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Original Article

Development of a Web Application for Predictive Accounting of Energy Resources

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Abstract *- To obtain statistical data on the production and consumption of energy resources, their processing and forecasting in individual and central heating points and boiler houses, technical accounting is required, providing tools for the effective operational management of energy resources. The author has developed an algorithm for creating an automated energy accounting system (standard, calculation, forecast). The forecast characteristic of the annual thermal energy consumption is obtained based on a regressive equation and can be applied to various types of buildings. Based on this algorithm, an engineering calculator has been developed for an automated energy accounting system (standard, calculation, forecast). DHTML programming was used as an implementation of the calculation algorithm.*

Keywords *- Technical and economic algorithms, Predictive accounting of energy resources, Web applications, Correlation analysis, Neural network.*

1. Introduction

The main objective of the conceptual project for developing a system of rationing of fuel and energy resources using engineering calculators and software products is to consolidate existing practices and methods for determining the planned consumption rates of fuel and energy resources based on a statistical analysis of production information. The conceptual project contains a description of the following main directions for developing a system for rationing fuel and energy resources:

- description of the methodology for planning fuel and energy consumption rates based on regression equations that take into account the influencing factors;

- description of the methodology for analyzing deviations of the plan-fact of fuel and energy consumption norms based on actual production indicators;

- recommendations on the implementation/development of engineering calculators and web applications of the enterprise system necessary to improve the accuracy of planning of fuel and energy consumption standards;

- recommendations on developing the energy accounting system and automating the compilation of energy balances.

The structure of the methodology description consists of 3 stages: theoretical foundations of the proposed method and assessment of practical applicability to technological objects.

The main methods of analyzing production information are:

- construction of a technical model;

- statistical data analysis.

Technical modeling allows calculating the ideal conditions for the flow of a physical process in compliance with predetermined "physical laws". This modeling method allows for obtaining ideal models, namely, theoretically achievable indicators of the production process and fuel consumption norms. Ideality in this context implies the absence of specified conditions for the error of real measurements, possible disturbances, and fluctuations of a physical or chemical process. A significant advantage of technical modeling is the ability to describe a situation that goes beyond the limits in which the simulated technological object operates and the ability to determine the "lowest achievable" indicator of the fuel and energy consumption rate. Statistical analysis operates with the concept of finding the relationship between the actual measurements made. This allows for obtaining a statistical relationship between the measured variables. Statistical dependence does not describe the law of nature. However, it can be used to explain a theoretical assumption made on the basis of technical modeling – calibration of a mathematical model based on the original physical model of the object. A significant advantage of the statistical model is the simplicity of determining the relationship between the measured values and the ability to use statistical dependencies to assess the real economic effect. For the purposes of determining the planned consumption rates of the fuel and energy complex, it will be most optimal to use static analysis and the construction of a mathematical model of the consumption rate of the fuel and energy complex in the form of a regression equation. From the viewpoint of evolution, approaches to rationing of fuel and energy consumption norms based on statistical analysis can be divided into 3 main stages:

- rationing based on static consumption norms of fuel and energy complexes;

- rationing based on discrete fuel and energy consumption norms;

- rationing based on dynamic fuel and energy consumption norms.

Static planned expenditure standards operate with indicators of fuel and energy consumption standards approved in the norms of the technical regulations and the passport of the production facility. The accuracy of planning based on these norms is low, and the deviation of the actual daily average values from the planned values may exceed 100%. The necessary data for calculating the consumption rate are the production facility's passport data, monthly material indicators, and energy balance. The automation of norm calculations is not possible at this stage. Discrete fuel and energy consumption rates have signs of statistical analysis of production information and are characterized by monthly or seasonal discreteness (winter-summer-off-season) and dependence on influencing factors (production load).

The accuracy of planning based on these norms is average, and the deviation of the actual daily average values from the planned values can reach 30-60%. Necessary data for calculating the consumption rate: daily average or aggregated consumption indicators for material flow (raw materials or manufactured products) and energy resources. At this stage, it is possible to automate the functions of primary production accounting and automate the calculation of specific indicators in a tabular processor (for example, MS Office Excel). It is possible to plan the consumption rate based on the regression equation of the dependence of fuel and energy consumption on the production load of the facility, taking into account seasonality.

Dynamic consumption norms of fuel and energy complexes are characterized by the discreteness of production indicators hours/day and dependence on an expanded number (compared with discrete norms) of influencing factors: external (load, weather) and internal (the quality of the technological regime, the condition of equipment and other indicators of production efficiency). The accuracy of planning based on these standards is high, and the deviation of the actual daily average values from the planned values is usually 5-30%. At this stage, it is necessary to organize the automatic collection of production data at the level of software solutions and use specialized statistical analysis software.

The planning of the expenditure rate is carried out based on a regression equation, taking into account the expanded number (compared with discrete) of influencing factors. The analysis of the existing systems for rationing the fuel and energy resources costs of production sites showed that discrete consumption rates are currently used. The use of dynamic norms at this stage is impossible due to incomplete system coverage by data sources (not all production facilities transmit production information to the enterprise system). Currently, discrete consumption rates are used. Dynamic norms are possible due to the extensive coverage of data sources.

Many authors have cited methods for implementing engineering calculations in software complexes, but the implementation algorithms are the main source of data for calculations [1-16]. The author has developed an algorithm for creating an automated energy accounting system (standard, calculation, forecast) [23]. In general, correlation analysis detects the relationship between several random variables. From the viewpoint of view of the narrow task of forming a regression equation describing the dependence of the expenditure rate on the factors affecting it, correlation analysis allows identifying the main factors for the formation of the regression equation. For this purpose, it is necessary to conduct a correlation analysis in the following areas: checking the correlation between ambient air temperature and coolant temperature. Within the framework of energy-saving programs, measures are being implemented aimed at reducing the external impact on the temperature of the incoming coolant, as well as the use of additional heat exchangers and materials for additional heating of the coolant.

The reverse situation is also possible when physical wear or breakage of the heat exchange equipment occurs; however, stopping the repair of the heat exchange equipment is impossible for economic reasons. It is necessary to take only those time periods that reflect the possible state of the heat exchange equipment for the future planned period. The author has developed an algorithm for creating an automated energy accounting system (standard, calculation, forecast). The forecast characteristic of the annual thermal energy consumption is obtained based on a regressive equation and can be applied to various types of buildings. Based on this algorithm, an engineering calculator has been developed for an automated energy accounting system (standard, calculation, forecast). DHTML programming was used to implement the calculation algorithm [19-22].

The research's scientific novelty consists of obtaining algorithms for creating an automated energy accounting system (standard, fact, forecast) and forecasting thermal energy consumption based on a DHTML web application.

2. Materials and Methods

For example, let us consider calculating the specific consumption of a heat carrier by an individual heating point (fig.1).

If you imagine a comparison of the diagram (visual distribution of points) of air temperature and temperature, you can see 2 clouds:

The lower cloud is the influence of the weather before the weather compensator, and the upper cloud is after the installation of the weather compensator. Here, the correlation before and after installation is:

- before installation – 82.39%;

- after installation – 80.21%.

Thus, the correlation is significant (the standard indicator is a value exceeding 75% for direct correlation and less than -75% for inverse correlation), and the temperature of the coolant should be removed from the variables of the regression equation.

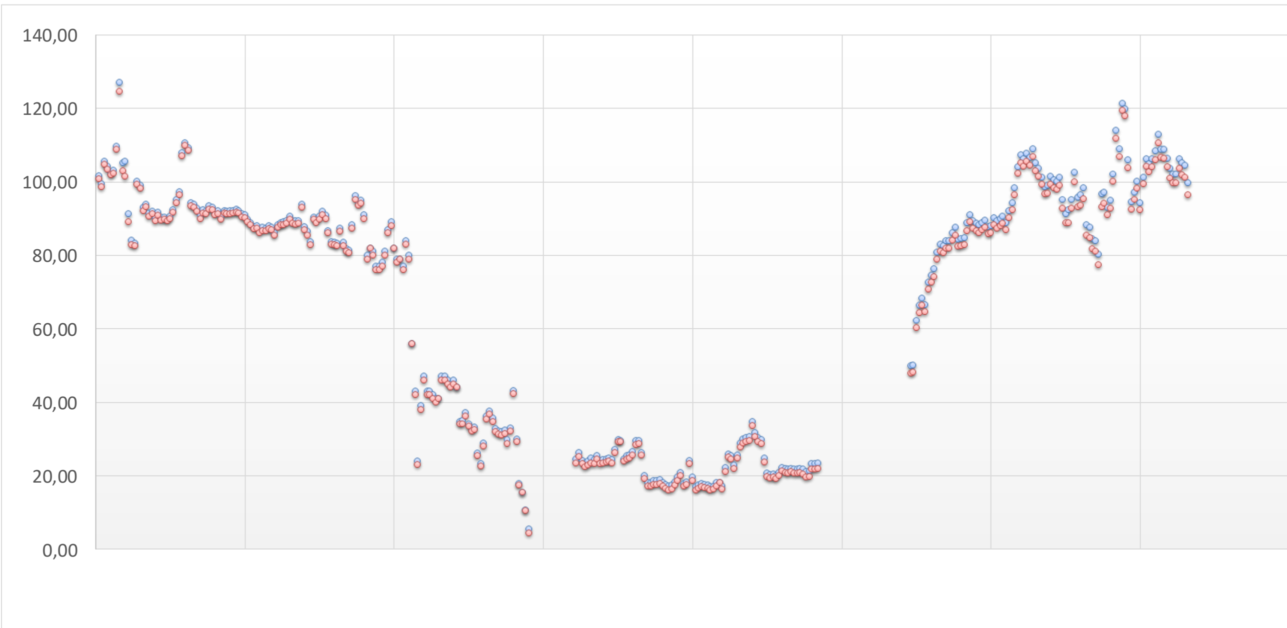

Fig. 1 Temperature of the coolant at the entrance to the individual heat point

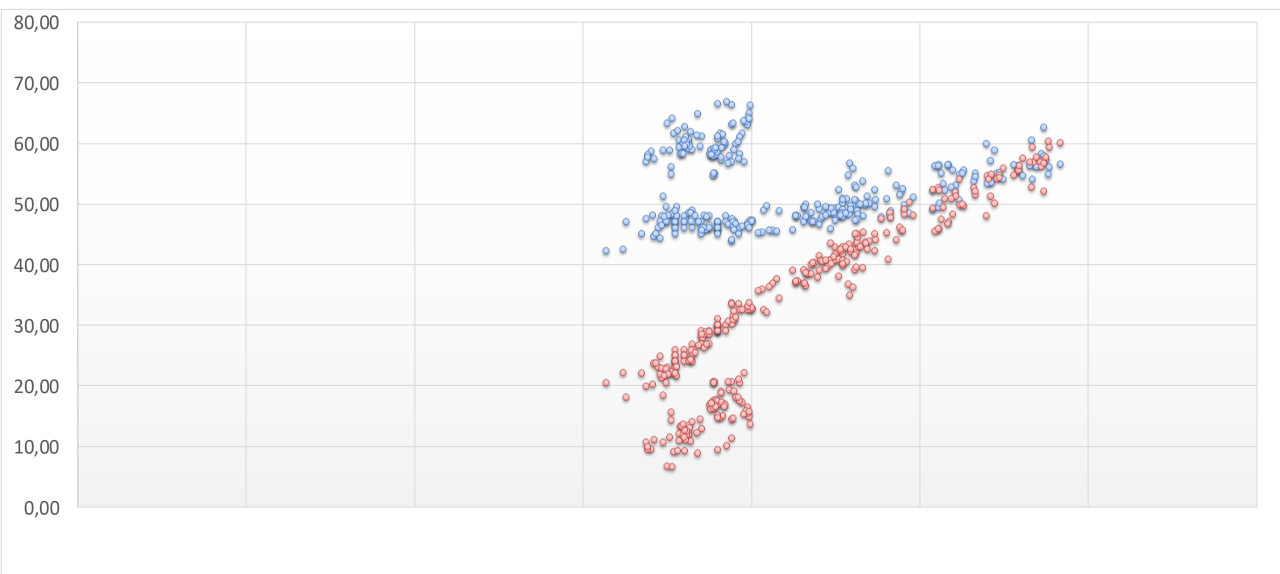

Fig. 2 Graph of the relationship between air temperature and coolant temperature

Determination of the correlation between the specific flow rate of the coolant and the influencing indicators of factor analysis (only for the dynamic flow rate of the coolant).

It is necessary to determine the controlled parameters and boundaries to influence factors for each controlled parameter that corresponds to the stable operation of an individual heating point and remove time periods that do not meet these conditions.

For example, for the specific consumption of the coolant, these indicators may be significant factors (according to the recommendations for selecting influencing factors):
- controlled variables of an individual heating point – coolant temperature and coolant flow;
- indicators of external observable variables of an individual heating point – outdoor air temperature.

For the specific flow rate of the coolant, the essential factors are:
- controlled variables;
- indicators of measurable external variables.

2.1. Construction of a regression equation

When constructing a regression equation, the accuracy indicator is R2 of at least 60% for the remaining time periods, after the stage of statistical data preparation and for the variables remaining after the stage of correlation analysis. Figure 3 shows an example of visualization.

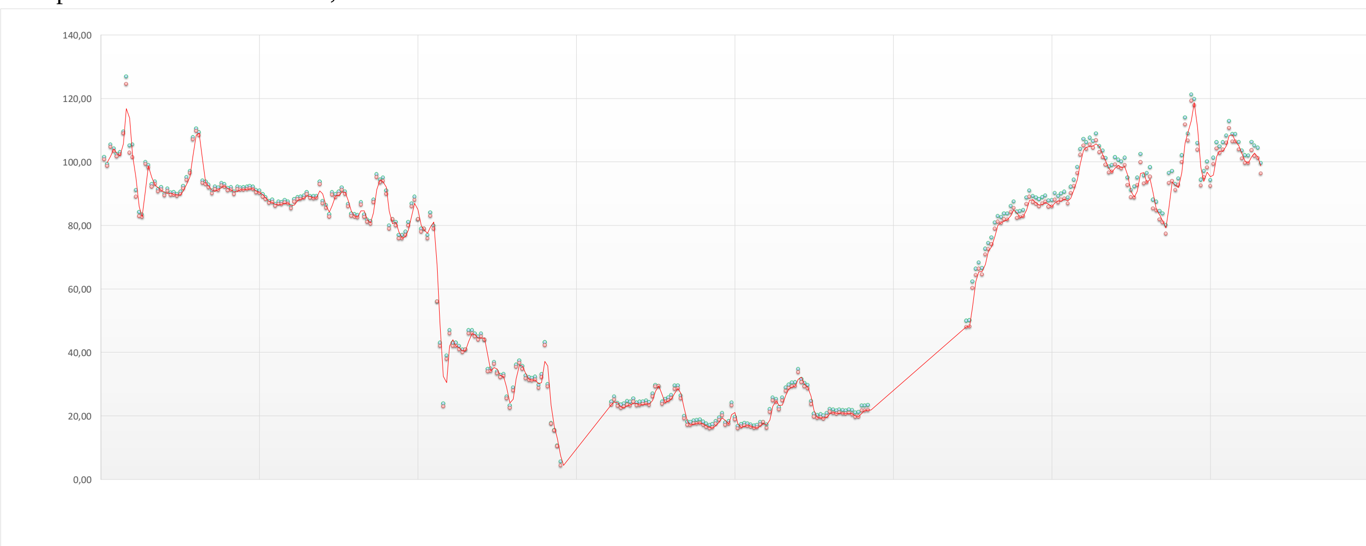

Fig. 3 Visualization of the mathematical model R2 -65%. Red is a fact; green is a model of the specific flow rate of the coolant from the air temperature indicators

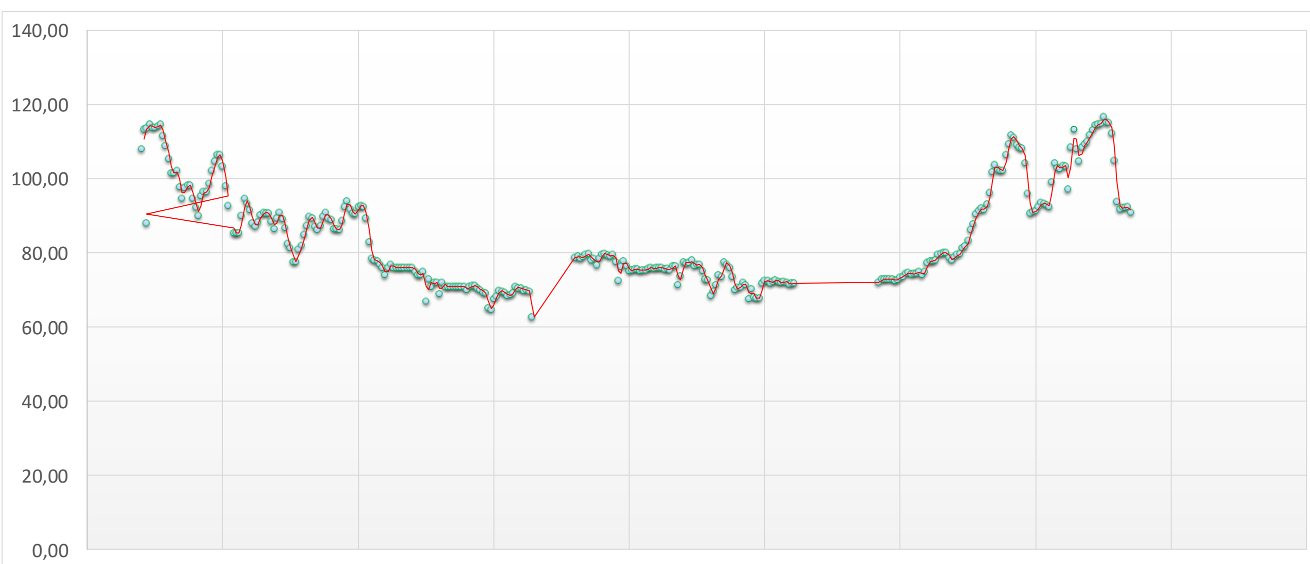

Fig. 4 Comparative analysis of R2 indicators for a linear model and a model based on a neural network model of specific coolant flow from air temperature indicators. Red is a fact, and green is a model

To construct a regression equation, methods of constructing a linear equation, a nonlinear equation, and, if necessary, constructing a mathematical model based on neural networks can be used (Figure 4).

With a sufficient R2 indicator, linear models can be used. However, when modeling with 5 or more factors, as well as with an unsatisfactory R2 indicator of a linear model, it is desirable to use a model on neural networks.

To check the prepared statistical data, one must use the following tools:

- Checking each variable for the p-value attribute. The P-value is the value used when testing statistical hypotheses. In fact, this is the probability of error when rejecting the null hypothesis (errors of the first kind). Hypothesis testing using p-value is an alternative to the classical verification procedure through the critical value of the distribution. Usually, the p-value equals the probability that a random variable with a given distribution will take a value no less than the actual value of the test statistics. It is desirable to achieve a p-value of no more than 0.05 for each variable of the equation;

- Verification (only for the dynamic planned consumption rate of the thermal energy) of statistical data set by random sampling to eliminate the error of randomly obtaining a model with a high R2 index. This work needs to be done since the data set (average half-hour values for a whole year of more than 16,000 measurements) can be large, and it is necessary to check the correctness of the data sample. Using automated static data analysis tools, randomly split all the data, where 2/3 of the sample is used to construct a regression equation (for neural networks, an n-dimensional surface), and the remaining 1/3 is used to test the mathematical model. Repeat this operation at least 10 times with a random sample of data periods. If the R2 indicator in the model indicators and the mathematical model validation indicators do not exceed a difference of more than 5% in 8 of 10 samples, then the statistics are correct. After checking the statistical data, you should proceed to the construction of a mathematical model.

The result of constructing a mathematical model is as follows:
- For linear and nonlinear equations – coefficients of the regression equation and the free term of the equation;
- For models based on neural networks – a mathematical algorithm in the form of a block with an input to which any statistical data can be submitted and an output that outputs the result in the form of calculated values of the objective function (specialized software for mathematical modeling based on regression equations is required for this function).

2.2. An example of calculating the planned consumption rate of thermal energy. Calculation of the planned dynamic flow rate of the coolant for an individual heating point

The process is divided into 4 stages:
- Data preparation;
- Cleaning of periods with violations of the technological regime;
- Conducting correlation analysis;
- Construction of a regression equation.
- The result of the completed steps will be a regression equation.

2.2.1. Data Preparation

The customers provided statistical information in the form of hourly average values of coolant consumption indicators for individual heating points for the annual period. It included 365 dimensions.

2.2.2. Cleaning of periods with violations of the technological regime

Statistical data is cleaned up on the indicators of factor analysis (indicators). Considering the norms of coolant consumption in an individual heating point and using a standard linear graph (trend), the periods are removed where the flow rate of the coolant differs from the standard by more than 15%.

The statistical data is cleaned up on the flow rate of the coolant. To do this, the author removes the periods corresponding to the flow rate of the coolant is different from the standard by more than 15%.

2.2.3. Correlation Analysis

To conduct a correlation analysis, it is necessary to build a matrix (or in Excel separately for each parameter: coolant temperature, coolant flow rate, outdoor air temperature, specific flow rate kcal/h • m3•degrees):

Data	Q, Gcal	T, degree	G, t/hour
January	133,55	108,05	101,61
February	142,04	113,40	99,40
march	144,57	113,54	105,51

Fig. 5 As can be seen from the matrix above, the specific indicator has a high correlation from the air temperature, and a low correlation from the coolant flow

2.2.4. construction of the regression equation (calculation of the coefficients of the regression equation).

Target parameter: coolant flow rate UD = f (coolant flow rate, air temperature).

The obtained coefficients of the equation are (equation 1):

$$UD = y * a + z * b + c \qquad (1)$$

, where y is the coolant flow rate, z is the temperature of the heat flow at the exit of the building, and a, b, and c is the coefficient.

The indicator R2 = 70%, which indicates sufficient accuracy of the regression equation.

Visualization of the expenditure rate for actual values (red = fact, green = model):

Fig. 6 Visualization of the consumption rate for actual values

The analysis is a daily work aimed at finding, identifying and reducing deviations of the actual specific consumption indicator and the planned norm of thermal energy.

The minimum time interval at which the analysis is performed:
- discrete planned consumption rate of thermal energy – daily values;
- dynamic planned consumption rate of thermal energy – hourly values for automation and daily values in the absence of process automation.

The description of the task of improving the accuracy of planning from the viewpoint of view of the business model, the task of rationing fuel and energy consumption norms is limited to the task of "reducing costs" of the block of increasing the profitability of operations. The norms of the technological regulations establish the minimum limits of the quality of products Q_{min}. As a result, the operational personnel of the production facility conducts a reserve mode Q_{max}. Moreover, for each team, the stock may differ. As a result, there is a process with a high spread variance of the actual values from the target indicator at the output. This increases the deviation of the planned consumption rate of the energy resource since the energy consumption is directly proportional to the quality of the output products.

Consequently, the objective of increasing the accuracy of energy consumption rates is to stabilize the technological regime and the quality of manufactured products. Thus, the role of rationing is reduced to minimize the share of energy in the cost of the product by determining the optimal indicators for the quality of products and consumption rates of energy resources. For the purposes of the plan-fact analysis, an additional component δ is introduced into the regression equation of the planned expenditure rate, denoting the percentage of the planned loss rate. This indicator is set expertly as the upper and lower bounds of the error corridor. Setting the planned loss indicator within ± 5% for dynamic fuel consumption rates and ± 10% for discrete ones is recommended. Consider the daily values of the actual specific consumption exceeding the specified threshold as significant and fix the reasons for these deviations for further analysis. The actual characteristic of the annual consumption of thermal energy is obtained on the basis of accounting data. The forecast characteristic of the annual thermal energy consumption is obtained based on a regressive equation and can be applied to various types of buildings. The determination of the forecast values is based on correlation analysis and the construction of regression equations. For the purposes of the plan-fact analysis, an additional component δ is introduced into the regression equation of the planned expenditure rate, denoting the percentage of the planned loss rate. Experts set this indicator as the upper and lower bounds of the error corridor.

In the form of a mathematical equation, this problem can be expressed as follows from the equation:

$$\frac{x}{y} = f(y, t, q, z) \pm \delta \tag{2}$$

where δ is the loss rate in %, y is the coolant flow rate, t is the outdoor air temperature, q is the temperature of the heat flow at the entrance to the building, z is the temperature of the heat flow at the exit of the building, x/y is the forecast characteristic.

An example of the rate of loss of coolant in individual heat points. Planned expenditure rate at the upper limit of the expenditure rate. Going beyond UD_{min} & UD_{max} at daily values should be recorded, and the reason for the deviation should be determined.

Two ways allow us to determine the reasons for deviating the actual expenditure rate from the planned one: expert assessment of production personnel and analysis of the correlation of events generated by specialized system models designed to assess the production efficiency of technological facilities.

The positive side of the expert assessment is the simplicity of the organization of the business process. The negative side is the high burden on the staff to collect and analyze poorly structured information and the high dependence of business on the competencies and knowledge of technologists. When using discrete fuel and energy consumption norms, it is recommended to apply an expert assessment when analyzing the reasons for deviating the actual consumption rate from the planned one.

The positive side of using specialized modules is to increase the objectivity and structuring of the reasons for deviating the actual from the planned norm, a high-efficiency level in collecting and analyzing information. The negative side is the high cost of implementation and maintenance and the need to increase the competence of production personnel to analyze information in specialized software. For example, the widespread use of statistical analysis methods for large amounts of data. It is recommended to implement additional modules for the use of dynamic fuel and energy consumption standards.

This calculation algorithm is based on the method of determining the amount of thermal energy and coolant in water systems of municipal heat supply. The thermophysical characteristics are translated into mathematical ones to create an engineering calculator. A web application for the calculation has been developed based on these algorithms. The forecast characteristic of the annual consumption of thermal energy is obtained on the basis of a regressive equation and can be applied to various types of buildings. The actual characteristic of the annual consumption of thermal energy is obtained on the basis of accounting data. Algorithm of the annual consumption of thermal energy for heating buildings (standard):

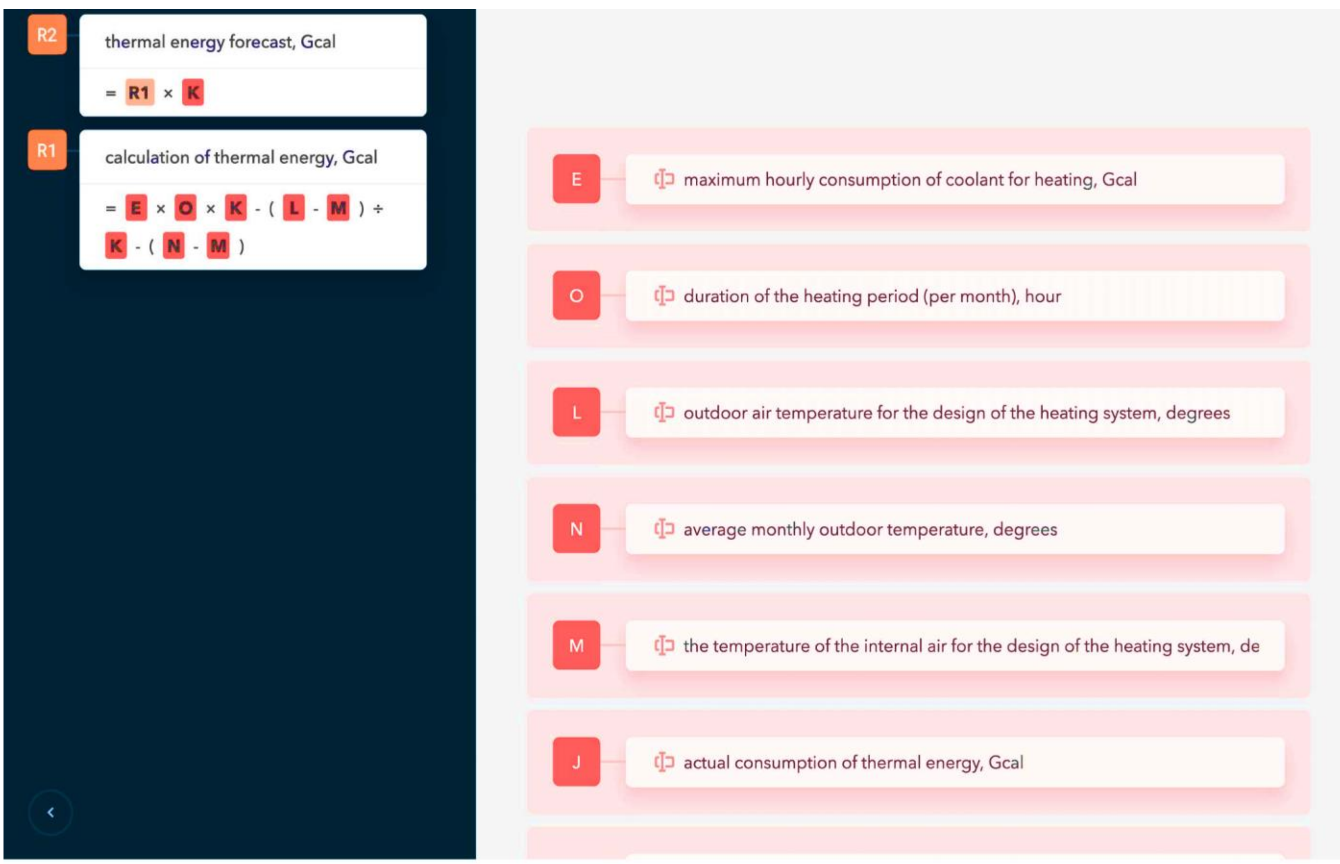

Fig. 7 Initial data for calculation in an engineering calculator

3. Results and Discussion

The web application provides a calculation of the projected consumption of thermal energy for heating the building.

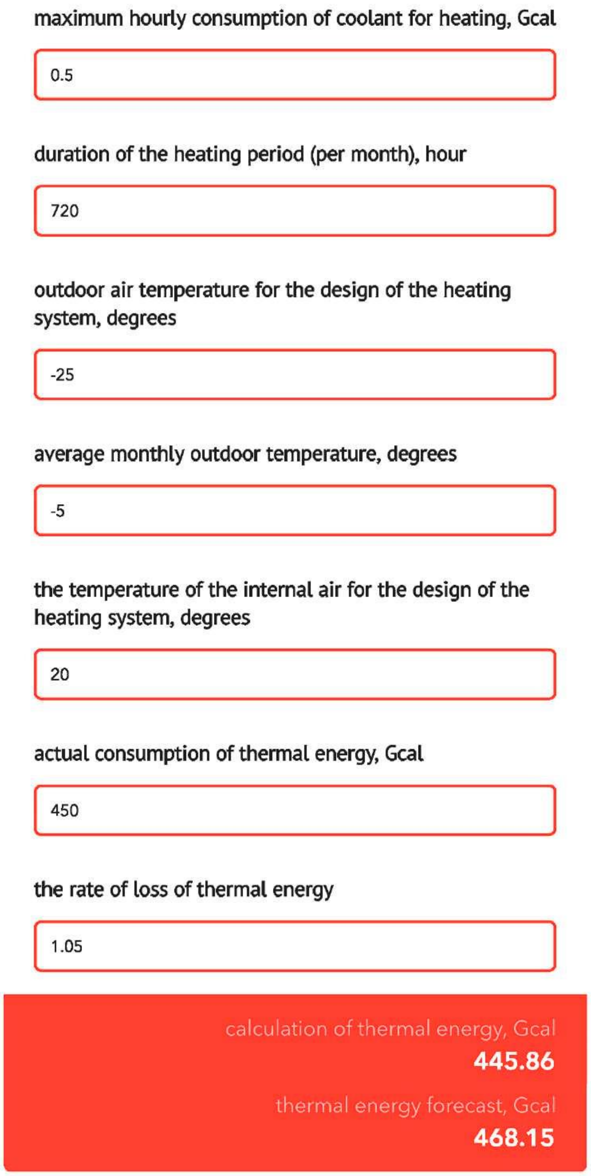

Fig. 8 Example of the implementation of the calculator of the forecast of heat consumption

The following parameters are used for the calculation: the maximum hourly heating consumption according to the project data is 0.5 Gcal per hour, the duration of the heating period is 720 hours per month, the outdoor air temperature for the design of building heating is -25 degrees, the average monthly outdoor air temperature is -6 degrees, the indoor air temperature is 20 degrees, and the actual heat consumption according to accounting data is 450 Gcal. The estimated consumption of thermal energy for heating the building is calculated to be 445.86 Gcal. The projected thermal energy consumption for heating the building was calculated to be 468.15 Gcal per month. Forecasting thermal energy consumption allows us to reduce the operational (logistics costs) costs for the supply of energy resources.

4. Conclusion

Currently, there is no forecasting of the consumption of energy resources during the operation of individual heating points and boiler houses. This leads to overspending on thermal energy. In some large enterprises, there is rationing of energy resources and, accordingly, forecasting. The problem is the influence of many factors on forecasting (production load, unplanned production delays and others). The construction of regressive equations will allow the processing of statistical data on the consumption of energy resources in the heat supply and predict the consumption rate in the future. The construction of regressive uranations will be done individually for each object based on data on its consumption of energy resources. To obtain statistical data on the production and or consumption of energy resources, their processing and forecasting in individual and central heating points and boiler houses, technical accounting is required, providing tools for the effective operational management of energy resources. The author has developed an algorithm for creating an automated energy accounting system (standard, calculation, forecast). The forecast characteristic of the annual consumption of thermal energy is obtained on the basis of a regressive equation and can be applied to various types of buildings. Based on this algorithm, an engineering calculator has been developed for an automated energy accounting system (standard, calculation, forecast). DHTML programming was used as an implementation of the calculation algorithm. The author obtained the best results from the modern methods described in the literature.

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