ЕНЕРГЕТИЧНА ЕФЕКТИВНІСТЬ ТА ЕНЕРГОЗБЕРЕЖЕННЯ

ENERGY EFFICIENCY AND ENERGY SAVING

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METHODOLOGICAL BASIS FOR A COMPREHENSIVE ASSESSMENT OF THE EFFICIENCY OF ENERGY PRODUCTION BY ENERGY-ENVIRONMENTAL INDICATORS

The solution to the problem of energy saving and improving environmental security can be provided only by a systematic approach, which should be based on the analysis of the efficiency and environmental friendliness of energy production.

A methodology was developed and implemented to assess the qualitative state of operation of specific thermal power facilities by energy and environmental characteristics in real time, taking into account the set of energy, environmental, passport and normalized performance of its units, facilities and devices.

The methodology in practice allows in a complex to determine simultaneously the level of energy efficiency and environmental safety with an assessment of compliance with the level of permissible values for concentrations of pollutants and hazardous substances of the working area and their hazard class. In this case, indicators and parameters of monitoring of various processes of each individual element and component of the energy production facility as a whole, which uses as a source of energy organic fuel, are used.

According to this methodology of comprehensive energy-environmental assessment of operating conditions of energy facilities can be compared different in design, thermal, environmental and other scale characteristics of thermal energy cycles, facilities, installations, units and other thermal energy equipment and optimize the choice of energy source for heat and energy production under different schemes of layout of units within the cycles.

Application of the methodology of assessment of energy-ecological efficiency of thermal energy processes allows to assess the energy-ecological feasibility of modernization or reconstruction of facilities in order to achieve the best performance of their operation in the heat and energy supply systems of various sectors of the country's economy. The use of the method is demonstrated by the example of calculating the coefficient of energy and environmental efficiency for energy boilers of different capacities.

Key words: *energy facility, methodology, objective assessment, environmental safety, energy efficiency, reliability of operation.*

1. Introduction

The desire of industrially developed countries, transnational companies, international production corporations, large enterprises, as well as the desire of private enterprises, organizations and people to create for themselves the most comfortable and convenient conditions of work, life and rest leads to an increase in the use of energy. Therefore, objectively, this steady tendency of human activity leads to an increase in energy production.

At the same time it becomes the reason of excessive technogenic impact on the environment [1].

This negative impact on the environment occurs against the background of continuous growth of energy production and consumption, which accompanies the development of civilization [2].

In recent decades, in many respects, it is these ecological changes that determine the sense of alarm of the world community and the premonition of a general pre-crisis state on Earth [3-5].

It is fundamentally important for mankind to preserve its sustainable development on Earth so as not to destroy its habitat and life environment.

Therefore, the main goal of mankind's progress in its development must be to ensure the safety, purity and reproducibility of the environment for future generations.

Now the primary program for the world economy is the ecological purity of its development.

2. Literature Analysis and Problem Statement

Parameter monitoring systems in which such point values are entered for control allow to estimate the real state of the equipment for further operation, significantly reduce the costs of maintaining the facility in working order due to timely scheduled repairs and equipment renovation, optimize technological processes, increase the reliability of energy production on the basis of implementation of optimal loading, and improve operational safety by reducing the probability of sudden uncontrolled equipment failures and emergencies, to extend the operating life of equipment, etc. [6,7].

Based on the results of these data the assessment of the real technical condition of the equipment, the suitability and operability of the facility, assesses the possibility of further operation or the need for restoration and renovation, as well as assesses the level of opportunities to improve the set of indicators through the use of modern innovative technologies and equipment with improved safety and operational capability of the energy facility [8,9].

To date, there is no comprehensive approach to solving these issues, but in accordance with the main provisions of the Energy Strategy of Ukraine for the period up to 2035 "Security, Energy Efficiency, Competitiveness" energy intensity of gross domestic product (GDP) based on large-scale energy saving and energy efficiency by increasing the use of its own fuel and energy resources (FER), increasing the level of energy independence of the state, modernization and renewal of fixed assets using modern equipment and technologies with a high level of energy efficiency and environmental safety, creating conditions for the expulsion of the global system for monitoring the state of atmospheric air. However, this requires a qualitative and far-sighted assessment and analysis of the real situation in the country's fuel and energy complex [10-11].

There is an objective need for the development and implementation of such a methodology for a comprehensive energy and environmental assessment of the operation of existing and design of new heat and power facilities (feasibility study), which should reveal the possibilities of understanding and the need to address the three main goals of the country's energy policy:

- increasing the energy and environmental safety of energy production;
- reduction of harmful environmental impact on the environment due to increased efficiency and environmental cleanliness of the use of energy resources;
- increasing the competitiveness of enterprises by reducing the specific energy consumption and the cost of gross emissions of harmful substances and environmental fines for exceeding real emissions in comparison with the established environmental standards.

3. The purpose and objectives of the study

The purpose of this study is to develop the theoretical foundations for conducting a comprehensive energy and environmental assessment (EEA) of the state of operation of an energy facility to determine the possibilities and measures to improve the efficiency of energy consumption of primary energy resources, increase the potential for energy saving while increasing the level of environmental safety of energy production for the environment.

The research objectives are:

analysis of a set of indicators, parameters, quantities and characteristics, the processing of which according to a certain algorithm will allow obtaining a capacious comprehensive assessment of the state of operation of installations, units, mechanisms and other equipment and the facility as a whole, taking into account the level of energy efficiency and environmental indicators of influence on the atmospheric air;

- development of the foundations of the algorithm for the implementation of a comprehensive energy and environmental assessment of the quality of operation or design of new energy facilities for their commissioning;
- development of a methodology and mathematical description for determining the coefficient of energy-environmental assessment (CEEA) of the state of heat-and-power facilities and equipment and comparing it with exemplary values;
- conducting energy-environmental assessments of the state of its operation on the actual TPF with the determination of the CEEA values and the development of measures to improve its performance..

In order to successfully solve these problems, preliminary studies of existing methods and criteria of energy technology efficiency developed by various authors were conducted [12-15].

However, the criteria and characteristics described in these works are descriptive in nature using probabilistic estimates, which complicates their application in specific cases on specific units and in specific installations. Their use in practice is associated with the need to preliminary establish certain relationships with various quantities, which may have different values for different units in different conditions and can change over time, are not enshrined in normative and legislative terms, and it is difficult to evaluate and apply them in working modes of operation.

Therefore, the paper presents a material and methodology that has a logical and analytical relationship, when using which it is possible to scientifically and clearly analytically obtain the numerical values of the CEEA of the state of heat power facilities and equipment and compare it with the exemplary values of high-quality operation of similar by the capacity and purpose of objects.

4. Rationale for the need and purpose of the energy-environmental assessment of the thermal power facility operation

The problem of a comprehensive assessment of the quality of energy production with high indicators of environmental safety and energy efficiency is that it is necessary to disclose the relationship of factors and indicators of the energy-environmental direction, to analytically describe their relationship and justify the development of such a characteristic, coefficient or criterion that characterizes the operating conditions of a feasibility study for complex connections.

It is necessary to take into account that the parameters, values and performance indicators used must be objective, their receipt must be confirmed by a clear parametric identification [16,17]. And the values of specific concentrations of harmful emissions of toxic and greenhouse gases must meet international standards [18, 19].

It is known that there is a close connection and proportional dependence of environmental indicators with the technical characteristics of energy processes of converting types of energy along the "chain" (chemical into thermal, thermal into electrical, etc.).

EEA is a simultaneous comprehensive examination of a heat and power facility with the establishment, using factors and indicators of environmental friendliness and efficiency of energy production and energy saving potential, taking into account the impact of this facility on the environment at the time of operation and environmental consequences after its shutdown for a long period or closing [20].

Energy and environmental monitoring is the basis for obtaining objective information on the conditions and performance of the feasibility study for a long period [21].

The implementation of systemic observations of the state of energy facilities, systems and territories, including energy and environmental control and forecasting changes and the development of sound recommendations for making managerial and organizational decisions on compliance with environmental safety requirements [22] guarantee the development and obtaining of an objective and qualitative assessment of the work of a specific feasibility study with the ability to develop recommendations to improve the performance of its operation.

The goal of energy and environmental management is the reasonable use of the results of EEA to characterize the quality of management and operation of a heat and power facility with the determination of the possibilities of permanently increasing the level of energy efficiency and environmental safety of energy production and assessing the achievement of the highest possible values.

In order for EEA to give an effective result, it is necessary to apply adequate criteria, which represent an appropriate system and interrelation of factors, parameters and indicators of the energy-ecological direction.

Among the existing indicators of environmental hazard, a special place is taken by the universal specific indicator introduced by the authors of [20] and characterizes the environmental safety g_i (kW/ mg) of a unit or a whole energy facility and shows the amount of useful energy (kW g or Gcal), which is produced per unit (mg) of harmful emissions into the environment. The use of this indicator makes it possible to objectively assess the effectiveness of the influence of various factors: thermodynamic, fuel, technological, operational [20] on the process of energy production.

Comprehensive EEA of indicators of energy and environmental conditions of operation. The feasibility study is based on the implementation of previous energy and environmental measures, namely: energy and environmental expertise and certification.

Taking into account all the heat and power equipment operating at the facility, based on the results of the examination, an energy-ecological passport of the heat power facility is drawn up [23], which includes the main indicators of TPF operation.

The introduction of an energy-ecological passport at each TPF makes it possible to create conditions for constant and high-quality control over the state of operation and the level of environmental cleanliness [24], to ensure a prompt response to emergency situations and to organize the implementation of appropriate measures to increase the level of environmental safety and energy efficiency on the basis of periodic integrated energy efficiency. environmental audit and continuous monitoring of the state of operation of the facility.

At the same time, when carrying out the EEA of a heat power facility according to this developed method, it is necessary to adhere to certain rules and principles:

– fixation of objective values and parametric identification of all main technological parameters, taking into account harmful emissions and the negative impact of the power facility on the environment and human health;

– application of a system of universal specific energy and environmental indicators to assess the state of operation of power facilities;

– application of regulatory methods to identify indicators of harmful emissions of carbon monoxide CO, nitrogen oxides NO_x, sulfur dioxide SO_2, benzapirene, vanadium oxide and other ingredients for various types of power facilities;

– application of the values of maximum permissible emissions of harmful substances, established concentrations and volumes of emissions of pollutants, technological standards of permissible emissions, hazard class of hazardous substances, normalized by the relevant legislative documents.

– EEA objects can be power facilities or systems, the operation of which is accompanied by harmful emissions, potentially capable of negatively affecting the environment and public health.

– The method and scheme of the EEA of power facilities must go through all stages in sequence to obtain the necessary objective information according to the algorithm proposed by the authors (Fig. 1), taking into account the data:

– - the type of main power equipment of a given capacity;

– - determination of the thermal characteristics of the fuel and the theoretical composition of combustion products (for example, the main technical and environmental indicators)

– - assessment of the concentration of emissions of harmful substances (particulate matter, sulfur oxides, nitrogen oxides, carbon oxides, vanadium oxide, etc.)

– - estimates of gross and specific environmental indicators;

– - comparison of the obtained data with the permissible values of the corresponding values.

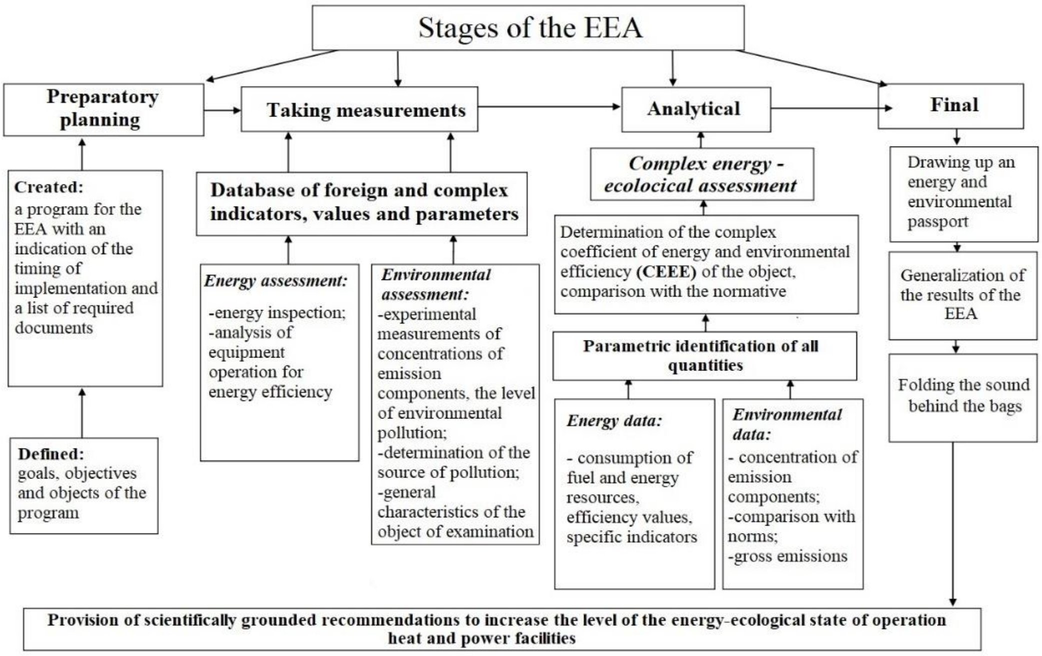

Fig. 1. General view of the algorithm for conducting an energy-ecological assessment of the operating conditions of a heat-and-power facility

The implementation of such an algorithm for conducting EEA allows you to reliably analyze the real state of the equipment and the entire power facility.

The energy-environmental assessment of the TPF ends with the calculation of the EEA factor .

The CEEA of a unit (facility) ε, based on the technological indicators of the operation of a power plant (power facility), characterizes the qualitative level of the unit's operation efficiency, while simultaneously determining the level of environmental safety:

$$\varepsilon = \frac{\eta_{бр}}{A}, \tag{1}$$

where: A is the total aggressiveness of flue gases, which is defined as:

$$A = \prod_{i=1}^{n} a_i; \tag{2}$$

Πa_i – is the product of specific values of aggressiveness of harmful components of harmful emissions, taking into account the general hazard level of flue gas emissions from the facility;

a_i – is the specific value of the aggressiveness of the harmful emission, which takes into account the hazard class and the maximum permissible concentration in the air of the working area, as well as the harmful emission.

The higher the value of ai, the more dangerous this component is in the composition of flue gases. The size a_i is determined by the formula:

$$a_i = \frac{C_{i_{\alpha=1}}}{j_i} + 1, \quad (3)$$

where: $C_{i_{\alpha=1}}$ – is the mass concentration of the harmful component in the exhaust flue gases with an excess air ratio αн equal to unity, which is defined as the ratio of the amount of air entering the installation to its amount required for complete combustion of the fuel ($\alpha_H = 1$) [22];

j_i – is the concentration of harmful emissions, which is determined as the product of the hazard class of the flue gas component and the maximum permissible concentration (MPC) according to the formula:

$$j_i = k_i \cdot MPC, \quad (4)$$

where k_i – component hazard class (Table 1).

Table 1. MPC value for pollutants in the working area with hazardous substances

Pollutant, formula	MPC (mg/m^3)	Hazard Class
Sulphur dioxide SO_2	10,0	2
Carbon monoxide CO	20	4
Nitrogen dioxide NO_2	2	3
Nitrogen oxide NO	5	3
Benzapiren	0,00015	1
Vanadium oxides	0,002	1

The hazard class of harmful emissions (k_i) is an indicator that characterizes the degree of danger to humans of substances that pollute the atmospheric air. Waste hazard class is established depending on the content of highly toxic substances in them by calculation method or according to the list of wastes given in the State Waste Classifier.

The mass concentration of a component with an air excess factor equal to one ($\alpha_H = 1$) is determined by the formula [22]

$$C_{i_{\alpha=1}} = C_i \cdot h, \quad (5)$$

where: C_i – is the mass concentration of the component, measured by the device, mg / m^3; h – is the dilution factor of combustion products, determined by the formula:

$$h = \frac{NO_2^{max}}{NO_2 + CO_2 + CH_4}, \% \quad (6)$$

where: $NO_2^{max} = 11,8\%$ – is the maximum allowable volumetric content of triatomic gases in dry combustion products in the absence of chemical and mechanical incompleteness of combustion and $\alpha_H = 1$; NO_2 – is the volumetric content of triatomic gases in dry combustion products, measured by the last heating surface by a gas analyzer, %; CH_4 - is the methane concentration in combustion products, measured by the last heating surface with a gas analyzer,% [22]. To determine ε in formula (1), the value η_{gr} is introduced - the gross efficiency (%), which is determined by the inverse balance

$$\eta_{gr} = 100 - \sum q, \quad (7)$$

where: $\sum q$ – is the sum of heat losses (%), determined by the formula:

$$\sum q = q_2 + q_3 + q_5, \quad (8)$$

where: q_2 – heat loss with exhaust gases, %; q_3 – heat loss with chemical undershoot, %; q_5 – heat loss through the outer surfaces of the boiler, %.

Units of value 1 in the formula (3) introduced to prevent formation of incorrect critical value, in cases when there are no emissions of certain components and values $C_{i_{\alpha=1}} = 0$.

Thus, the following values of the main quantities characterizing energy efficiency and environmental safety have been introduced into the EEA.

The last of them includes the meaning and influence of the toxicity class, concentration and aggressiveness of the release.

The higher the value of the EEA, the higher the quality of the energy-ecological operation of the facility, the higher the level of energy efficiency (high efficiency) and environmental cleanliness (low values of specific concentrations of harmful emissions) [25].

In fact, CEEA ε is an indirect value that characterizes the profitability and environmental feasibility of operating equipment or a power facility in conditions of limiting its impact on the environment. The use of economic levers to solve the problem of increasing the energy and environmental efficiency of energy production is a relevant and appropriate tool [26].

In order to assess the real state of the facilities in operation and compare them with the passport values of the main energy and environmental characteristics, it is advisable to calculate the normalized CEEA ε^n of units and installations according to the formula:

$$\varepsilon^n = \frac{\eta_{бр}}{A^н}. \quad (9)$$

The normalized value of the CEEA will allow real-time operation of the facility to monitor the main characteristics of the operation and compare different types of units. The higher the value of the normalized CEEA (ε^n), the more efficient and environmentally safe this energy facility is considered for energy production.

5. Results of a comprehensive energy and environmental assessment of real energy facilities

At the initial stage of the EEA of real power plants and facilities, it is advisable to determine the normalized value of the EEA coefficient ε^n.

For this purpose, we use the concentrations and aggressiveness of emissions established in Ukraine by the relevant regulatory document (Table 2).

Table 2. Established concentrations and volumes of pollutant emissions discharged from the gaseous fuel boiler [27]

Source of education name, brand, type of fuel	Pollutant (name)	Maximum mass concentration of pollutants substances, mg / m^3	Technological standard of permissible emissions in accordance with the legislation of different countries, mg/m^3		Approved maximum permissible emission, mg/m^3	
			Ukraine	EU	Ukraine	EU
Gas fired boiler	Nitrogen oxides (in terms of nitrogen dioxide NO_x)	700	150	150	500	
	Carbon monoxide CO	200	250	100	200	

According to the passport data, the efficiency value for power boilers KVGM-100, KVGM-10, PTVM-180 are equal respectively 93%, 92%, 88,8%.

The determination of the permitted concentration of hazardous emissions is carried out according to the formula (4) using the values of the Table 2:

$$j_{NO_x} = 2 \cdot 3 = 6 \text{ mg / m}^3,$$

$$j_{CO} = 4 \cdot 20 = 80 \text{ mg / m}^3 .$$

Determination of the specific standardized value of the aggressiveness of harmful emissions is carried out using the data in Table 2 and formula 3

$$a^{н}_{NO_x} = \frac{500}{6} + 1 = 84,3,$$

$$a^{н}_{CO} = \frac{200}{80} + 1 = 3,5.$$

The general standardized aggressiveness of flue gas emission according to the formula (4) is:

$$A^{н} = 84,3 \cdot 3,5 = 295,16.$$

To determine the normalized value of the CEEA for boiler units of various types, we use the formula (9):

$$\varepsilon^{n}_{KVGM-10} = \frac{92}{295,16} = 0,311,$$

$$\varepsilon^{n}_{KVGM-100} = \frac{93}{295,16} = 0,315,$$

$$\varepsilon^{n}_{PTVM-180} = \frac{88,8}{295,16} = 0,30.$$

From Table 3, it can be seen that the normalized value of the CEEA ε^{n} for various types of boilers is almost the same, since for all of them the same MPC values for the emission components are set. Minor differences in the CEEA values of different boilers are influenced by different values of the efficiency rating data.

The results of determining the CEEA for boilers of various types are presented in Table 3.

Table 3. Standardized CEEA values for power boilers of various types

№	Boiler type	Permitted concentration of harmful emissions, j_i, mg/m^3		MPC, mg/m^3		Specific value of emission aggressiveness, a		Boiler efficiency rating, %	General aggressiveness, A	Normalized CEEA value ε^{n}
		NO_x	CO	NO_x	CO	NO_x	CO			
1	KVGM-10	6	80	500	200	84,33	3,5	92	295,16	0,311
2	KVGM-100	6	80	500	200	84,33	3,5	93	295,16	0,315
3	PTVM-180	6	80	500	200	84,33	3,5	88,8	295,16	0,3
4	BKZ-160-100PT	6	80	700	250	116,7	3,13	91,8	364,6	0,218
5	BKZ -220-100GZ	6	80	700	250	116,7	3,13	91,15	364,6	0,250
6	BKZ -210-140PT	6	80	700	250	116,7	3,13	91,5	364,6	0,251

Conclusions. The methodology proposed by the authors for conducting a comprehensive EEA of heat and power facilities allows for systemic surveys of the operating conditions of existing power facilities and those that are being designed.

The developed algorithm for the implementation of EEA makes it possible to determine the CEEA $\mathcal{E}$ of real units and objects with an analysis of the possibility of implementing measures to increase their efficiency and environmental safety through the introduction of new methods and technologies during their reconstruction or modernization.

The proposed method is also universal from the point of view of international application, since it allows you to research, analyze and recommend the best ways to implement measures to improve the energy and environmental performance of any heat and power facilities. At these facilities, heat and power equipment of various thermal and electrical capacities of any origin and technology is used, such as steam turbine units of thermal power plants, combined heat and power plants, boiler houses, gas turbine and combined cycle plants, cycles using renewable energy sources, and the like.

In the work on the developed methodology, the normalized CEEA was determined with the definition of the following features:

- the lower the concentration of harmful components in the flue gases and the higher the efficiency, the higher the value of the complex CEEA $(\mathcal{E})$

-the normalized value of the complex CEEA $\mathcal{E}^{n}$ for boilers of the type KVGM-10, KVGM-100, PTVM-180 are equal to $\mathcal{E}^{n}_{KVGM-10}$ =0,311; $\mathcal{E}^{n}_{KVGM-100}$ =0,315; $\mathcal{E}^{n}_{PTVM-180}$ =0,30, characterizing the general possibility of improving the indicators of energy-ecological efficiency of energy production.

The implementation of a comprehensive EEA at energy facilities allows to objectively assess the energy efficiency of TPF use, determine the environmental aspects of the impact of energy systems and develop an optimal development strategy for the facility.

The results obtained lay the foundation for the transition to a new level of energy conservation management at energy facilities. This approach creates conditions for improving the quality of equipment operation, ensuring the implementation of objective monitoring of a set of parameters and technical and economic indicators of the operation of energy production facilities, their real state and optimization of overhaul periods with lengthening the motor resource of facilities [26].

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МЕТОДОЛОГІЧНІ ОСНОВИ КОМПЛЕКСНОЇ ОЦІНКИ ЕФЕКТИВНОСТІ ВИРОБНИЦТВА ЕНЕРГІЇ ЗА ЕНЕРГО-ЕКОЛОГІЧНИМИ ПОКАЗНИКАМИ

Авторами запропонована універсальна загальна методика здійснення комплексного енерго-екологічного аналізу із визначенням реального стану експлуатації теплоенергетичних об`єктів та обладнання енерговиробництва з використанням ємного універсального коефіцієнту енерго-екологічної ефективності, який дозволяє у комплексі визначати одночасно рівень енергетичної ефективності і *екологічної безпеки виробництва теплової і електричної енергії за показниками та характеристиками роботи устаткування.*

Оцінка якісного стану експлуатації конкретних теплоенергетичних об`єктів визначається порівнянням даного коефіцієнту із його нормованим значенням, яке розраховується у відповідності до паспортних даних агрегатів енергоперетворення, нормованих величин емісії шкідливих викидів в атмосферу для конкретного типу теплоенергетичних агрегатів, значень гранично-допустимих концентрацій забруднюючих речовин робочої зони та класу небезпеки цих шкідливих речовин.

За даною методикою проведення комплексного енерго-екологічного аналізу енергетичних об`єктів можливо порівнювати різні за конструктивними, тепловими, екологічними і іншими масштабними характеристиками теплоенергетичні цикли, об`єкти, установки, агрегати та інше теплоенергетичне обладнання.

Використання методики продемонстровано на прикладі розрахунку коефіцієнту енерго-екологічної ефективності для енергетичних котлів різної потужності.

Ключові слова: *енергетичний об'єкт, методологія, комплексна оцінка, екологічна безпека, енергоефективність, надійність експлуатації.*

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