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# APPLIED BASICS OF BUILDING A SYSTEM OF ENERGY MANAGEMENT AT A HIGH-TECH ENTERPRISE

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**Abstract**

The introduction of energy-saving measures and technologies that improve economic efficiency has recently been one of the key drivers for the development of modern high-tech enterprises in recent years. Energy management is one of the systematic approaches to energy savings. Its implementation necessitates development and application of an introduction algorithm of energy management system the structure of which interconnects individual – organizational, economic and technical measures and technologies.

***Key words:*** high-tech enterprise, energy saving, improvement of energy efficiency, energy management, energy management system, automation, energy audit.

**Introduction**

Improvement of the energy efficiency in industrial enterprises is currently one of the top priorities for the development of high-tech industries. Energy savings can significantly reduce the enterprise's costs for fuel and energy resources used in manufacturing processes, as well as the amount of harmful emissions and waste produced by the enterprise activities, assisting in the reduction of environmental risks associated with its operation. As a result, their economic efficiency improves significantly. Furthermore, the cost of production is reduced, as is the price for end users, which contributes to the company's increased market competitiveness.

At the same time, a systematic approach to the implementation of energy-saving measures and technologies is required to reduce the consumption of fuel and energy resources at all stages of production and achieve long-term results in improving the energy efficiency of enterprise.

Energy management is one of the most popular system approaches to energy savings in modern industry. It is a single interconnected set of measures, technologies, equipment and specialized software that is then consolidated into a single energy management system.

**Conflict setting**

The establishment of an energy management system is a costly endeavor that necessitates a significant investment of financial resources. The task force should create a unified algorithm for the implementation of such a system in order for it to be successful. Without such an algorithm, there is a risk of insufficient coordination among organizers, inefficient investment spending and so on. This algorithm covers all stages of the system development, from strategic planning to the implementation of basic energy-saving technologies.

**Research findings**

The practical implementation of an energy management system necessitates the resolution of a number of rather complex organizational and technical issues. In this case, an important factor is their organic interconnection within the framework of the algorithm for the formation of an energy management system, which allows the most efficient use of the time, economic, technical and intellectual resources of an enterprise [1]. The development of such an algorithm should take into account the enterprise economic potential, the existing technological backlog in the field of energy conservation as well as the scale and specifics of its activities. Furthermore, when developing an algorithm, developers have the opportunity to perform preliminary efficiency calculations and analyze the parameters of the system being created, allowing them to identify the most important technologies and directions for improving energy efficiency of the enterprise in advance. The universal algorithm for the creation of an energy management system is shown below (Fig. 1).

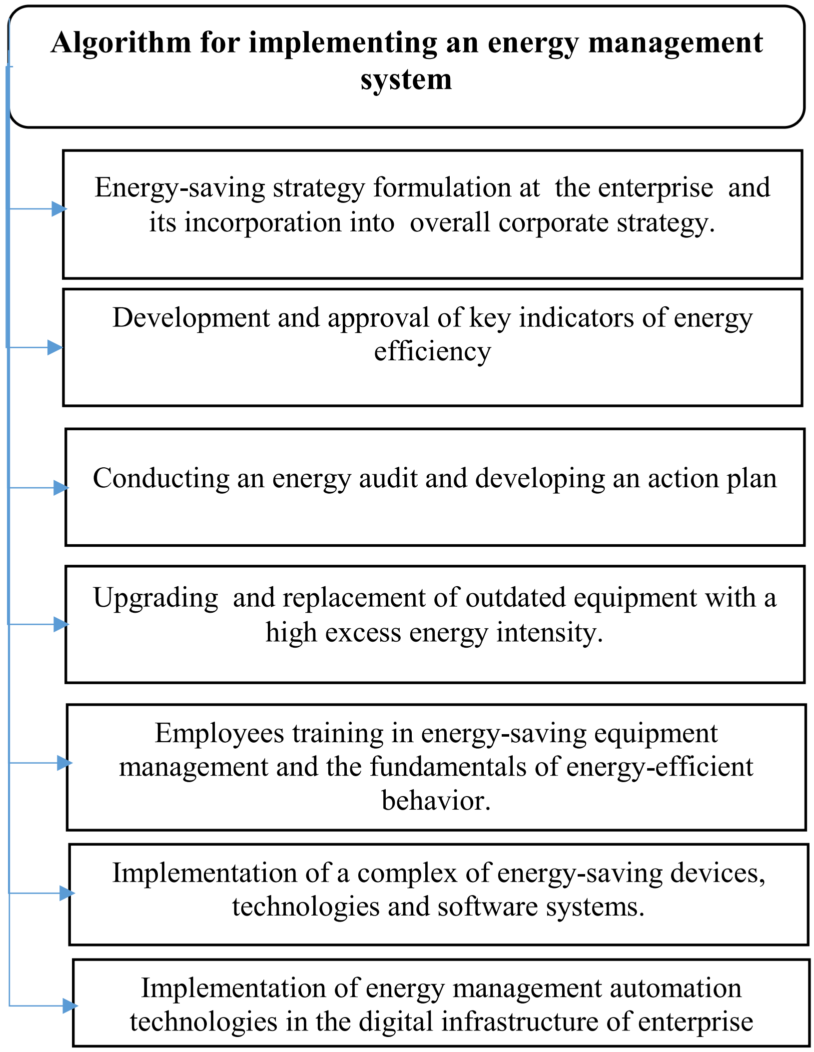


**Fig. 1 The algorithm for implementing an energy management system at a high-tech enterprise**

The algorithm for implementing an energy management system at a high-tech enterprise, as depicted in Fig. 1, consists of seven interconnected blocks (stages), the distribution logic of which corresponds to the system approach. Let us take a closer look at each stage of this algorithm.

The first of these, depicted in Fig.1 is the stage 1, the formulation of an energy-saving strategy for the enterprise and its integration into its overall corporate strategy. The developed energy management system is one of the enterprise major subsystems and interacts closely with the majority of its technological subsystems, having a direct impact on the technological and economic efficiency indicators of the enterprise. At the same time, it plays an important role in the structure of the organizational and economic mechanisms of the enterprise.

Taking these factors into consideration, the primary task in its development is the development of an energy-saving strategy which will be implemented through the development of a system. This will allow it to determine its initial goal, tasks and priorities, as well as link them to available resources and target time parameters for completing individual tasks. The strategy itself should take into account the general economic priorities and performance targets of the enterprise [2]. Not only should responsible specialists be involved in the development of the enterprise, but so should heads of departments and representatives of the enterprise top management.

The second step at this stage is to incorporate the energy-saving strategy into the enterprise overall corporate strategy. Its implementation reflects, at the strategic planning level, the integration of the energy management system itself into the structure of the enterprise organizational and economic mechanism. The corporate key priorities and tasks of the strategy are interconnected with the enterprise performance targets and strategic objectives, directly influencing the development strategies of the production subsystem, technological development, innovative development and digital transformation among other things. At this stage, it is critical to conduct a thorough analysis of such relationships and mutual influence in order to anticipate possible changes in the strategic development trajectories of the remaining enterprise subsystems and optimize them as part of the adjustment of individual blocks of the corporate strategy.

The development and approval of key energy efficiency indicators (KenIs) is carried out based on the results of the development of the energy saving strategy. This stage represents the transition of work on planning the implementation of the energy management system from the strategic to the tactical level. The essence of energy-saving measures lies in their purposeful implementation, with mandatory fixation of the achieved level of energy efficiency growth. The fixation of the achieved energy effect enables objective indicators to be used to evaluate the effectiveness of specific technologies as well as the effectiveness of their implementation at a given enterprise.

To address this issue, it is proposed that a special type of indicator – key indicators of energy efficiency – be developed and implemented within the framework of the energy management system. These indicators are designed to evaluate the energy efficiency of various enterprise subsystems, stages of production, internal operations and processes. The goal of their implementation is a dynamic analysis and detailing of changes in the level of energy efficiency at all levels of the enterprise hierarchy, followed by an assessment of the effectiveness and contribution to the overall energy effect of individual energy-saving measures and technologies. The results of the analysis can be used for further optimization and technological development of the energy management system, as well as screening out and excluding objectivity because the effectiveness of their use is largely dependent on the level of professionalism, motivation and availability of the necessary energy-efficient competencies among the employees themselves. In accordance with this, it is proposed that, in addition to the introduction of KenIs, key efficiency indicators (KefIs) for staff and employees responsible for energy conservation be introduced.

The main goal of introduction of KefI scorecard is to actively involve all employees responsible for its implementation in the operational processes of energy conservation management, by assigning specific KPI values to them based on their work profile. Employees for whom such indicators are developed include, first and foremost, heads of energy-saving departments, employees responsible for working with energy-saving equipment and specialized software, as well as specialists responsible for maintaining and modernizing the enterprise energy infrastructure. Thus, based on the coordinated implementation of KenIs and KefIs, the company's management gains access to a comprehensive toolkit for assessing both energy-efficient measures, technologies and equipment, as well as evaluating and analyzing the contribution of employees to overall energy efficiency of the company.

An energy audit and the development of a set of preparatory measures are the next steps in the formation of an energy management system. The primary tasks of conducting an energy audit (energy inspection) are to identify the current level of energy consumption of the enterprise, the main subsystems, sections and equipment with excessive energy intensity, the analysis of the technological state and its engineering and energy communications, the determination of the energy base line, and the selection and evaluation of promising energy-saving technologies, equipment, and integrated solutions.

An energy audit typically consists of two major stages: a cameral (cabinet) audit and an instrumental examination. The cabinet auditing entails gathering, systematizing and thoroughly analyzing all enterprise reporting documentation relating to various parameters of its energy consumption and individual energy technological indicators. Specialists form an initial picture of the general dynamics of the energy consumption of enterprise over the last five years based on the results of its implementation, identifying its most energy-intensive subsystems and production stages.

The second stage is an instrumental examination, which includes a site visit and direct hardware diagnostics and analysis of the enterprise buildings, energy and engineering communications. Instrumental energy audits are primarily concerned with measuring and assessing the consumption of energy carriers and steam, thermal imaging surveys, measuring water consumption in hot and cold water supply systems, multimetric surveys (assessment of the enterprise's internal environment parameters such as noise level, illumination, humidity and temperature, among others), measurement and evaluation of power supply systems and so on. Specialists use a variety of specialized equipment to conduct instrumental examinations, including noise meters, lux meters, thermal imagers, power consumption and power quality indicators, ultrasonic liquid flow meters, heat flux density meters and other similar devices.

Specialists systematize and analyze the main identified problems (for example, technical deterioration of enclosing structures and the formation of "cold bridges", high wear and tear of engineering communications and the presence of leaks in the hot water supply system, excessive power consumption from aspects of lighting systems, and so on) based on the summary data obtained from both stages of the energy audit, and develop technical solutions to eliminate them. Furthermore, based on the results of an energy audit, they can develop the most optimal configuration of preparatory measures aimed at comprehensively preparing the enterprise for the introduction of energy-saving technologies by obtaining comprehensive data on the technical condition of the enterprise energy system, the types of equipment operating on its basis and the specifics of technological processes.

The fourth stage of a high-tech enterprise energy management system implementation algorithm is the modernization and replacement of obsolete equipment with a high excess level of energy intensity. The majority of the necessary reporting and analytical data for this stage's implementation is created during the energy audit stage.As experience shows, the use of outdated equipment with high excess energy intensity leads to the greatest unproductive energy losses compared to other negative factors. According to various scientists and experts, the share of losses from production equipment with no or low level of energy efficiency in various industries is up to 70-80%% of total losses and unproductive use of energy. This is explained by the fact that production equipment, due to the specifics of the technological organization, represents the largest share among the entire fleet of energy-consuming equipment operating on its basis.

One of the main reasons for the high energy intensity of production equipment is the use of outdated equipment at the enterprise, the design and creation of which took place back in those periods of time when its developers, in principle, did not have the task of reducing its energy intensity and increasing energy efficiency. The use of such obsolete equipment, unfortunately, is one of the fundamental problems of Russian industry associated with a difficult crisis in its development that occurred in the 90s of the last century.

The stage under consideration is one of the most expensive steps in implementing an energy management system, because modern energy-efficient production equipment is primarily produced in Western and East Asian countries, and individual CNC machines, machining centers, and industrial robots can cost tens of millions of rubles. At the same time, keep in mind that the necessary modernization of the enterprise's equipment fleet may necessitate the replacement of a number of such machines or machining centers.

It is in this context that the accuracy and depth of a previous energy audit is especially important, as it allows the ranking of individual equipment in terms of energy intensity and energy efficiency. This allows you to initially identify the most energy-intensive machines and other equipment that most significantly affect the level of energy efficiency of the enterprise's production system in order to focus on their modernization or replacement in the first place, while obtaining the maximum energy efficiency.

Energy management differs from other approaches to energy conservation in that it pays equal attention to the introduction of energy-saving measures and technologies as well as the participation of its employees in the processes of improving the enterprise energy efficiency, including both those responsible for energy conservation and other specialists and workers [4]. This is due to the significant impact of enterprise personnel on overall energy efficiency indicators, as the impact of introducing even the most modern energy-saving technologies can be leveled or reduced if employees lack the basic interest, motivation, and competencies to use these technologies in a timely manner and rationally handle the equipment entrusted to them.

As a result, the fifth stage of the energy management system implementation algorithm is to train staff on how to manage energy-saving equipment as well as the fundamentals of energy-efficient behavior. From the standpoint of system implementation, this stage should take place before the direct introduction of energy-saving equipment and technologies, so that by the time they are integrated into the enterprise's various technological systems, the personnel have already acquired the necessary skills and energy-efficient competencies, as well as been trained in the fundamental principles of energy-efficient behavior.

The implementation of this stage is carried out within the framework of several successive sub-stages. The first of the sub-stages is the training in the principles and methods of energy efficiency improvement for representatives of the management of the relevant divisions (departments) of the enterprise, directly related to the management of the energy management system. The blocks of competencies they master include the basics of energy saving in industry, the selection, evaluation and analysis of energy efficient technologies, strategic and tactical planning in the field of increasing the energy efficiency of an enterprise, the practical fundamentals of managing an energy management system based on the development and analysis of its KPIs and KPIs of employees.

The second sub-stage is the training of specialized personnel responsible for the implementation, maintenance and technical support of individual components of the system. Such specialists may include power engineers responsible for the implementation and maintenance of the software components of the system, programmers, engineering and technical personnel, and specialists from equipment repair departments. Training of specialists from the above categories implies mastering not only the basic principles of energy saving, but also energy-efficient engineering competencies. Mastering these competencies, they subsequently acquire the necessary skills for comprehensive maintenance and support of various components of the system, learn the principles of managing its individual technologies and equipment, its technological modernization and scaling depending on the changes made to the energy saving strategy of the enterprise.

Employees and workers who do not interact directly with the energy management system are trained in the third sub-stage. The primary goal of their training is to gain knowledge in the areas of energy-efficient workplace behavior and the rational use of energy equipment available to them. As demonstrated by practice, successful implementation of this stage not only reduces energy losses at the enterprise due to the so-called “human factor”, but also creates conditions for the active dissemination of an energy-efficient culture among its employees and workers. It becomes an integral part of the overall corporate culture after being assimilated by them at the level of consciousness and motivation and is actively distributed, among other things and among new employees.

In fact, the sub-stages formed above represent three interconnected educational and practical circuits, the construction of which ensures the participation of representatives from all levels of the enterprise hierarchy in energy saving processes. The benefit of this approach is the establishment of numerous points of contact for the energy management system, as well as the participation of the vast majority of employees and workers in energy-saving processes.

Besides, from the standpoint of intra-organizational interaction, the implementation of such interconnected structures allows minimizing potential administrative and bureaucratic barriers in solving various problems of system development by combining managers and specialists from different departments within separate circuits. As a result, they can communicate about the joint implementation of energy-efficient competencies and the assimilation of energy-saving principles and ideology.

The practical implementation of the stage under consideration necessitates the involvement of experienced teachers, scientists and experts in the educational process. Given the scope of educational programs, even a medium-sized enterprise cannot complete this task with a single team of energy management system developers. The best approach to its solution, in our opinion, is the organization of collaboration with leading technical universities, on the site of which there are educational units (chairs, departments) specializing in training specialists in the field of energy saving and digital transformation of the energy sector.

The sixth stage of energy management system implementation is the installation of a complex of energy-saving equipment, technologies and software systems. Members of the system formation team carry out the final design and modeling of its architecture within the framework of this stage, based on the data collected and systematized at the third stage of the algorithm based on the results of the energy survey. Taking into account the developed architecture, specific technologies and energy-saving equipment are chosen, and a roadmap for their implementation is created. On the basis of the roadmap, tactical and operational plans for their implementation are developed, including direct preliminary adjustments to the enterprise's existing power equipment and engineering and energy communications features. The suppliers of selected technologies, application software packages, integrated technological solutions and energy-saving equipment are determined by the system developers. Following this, the centralized purchase of the listed components of the software and hardware components of the energy management system is carried out.

Based on the above mentioned activities, the developers, in collaboration with technical specialists and experts from the manufacturing companies of the acquired technologies, integrated solutions, and equipment are gradually integrating it into the technological systems of the enterprise. First and foremost, the basic hardware and elements of the future hardware and software infrastructure of the energy management system are introduced. One of the critical conditions is the smooth implementation of these types of activities, ensuring their minimal impact on the current performance of the enterprise including forced shutdowns for the introduction of equipment for large sections of the power system of enterprise which may result in a halt in production. Furthermore, immediately following installation, all equipment is subjected to a stress testing procedure to determine the level of fault tolerance and, if necessary, to optimize the parameters and settings of its operation.

The next step is to deploy software and information systems that integrate the previously installed equipment into their structure. In today's energy management systems, software is just as important as the energy-saving equipment. It includes features like centralized data collection, systematization and analysis of all data on energy consumption and energy efficiency of enterprise technological systems, mechanisms for managing the energy management system itself and flexible configuration and optimization of its parameters.

Furthermore, on the basis of the deployed software infrastructure, a unified energy saving control center is being formed, allowing enterprise management and system management personnel to receive the entire amount of data on the enterprise's energy parameters in real time. This opens up numerous opportunities for flexible and operational analysis of thousands of processes at the enterprise level, significantly improving the quality of management decisions made as part of the regulation and optimization of the energy management system, taking into account the achievement of the target criteria for improving energy efficiency specified in tactical and operational plans.

The incorporation of energy management automation technologies into the enterprise digital infrastructure is the final step in the development of the energy management system. Its implementation is already taking place on the basis of fully deployed hardware and software components, constituting a stage in their continued technological evolution in accordance with the Industry 4.0 methodology. At this stage, the primary activities are the technological interconnection of energy-saving equipment with the existing digital infrastructure of enterprise and the creation of end-to-end technological circuits. The creation of such circuits allows for the active influence of energy-saving equipment and technologies on the operating modes of production equipment and enterprise technological systems.

The active integration of software into the digital infrastructure of enterprise is the second step within the framework of the stage under consideration. The goal of this step is to create a common digital space in which the technological, economic and energy efficiency parameters of enterprise are interconnected. Traditional energy management systems have long been constrained by rigid administrative frameworks, and their operation has been carried out through sets of predetermined fixed procedures in the existing practice of energy conservation. As a result, their work processes were mostly isolated and separated from the main production and technological processes and industrial equipment of the enterprise. As a result, the effectiveness of such energy management systems has decreased, making it impossible for them to fully realize the energy-saving potential of enterprise.

In contrast, the integration of technologies and equipment of energy management system into the already existing digital infrastructure of the enterprise allows it to become a full participant in the main activities of enterprise, forming a projection of increasing energy efficiency within the framework of a common digital space. In practice, this means that the system can actively influence the processes of managing energy supply and energy savings at the enterprise. As a result, it can automatically implement adaptive control and regulation of the energy system of the enterprise in real time. It also gains the necessary degree of freedom and access level to respond as quickly as possible to various emergency situations, accidents, and equipment failures caused by power outages.

The algorithm for the development of an energy management system at a high-tech enterprise was considered above. One of the most important characteristics and competitive advantages of such systems over traditional approaches to energy savings is their ability to undergo digital transformation based on Industry 4.0 technologies and then be integrated into the enterprise's digital infrastructure. First of all, organic integration into its cyber-physical system which is the main technological platform that unites the entire complex of digital technologies and processes on its basis. Such integration opens up qualitatively new opportunities for automation and technological development of the energy management system itself.

## Conclusion

The development of energy management systems is currently one of the most promising areas of modern energy conservation. Such systems are highly adaptable and scalable and they can incorporate a wide range of energy-saving technologies and methods for improving the energy efficiency of high-tech enterprises. At the same time, they are open systems in their structural essence and, as such, can be optimized and upgraded at any time without the need for a complete shutdown and shutdown of existing equipment.

The developed algorithm for building energy management systems has a high degree of universality and can be used to implement such systems in enterprises of various industries, regardless of their scale. It considers and arranges in a logical sequence all of the necessary stages of creating a system, takes into account both technical and analytical measures,and works with enterprise personnel to form their energy-efficient workplace behavior.

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# ԷՆԵՐԳԻԱՅԻ ԿԱՌԱՎԱՐՄԱՆ ՀԱՄԱԿԱՐԳԻ ՍՏԵՂԾՄԱՆ ԿԻՐԱՌԱԿԱՆ ՀԻՄՈՒՆՔՆԵՐԸ ԲԱՐՁՐ ՏԵԽՆՈԼՈԳԻԱԿԱՆ ՁԵՌՆԱՐԿՈՒԹՅՈՒՆՈՒՄ


**Գոլով Ռ.Ս.**
*Մոսկվայի ավիացիոն համալսարան*


Տնտեսության արդյունավետությունը բարելավող էներգախնայող միջոցների և տեխնոլոգիաների ներմուծումը վերջերս դարձել են ժամանակակից բարձր արդյունաբերական ձեռնարկությունների զարգացման առաջատար ուժերից մեկը:

Էներգիայի կառավարումը էներգախնայողության համակարգային մոտեցումներից մեկն է: Դրա իրականացումը անհրաժեշտ է դարձնում էներգիայի կառավարման համակարգի զարգացումը և կիրառումը, այն ներմուծման մի այնպիսի ալգորիթմ է, որի կառուցվածքը փոխկապակցում է անհատական, կազմակերպչական, տնտեսական և տեխնիկական միջոցները և տեխնոլոգիաները:

***Բանալի բառեր:*** բարձր արդյունաբերական ձեռնարկատիրություն, էներգախնայող, էներգիայի արդյունավետության բարելավում, էներգիայի կառավարում, էներգիայի կառավարման համակարգ, ավտոմատացում, էներգիայի աուդիտ:

## ПРИКЛАДНЫЕ ОСНОВЫ ПОСТРОЕНИЯ СИСТЕМЫ ЭНЕРГЕТИЧЕСКОГО МЕНЕДЖМЕНТА НА ВЫСОКОТЕХНОЛОГИЧНОМ ПРЕДПРИЯТИИ

**Голов Р.С.**
*Московский авиационный институт*

Одним из ключевых драйверов развития современных высокотехнологичных предприятий в последние годы стало внедрение энергосберегающих мероприятий и технологий, позволяющих повысить уровень их экономической эффективности. Одним из системных подходов к энергосбережению выступает энергетический менеджмент. Его реализация требует разработки и применения алгоритма внедрения системы энергоменеджмента, в структуре которой взаимоувязываются отдельные организационные, экономические и технические мероприятия и технологии.

***Ключевые слова*:** высокотехнологичное предприятие, энергосбережение, повышение энергетической эффективности, энергетический менеджмент, система энергоменеджмента, автоматизация, энергетический аудит**.**

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