Use of big data technologies for the implementation of energy-saving measures and renewable energy sources in buildings

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Abstract

Currently, one of the directions of energy saving in the industrial and social sectors of the Russian economy is the introduction of technically and economically feasible energy-saving measures and renewable energy sources (RES). However, it is often impossible to substantiate the effectiveness of introducing renewable energy sources reasonably. This is due to the fact that the comparison should be conducted in conditions of identical labor and raw materials resources, climatic conditions, etc. In other words, it is necessary to compare the energy saving measures and the use of renewable energy technologies under comparable conditions, which in many cases requires the solution of a number of complex problems.

Based on the analysis of existing methodological approaches to the collection, compilation and processing of large data sets, including statistical, neural network and fuzzy methods, a method for combined analysis and modeling of energy consumption processes in buildings has been developed.

At the same time, a methodology was proposed for the selection of a set of measures to optimize the energy efficiency of buildings. The original model and method of choosing energy saving measures, taking into account a flexible multi-level structure, as well as various compatibility and significance of the indicators being evaluated, are proposed. The proposed visualization algorithm allows to combine on one graph economic criteria of energy-saving projects payback and energy-saving effect, which is a reflection of natural indicators of energy efficiency.

This model allows to formalize the process of increasing the buildings energy efficiency, and can be useful for energy managers, who are responsible for energy flows optimization.

Keywords - big data; energy consumption; energy efficiency of buildings; regression analysis; energy saving measures, renewable energy sources; forecasting method.

I. INTRODUCTION

The problem of confirming and predicting the energy-saving effect is subject to the contradiction between, on the one hand, the constantly accumulating volume of heterogeneous and diverse information (data on energy consumption volumes, including measurement data obtained from various sensors, expert estimates, data on physical and geometric parameters of buildings, climatic and geo-information data, socio-economic conditions, types of RES, their efficiency under the conditions in question, etc.), characterized by various structures and semantics which is coming from different sources, and on the other hand, the absence of typical approaches to the evaluation, aggregation and generalization of such information into multidimensional data base that characterize various aspects of energy consumption and optimization of energy efficiency at variable stages of the life cycle of buildings of different types.

In this connection, the fundamental scientific problem of analyzing big data, which is used in the future for the formation of predictive functions of energy consumption and decision-making on improving the energy efficiency of buildings of various types, arises. As an approach of eliminating these contradictions and above problem, a method was chosen to break up the problem into key problems with a consistent solution.

II. PROBLEM DESCRIPTION AND WAYS OF IT SOLVING

To address the contradiction, four key problems have been consistently solved. Since the description of all the studies carried out substantially exceeds the permissible size of this article, only the theses of statement of problems and the results obtained are given below.

The key problem 1: justification of the project requirements, requirements for accuracy of measuring sensors, installation locations, methods for collecting and processing the data. The solution is aimed at analyzing and identifying scenarios for solving the problems of forming requirements for big data, at determining the requirements for the accuracy of measuring sensors, their installation locations for measuring the energy consumption of buildings, the methods for collecting and processing the data received, to the format and accuracy of the data to estimate the energy consumption of buildings of various types with the possibility use of RES.

The key problem 2: collection, generalization and semantic integration of extremely large amounts of data. The solution of this key problem is aimed at developing the concept of collecting, generalizing and integrating data from heterogeneous sources, for example, on the types and power of RES applied, the geometric and topological features of buildings, measuring information (temperature, humidity, power, etc.), behavior of residents / visitors, climatic and meteorological data. The solution to this problem is the software for semantic data integration, which is responsible for searching and routing information intended for analysis, modeling and visualization modules. The developed mathematical apparatus is equipped with means for assessing the accuracy and reliability of the information received by various modules with the established requirements.

The key problem 3: analysis of extremely large amounts of data and the extraction of knowledge. The result of solving this key problem is the creation of a set of methods and analysis techniques to detect dependencies, typical situations and useful information from extremely large amounts of data coming from various sources to support prescriptive analysis and decision making to improve the energy efficiency of specific buildings. The information extracted is unique to each building, and therefore energy efficiency measures based on the information extracted will be the most accurate for it. At this stage, various mathematical models are used, using both mathematical multifactor regression and self-configuring genetic algorithms based on artificial neural networks.

The key problem 4: modeling and confirming the energy saving effect in the implementation of energy saving measures and RES in buildings of various types. Taking into account the full life cycle of buildings from their design, construction, operation to modernization and destruction / disposal [1], it can be noted that the share of energy consumption in buildings, for example, in Germany is about 40% of total energy consumption [2] and about 36 % - in Russia, including 23% of energy consumption in residential buildings [3]. At the same time, the smaller share of energy consumption by buildings in Russia, as compared to Germany, is due to lower housing provision and significant differences in the structure of the economic sectors. At the same time, buildings in Russia still have a higher level of specific energy consumption per square meter, and, as a consequence, significant energy saving potential (from 24 to 47%, depending on the type of building) [4].

III. TASKS SOLVED FOR MODEL CREATING

Within the framework of the final key problem, the following specific tasks have been accomplished:

Task 1: Analysis of conditions and methods for modeling the energy consumption of buildings. The purpose of this task is to analyze the parameters of buildings of various types, including building envelopes, occupancy profiles, environmental characteristics in accordance with several scenario options for energy consumption. For this task, the parameters influencing the energy consumption of buildings of various types, including use of RES, have been defined. Simulated energy consumption of buildings to optimize their energy efficiency based on the prescriptive approach has been done.

Task 2: Analysis of Russian legislation in the field of both improving the energy efficiency of various buildings and using renewable energy sources. The given task consists in the analysis of systems of optimization of energy consumption of buildings in accordance with the Russian legislation in the field of energy saving and energy efficiency improvement taking into account the real state of engineering systems of buildings and the latest achievements in the field of renewable energy.

Task 3: Development of a model of energy flows in typical buildings and data input / output specifications obtained from measuring sensors. A methodology is proposed for creating and optimizing the proposed energy flow models in buildings, depending on specific conditions and parameters. The Russian legislation on energy efficiency of buildings and use of RES was taken into account in the model development. In the course of solving this problem, the main technical requirements for input and output data of energy flow patterns in buildings in general and in relation to their individual elements have been determined. Additional sources of data are also taken into account, for example, meteorological and climatic data.

Task 4: Creating an integrated model for the calculation and modeling of energy flows in buildings.

A complex model has been developed for predictive analysis to optimize the energy efficiency of buildings of various types, based on energy flow models and data measurement results for buildings of various types.

Task 5: Development of forecast data formats and measures to optimize the energy efficiency of buildings with the optional use of RES.

It should be noted that the work was carried out during the period of active development of methods and approaches to collect, summarize and integrate large and super-large data. Studies (both theoretical and practical) in this area are devoted to the work of leading Russian and foreign specialists, such as T.A. Gavrilova, V.V. Gribova, Yu. A. Zagorulko, N.V. Lukashevich, O.A. Nevzorova, Rybina G.V., Sosnin P.I., Khoroshevsky VF. and others. Almost all the largest suppliers of information technologies and services (IBM, Oracle, Microsoft, Google, Yandex, Hewlett-Packard, EMC, etc.) are actively researching and developing in this field. At the moment, effective models and technologies for collecting, summarizing and integrating large data have been created and are being implemented, both from formalized and nonformalized sources. Moreover, for the generalization and integration of data with a view to the subsequent extraction of knowledge from them, as a rule, various ontological models of data representation and generalization are used.

To solve the problems of analysis, optimization and improvement of energy efficiency of buildings, statistical methods are mainly used [5]. At present, in addition to these methods and models, intensive research is being conducted in the field of developing intelligent methods and technologies, which, first of all, include neural network and fuzzy methods and technologies [6]. They have both undoubted advantages and limitations [7].

The merits of fuzzy methods, models and technologies include the following: the possibility of using different-quality data, including expert ones, as well as presented through various scales; simplicity of knowledge representation; the possibility of a linguistic interpretation of the results; the possibility of presenting inaccuracies and uncertainties in the data; the possibility of representing and modeling non-linearity; the possibility of parallelizing fuzzy calculations; the possibility of using in real time. The limitations of fuzzy methods, models and technologies are: the complexity of expert knowledge base formation; complexity of checking the completeness and consistency of the knowledge base; complexity of structural and parametric optimization of the knowledge base; lack of opportunity for learning; lack of the ability to automatically acquire knowledge.

Advantages of neural network methods are: the ability to identify patterns in data, their generalization; the possibility of representing and modeling non-linearity; a typical approach to solving various problems; adaptability and ability for learning; the possibility of parallelizing calculations; the possibility of presenting inaccuracies and uncertainties in the data; the possibility of using in real time.

The disadvantages of neural network methods, models and technologies are: the complexity of explaining the results of functioning; a large number of cycles and long duration of learning; complexity and heuristics of the formation of topology and parameters of the neural network model, adequate to the task; the complexity of forming a representative and consistent teaching option. Currently, active research is being carried out in the field of creating hybrid neuro-fuzzy methods, models and tools that allow each other to complement one another, compensating for the limitations and shortcomings inherent in each of the approaches separately [8].

IV. THE MODEL DESCRIPTION

Solving the problems of analyzing and optimizing the energy efficiency of buildings, taking into account the various types of uncertainty, requires the joint application of analytical, neural network and fuzzy models. Within the scope of the work, a comprehensive design model of the energy flows of the building with the possibility of using RES was created, which was used to form a learning sample. At the same time, the fuzzy model itself is also composed taking into account the limitations that are a consequence of the thermal and electrical dependencies characteristic of the types of buildings analyzed.

The method of combined analysis and modeling of energy consumption processes in buildings, which comprises the capabilities of analytical, neural network and fuzzy logic approaches, has made it possible to expand the capabilities and improve the quality and efficiency of prescriptive analysis and modeling of the energy balance of buildings. The work identifies necessary and sufficient conditions for the minimum number and composition of input data to meet the required accuracy and reliability of the analysis results. Differences are shown for prognostic functions with daily, weekly, seasonal periodicity of energy consumption.

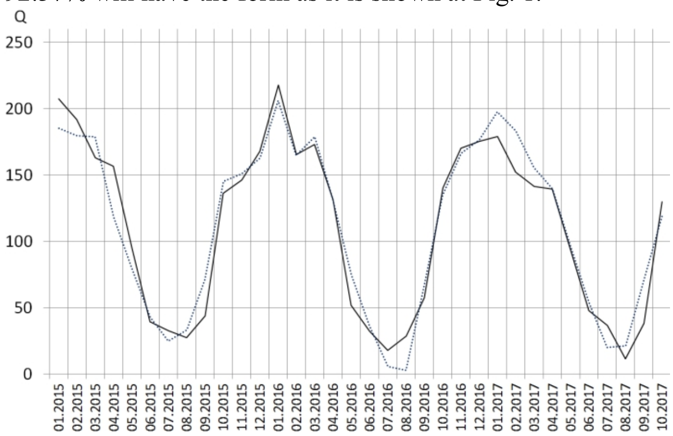
A minimal set of initial factors for constructing forecast models with an accuracy of at least 90% is proposed. Thus, when analyzing typical buildings for water sports typical for university campuses, a feasible analysis based on the five-factor regression model is shown.

Accepted: factor x1 - the average monthly outside air temperature for the period in question, ° C; x2 is the relative humidity of the outside air, %; x3 - consumption of electrical energy in the building, kWh; x4 - number of visitors to the basin during the period under review, people; x5 - time of work of power-consuming equipment (furnaces of saunas), h; y - thermal energy consumption of the building, Gcal. Design coefficients for factors have the dimension of the inverse dimension of the factors to which they relate, and multiplied by "Gcal". The dimension of the absolute term is "Gcal".

Using the created mathematical apparatus, with respect to the variables x1-x5 we obtain the predictive function with the coefficient of determination $R2 = 0.923733$:

$$y = 154.6 - x1 \cdot 5.7 - x2 \cdot 1.2 - x3 \cdot 0.00003 + x4 \cdot 0.003 + x5 \cdot 0.096 \quad (1)$$

Thus, the resulting forecast function with an accuracy of 92.37% will have the form as it is shown at Fig. 1.



— - actual heat consumption • • • - simulated heat consumption

Fig. 1. Actual and forecast functions

V. BASED ON THE MODEL METHOD OF ENERGY SAVING MEASURES SELECTION

In the course of solving the problem, a methodology was proposed for the selection of a set of measures to optimize the energy efficiency of buildings. The original model and method of choosing energy-saving measures, taking into account a flexible multi-level structure, as well as various compatibility and significance of the indicators being evaluated, are proposed. Having located all the technologies on the graph Fig. 2, where the abscissa indicates a simple payback period, and the ordinate axis - the amount of capital expenditure for the implementation of the measure, you can get a visualized technologies comparison tool in relation to the object.

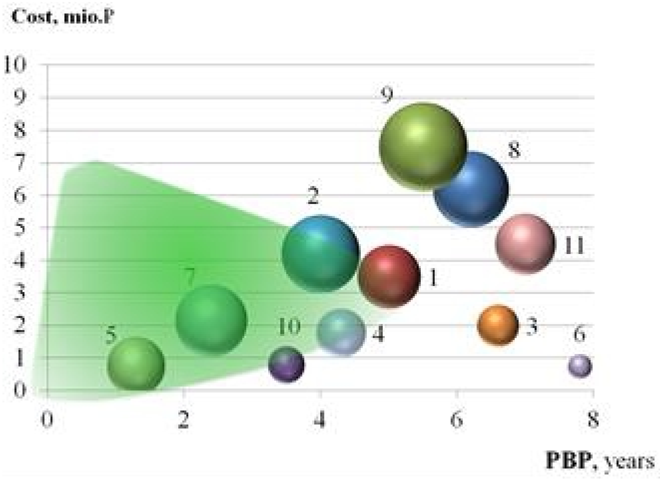


Fig. 2. Ranking of technical and economic attractiveness of energy-saving measures for the typical Moscow building of water sports (with swimming pools).

The following technologies are shown at Fig. 2:
1 - Weather-compensation control of heat consumption; 2 - Individual devices for auto-adjustment of heating systems; 3 - Rinsing of radiators and distributing pipelines; 4 - Stabilization of voltage; 5 - Ball mixers with aerators; 6 - Two-position feed at toilet bowl; 7 - LED; 8 - Heat pump; 9 - Heat pump with recuperation of wet vents; 10 - Solar thermal collector; 11 – Solar photovoltaic unit.

Green on the chart indicates the area of the most appropriate and effective technologies, suitable for use in this facility. The expediency of application here was determined by two factors described earlier - the volume of annual energy savings (proportional to the diameter of each ball in the diagram) and a simple payback period. It should be noted that the proposed model of visualization displays and allows to prioritize also technologies that have not been selected according to economic criteria.

Based on the results of the work, formats and forms for presenting the forecast data on energy consumption are proposed, taking into account the changes in the essential energy characteristics of buildings, the properties of their engineering systems, and the use of renewable energy sources. The results of this work were used by the Analytical Center under the Government of the Russian Federation [9] and the Ministry of Construction and Housing and Communal Services of the Russian Federation [10] in preparing the Methodological Recommendations for calculating the effects from the implementation of energy saving measures and improving energy efficiency of buildings.

VI. CONCLUSION

The problem of confirming and predicting the energy-saving effect due to the above-mentioned contradictions in the accumulation of heterogeneous and diverse information and the absence of typical approaches to its assessment can be solved by applying the sequence of solving key problems described in the article.

The scientific task of analyzing big data that can be used in the future to form intellectual functions of energy consumption must be solved only by using the method of combined application of algorithms for mathematical statistics and neural network algorithms.

The practical task of making decisions to improve the energy efficiency of buildings of various types can be solved only through the method of expert assessments based on visualization of the results obtained in solving key problems

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