Matrix model of energy audit

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Abstract. The work attempts to build a mathematical model of energy audit as an activity associated with a complex of technical, organizational and economic events. Measures of these events are aimed at identifying the possibility of cost-effective optimization of the consumption of energy resources at industrial enterprises. The goal of the energy audit is to identify sources of wasteful energy consumption and energy losses, to develop a comprehensive energy saving program, and to increase energy efficiency. The logical basis of the activity under consideration is the presentation of the combination of energy and material flows in the enterprise, as a set of connected graphs. The number of graphs considered is determined by the many types of material and energy flows (electricity, thermal energy, enterprise products, etc). The node of the graph, depending on the details of the description, can be either an entire enterprise, which will be a set of interacting enterprises, or a workshop, or installation, etc.

1. Introduction

Our country has large reserves of energy resources and a powerful fuel and energy complex (FEC), which is the basis for economic development. Therefore, the most important priority area of the Russian energy policy is the rational use and energy saving graph.

Federal Law of November 23, 2009 No. 261-ФЗ “On Energy Saving and Improving Energy Efficiency ...” [1-2] introduced new rules in the Russian Federation aimed at reducing energy consumption and energy conservation.

The result of energy saving should improve the financial position of the enterprise and increase its competitiveness in the Russian and world markets.

For any industrial enterprise, there is a choice of the main direction for energy conservation. This is the development of a program based on an analysis of the actual state of fuel use and energy resources Techno-economic resources. Such data can be obtained in the course of energy audits (energy audits) of an enterprise, which is a search for possible reserves of energy savings.

Energy inspections are carried out in accordance with the Federal Law of the Russian Federation [3], as well as a number of Decrees of the Government of the Russian Federation: [3–7]; by decree of the President of the Russian Federation [8]; By order of the Government of the Russian Federation [9] by Order of the Ministry of Energy of the Russian Federation [10].

The energy inspection procedure gives the enterprise management a clear understanding of the current state of energy system efficiency. It is made in compliance with international standards, the possibilities and ways to achieve these standards.

Energy audit is an interconnected set of technical, organizational, economic measures aimed at identifying the possibility of cost-effective optimization of the consumption of energy resources.
The purpose of which is to identify sources of irrational energy costs and unjustified energy losses; development of a targeted, comprehensive energy conservation program; increase in energy efficiency; updating and improving these methods.

Since the energy audit reflects the activities of the enterprise from the energy saving point of view and energy efficiency, the totality of characteristics describing the topology of the material and energy flows will be associated with the economy of the enterprise.

If an industrial enterprise is defined by a set of networks of material and energy flows (electricity, heat, water, gas, etc. supply), a given flow network can be represented by a directed graph in which branches represent certain material and energy flows, and the peaks are generalized nodes of consumption, co-building, transmission of these flows. The generalized node of the graph, depending on the scale of the description, can represent the whole enterprise, workshop, production line or a separate device [12].

![Figure 1. Scheme of the enterprise graph in general.](image1)

We represent the enterprise as a set of graphs $G_k$, where each value of $k$ corresponds to a certain type of flow (electricity, thermal energy, production of the enterprise, etc.). A directed graph will have many vertices and directed edges:

$$G_k = \{V_{ik}, U_{ijk} \mid i, j = 0, ..., N\}, \ k = 1, ..., K,$$

(1)

where $K$ is the number of types of material-energy carriers, $N$ is the number of generalized nodes for a given level of description of the enterprise, $V_{ik}$ is the $i$-th node of the $k$-th graph, $U_{ijk}$ is the edge connecting the $i$-th and $j$-th nodes of $k$-th graph Matrix model of energy audit.

![Figure 2. Scheme of a graph of an industrial enterprise with 4 types of network.](image2)
We introduce the function $E(x)$, which will express the economic content of the edge of the enterprise graph in units - kW * h, rub., Unit products, etc. Then, for the graph in Figure 1, the energy efficiency $e$ will be expressed as

$$e = \frac{E(U_{101})}{E(U_{011})} \tag{2}$$

where $U_{101}$ is the graph edge “Products”, $U_{011}$ is the edge “Energy Consumption”.

A detailed description of the enterprise produces many more complex graphs. The exception will be the graphs of finished products and networks of other material carriers that do not participate in long chains of production cycles. As an example, Figures 2 show two networks consisting of isolated nodes and ribs — a fuel supply network and a finished product outlet network.

For complex graphs, an analysis of energy efficiency must be carried out on the matrix approach basis. This would allow to create an algorithm for solving different kind of energy saving problems and fulfilling the various tasks, using the same approach.

Let $M_{ijk}$ be the incidence matrix of the graph of the $k$-th carrier network, $U_{io1}$ be the useful output of the $i$-th node, $H(x)$ be the Heaviside function, $\varepsilon$ be the set of indices corresponding to energy carriers, then the energy efficiency of the $i$-th node

$$e_i = \frac{E(U_{io1})}{\sum_{j,k \in \varepsilon} H(-M_{ijk})E(U_{ijk})} \tag{3}$$

Figure 3. Scheme of a graph of an industrial enterprise with matrix parameters.

As an example, consider the graph of energy flows of an industrial enterprise, shown in the Figure 3. The graph describes three networks: the electric network (1), the heating network (2) and the network of products (3). The type of network the variable belongs to is determined by the value of the 3rd index. In the graph, two nodes are indicated by several variables - these are nodes 3 and 5. This is done because they are nodes of several networks. The ribs of the graph can be divided into three types: describing the transfer of energy between nodes - $U_{121}, U_{231}, U_{251}, U_{201}, U_{301}$; the loss of energy - $U_{452}, U_{302}, U_{402}, U_{501}, U_{502}$; and the yield of finished products - $U_{353}, U_{573}$. For the 2nd node, formula (3) takes the form

$$e_3 = \frac{E(U_{363})}{E(U_{231})+E(U_{432})} \tag{4}$$

We indicate the expected physical dimensions for energy flows and description the ribs in Figure 3. The ribs of the electrical network $U_{121}, U_{231}, U_{251}, U_{201}, U_{301}$ will have a dimension in kW*h/year. The
ribs of thermal network $U_{432}, U_{452}, U_{302}, U_{402}$ will have the dimension Gcal/year (BTU) or tons of fuel equivalent/year. The product network ribs $U_{363}, U_{573}$ have a dimension of pieces/year or cost of products thousands rubles (thousands $$/year). We describe the equipment that the nodes represent. The electric network contains nodes: $V_{21}$ is the equipment of substations (transformers, power lines, etc.); $V_{31}, V_{51}$ – these are electrical equipment in enterprises, indicating, if possible, their energy efficiency classes. The heat network contains nodes; $V_{42}$ – this is the boiler, transmission lines of thermal energy, etc.; $V_{32}, V_{52}$ – this is the heat-consuming equipment, indicating, if possible, their energy efficiency classes. The product network contains nodes $V_{33}, V_{53}$ representing the type and quantity of products.

2. Conclusion
In general, such an approach to the analysis of material and energy flows introduces a higher level of abstraction, allowing one to analyze the graph topology, convenient for the analysis of complex systems of the objects under consideration. In addition, a high level of abstraction simplifies the algorithmization with the aim of using secondary energy resources or replacing part of the material and energy flows by introducing renewable energy sources and modern energy storage systems [3].

A good example is the usage of heat from the transformer oil cooling system of power transformers when heating the premises of an electrical substation (a heat pump to increase the temperature in the water heating system relative to transformer oil) [13,14].

Given the tendency to increase the possible number of energy-saving measures, as well as the natural restrictions on the number of simultaneously processed objects, attempts to propose an approach to visualization and algorithmization heterogeneous information when comparing energy-saving projects for individual enterprises becomes relevant.

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