specific consumption of electricity for the department of the fire refining as a whole can be established. For example, for a certain month during which the planned production of refined copper is 748 tones, the planned energy consumption for the copper refining department is given in Table 2.

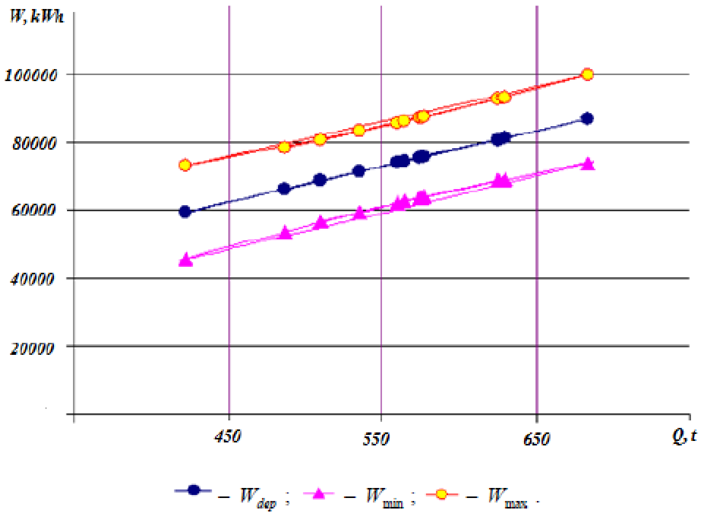

Figure 4 – Group energy characteristics of the copper fire-refining department

Table 2 – Annual production targets and energy consumption for the copper fire-refining department

$Q_{пл}$, **t**	$W_{dep.pl}$, **MWh**	$W_{max.pl}$, **MWh**	$W_{min.pl}$, **MWh**	$d_{dep.pl}$, **kWh/t**	$d_{max.pl}$, **kWh/t**	$d_{min.pl}$, **kWh/t**
748	93566.4	107831.3	79301.5	125.09	144.16	106.02

Thus, knowing the planned of production of the product for the department of the enterprise can be defined the planned energy consumption for the respective future periods. In order to account for the random nature building group energy characteristics of the department should determine the minimum and maximum size of the planned power consumption ($W_{min.p1}$ and $W_{max.p1}$), using the equation limits of the confidence interval to energy characteristic (Fig. 3). Similarly (and for the same reason) should establish minimum and maximum amount the planned specific consumption of electricity per unit ($d_{min.p1}$ and $d_{max.p1}$), the use of which allows for more objective monitoring energy efficiency at the department of the enterprise.

Conclusions:

1. Considering the advantages and disadvantages of determining the specific energy costs and building energy efficiency monitoring systems, it can be argued that one of the promising directions for further development of the methodology of such monitoring is the establishment of IEMS at production facilities.

2. When considering individual baselines of energy consumption as individual energy characteristics of process facilities, it is necessary to use them as basis for building group energy characteristics of individual production units and the enterprise as a whole. With such group energy characteristics, more accurate and reasonable target indicators of specific energy consumption for production of products in individual units and at the enterprise as a whole can be set for the respective future periods.

3. Building and implementing IEMS allows for operational control of energy efficiency of process facilities by creating individual systems for monitoring energy efficiency, as well as successfully carry out such monitoring at the enterprise and its subdivisions over longer periods of time using specific energy consumption indicators.

4. Therefore, Ukraine’s existing insufficiently correct system of monitoring the electricity efficiency based on the determination of its specific costs will be gradually improved and eventually may be fully replaced by creating and applying individual systems for monitoring energy efficiency in production.

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МЕТОДИЧНІ ПИТАННЯ ВПРОВАДЖЕННЯ СИСТЕМ ЕНЕРГЕТИЧНОГО МОНІТОРИНГУ ПРОМИСЛОВИХ ПІДПРИЄМСТВ

Статистика показує, що витрати на енергію є однією з найбільших складових операційних витрат промислових підприємств. Отже, підвищення енергоефективності може призвести до суттєвого збільшення прибутку підприємства та зменшення його впливу на довкілля. Для підвищення результативності діяльності у сфері енергоефективності на промисловому підприємстві необхідно впровадити систему енергоменеджменту. Одним із компонентів цієї системи є енергомоніторинг, який, у свою чергу, базується на періодичному зборі та аналізі даних для оцінки стану об'єктів моніторингу з точки зору енергоефективності. У цій роботі показано роль енергомоніторингу в системі енергоменеджменту промислового підприємства. У статті пропонується концепція створення системи енергомоніторингу на промислових підприємствах, яка базується на поєднанні системи моніторингу на основі показників питомого споживання енергії та використання групових енергетичних характеристик виробничих потужностей. Впровадження таких систем енергомоніторингу дозволить проводити оперативний контроль енергоефективності виробничих потужностей шляхом створення індивідуальних систем моніторингу енергоефективності, а також успішно проводити такий моніторинг на підприємстві та в його підрозділах протягом більш тривалих періодів часу, з використанням конкретних показників енергоефективності. Тут також містяться загальні вказівки щодо проведення енергетичного моніторингу промислових підприємств. Ці загальні вказівки були сформовані на основі результатів вивчення різних методик та наукових публікацій у сфері енергетичного моніторингу, а також на основі практичного досвіду розробки та впровадження систем енергоменеджменту. Особлива увага приділяється питанням формування набору показників енергоефективності, а також обробки та аналізу інформації про об'єкти енергетичного моніторингу промислових підприємств.

Ключові слова: *базовий рівень енергії, енергоефективність, питоме споживання енергії, показник питомого споживання енергії, промислове підприємство, система енергоменеджменту, система моніторингу енергії.*

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