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СЕЗОННЫЕ И ДОЛГОСРОЧНЫЕ ТЕНДЕНЦИИ ЭЛЕКТРОПОТРЕБЛЕНИЯ ТЕХНОЛОГИЧЕСКИХ ПОДРАЗДЕЛЕНИЙ ГОРНО-ОБОГАТИТЕЛЬНОГО КОМБИНАТА

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Аннотация: Рассмотрена проблема повышения энергоэффективности горнодобывающих предприятий, которая напрямую влияет на себестоимость продукции и конкурентоспособность отрасли. Несмотря на устойчивый рост электропотребления, многие предприятия не используют системный подход к нормированию, учету и прогнозированию энергозатрат. Объект исследования: система электроснабжения Маднеульского горно-обогатительного комбината. Целью работы является проведение комплексного анализа энергопотребления предприятия, выявление закономерностей и зависимостей, разработка регрессионных моделей для прогнозирования потребления электроэнергии и предложение мер по оптимизации режимов работы оборудования. Использовались методы статистического анализа, регрессионного моделирования (линейная, экспоненциальная и параболическая аппроксимация), критерий Фишера для проверки адекватности моделей, расчет доверительных интервалов, а также анализ временных рядов электропотребления за 5-летний период. Построены регрессионные модели электропотребления для каждого подразделения, выявлены сезонные зависимости, рассчитаны среднеквартальные и среднегодовые показатели, определены доверительные интервалы. Установлено, что наиболее значимые сезонные колебания наблюдаются в подразделениях вскрыши, погрузки баритовой руды, добычи и дробления базальтового камня. Предложено использовать линейные регрессионные модели для инженерных расчетов как наиболее простые и адекватные. Выявлены подразделения с нестабильным и стабильным энергопотреблением, что позволяет дифференцировать подход к энергосбережению. Результаты исследования могут быть использованы для разработки программ энергосбережения, планирования закупок электроэнергии, оптимизации тарифных решений и внедрения автоматизированных систем контроля и учета энергоресурсов.

Ключевые слова: горно-обогатительный комбинат, электропотребление, регрессионный анализ, математическое моделирование, доверительный интервал, критерий Фишера, сезонные колебания, оптимизация режимов, энергосбережение.

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Seasonal and long-term trends in power consumption of technological units of the mining and processing plant

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Abstract: The article is devoted to the urgent problem of increasing the energy efficiency of mining enterprises, which directly affects the cost of production and the competitiveness of the industry. Despite the steady growth of electricity consumption, many enterprises do not use a systematic approach to rationing, accounting and forecasting energy costs. Object of study: the power supply system of the Madneulsky Mining and Processing Plant. The purpose of the work is to conduct a comprehensive analysis of the enterprise's energy consumption, identify patterns and dependencies, develop regression models for forecasting electricity and propose measures to optimize equipment operating modes. The methods of statistical analysis, regression modeling (linear, exponential and parabolic approximation), Fisher's criterion for checking the adequacy of models, calculation of confidence intervals, as well as analysis of time series of electricity consumption over a 5-year period were used. Regression models of power consumption for each division were built, seasonal dependencies were identified, average quarterly and average annual indicators were calculated, confidence intervals were determined. It was found that the most significant seasonal fluctuations were observed in the overburden, barite ore loading, basalt stone mining and crushing divisions. It was proposed to use linear regression models for engineering calculations as the simplest and most adequate. Divisions with unstable and stable power consumption were identified, which allows differentiating the approach to energy saving. The results of the study can be used to develop energy saving programs, plan electricity purchases, optimize tariff decisions and implement automated energy resource monitoring and accounting systems.

Key words: mining and processing plant, power consumption, regression analysis, mathematical modeling, confidence interval, Fisher criterion, seasonal fluctuations, optimization of modes, energy saving.

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Introduction

The strategic documents of the Russian energy industry emphasize the key role of scientific developments in optimizing production processes. Special attention is paid to improving the efficiency of electricity use and the introduction of resource-saving technologies. In mining enterprises, the steady growth in electricity consumption is directly related to the need to save energy and improve the quality of its use [1, 2]. Despite this, many enterprises still do not pay due attention to a systematic approach to this problem: there is no in-depth analysis of established electricity consumption standards and potential ways to reduce power consumption through modernization and the introduction of innovative solutions are not explored. In addition, the importance of forecasting the volume of electricity consumption is ignored, which is a critical element for proper planning and the establishment of reasonable standards [3, 4].

There is a widespread tendency for enterprises to focus on meeting production targets, leaving energy efficiency issues in the background. This leads to significant financial losses and a decrease in overall competitiveness. Consequently, the development and implementation of integrated energy saving programs, including modern monitoring systems and automated energy control [5, 6], is becoming not just a recommendation, but an urgent necessity for the sustainable development of the industrial sector.

In this regard, the analysis of energy consumption at mining and processing plants and optimization of operating modes of basic electrical equipment such as excavators and drilling rigs are of particular importance [7]. Carrying out such work makes it possible to identify potential areas for reducing energy costs and ultimately increase the overall economic efficiency of mining operations [8, 9].

The object of the study is the power supply system of the Madneupolsky Mining and Processing Plant.

Brief description of the research object

The Madneupolsky Mining and Processing Plant is a large industrial enterprise located in Russia, specializing in the extraction and processing of minerals. The main products of the plant are copper and barite ore, as well as basalt stone. The combine conducts large–scale open-pit mining of deposits. The Madneupolsky Mining and Processing Plant is characterized by a complex energy economy, since the main production processes, such as the operation of excavators, crushing plants, drilling rigs and loading equipment, require significant energy costs. This makes the issues of energy efficiency and optimization of electricity consumption especially important for reducing the cost of production and increasing the overall profitability of production. Thus, The Madneupolsky Mining and Processing Plant is one of the most important resource-intensive mining facilities, where effective control of energy and technological processes plays a critical role in the sustainable development of the enterprise.

Research methods

When conducting a comprehensive energy survey of The Madneupolsky Mining and Processing Plant, the following methods should be used:

- collection and processing of data on actual electricity consumption for various periods; comparison with regulatory (planned) indicators; identification of seasonal and technological fluctuations;
- systematic inspection of the company's power supply system; evaluation of the efficiency of electrical equipment; identification of losses in networks and transformers;
- development of specific electricity consumption rates per unit of production (1 ton of ore, 1 m^3 of rock mass, etc.); comparison with industry standards and indicators of similar enterprises;
- use of metering devices (meters, sensors, electricity quality analyzers); load measurements at key sites (transformer substations, motors, conveyors); implementation of automated control systems;
- creation of mathematical and computer models of the power system operation; forecasting of power consumption in case of changes in production conditions; analysis of scenarios for the introduction of energy-saving technologies [10, 11];
- technical and economic analysis: estimation of the cost of electricity in the cost structure of production; calculation of the economic efficiency of equipment modernization; determination of optimal tariff solutions;
- investigation of equipment operating modes: analysis of efficiency of electric

motors, pumps, fans, etc. [12, 13]; identification of "bottlenecks" with increased energy consumption; testing of alternative operating modes (frequency control, optimization of inrush currents) [14].

The indicators of electricity consumption for each division are recorded in the memory of electronic meters. These data serve as the primary basis for the subsequent analysis of load graphs. Since the operation of technological equipment can be uneven, this leads to significant fluctuations in the level of power consumption. These fluctuations are observed within different time intervals, from daily to annual. In this regard, the key task of the analysis is not only to identify these deviations, but also to assess their impact on specific energy consumption, as well as to find ways to smooth them out. In addition, as part of the analysis, it becomes necessary to calculate the mathematical expectation of the level of electricity consumption for the selected period (month, quarter or year). This value represents the average expected amount of consumption. To estimate the spread of data around this average, a confidence interval is calculated, which clearly demonstrates the range of possible fluctuations. Both of these parameters are determined using mathematical statistics methods, which ensures the accuracy and objectivity of the conclusions.

Modeling of the average loads of a mining and processing plant over a monthly period

To identify cyclical patterns in the change in the level of electricity consumption within each month for a period of 5 years, it is necessary to conduct an appropriate analysis [15, 16]. For this purpose, it is necessary to create average monthly load schedules for all structural departments of the quarry. These graphs will display the dynamics of average monthly electricity consumption calculated over a five-year interval. The calculation of the monthly average power consumption (W_m) is performed as the arithmetic value of consumption for a specific month i for all years of the observed period:

$$\bar{W}_{m.i} = \frac{\sum_{j=1}^{n} W_{m.i,j}}{n}, \qquad (1)$$

where i — the month number; j — the year number; n — the number of years.

According to the power consumption data obtained at the The Madneupolsky Mining and Processing Plant quarry using expression (1), the average monthly values of power consumption for the quarry units were calculated, which are shown in Figure, *a*, *b*.

Based on the data presented in Figure, a regression analysis was performed using specialized software. To mathematically describe the dependence of the level of power consumption on the ordinal number of the month and increase the accuracy of the model, approximating functions were selected in the form of the following regression equations:

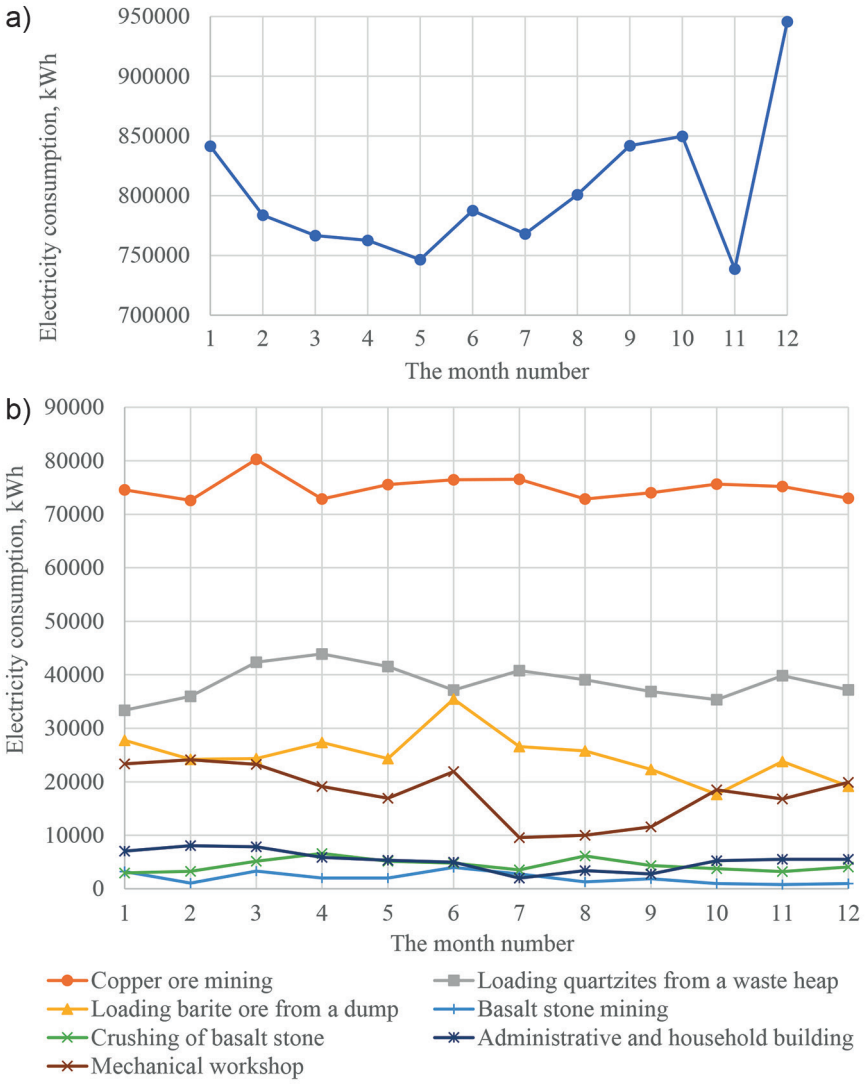
$$W_m = a_0 + a_1 \cdot i, \qquad (2)$$

$$W_m = a_0 \cdot \exp(a_1 \cdot i), \qquad (3)$$

$$W_m = a_0 + a_1 \cdot i + a_2 \cdot i^2, \qquad (4)$$

where a_0, a_1, a_2 — coefficients determined by the least squares method.

The adequacy of the regression equations (2) — (4) is determined using the Fisher criterion. The width of the confidence interval is determined using the Student's coefficient ($t_{\alpha,k}$). The coefficient value was chosen for a confidence probability of $p = 0.95$, which corresponds to a significance level of $\alpha = 0.05$ for the total number of observations $n = 12$. With these parameters, the number of degrees of freedom was $k = n - 2 = 10$, which corresponds to the tabular value of the *t*-criterion $t_{(0,05;\,10)} = 2.23$.



Average monthly values of electricity consumption by divisions of the quarry of the mining and processing plant

Среднемесячные значения электропотребления по подразделениям карьера горно-обогатительного комбината

Table 1 shows the obtained dependences of electricity consumption by quarry divisions of the mining and processing plant. The equations have linear (2), exponential (3), and parabolic forms (4).

The values of the pairwise correlation coefficient r, which characterizes the closeness of the relationship between the power consumption of W_m and the month number i, are shown in Table 2.

For example, Table 3 shows the results of checking regression equations for adequacy using the Fisher criterion for linear regression equation (2).

A similar check was carried out for equations (3), (4). As can be seen from

Table 1

Dependence of electricity consumption by divisions of a quarry of a mining and processing plant
Зависимости потребления электроэнергии по подразделениям карьера горно-обогатительного комбината

No.	Division name	The equation of dependence
1	Overburden	$W_m = 7{,}61 \cdot 10^5 + 6{,}49 \cdot 10^3 \cdot i$ $W_m = 7{,}63 \cdot 10^5 \cdot e^{0{,}0075 \cdot i}$ $W_m = 8{,}47 \cdot 10^5 - 3{,}04 \cdot 10^4 \cdot i + 2{,}83 \cdot 10^3 \cdot i^2$
2	Copper ore mining	$W_m = 7{,}56 \cdot 10^5 - 99{,}2 \cdot i$ $W_m = 7{,}55 \cdot 10^4 \cdot e^{-0{,}00126 \cdot i}$ $W_m = 7{,}42 \cdot 10^4 + 5{,}08 \cdot 10^2 \cdot i - 46{,}7 \cdot i^2$
3	Loading of quartzite from the dump	$W_m = 3{,}89 \cdot 10^4 - 47{,}3 \cdot i$ $W_m = 3{,}86 \cdot 10^4 \cdot e^{-0{,}000635 \cdot i}$ $W_m = 3{,}44 \cdot 10^4 + 1{,}86 \cdot 10^3 \cdot i - 146 \cdot i^2$
4	Loading of barite ore from the dump	$W_m = 2{,}78 \cdot 10^4 - 5{,}74 \cdot i$ $W_m = 2{,}81 \cdot 10^4 \cdot e^{-0{,}0254 \cdot i}$ $W_m = 2{,}53 \cdot 10^4 + 449 \cdot 10^3 \cdot i - 77{,}6 \cdot i^2$
5	Basalt stone mining	$W_m = -3{,}22 \cdot 10^2 + 665 \cdot i$ $W_m = 1{,}84 \cdot 10^3 \cdot e^{0{,}0333 \cdot i}$ $W_m = 7{,}47 \cdot 10^3 - 2{,}93 \cdot 10^3 \cdot i + 299{,}6 \cdot i^2$
6	Crushing of basalt stone	$W_m = 2{,}73 \cdot 10^3 + 639{,}4 \cdot i$ $W_m = 2{,}85 \cdot 10^3 \cdot e^{0{,}146 \cdot i}$ $W_m = 15{,}7 + 2{,}68 \cdot 10^3 \cdot i - 291{,}3 \cdot i^2$
7	Administrative and household building	$W_m = 2{,}18 \cdot 10^3 - 288{,}3 \cdot i$ $W_m = 6{,}94 \cdot 10^3 \cdot e^{-0{,}0523 \cdot i}$ $W_m = 1{,}02 \cdot 10^4 - 1{,}58 \cdot 10^3 \cdot i + 99{,}5 \cdot i^2$
8	Mechanical workshop	$W_m = 2{,}26 \cdot 10^3 - 727 \cdot i$ $W_m = 2{,}22 \cdot 107 \cdot e^{-0{,}0403 \cdot i}$ $W_m = 3{,}05 \cdot 10^4 - 4{,}09 \cdot 10^3 \cdot i + 258{,}7 \cdot i^2$

Table 2

Values of the pair correlation coefficient for the electricity consumption regression equations
Значения величины коэффициента парной корреляции для уравнений регрессии электропотребления

Number of divisions	1	2	3	4	5	6	7	8
r	0,4007	–0,1627	–0,0479	–0,6742	0,4076	0,7625	–0,5553	–0,0851

the data obtained in Table 3, the ratio is fulfilled for all divisions and for the three selected types of regression equations: $F(\alpha, k_1, k_2) < F_{calc}$, which indicates the adequacy of all the dependencies obtained. This gives reason to assert that all the dependencies obtained are valid and can be used for calculations. As the simplest for engineering calculations, the linear dependence of W_m on i is recommended. According to the information presented in Table 3, the most pronounced correlation between power consumption (W_m) and the time factor is observed in the following quarry production areas: stripping operations, loading of barite ore from the dump,

Table 3

Results of testing the regression equations for adequacy using the Fisher criterion for a linear regression equation
Результаты проверки уравнений регрессии на адекватность с использованием критерия Фишера для линейного уравнения регрессии

Number of divisions	α	k_1	k_2	m	S_1^2, $(kWh)^2$	W, kWh	W_1, kWh	$W_{risidual}$, kWh	$F(\alpha, k_1, k_2)$	$F_{calc.}$
1	0,05	1	10	5	$3{,}15 \cdot 10^3$	$3{,}75 \cdot 10^{10}$	$1{,}25 \cdot 10^{10}$	$2{,}5 \cdot 10^{10}$	4,96	5,05
2	0,05	1	10	5	$5{,}18 \cdot 10^6$	$2{,}99 \cdot 10^7$	$1{,}04 \cdot 10^7$	$1{,}95 \cdot 10^7$	4,96	5,3
3	0,05	1	10	5	$1{,}1 \cdot 10^7$	$1{,}07 \cdot 10^8$	$4{,}38 \cdot 10^7$	$6{,}32 \cdot 10^7$	4,96	6,9
4	0,05	1	10	5	$5{,}66 \cdot 10^6$	$6{,}03 \cdot 10^7$	$2{,}26 \cdot 10^7$	$3{,}77 \cdot 10^7$	4,96	6
5	0,05	1	10	5	$2{,}71 \cdot 10^7$	$2{,}02 \cdot 10^8$	$8{,}13 \cdot 10^7$	$1{,}21 \cdot 10^8$	4,96	5,41
6	0,05	1	10	5	$1{,}29 \cdot 10^6$	$2 \cdot 10^6$	$1{,}28 \cdot 10^6$	$7{,}2 \cdot 105$	4,96	6,3
7	0,05	1	10	5	$2{,}67 \cdot 10^6$	$2{,}9 \cdot 10^7$	$1{,}07 \cdot 10^7$	$1{,}83 \cdot 10^7$	4,96	5,82
8	0,05	1	10	5	$2{,}17 \cdot 10^7$	$1{,}02 \cdot 10^9$	$8{,}67 \cdot 10^8$	$1{,}53 \cdot 10^8$	4,96	5,61

Table 4

Dependence of average quarterly electricity consumption by technological divisions of the mining and processing plant quarry
Зависимость среднеквартального электропотребления по технологическим подразделениям карьера ГОК

Number of blocks	I	II	III	IV
W_q, kWh	Overburden (No. 1)			
	2 406 820	2 296 640	2 410 720	2 174 600
	Copper ore mining (No. 2)			
	227 483	224 833	223 400	224 300
	Loading of quartzite from the dump (No. 3)			
	114 280	122 580	116 720	123 275
	Loading of barite ore from the dump (No. 4)			
	72 287	77 166	77 111	52 137
	Basalt stone mining (No. 5)			
	7634	8033	3200	1800
	Crushing of basalt stone (No. 6)			
	11 435	18 401	15 378	16 121
	Administrative and household building (No. 7)			
	22 400	15 120	7800	16 000
	Mechanical workshop (No. 8)			
	71 180	57 960	32 980	54 375

Table 5

Statistical indicators of quarterly electricity consumption
Статистические показатели квартального электропотребления

Number of divisions	1	2	3	4	5	6	7	8
M, kWh	2 322 195	224 991	119 214	69 675	5 167	14 700	15 330	54 124
S_n, kWh	111 705	1732	4415	11 914	1174	1039	3279	11 591
$t_{\alpha,k} S_n$, kWh	480 331	7447	1897	51 229	5050	13 200	14 100	51 131

extraction and crushing of basalt stone, as well as the administrative and household building. For copper ore mining units, quartzite loading from the dump, and a machine shop, the dependence of power consumption is largely determined by random factors, which corresponds to the nature of the work of these units.

Investigation of averaged quarterly electrical load schedules

To analyze power consumption within a quarter, it is necessary to consider the average quarterly schedules of electrical loads for all quarry units [17, 18]. Similarly, as in the analysis of the averaged monthly load schedules, the values of power consumption W_q are determined. These data are shown in Table 4.

The results of the statistical analysis of the information contained in Table 4 indicate that electricity consumption in all production areas of the quarry within the quarter corresponds to a normal distribution.

Table 5 shows the key statistical indicators calculated on the basis of these data: mathematical expectation (M), standard deviation (S_n) and confidence interval ($t_{\alpha,k}$, S_n).

Study of annual electrical load schedules

To analyze the annual electricity consumption for a number of years from 2011 to 2015, it is necessary to consider the annual schedules of electrical loads for all departments of the quarry.

Similarly, as in the analysis of the averaged monthly and quarterly load schedules, the values of power consumption W_y are determined. These data are shown in Table 6.

Table 6 is a valuable data source that makes it possible to analyze the dynamics of an enterprise's energy consumption over 5 years. The key conclusion is that the total power consumption of the quarry has a pronounced tendency to decrease significantly. This indicates large-scale changes in production activities, technological processes, or targeted energy conservation efforts. The analysis of Table 6 makes it possible to analyze individual mining and processing plant units in terms of energy consumption and process characteristics.

• Group 1: Units with a significant reduction in energy consumption (more than 30%).

1. Overburden (No. 1).

Dynamics: The most energy-intensive division. Consumption fell from 11.35 million kWh in the first year to 7.52 million kWh in the last (a decrease of ~34%). Stripping (removal of waste rock to access ore) is the most energy–intensive process in a quarry, usually performed with powerful equipment (excavators, bulldozers, dump trucks). Such a significant decrease indicates one or more factors: reduction of overburden volumes: transition to mining at the lower horizons of the quarry, where less overburden is required; technology optimization: introduction of more efficient opening schemes that reduce the volu-

Table 6

Dependence of annual electricity consumption by technological divisions of the mining and processing plant quarry for 5 years
Зависимость годового электропотребления по технологическим подразделениям ГОК за 5 лет

Years	1	2	3	4	5
W_y, kWh	Overburden (No. 1)				
	11 349 000	10 350 800	9 448 200	7 771 000	7 524 900
	Copper ore mining (No. 2)				
	607 900	731 900	1 360 100	992 400	989 530
	Loading of quartzite from the dump (No. 3)				
	535 000	456 600	515 900	546 000	203 700
	Loading of barite ore from the dump (No. 4)				
	461 000	167 506	238 700	249 200	453 200
	Basalt stone mining (No. 5)				
	41 200	10 700	30 760	34 100	35 340
	Crushing of basalt stone (No. 6)				
	32 400	28 780	12 200	42 300	37 560
	Administrative and household building (No. 7)				
	58 000	58 600	40 900	65 000	52 600
	Mechanical workshop (No. 8)				
	58 000	58 600	53 300	65 000	52 600

me of rocks being moved; equipment replacement: transition to more modern and energy-efficient equipment (for example, excavators with an energy recovery system). In this department, first of all, it is necessary to conduct an analysis of the effectiveness of energy conservation measures. The reduction here gives the maximum economic effect.

2. Loading of quartzite from the dump (No. 3).

Dynamics: A sharp drop from 535 thousand kWh (1 year) to 203.7 thousand kWh (5 year) (a decrease of ~62%). Loading from the dump means working with previously extracted and stored material. Such a sharp drop, especially in the last year, may mean: the cessation of mining of this dump; a change in the technological scheme: perhaps quartzites are no longer stored in the dump, but immediately go for processing, or their extraction is stopped.

• Group 2: Divisions with unstable dynamics (cyclical or changing trends).

1. Copper ore mining (No. 2).

Dynamics: severe instability. Growth in the third year reached a peak (1.36 million kWh), followed by a decline. This division is a key stage of production. Fluctuations directly reflect changes in ore production volumes. The peak in the third year may be associated with the development of a rich site, the introduction of new equipment or the fulfillment of a large order. A subsequent decrease may indicate depletion of reserves at a particular site, a decrease in the metal content in the ore (more work is required to obtain the same volume of concentrate), or a general decrease in production plans. High volatility of consumption

makes it difficult to plan energy supply. It is necessary to make forecasts that are closely related to the mining plan.

2. Loading of barite ore from the dump (No. 4).

Dynamics: very unstable schedule. A sharp decline in the second year, followed by an increase in the last year. Similar to the loading of quartzites, this is mainly due to working with dumps. An analysis of the dynamics suggests that in the second or third year, the stored ore was almost not shipped, but by the fourth or fifth year, demand for it appeared again, and the dump began to be developed. This production has a pronounced "spot" character, its energy consumption is unpredictable and depends solely on market conditions.

- Group 3: Units with stable low consumption.

1. Basalt stone mining (No. 5) and crushing (No. 6).

Dynamics: low and relatively stable energy consumption with small fluctuations. This is probably an auxiliary or by-product (for example, the extraction of building materials for their own needs or for sale). Stability indicates a constant but small amount of work. The energy saving potential here is low due to the small absolute volumes. However, it is worth checking the specific energy consumption rates per unit of production.

2. Administrative and household building (No. 7) and mechanical workshop (No. 8).

Dynamics: consumption is extremely stable from year to year. The stability of administrative and household building consumption indicates a constant number of personnel and a constant mode of operation of auxiliary systems (lighting, heating/ ventilation, computers). This is the "constant" workload of the enterprise. It can only be reduced by well-known measures: replacing lighting with LED, installing frequency controls on fans, and insulating the building.

In general, it should be noted that the company is conducting a large-scale restructuring of mining operations [19], which leads to a significant reduction in energy consumption, especially during stripping. This could be caused by a transition to new jobs, a change in career configuration, or a general decrease in production activity. The extraction of the main products (copper ore) is unstable, which creates problems for energy management and the purchase of electricity. The specific power consumption should be calculated (kWh/ton of extracted ore, kWh/m^3 of overburden). This will show whether the reduction is due to a real increase in energy efficiency or simply by reducing the amount of work. The main attention to energy-saving measures should be given to the copper ore stripping and mining division, since even a small percentage of savings there will give the greatest financial effect [20]. Despite the stability, the administrative and household building and the workshop are typical facilities for the implementation of low–cost energy-saving measures (lighting, insulation). Based on this, it is necessary to develop a power consumption forecasting model based on a mining plan rather than a data sample in order to better plan energy purchases and avoid peak loads.

Conclusions

1. The greatest potential for energy saving at the Madneupolsky Mining and Processing Plant is concentrated in units with high and seasonally dependent energy consumption, such as stripping operations and loading of barite ore. Overburden division (No. 1), being the most energy-intensive (average quarterly consumption ~2.32 million kWh), showed a decrease in annual electricity consumption by ~34% over 5 years (from 11.35 to 7.52 million

kWh). However, the high standard deviation (S_n = 111 705 kWh) indicates a wide range of data and the need to analyze specific indicators.

2. Statistical analysis of quarterly workloads has confirmed that consumption in all departments is subject to the normal distribution law. At the same time, the largest relative variation in data (the ratio of Sn to M) is observed in the mining units (No. 5, ~22.7%) and loading of barite ore (No. 4, ~17.1%), which characterizes their work as unstable.

3. Linear regression models are adequate and the simplest for practical use in predicting power consumption at the engineering level. Checking the adequacy of linear regression models using the Fisher criterion for all departments showed that the calculated value of the criterion exceeds the tabular value for all departments (for example, for overburden: 5.05 > 4.96). This proves the adequacy and statistical significance of the obtained models for forecasting.

4. Energy consumption in copper ore mining and quartzite loading units is characterized by a high random component, which requires forecasts to be linked to mining plans, and not only to historical data.

5. The consistently low level of energy consumption of auxiliary units (administrative and household complex, workshop) indicates the possibility of using typical low-cost energy-saving measures (LED lighting, frequency control).

6. The overall decrease in electricity consumption at the plant over 5 years indicates the ongoing restructuring of production, however, in order to assess real efficiency, it is necessary to switch to the analysis of specific indicators (kWh/ton of products).

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