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DETERMINING THE BOUNDARIES OF THE ENERGY AUDIT SCOPE OF WORK. MATHEMATICAL MODEL

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Rozen V.[1], Rozen P.[2]

Author for correspondence: Rozen Victor,
e-mail: v_p_rozen406@ukr.net

[1] Dr. of Sciences (Tech.), Professor
http://orcid.org/0000-0002-0440-4251

[2] Postgraduate Student
http://orcid.org/0009-0003-7934-3398

[1, 2] Institute of General Energy of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

The Law of Ukraine "On Energy Efficiency" establishes that an energy audit is a systematic analysis of energy use and energy consumption within the boundaries determined by the nature and scope of energy audit work in order to determine, quantify and prepare a report on the possibilities of improving the energy efficiency.
When conducting an energy audit, it is important to determine not only the areas of work, but also the scope of work, which is determined by setting boundaries. Currently, the boundaries of energy audit are determined according to the experience and intuition of energy auditors.
The paper considers the issue of determining the boundaries of the energy audit scope in industry using the theory of intelligent systems. The importance of using pattern recognition and classification methods for solving problems of energy efficiency improvement is emphasized. It is proposed that classification methods be used to determine typical classes of consumers of fuel and energy resources, making it possible to determine the boundaries and conduct an energy audit. The automatic classification method – the hypersphere method - was chosen as the classification method. The input information for the description of production systems is determined, including indicators, metrics and parameters of energy efficiency.
An algorithm for the hypersphere method is developed and practical calculations are given for the conditions of the compressed air production system of a metallurgical enterprise in Zaporizhia. The characteristics of the equipment subject to priority inspection are provided. This algorithm can be used to solve a wide range of problems in the field of renewable energy. Ref. 12. Tab. 5.

Keywords: *classification, the consumer, fuel and energy resources.*

МАТЕМАТИЧНА МОДЕЛЬ ВИЗНАЧЕННЯ МЕЖ ОБСЯГУ РОБІТ З ЕНЕРГЕТИЧНОГО АУДИТУ

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Розен В. П.[1], Розен П. В.[2]

Автор для кореспонденції: Розен Віктор,
e-mail: v_p_rozen406@ukr.net

[1] д-р. техн. наук, професор
http://orcid.org/0000-0002-0440-4251

[2] аспірант
http://orcid.org/0009-0003-7934-3398

[1, 2] Інститут загальної енергетики Національної Академії Наук України, Київ, Україна

Законом України «Про енергетичну ефективність» встановлено, що енергетичний аудит – це систематизований аналіз використання енергії та споживання енергії у межах, визначених характером та обсягом робіт з енергетичного аудиту з метою визначення, кількісного вираження та підготовки звіту про можливості підвищення рівня енергоефективності.
Під час проведення енергетичного аудиту важливо визначити не тільки напрями роботи, а також обсяг роботи, який визначається встановленням меж. На теперішній час межі проведення енергетичного аудиту визначаються відповідно досвіду та інтуїції енергоаудиторів.
У роботі розглядається питання визначення меж обсягу робіт з енергоаудиту виробничих систем з використанням теорії інтелектуальних систем. Зазначено важливість використання методів розпізнавання образів і класифікації для вирішення задач підвищення рівня енергетичної ефективності.

Запропоновано використовувати методи класифікації для визначення типових класів споживачів паливно-енергетичних ресурсів, що дозволило визначити межі проведення енергетичного аудиту. В якості методу класифікації було обрано метод автоматичної класифікації – метод гіперсфер. Визначена вхідна інформація опису виробничих систем до якої входять індикатори, показники та параметри енергетичної ефективності.

Розроблено алгоритм методу гіперсфер та наведені практичні розрахунки для умов системи виробництва стисненого повітря металургійного підприємства м. Запоріжжя. Надана характеристика обладнання, що підлягає першочерговому обстеженню. Цей алгоритм можна використовувати для вирішення широкого спектру задач в сфері ВДЕ. Бібл. 12, Табл. 5.

Ключові слова: *класифікація, споживач, паливно-енергетичні ресурси.*

Introduction. Given its international commitments to climate change mitigation, Ukraine has been paying increasing attention to energy efficiency and energy conservation in recent years. Thus, in 2021, the Law of Ukraine “On Energy Efficiency” (No. 1818-IX) was adopted. The law transposes most of the provisions of Directive 2012/27/EU on energy efficiency and Regulation (EU) 2017/1369.

Articles 10 “Energy Audits” and 11 “Energy Auditors” of this Law define the legal framework for conducting energy audits, as well as the qualifications of energy auditors.

As required by the Law, in 2023, the CMU adopted Resolution No. 1258 “On Approval of the Procedure and Requirements for Energy Audits of Processes and Transport”. The provisions of Article 8(7) of Directive 2012/27/EU on the content of energy audits were transposed into the CMU Resolution.

In June 2024, amendments to the Law revised the approach to energy audits, moving to a model based on energy consumption. Currently, business entities with an average annual energy consumption of 100 thousand MWh per year or more are required to conduct an energy audit every four years. Although this threshold is 36 times higher than that in the EU, it is only the first step towards the introduction of mandatory energy audits and lower thresholds are expected to be introduced in the coming years.

Since industrial enterprises will be obliged to conduct energy audits, this will increase production costs regardless of whether the audit is conducted in-house or with the involvement of a specialized audit company.

According to the Law of Ukraine “On Energy Efficiency”, an energy audit is a systematic analysis of energy use and energy consumption within the limits determined by the nature and scope of energy audit work in order to identify, quantify and prepare a report on opportunities to improve energy efficiency. The same definition is given by the standard DSTU ISO 50002-2016 Energy audit. Requirements and guidelines for their conduct. That is, the nature and scope of energy audit work are the determining factors that affect everything, especially the duration of the work and its cost. Thus, when conducting an energy audit, it is very important to correctly determine the nature and scope of energy audit work.

According to DSTU ISO 50002-2016, *the energy audit scope of work is the extent of energy uses and related activities to be included in the audit, as defined by the organization in consultation with the energy auditor. This scope* can include several boundaries.

The energy audit scope of work is determined by its boundaries. The energy audit scope of work can be determined by energy and economic indicators and parameters, including:

- specific energy consumption per unit of output;
- energy intensity of production;
- energy saving potential;
- parameters of the energy consumption mode;
- volume of energy consumed;
- capacity of energy consumers;
- technical specification of energy consuming equipment;
- installed capacity of energy consumption;
- economic indicators;
- payment for the consumed energy;
- energy efficiency indicators, etc.

Usually, the boundaries for dividing consumers into large, medium and small are set almost arbitrarily by developers of energy audit methodologies or government agencies. The problem of determining the boundaries of consumer division according to the established criteria is encountered when solving the following tasks:

- division of enterprises by the volume of energy consumed to develop specific energy consumption rates;
- determining the boundaries of external and internal energy audit;
- coordination of energy consumption with the real conditions during the implementation of renewables [1];
- determining the optimal power value according to the criterion of costs for the construction of renewables;
- analyzing the modes of electricity consumption of electricity supply systems [2];
- assessing the reliability of a combined power supply system using renewables;
- determining the criteria for the required power generated by solar and wind power plants [2];
- assessing the mathematical expectation of power imbalances of the combined power system; [1];

– determining restrictions on the operating mode of the backup energy source [1];
– determining the criteria: power, current efficiency for solving the problem of assessing the efficiency of biomass mini-boilers within an administrative unit or heat-generating organization.

It should also be noted that traditional energy sources are the main source of greenhouse gas emissions that cause global warming. The use of renewables helps to reduce these emissions and reduce air and water pollution. To assess the effectiveness of renewables implementation, information received during a preliminary energy audit of facilities of different hierarchical levels is used. It is important to reduce the cost of determining the amount of energy and economic information, which depends on the scope of the energy audit.

The purpose of this paper is to increase the validity of decision-making regarding the boundaries of the scope of work during an energy audit by applying a mathematical method of classifying fuel and energy resource consumers based on the hypersphere method.

To achieve this goal, the following tasks were solved:

Determination of factors influencing energy efficiency that the decision maker sets.

Development of mathematical support for determining typical classes of consumers by energy and economic indicators and parameters.

The study's object is to establish the energy audit scope of work by examining energy and economic indicators and parameters of industrial enterprise energy consumption.

When conducting an energy audit, the correct solution to this issue is to direct the energy audit team's efforts to auditing just such a number of consumers as to improve the quality of the energy audit without increasing its duration. Therefore, it is important to establish which energy-consuming equipment in the company's workshops should be the focus of the auditor's attention in the first place.

Materials and results of the study. Today, the practice of conducting energy audits of industrial enterprises has become widespread. There are various methods for conducting energy audits [3, 4]. Some audit companies have become highly specialized in certain types of energy carriers and types of consumers. However, at present, energy auditors determine the class of the most energy-intensive consumers only based on their own experience and do not use mathematical methods that could simplify the procedure for selecting consumer classes.

To determine the classes of consumers that are similar according to the established criterion, when solving the issue of determining the energy audit scope of work, the methods of pattern recognition and classification theory are most suitable [5, 8, 12]. The use of statistical analysis method is based on the assumption of homogeneity of the population of energy consumers under study. However, a real statistical population is almost always internally differentiated, which corresponds to the hypothesis of class compactness [8]. This hypothesis makes it possible to solve the problem of dividing the population of energy consumers under study into homogeneous groups (classes, clusters, taxa) according to certain criteria.

Classification is the division of elements of a given set into subsets of more similar objects [8]. To determine the energy audit scope of work, we will classify electricity consumers using the hypersphere method by ordering them into a variational series.

The hypersphere method was first applied in the electric power industry to classify daily electrical load schedules of industrial enterprises in [10] and later to solve the problem of zoning administrative units of the Volyn region according to their energy security status [11]. The hypersphere method belongs to the automatic classification methods, which allows excluding the decision maker from the classification process, but it does not reveal the internal structure of classes, such as hierarchical classification methods [11].

Let us represent the consumers of energy as a set X, whose elements are given by the numerical attributes p:

$$x_j = x_{j1},\ x_{j2},\ \ldots,\ x_{jp}, \qquad p \geq 1, \qquad j = 1,\ 2,\ \ldots,\ n \tag{1}$$

A class of energy consumers is a subset ω_i of similar consumers. As a measure of similarity (closeness) between two energy consumers, we will use the Euclidean distance between them d_{ij}:

$$d_{ij} = \sqrt{\sum_{m=1}^{p} \left(x_{im} - x_{jm} \right)^2}, \qquad i, j \in \{1,\ 2,\ \ldots,\ n\} \tag{2}$$

Euclidean distance is the most common proximity measure used in object classification tasks [8, 10].

Having ordered all the elements d_{ij} *of* the matrix in ascending order, let's construct a series of variations:

$$d_{(1)} < d_{(2)} < \ldots < d_{(s)}, \qquad s = \frac{n(n-1)}{2}. \tag{3}$$

If there are classes of consumers, the distances $d_{(s)}$ between homogeneous pairs of energy consumers will be concentrated on the left side of the variational series (3), and the distances between heterogeneous energy consumers – on the right side. To study the variational series of energy consumers, we will construct an auxiliary numerical sequence of the following form:

$$r_{(1)},\ r_{(2)},\ \ldots,\ r_{(s-1)}, \qquad s = \frac{n(n-1)}{2}, \tag{4}$$

where

$$r_{(i)} = \frac{d_{(i+1)}}{d_{(i)}}, \qquad i = 1,\ 2,\ \ldots,\ (s-1)\,. \tag{5}$$

It should be noted that there may be several types of energy consumers at an enterprise with the same level of classification criteria. This can lead to uncertainty when analyzing the auxiliary numerical sequence, since the distances between them $d_{ij} = 0$. To avoid this, the level of energy intensity of these consumers relative to each other must be changed slightly (by 0.1%).

To further clarify the structure of energy consumers, we will study the behavior of two auxiliary variational series obtained by sifting the elements of the auxiliary numerical sequence.

The algorithm for forming the auxiliary variational series is as follows:

Let's find the Euclidean distances from the first energy consumer x_{11} to all the others.

In the numerical sequence $d_{12},\ d_{13,}\ \dots\ ,\ d_{1n}$ find the minimum and maximum elements – d_{min} and d_{max}.

Repeat this operation for each energy consumer x_i and form two sets of distances from the results obtained $\widetilde{D}_{min} = \left\{d^{(1)}_{min},\ d^{(2)}_{min},\ \dots,\ d^{(n)}_{min}\right\}$
and
$\widetilde{D}_{max} = \left\{d^{(1)}_{max},\ d^{(2)}_{max},\ \dots,\ d^{(n)}_{max}\right\}$.

Most elements of the set $\widetilde{D}_{min}$ correspond to homogeneous pairs of energy consumers, if the elements of the set are available in time $\widetilde{D}_{max}$ can correspond to both homogeneous and heterogeneous pairs of energy consumers.

The resulting sets $\widetilde{D}_{min}$ and $\widetilde{D}_{max}$ contain at least three equal distances corresponding to the same pair of energy consumers x_i, x_j and x_j, x_i. By excluding one of these distances from the sets $\widetilde{D}_{min}$ and $\widetilde{D}_{max}$ and arranging the remaining ones in ascending order, we get new sets – variational series of distances:

$$\widetilde{D}_{min} = \left\{d^{(1)}_{min},\ d^{(2)}_{min},\ \dots,\ d^{(n)}_{min}\right\}; \tag{6}$$

$$\widetilde{D}_{max} = \left\{d^{(1)}_{max},\ d^{(2)}_{max},\ \dots,\ d^{(n)}_{max}\right\}; \tag{7}$$

whose elements correspond to different pairs of energy consumers.

The behavior of the variational series $\widetilde{D}_{min}$ and $\widetilde{D}_{max}$ can be used to determine the structure of energy consumer groups at the enterprise. If the variational series $\widetilde{D}_{min}$ has no peaks, then the enterprise's energy consumers are homogeneous according to the chosen criterion for determining the energy audit scope of work or they can be divided into closely spaced classes with constant density. If this series contains at least one local minimum, then the company's energy consumers can be divided into classes with different densities. Among them may be those that contain one element each – individual consumers that differ greatly from others in terms of energy intensity, the number of which can be determined.

If the variational series $\widetilde{D}_{max}$ has no peaks, then the enterprise's energy consumers are homogeneous according to the selected criterion or consist of closely spaced classes. If this series has at least one significant local minimum, then the enterprise's energy consumers can be divided into k classes, in which the maximum distances of heterogeneous pairs have a different order.

Let's form new sets of elements that will be used to classify consumers using the hypersphere method. Having excluded from the sets $\widetilde{D}_{min}$ all elements for which there is a correlation:

$$d^{(i)}_{min} = 0\left(d^{(1)}_{max}\right) \tag{8}$$

and adding them to the set $\widetilde{D}_{max}$, we will get new sets – variational series:

$$\widetilde{D}_{min} = \left\{d^{(1)}_{min},\ d^{(2)}_{min},\ \dots,\ d^{(u)}_{min}\right\}, \qquad u \le n - 1 - k \tag{9}$$

$$\widetilde{D}_{max} = \left\{d^{(1)}_{max},\ d^{(2)}_{max},\ \dots,\ d^{(n)}_{max}\right\}, \qquad 1 \le n - 1 + k \tag{10}$$

Then we can assume that almost all elements of the set are generated by homogeneous pairs of energy consumers. The subset of pairs of energy consumers, each of which generates an element of variational series (12), is denoted by L_{min}:

$$L_{min} = \left\{\left(x_i, x_j\right) \in X \times X : d\left(x_i, x_j\right) \in R_{min}\right\} \tag{11}$$

The state of energy consumers in the hyperspace is set by a point, the location of which is determined by the value of indicators or parameters of the criteria that determine the depth of the energy audit.

The hypersphere method has the following algorithm. First, the compaction points of the general group of energy consumers are found, which are initially taken as the centers of the classes,

At the same time, a preliminary classification is performed. The compaction points are found using the method of hyperspheres moving in the plane. The movement of hyperspheres starts from different, so-called, reference points and ends at the compression points. Energy consumers that are switched on during the movement of one hypersphere are considered to be consumers of the same class. If several hyperspheres stop at the same point, all energy consumers that are switched on by them during movement are combined into one class. Thus, we get as many classes as the number of compaction points detected by the hypersphere. The resulting number of classes depends on the size of the hypersphere radius. The determination of the optimal value of this radius d_{opt} follows from the variational series analysis data (4). The issue of determining d_{opt} is considered in [7, 9, 10].

To determine d_{opt} we first find the average value of $\bar{d}$ of variational series (4):

$$\bar{d} = \frac{\sum_{i=1}^{s} r_{(i)}}{s}, \tag{12}$$

Then the value of the radius of the hypersphere is as follows:

$$d_{opt} = max\left(\bar{d}, d_{min}^{(u)}\right) + d_{min}^{(1)} \tag{13}$$

where $d_{min}^{(u)}$, $d_{min}^{(1)}$ are the last and first members of the variational series.

Then, the preliminary classification is refined, taking into account the possibility of classes with non-empty intersection.

Model calculations of the distribution of energy-consuming equipment into classes by installed capacity. Let us consider the distribution of energy-consuming equipment by the criterion of the installed capacity of such consumers as electric motors. The compressed air production system is the most energy-intensive (in terms of electricity consumption) at iron works in Zaporizhzhia. Air compressor units operate 24 hours a day as the production cycle is continuous, so the distribution can be performed both by installed capacity and electricity consumption.

The compressed air production system uses electrical equipment, the technical characteristics of which are given in Table 1.

Table 1. Technical specification of the equipment of the compressed air system of an iron works

No.	Air compressor	Capacity, m^3/min	Pressure, bar	Power of the electric drive, MW
Air compressor workshop No.1				
1	K-250-61-5	250	9	1.600
2	K-250-61-1	250	9	1.600
3	K-250-61-5	250	9	1.600
4	TsTK-275/9	250	9	1.600
5	K-500-61-5	500	9	3.150
6	K-500-61-5	500	9	3.150
Air compressor workshop No.2				
1	K-250-61-1	250	9	1.750
2	K-250-61-1	250	9	1.750
3	K-250-61-1	250	9	1.750
4	K-250-61-1	250	9	1.750
5	K-1500-62-2	1,500	7	10.000
6	K-1500-62-2	1,500	7	10.000
Air compressor workshop No.3				
1	K-250-61-1	250	9	1.500
2	K-250-61-1	250	9	1.500
3	K-250-61-1	250	9	1.500
4	K-250-61-1	250	9	1.500
Air compressor workshop No.4				
1	K-345-91-1	345	12.5	3.500
2	K-250-61-5	250	9	1.600
Air compressor station of the oxygen production shop				
1	K-1700-61-1	1,700	7	10.000
2	K-1500-62-2	1,500	7	9.000
3	K-1700-61-1	1,700	7	10.000
4	K-1500-62-2	1,500	7	9.000
5	K-1500-62-2	1,500	7	10.000
6	K-1500-62-2	1,500	7	10.000
7	K-1500-62-2	1,500	7	10.000

According to Table 1, we compile the general group of energy consumers:

$$X = \begin{Bmatrix} 1.6;\ 1.6;\ 1.6;\ 1.6;\ 3.15;\ 3.15;\ 1.75;\ 1.75;\ 1.75;\ 1.75; 10;\ 10; \\ 1.5;\ 1.5;\ 1.5;\ 1.5;\ 3.5;\ 1.6;\ 10;\ 9;\ 10;\ 9;\ 10;\ 9;\ 10;\ 10;\ 10 \end{Bmatrix}$$

Let's find the value of the Euclidean distance $d_{ij} = d\left(x_i, x_j\right)$ between each two consumers.

Since we are performing a single-attribute distribution (a special case of (2)), the distance between two consumers is

calculated by the formula: $d_{ij} = \left|x_{im} - x_{jm}\right|$
For instance, $d_{12} = \left|d_{11} - d_{21}\right| = \left|1.6 - 1.6\right| = 0$,
$d_{15} = \left|d_{11} - d_{51}\right| = \left|1.6 - 3.15\right| = 1.55.$

Based on the results of these calculations, we develop the set D (3). The values of the elements of the set D are given in Table 2.

Table 2. Values of the elements of the set D

d_{11}	0.001	0.001	…	…	…	8.4	8.4	8.4
0.001	d_{22}	0.001	…	…	…	8.4	8.4	8.4
0.001	0.001	d_{33}	…	…	…	8.4	8.4	8.4
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
8.4	8.4	8.4	…	…	…	$d_{23\,23}$	0.001	0.001
8.4	8.4	8.4	…	…	…	0.001	$d_{24\,24}$	0.001
8.4	8.4	8.4	…	…	…	0.001	0.001	$d_{25\,25}$

According to Table 2 and according to (4), we construct the main variational series $d_{(s)}$. The results of the calculations are summarized in Table 3. To avoid uncertainty, we change the value of distances equal to "0" to 0.001.

Table 3. Main variational series $d_{(s)}$

$d_{(s)}$={	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	…	…	…	…	…	…	…	…	…	…
	1.90	1.90	2.00	2.00	2.00	2.00	5.50	5.50	5.85	5.85
	5.85	5.85	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.85
	6.85	6.85	6.85	685	6.85	6.85	6.85	6.85	6.85	6.85
	…	…	…	…	…	…	…	…	…	…
	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50 }

To study the main variational series $d_{(s)}$, using (4) and (5), we develop an auxiliary numeric sequence $r_{(i)}$ (Table 4).

Table 4. Auxiliary numeric sequence $r_{(i)}$

$r_{(i)}$={	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1.00	1.05	1.00	1.00	1.00	2.75	1.00	1.06	1.00	1.00
	1.00	1.11	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.00
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00}	

Since the main variation series does not have statistically significant local minima, we will continue the study of the general group of energy consumers by examining the behavior of two auxiliary variation series $\widetilde{D}_{min}$, $\widetilde{D}_{max}$. The auxiliary variation series are obtained according to (6) and (7).

$$\tilde{D}_{min} = \begin{Bmatrix} 0.001; & 0.001; & 0.001; & 0.001; & 0.001; \\ 0.001; & 0.001; & 0.001; & 0.001; & 0.001; \\ 0.001; & 0.001; & 0.001; & 0.001; & 0.001; \\ 0.001; & 0.350 & 0.001; & 0.001; & 0.001; \\ 0.001; & 0.001; & 0.001; & 0.001; & 0.001; \end{Bmatrix}$$

$$\tilde{D}_{max} = \begin{Bmatrix} 8.4; & 8.4; & 8.4; & 8.4; & 6.75; \\ 6.75; & 8.25; & 8.25; & 8.25; & 8.25; \\ 8.5; & 8.5; & 8.5; & 8.5; & 8.5; \\ 8.5; & 6.5; & 8.4; & 8.5; & 7.5; \\ 8.5; & 7.5; & 8.5; & 8.5; & 8.5; \end{Bmatrix}$$

To select classes, we use the hypersphere method.

Let's find the average value $\bar{d}$ of auxiliary variational series (4):

$$\bar{d} = \frac{1217.945}{300} = 4.06$$

By the formula $d_{opt} = max\left(\bar{d}, d_{min}^{(u)}\right) + d_{min}^{(1)}$ determine the radius of the hypersphere:

$$d_{opt} = 4.06 + 0.001 = 4.061$$

As reference points, let's choose a pair of consumers of the general group with the largest distance $d_{(s)} = 8.5$.

For instance, $\bar{x}_{13}^{(0)} = 1.5$ та $\bar{x}_{20}^{(0)} = 10$. Let's draw two hyperspheres of radius $d_{opt} = 4.06$ with centers at points $\bar{x}_{13}^{(0)}, \bar{x}_{20}^{(0)}$ and define subsets of points $M_{13}^{(0)}$,$M_{20}^{(0)}$:

$$M_{13}^{(0)} = \begin{Bmatrix} 1.6;\ 1.6;\ 1.6;\ 1.6;\ 3.15;\ 3.15;\ 1.75;\ 1.75; \\ 1.75;\ 1.75;\ 1.5;\ 1.5;\ 1.5;\ 1.5;\ 3.5;\ 1.6 \end{Bmatrix};$$

$$M_{20}^{(0)} = \{10; 10; 10; 9; 10; 9; 10; 10; 10\},$$

Let's determine the centers of compression (average values) of the subsets $M_{13}^{(0)}$, $M_{20}^{(0)}$:

$$\bar{x}_{13}^{(1)} = 1.925, \bar{x}_{20}^{(1)} = 9.89$$

Similarly, we define the subsets $M_{13}^{(1)}$, $M_{20}^{(1)}$. To do this, we will use the centers of compression as reference points $\bar{x}_{13}^{(1)} = 1.925$,$\bar{x}_{20}^{(1)} = 9.89$ and draw two hyperspheres of radius $d_{opt} = 4.06$ with centers at points $\bar{x}_{13}^{(1)}$ and $\bar{x}_{20}^{(1)}$.

Let's determine subsets of points $M_{13}^{(1)}$, $M_{20}^{(1)}$:

$$M_{13}^{(1)} = \begin{Bmatrix} 1.6;\ 1.6;\ 1.6;\ 1.6;\ 3.15;\ 3.15;\ 1.75;\ 1.75; \\ 1.75;\ 1.75;\ 1.5;\ 1.5;\ 1.5;\ 1.5;\ 3.5;\ 1.6 \end{Bmatrix};$$

$$M_{20}^{(1)} = \{10; 10; 10; 9; 10; 9; 10; 10; 10\}.$$

and find their centers of compression $\overline{x}_{13}^{(2)} = 1.925, \bar{x}_{20}^{(2)} = 9.89$.

We verify the condition that the distances between the centers of compression of the sets $M_{13}^{(0)}$, $M_{13}^{(1)}$ and $M_{20}^{(0)}$, $M_{20}^{(1)}$ respectively, are less than $\frac{\varepsilon}{2} = \frac{d_{(1)}}{2} = 0$. Since $d\left(\bar{x}_{13}^{(1)}, \bar{x}_{13}^{(0)}\right) = 0$ and $d\left(\bar{x}_{20}^{(1)}, \bar{x}_{20}^{(0)}\right) = 0$, we finally select subsets of points:

$$M_{13}^{(1)} = \begin{Bmatrix} 1.6;\ 1.6;\ 1.6;\ 1.6;\ 3.15;\ 3.15;\ 1.75;\ 1.75; \\ 1.75;\ 1.75;\ 1.5;\ 1.5;\ 1.5;\ 1.5;\ 3.5;\ 1.6 \end{Bmatrix};$$

$$M_{20}^{(1)} = \{10; 10; 10; 9; 10; 9; 10; 10; 10\}.$$

After selecting two subsets, we find the difference of the sets $A_1 = A_0 \setminus \bigcup_{i=1}^{2} M_i,\ A_0 = X$. Because $A_1 = 0$, the first stage is over. As a result of the calculations, the following preliminary classes were obtained $M_1 = M_{13}^{(1)}$та $M_2 = M_{20}^{(1)}$.

Thus, we identify two classes of electrical equipment – compressors – one of which is characterized by a higher installed capacity than the other class. This class determines the energy audit scope of work and includes compressors K-1500-62-2 and K-1700-61-1 with a capacity of 9 and 10 MW, which are subject to a priority audit.

Conclusions. As a result of the research, the following have been developed:

1. An algorithm for classifying energy consumers by various factors, based on the use of the hyper-sphere method, which allows determining the scope of work during an energy audit.

2. Methodology for determining the boundaries of energy audit, which allows focusing on certain consumers with the greatest energy saving potential, which will save time and improve the quality of energy audits.

3. This methodology can be used for a wide range of tasks in the field of renewable energy, starting from the implementation stage and ending with an energy audit of existing generation.

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