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On the forecasting of trends of specific mixed loads of electric consumers of microdistricts and cities change in the conditions of inadequate data

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Abstract. The paper gives a brief analysis of modern methods of analysis, confirmation and prediction of specific mixed loads of electric consumers in housing estates and cities and formulates the main problems afflicting the reorganization of the industry, taking into account the requirements of digitalization of the economy. In order to identify the advantages and disadvantages of various solutions for optimizing the compilation of energy balances, a mathematical model is constructed, which allows analyzing the needs of microdistricts and cities in electrical energy and realizes the forecast of the development of urban energy systems in different socio-economic and climatic conditions.

Keywords: forecasting, approksimation, mixed electric loads, predicting FEB, quality life of the population, autoregressive model, correlation, microdistrict.

1. Introduction

Planning of operational parameters and technical and economic indicators is one of the most important tasks of the industrial and municipal complexes of the Russian Federation. One of the main indicators in planning the operation of the power system is the forecast of the expected demand for secondary energy resources in the whole system, groups and individual consumers, hubs of the power system. The need for accurate forecasting is due to technological and economic reasons. Accurate calculation provides reliability and reserve system capacity, which should be optimal from technical point of view. In the economic aspect, a correct forecast allows consumers to better plan the purchase of energy resources, taking into account changes in the tariff policy, climatic and meteorological factors, technological, social and other features.

Reducing non-production costs and specific energy consumption by 40% by 2020, as well as increasing energy efficiency by industrial and municipal systems are among the main tasks set for the energy sector and fixed in Presidential Decree of June 4, 2008 N 889 "On some measures to improve the energy and environmental efficiency of the Russian economy" and the requirements for sectoral and regional energy and resource saving programs.

The achievement of the task set by industrial and municipal systems is impossible without digitizing the tools for analyzing and planning consumption of fuel and energy resources by objects of municipal and industrial spheres of various scales, which corresponds to the "Digital Economy Development Program in the Russian Federation till 2035".

Conversion of fuel and energy balances to a digital format will allow improving the quality and reliability of energy declarations introduced instead of mandatory energy audit in accordance with the Federal Law No. 261-ФЗ "On energy saving and energy efficiency increase" dated December 23, 2009. At the same time, a significant national economic effect is to reduce the volume and cost of work both on filling energy declarations with data on fuel and energy resources in physical terms, and on aggregating their economic equivalents when making a forecast of demand for energy resources at the level of consumers and their associations, as well as for the entire power system.

2. The status of the task of forecasting the loads of mixed electricity consumers in Russia

The solution of the actual for the power industry problem of compiling forecast balances of fuel and energy resources is based on the use of complete and reliable information about the processes in equipment and the energy system as a whole. In view of the well-known specifics of the power systems, the main method of obtaining such information is the mathematical modeling [1]. Dominant today, purely numerical simulation and various software and computing systems for its implementation do not always provide the necessary completeness and reliability of the information indicated [2]. In this regard, inevitably there is a need to apply very significant simplifications and limitations, which leads to a decrease in the accuracy of the forecast [3].

As a result of insufficient theoretical development of mathematical models for forecasting fuel and energy balances (FEB) for heat supply systems of industrial and municipal facilities, there is a contradiction between the need for high-precision mathematical models and the results of calculating and predicting FEB on one hand, and the existing level of accumulation and analysis of statistical data on the another hand.

The aim of the work is to develop methods, algorithms and software tools for analyzing and planning the balances of energy resources consumed by industrial and municipal systems under conditions of insufficient data.

Achievement of the goal has been provided by consistently solving the following groups of tasks:

1. Preparation of a brief overview of the methods of energy consumption planning recommended by the current legislative and regulatory framework in order to ensure a balanced industrial and regional development of the country, as well as a description of the methodology and sufficiency of the application of specialized geo-information systems and engineering software compiling forecast balances of fuel and energy resources.

2. Assessment of the limits of applicability of the most used deterministic and stochastic information methods for planning balances of fuel and energy resources consumed by industrial and communal energy systems and forming requirements for the completeness of the array of source data sufficient to compile the predicted function of energy consumption by an object.

3. Development of principles, models and methods for improving the procedure for formulating forecast balances of fuel and energy resources for groups and individual industrial and communal systems, both using statistical methods and using artificial neural networks.

4. Testing of methods for determining the contribution to improving the accuracy of prediction by climatic and meteorological factors, technological, social and other features of the analyzed systems with the subsequent creation of a balanced set of regulatory, environmental and economic measures to stimulate the implementation of the identified reserves for improving energy efficiency.

The scientific novelty of the research resides in the development of a methodology consisting of methods and approaches, the use of which through the digitization of energy balances provides a solution to a major applied task of improving the energy efficiency of industrial and municipal heat and power systems in conjunction with industrial and regional economic development.

The practical value of conducting industrial experiments and energy audits of a number of enterprises of energy-intensive industries is to accomplish the state goal of a 40% reduction in the energy intensity of GDP by 2020 compared with 2007 and to determine priorities for using approaches to digitization of the energy sector and reducing the cost of energy balances by automating the procedure for forecasting the volume of consumption of fuel and energy resources of industrial and municipal consumers in the conditions of insufficient data.

3. General formulation of the problem and solution methodology

In the period from 2008 to 2016 12 regulatory documents were issued on the items of calculating and forecasting energy-saving effect, incl. taking into account comparable conditions (figure 1). Let us consider in more detail some provisions relating to the issues of forecasting the fuel and energy resources consumption.

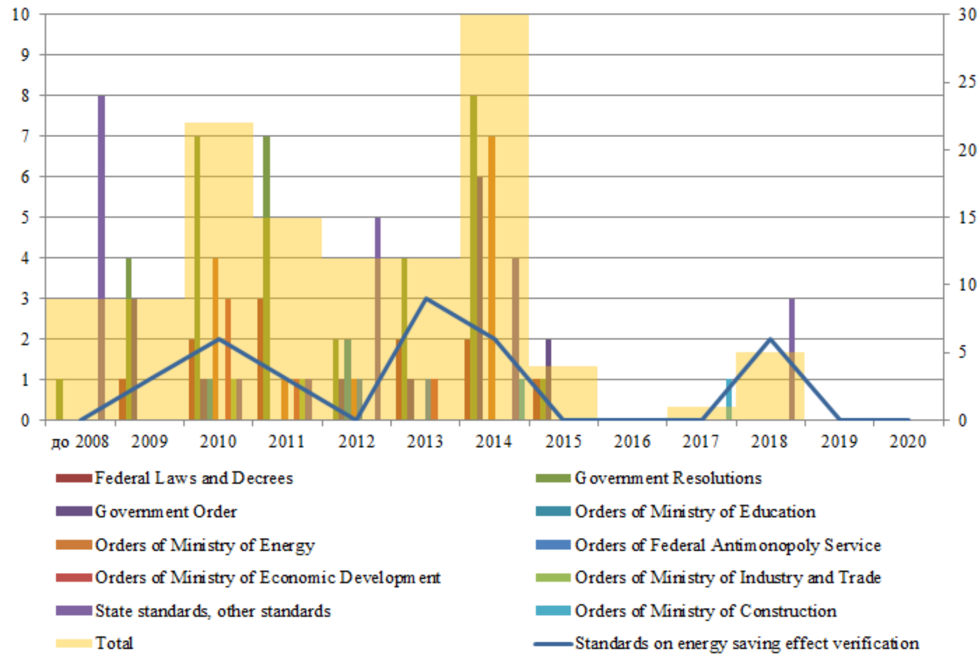

Figure 1. The intensity of the publication of the regulatory framework for energy saving and energy efficiency [4]

In order to improve the performance of the Federal Law # 261 [5], in 2010 a method was introduced for calculating the values of target indicators in the field of energy saving and energy efficiency, including in comparable conditions [6]. This document defines the procedure for calculating the target indicators of regional and municipal programs in the field of energy saving and energy efficiency. Target indicators are determined by calculating the shares and ratios of indicators of the estimated year and the year preceding the year when the implementation of regional and municipal programs began. The mathematical apparatus proposed in the document is primarily focused on analytics [7] of the activities included into regional and municipal programs of the subjects of the Russian Federation, and is not intended for use in the preparation of energy consumption forecasts of the analyzed regions. At the same time, the inaccuracy of the data, their partial unreliability leads to the need to use mathematical tools suitable for prediction in conditions of insufficient data [8].

The method of direct counting [9] used in a number of documents in combination with the method of direct extrapolation, which consists in predicting through the transfer of events and states of the past to the future, makes it possible to determine the need for energy resources. To use the method, the stability of the process of energy consumption of the object and the absence of a sharp influence of qualitative and quantitative changes in power/weight ratio are necessary. In determining the maximum load [10], this method uses a technique based on the calculation of specific values as a function of the number of power receivers: apartment, workshop, factory, city, region. In general, the technique is determined by the expression:

$$\mathrm{P}_{flat\ sp.} = \mathrm{a} + \frac{\mathrm{b}}{\sqrt{\mathrm{n}}}, \tag{1}$$

where n is the number of apartments in the object;
a, b - coefficients corresponding to housing with one of V following types of electrification:
I. with natural gas stoves;
II. with LPG / solid fuel stoves;
III. with electric stoves up to 8.5 kW;
IV. with electric stoves up to 10.5 kW; with luxury apartments;
V. with household air conditioners.

This approach, when moving to the level of a microdistrict and above, is not very useful due to the almost complete absence of reliable information suitable for analysis.

Forecasting methods based on statistical processing of time series [11] carry out forecasting of loads and modes of energy system objects interconnected in a hierarchical tree structure. StatPlus [12], Statgraphics [13], Exel [14], StatSoft Statistica [15], Deductor academic [16], Gretl [17], JMulTi [18], EViews [19], SPSS Statistics [20] - software packages regression and econometric models of time series, realizing the estimation of parameters by the method of least squares [21], the maximum likelihood method, the generalized method of moments [22], the autoregressive model [23], the moving average, etc.

4. Materials and Methods: drawing up the forecast function of power consumption, city of Anadyr

For the analysis, the power supply system of the town of Anadyr was selected, receiving electrical energy from two sources (figure 2). The distinctive feature of the power system is its isolation from the country's unified power system. The not quite exact correspondence of the volumes supplied to the network and the consumed electric energy indicates the absence of the ASTUE system. According to the data for 2017, the error from the manual collection of data on electrical consumption is 4.1%. We would apply the mathematic apparatus for analyzing statistical data in the conditions of their insufficiency and partial unreliability for further analysis.

An analysis of the total electricity consumption of the town of Anadyr including utilities, street lighting, road infrastructure, enterprises [24], etc. was carried out on the basis of hourly data for 2017. Regression analysis was carried out on the basis of determining the correlation for 7 factors:

1. T - air temperature at a height of 2 meters above the ground, ºC;
2. P0 - atmospheric pressure at the station level, mm Hg;
3. U - relative humidity at a height of 2 meters above the surface of the earth, %;
4. DD - the angle of the wind direction at a height of 10-12 meters above the earth's surface, averaged over a 10-minute period immediately preceding the observation period, m / s;
5. FF - wind speed at a height of 10-12 meters above the earth's surface, averaged over a 10-minute period immediately preceding the time of observation, m / s;
6. N - total cloudiness, %;
7. P - duration of daylight hours, min.

The use of regression analysis with $R^2 = 0.8448$ allowed to describe the following dependence of the power consumption of the city:

$$W = 2923.2 - 53.1 \cdot T + 3.4 \cdot P0 + 2.6 \cdot U - 0.4 \cdot DD + 21.8 \cdot FF + 267.9 \cdot N + 1.4 \cdot P \tag{2}$$

Using a polynomial definition with $R^2 = 0.8669$ allowed to reveal a similar relationship (figure 3):

$$W = -5E\text{-}06x4 + 0.0041x3 - 0.9798x2 + 62.434x + 5321.7 \quad (3)$$

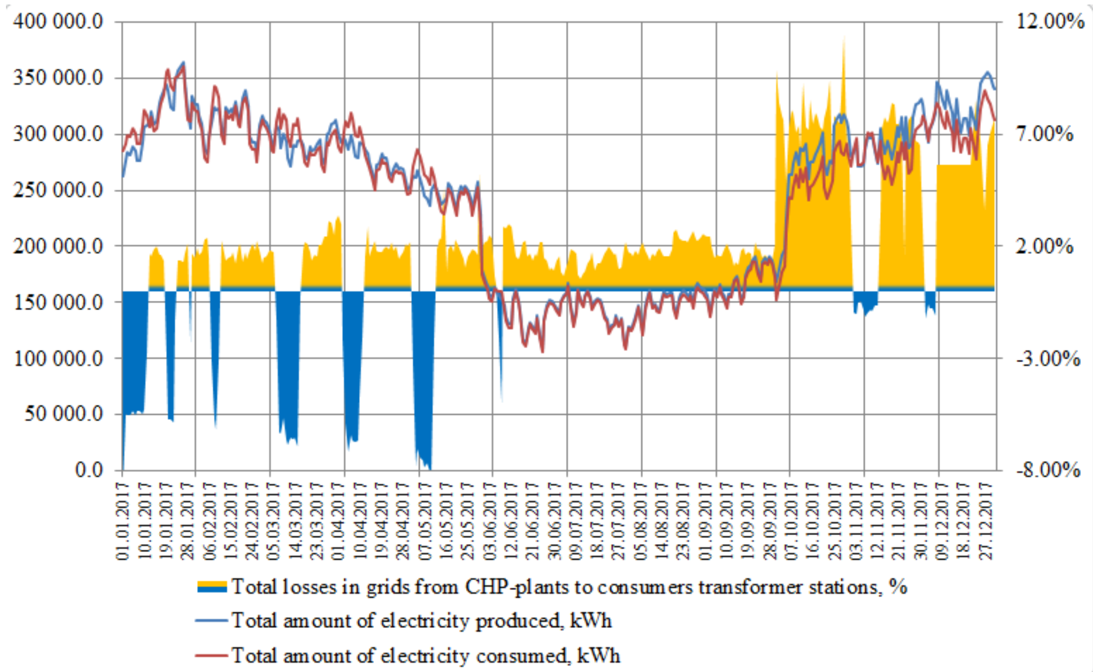

Figure 2. The production and consumption of electricity in town of Anadyr

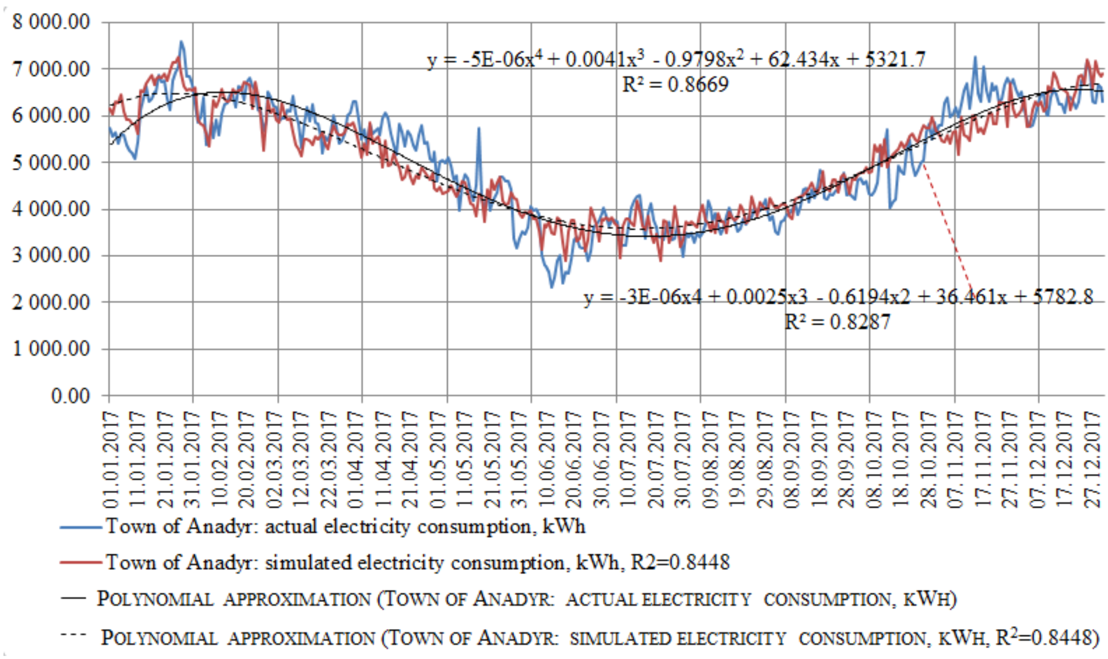

Figure 3. Analysis of electricity consumption in Anadyr

Despite the rather high correlation coefficient of the correspondence of the polynomial to the actual values, the use of such an approach to predict power consumption is impossible, due to the lack of consideration of a number of influencing factors [25].

The significance of the impact of climatic factors has been analyzed based on the data received (table 1).

Table 1. The significance of the impact of climatic factors on the power consumption of the town of Anadyr

T, °C	P_0, mm Hg	U, %	DD	FF, m/c	N, %	P, min
15.1%	1.0%	0.8%	0.1%	6.2%	76.3%	0.4%

Obviously, the largest dependence in 76.3% with the power consumption of the city is shown by the factor N - total cloudiness. At the same time, an additional analysis of the correlation between the power consumption of the city and the wind direction with a breakdown of the wind rose with a frequency of 22.5° (figure 4), taking into account the directional pattern of the city's roads, did not reveal such a connection.

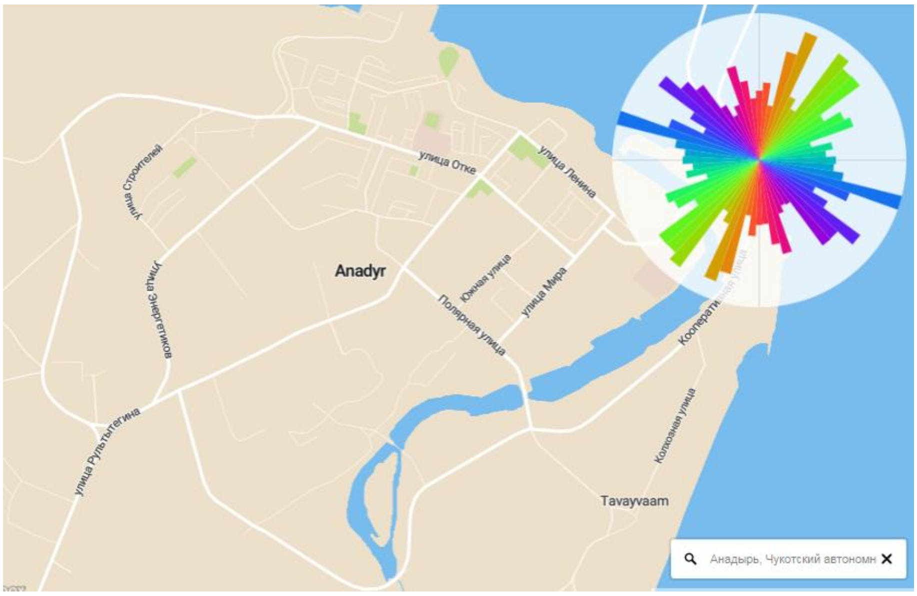

Figure 4. Visualization of the orientation of the streets of Anadyr on an interactive map [26]

5. Results: Analysis of trends in the change of specific loads of electric consumers in Moscow microdistrict and the administrative center of Anadyr

The total area of housing in the town of Anadyr [27] is 335.8 thousand square meters. The housing stock of the city has 157 houses [28] and a total of 5,405 apartments. The population is 15604 people. The total power consumption of the city is 1 849 332.41 kWh per year. For comparison, we took the electricity consumption data from 12 residential buildings in the Lyublino district of Moscow. The total area of housing is 111 394.00 sq.m., and it has 1935 apartments. The population is 5347 people. The total electricity consumption is 387 339.59 kWh per year, taking into account the fact that this figure does not take into account other electric consumers in the area other than electricity consumption by residential buildings. The results of the calculation of various specific values of power consumption are presented in table 2.

Table 2. The calculated specific values of the consumed electrical energy of the town of Anadyr and the microdistrict of Lyublino of Moscow city

Specific power consumption	Wh / 1 м^2	Wh / 1 pers.	Wh / 1 flat	Wh /(1pers. 1 м^2)
Anadyr	0,628	345,86	342,15	0,35293
Moscow	0,396	291,96	806,77	0,06589

Such a discrepancy of values can be explained by the working hypothesis that Moscow has now achieved a higher level of energy intensity of residential buildings due to a higher standard of living [29]. At the same time, a higher standard of living leads to the purchase of appliances that have lower power consumption due to a higher energy efficiency class, which somewhat reduces the specific power consumption.

From the point of view of the current regulatory documentation [30] on the design of newly constructed and reconstructed electrical networks of cities, districts and microdistricts, there are approved specific values of energy consumption (table 3), similar to those calculated.

Table 3. Normative specific values of the consumed electric energy of the town of Anadyr and the microdistrict of Lyublino, city of Moscow

		Anadyr	microdistrict of Moscow
кW / 1 м^2	Actual specific value, including all loads, кW / 1 м^2	0,628	0,3969
	Specific value according to RD 34.20.185-94, кW / 1 м^2	0,093	0,109
кW / 1 pers.	Actual specific value, кW/pers.	0,34586	0,29196
	Specific value according to RD 34.20.185-94, кW/pers.	0,528 (allowable range 0,396 – 0,528)	~0,27 (allowable range 0,24-0,32)
кW / 1 flat	Actual specific value, кW/ flat	0,34215	0,80677
	Specific value according to RD 34.20.185-94, кW/flat	0,620125	0,620125

These figures take into account the following electric loads: dwellings, public buildings (administrative, educational, scientific, medical, commercial, entertainment, sports), communal utilities, outdoor lighting, electric transport (non-metro), water supply and sewerage systems, heat supply systems. The central areas of the city include established areas with a significant concentration of various administrative institutions, educational, scientific, design organizations, trade, public catering, entertainment enterprises, etc. Due to incomparable conditions, the specific electricity consumption per 1 m^2 is not analyzed, because in the data of the town of Anadyr, all the loads of the town have been taken into account, while the normative specific indicators show values that take into account only the load of residential buildings.

The forecast of trends in the change in specific loads of electricity consumers in microdistricts and towns under conditions of insufficient data shows that, according to the parameter "specific electricity consumption per person" (figure 5), the housing stock of the city of Anadyr has a growth potential of 52.6%. At the same time, the Moscow microdistrict demonstrates the excess of specific power consumption by 8.1%.

According to the parameter "specific electricity consumption per apartment" (figure 6), the housing stock of the city of Anadyr has a growth potential of 81.5%. The difference between the levels of electricity consumption for an apartment for the administrative center of Anadyr and the microdistrict of Moscow, which are similar to housing standards, is 136%. At the same time, the Moscow microdistrict demonstrates the excess of specific power consumption by 29.9%.

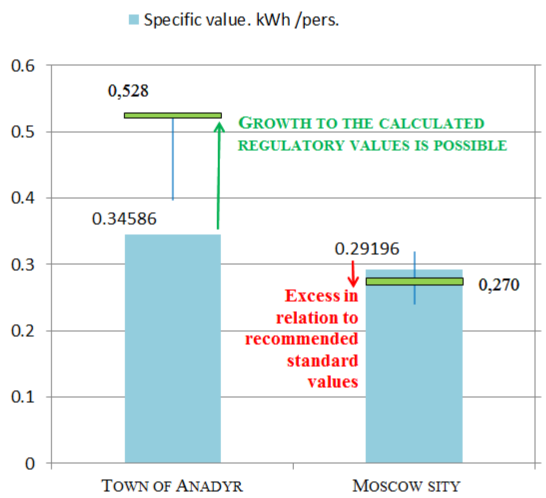

Figure 5. The results of the analysis of specific energy consumption per person.

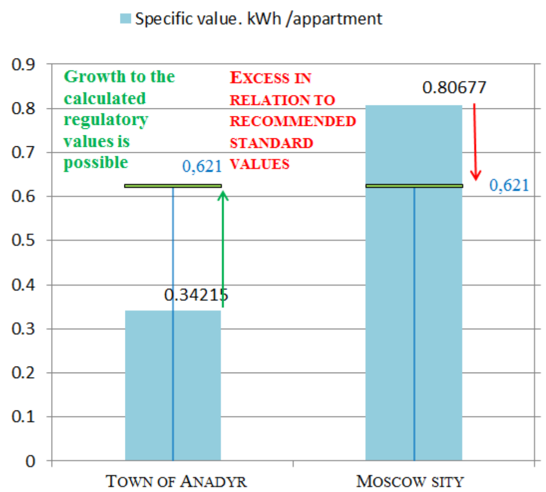

Figure 6. The results of the analysis of specific energy consumption per apartment

6. Conclusions:

1. The approach of using regression models is suitable to solve the problems of forecasting the volume of electricity consumption of mixed loads of housing estates and cities in the conditions of insufficient data accuracy.

2. The assessment of the impact of the quality of life of the population on the level of electricity consumption by housing is given. The difference in the actual specific power consumption for Anadyr and Moscow is 136%.

3. The discrepancy between the values of specific amounts of electrical consumption in RD 34.20.185-94 "Instructions for the design of urban electrical networks" and the actual levels of specific power consumption is shown. The above method can be used to update obsolete specific values.

4. The proposed approach can be used to predict energy demand, taking into account the aging factors of buildings and networks, increasing comfort and loads, renovation, urbanization of suburbs, etc.

Acknowledgments
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