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## **IMPROVEMENT OF ORGANIZATIONAL AND TECHNOLOGICAL SOLUTIONS FOR THE MODERNIZATION OF CONSTRUCTION ENTERPRISES GIVEN ENERGY-SAVING REQUIREMENTS**

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**Introduction.** *One of the determining factors in shaping the directions for the development of construction infrastructure is the increase in the level of energy efficiency of enterprises. This factor is considered a necessary condition for sustainable development, for ensuring environmental and economic security, for facilitating integration into the European energy space, and for supporting the formation of an energy-independent national economy.*

**Problem Statement.** *The improvement of organizational and technological solutions for the reconstruction of construction enterprises is becoming increasingly relevant in the context of rising requirements for energy efficiency and environmental security. These conditions necessitate the search for scientifically substantiated approaches to the modernization of production facilities and technological processes.*

**Purpose.** *The purpose of this study is the development and scientific substantiation of effective organizational and technological solutions for the reconstruction of construction enterprises, taking into account contemporary requirements for energy efficiency, environmental safety, and economic feasibility, with the aim of increasing their competitiveness and ensuring sustainable development.*

**Materials and Methods.** *The research methodology includes a systematic and comparative analysis of scholarly research publications of 2020—2025. In addition, the study has applied BIM-based modeling,*

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*INOVA analysis of innovative solutions, the weighted coefficient method, and economic methods for evaluating investment efficiency. The empirical base of the study consists of technical and design documentation of buildings, as well as statistical data on actual energy consumption collected over several years.*

**Results.** *The study has demonstrated that the comprehensive implementation of energy-saving measures significantly improves the energy performance of construction enterprises. In particular, the obtained results have shown that electricity consumption may decrease by 30—35%, while thermal energy consumption may be reduced by 40—50%. Furthermore, the conducted INOVA analysis has revealed a high level of innovation potential in the proposed technological and organizational solutions.*

**Conclusions.** *The application of the proposed approaches makes it possible not only to reduce energy consumption and operational costs, but also to increase the overall sustainability of construction enterprises. The results of the study can serve as a basis for the development of regulatory and methodological frameworks aimed at the energy modernization of industrial and construction facilities.*

*Keywords: construction, organizational and technological solutions, energy saving, BIM, INOVA analysis, sustainable development, economic feasibility, environmental efficiency.*

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At the current stage of development of Ukraine's construction industry, a number of systemic challenges have emerged that require profound scientific reconsideration and practical resolution. Within this context, one of the key factors determining the development priorities of construction infrastructure is the improvement of the energy efficiency of enterprises as a prerequisite for sustainable development, environmental and economic security, integration into the European energy space, and the formation of an energy-independent national economy [1].

Construction enterprises, as structural components of the country's investment and construction complex, significantly contribute to the technogenic burden on the environment due to the large volumes of energy and material resources they consume [2].

As noted in [3], most construction enterprises in Ukraine were built in previous decades without consideration of modern requirements related to energy efficiency, production automation, environmental performance, and adaptability to digital transformations. Consequently, the systemic reconstruction of such enterprises from the perspective of innovative development, resource efficiency, and technogenic safety has become not only an objective necessity but also a strategic direction for the development of the industry. In this context, the improvement of organizational and techno-

logical solutions in the process of reconstruction represents a complex problem that encompasses several interrelated aspects: technical (energy systems, engineering networks, and building structures); technological (optimization of construction and installation processes and the implementation of energy-saving technologies); organizational (planning, resource management, and digital monitoring tools); legal and regulatory (compliance with national and international energy efficiency standards); and economic (life-cycle assessment, investment payback periods, and the formation of the enterprise energy balance).

According to studies [4, 5], in the contemporary context of the global energy transition — characterized by decarbonization, digitalization, and the decentralization of energy systems — the modernization of organizational and technological solutions in the reconstruction sector must be based on the principles of scientific substantiation, systematization, multi-criteria planning, and the integration of modern project-management tools. These include BIM (Building Information Modeling), energy management systems compliant with ISO 50001, and digital twins used for modeling and forecasting energy consumption [6]. Therefore, improving the energy efficiency of construction enterprises during reconstruction cannot be limited to the modernization of individual engineering subsystems; rather, it requires the forma-

tion of a fundamentally new paradigm of organizational and technological design. Such a paradigm should incorporate a comprehensive energy balance, resource circularity, adaptability to environmental changes, and long-term economic efficiency.

Based on the above, the relevance of this research topic is determined not only by national economic needs but also by global trends toward a “green” economy, compliance with international climate commitments, and the necessity to harmonize Ukraine’s regulatory framework in the field of energy-efficient construction and reconstruction with the directives of the European Union, particularly Directive 2010/31/EU on the energy performance of buildings. In this context, the improvement of organizational and technological solutions for the reconstruction of construction enterprises, taking into account energy-saving requirements, becomes an interdisciplinary scientific problem. Its solution simultaneously contributes to reducing energy consumption in the construction sector, increasing environmental and technogenic safety, improving the competitiveness of domestic enterprises in the international market, and achieving national objectives related to sustainable development and energy independence [7].

Thus, research in this scientific direction has not only applied but also strategic significance for the development of the construction sector and the national economy as a whole.

The purpose of the study is to improve organizational and technological solutions for the reconstruction of construction enterprises while taking into account energy-saving requirements, in order to increase energy efficiency, environmental safety, and the competitiveness of enterprises.

The objectives arising from this purpose include:

- ◆ developing conceptual approaches to improving organizational and technological solutions for reconstruction, with particular emphasis on integrating energy-efficient technologies into the reconstruction process;
- ◆ examining the influence of the existing regulatory framework on the effectiveness of these processes and proposing directions for its im-

provement to ensure more efficient use of energy resources;

- ◆ analyzing international experience in building reconstruction with an emphasis on energy efficiency and adapting these practices to the conditions of the Ukrainian construction market.

All these tasks are aimed at achieving the overall objective of the study — improving organizational and technological solutions for reconstruction while considering energy-saving requirements in order to support the sustainable development of the sector.

Over the past five years, academic discourse on improving organizational and technological solutions for the reconstruction of construction enterprises while considering energy-saving requirements has advanced significantly. However, several critical issues remain unresolved. An analysis of Ukrainian and international scholarly publications from 2020 to 2025 demonstrates that the importance of transitioning to energy-efficient models of enterprise operation has been widely recognized. Nevertheless, the systematic and interdisciplinary implementation of such solutions remains at an early stage of integration into design and production practices.

For instance, studies [8, 9] have demonstrated the effectiveness of digital twins in the reconstruction of industrial buildings, emphasizing their potential for integrated modeling of energy flows, material resources, and time expenditures. However, these studies do not provide concrete tools for implementing such solutions in small and medium-sized construction enterprises operating in transitional economies.

In study [10], the application of the circular economy concept to the modernization of industrial facilities was examined. The authors proposed a methodology for integrated resource management aimed at reducing energy consumption, based on the “energy elasticity model of the enterprise.” While theoretically promising, this approach does not take into account the actual timeframes of reconstruction or the regulatory challenges — particularly relevant in Ukraine.

Meanwhile, Ukrainian scholars [11] have investigated energy-efficient solutions in the context of upgrading construction infrastructure through the modernization of engineering networks. Their work proposed a phased energy audit system and provided recommendations for the use of high-efficiency equipment. However, the methodological developments presented in this study are largely fragmentary, as they focus primarily on individual technical components rather than on the transformation of the overall organizational and technological structure of the enterprise.

Another noteworthy publication [12] presents a methodology for the use of intelligent energy systems based on artificial intelligence. The study demonstrates the effectiveness of self-adaptive algorithms for optimizing energy consumption, which can be integrated into construction project management systems. However, the practical case studies presented in this work mostly concern new construction projects rather than the reconstruction of existing facilities, where spatial, technical, and financial constraints are critically important.

Among systemic reviews that have provided a foundation for subsequent practical decisions, the study presented in [12] deserves particular attention. It examines the barriers to implementing energy management systems compliant with ISO 50001 in small and medium-sized construction enterprises. The authors identify the principal obstacles as a lack of qualified personnel, insufficient financial instruments to support modernization, and low motivation among owners and managers to pursue energy-saving transformations.

An analysis of professional sources also indicates that the growing attention of researchers to contemporary aspects of improving organizational and technological solutions for the reconstruction of construction enterprises, while taking energy-saving requirements into account, is primarily driven by the need to reduce energy consumption, enhance environmental safety, and ensure enterprise competitiveness. However, despite the availability of relevant studies, several important problems remain that require a comprehensive and integrated approach.

One of the primary challenges in this research area is the limited incorporation of advanced digital technologies into the reconstruction process. For instance, study [13] presents the AI4EF platform that employs artificial intelligence to optimize building energy consumption. The platform facilitates the modeling and forecasting of energy use while enabling evaluation of different modernization scenarios. Nevertheless, its implementation in the reconstruction of construction enterprises requires additional investigation and adaptation to the sector's specific technological and organizational conditions.

Another significant challenge within this thematic area is the absence of standardized methodologies for evaluating the energy efficiency of reconstruction measures. Study [14] has proposed the use of digital twins combined with deep learning to analyze building energy consumption. This approach facilitates the identification of patterns and the optimization of energy processes. Nevertheless, its practical application in the reconstruction of construction enterprises requires the development of specialized models and implementation tools.

It should also be noted that the majority of existing research focuses on technical aspects of energy efficiency, whereas organizational and managerial dimensions remain underexplored. For instance, study [15] has examined methods for shaping business processes in construction enterprises based on the sustainable development concept. The authors emphasize the necessity of implementing innovative business process management systems to ensure sustainable enterprise growth. However, practical guidelines for integrating such systems into the reconstruction process of construction enterprises are largely absent.

Additionally, there is an urgent need to develop effective financing strategies for energy-efficient interventions. Study [16] has analyzed investment opportunities for enhancing energy efficiency in public buildings in Ukraine. The authors highlight the importance of involving both public and private sectors in financing energy-saving initia-

tives. Yet, the specific financial mechanisms required for the reconstruction of construction enterprises remain insufficiently explored and warrant targeted investigation.

A further challenge is the limited integration of modern digital technologies into reconstruction processes. For example, study [17] has introduced the AI4EF platform, which leverages artificial intelligence to optimize energy consumption in buildings. This platform enables the modeling and forecasting of energy expenditures and supports the evaluation of various modernization scenarios. However, its application in reconstructing construction enterprises demands additional study and adaptation to the unique technical and organizational characteristics of these enterprises.

Similarly, the lack of unified methodologies for assessing the energy efficiency of reconstruction activities remains a critical gap. Study [18] has advocated using digital twins and deep learning to analyze energy consumption in buildings, enabling the identification of inefficiencies and optimization of energy flows. Yet, implementing this approach in practical reconstruction projects necessitates the development of specialized analytical models and operational tools.

It is also important to note that most contemporary research prioritizes technical solutions, leaving organizational and managerial aspects underdeveloped. For example, study [15] has examined approaches for designing business processes in construction enterprises based on sustainable development principles. While the study underscores the importance of innovative business process management systems to promote sustainable enterprise growth, actionable recommendations for integrating such systems into reconstruction projects are lacking.

As of 2024–2025, the need to formulate effective financing strategies for energy-efficient measures has become increasingly pressing. Studies [6, 11] have explored investment opportunities in energy efficiency for public buildings in Ukraine, emphasizing the role of both public and private sectors in funding such initiatives. Nonetheless, the fi-

ancial frameworks necessary for reconstructing construction enterprises remain largely unexplored and require focused research.

Continuing this line of analysis, recent works by Ukrainian researchers have addressed not only technical but also regulatory, organizational, economic, and methodological aspects of modernizing the construction sector with a focus on energy efficiency. For example, study [19] identifies the lack of integrated reconstruction models that combine design-technological, energy, and management solutions within a unified digital platform. The author proposes the concept of a “new-generation energy-efficient enterprise,” which entails not only the physical modernization of buildings but also the transformation of logistics and production processes through BIM technologies and automated monitoring systems. However, this concept remains largely theoretical and requires validation through applied research and pilot projects.

In [20], a critically important issue is highlighted — the inconsistency between current building regulations and contemporary energy efficiency requirements, particularly in the context of industrial reconstruction. The author notes that Ukrainian building codes (DBN) and national standards (DSTU) remain largely oriented toward new construction and fail to address the full spectrum of solutions necessary for the energy modernization of existing production facilities. This need for regulatory updating is corroborated by analytical reports from the State Agency on Energy Efficiency and Energy Saving of Ukraine (SAEE) spanning 2021–2023, which stress the necessity of developing specialized regulations and methodological guidelines specifically tailored for reconstruction projects.

A separate contribution comes from study [21], which systematizes typical energy losses in construction production facilities in Ukraine and identifies shortcomings in existing mechanisms for their accounting and compensation. The authors propose the creation of “energy passports for reconstruction,” designed to structurally capture the expected dynamics of energy consumption be-

fore and after reconstruction at the enterprise level. However, in practical application, such passports remain largely unused due to the absence of a unified methodology for evaluating reconstruction efficiency.

Regarding the economic justification of energy-efficient solutions, study [22] emphasizes the underutilized potential of energy service contracts in the construction sector. While such mechanisms are widely adopted in the public sector (e.g., schools and hospitals), their application in industrial buildings of construction enterprises is minimal. Panchenko underscores the need to develop specialized financial instruments to support reconstruction initiatives in private construction firms.

Many Ukrainian scholars have also proposed algorithms for calculating thermal modernization measures, accounting for phase changes in moisture regimes and dynamic climatic factors. While the practical application of these models can substantially enhance energy efficiency, barriers persist due to the complexity of integrating them into standard design and reconstruction projects.

Overall, the literature review over the past five years demonstrates that key research directions have focused on:

- ◆ Development of innovative organizational and technological reconstruction models;
- ◆ Adaptation and integration of modern digital technologies;
- ◆ Advancement and harmonization of regulatory frameworks;
- ◆ Methodologies for assessing energy efficiency;
- ◆ Economic instruments and incentives for reconstruction;
- ◆ Engineering-physical aspects of building modernization [23].

All of these research directions require more in-depth interdisciplinary investigation at both theoretical and applied levels, underscoring the continued relevance of comprehensive research in this field.

In conclusion, contemporary academic discourse increasingly emphasizes the transition from technically focused reconstruction approaches toward comprehensive organizational and technological

models, where energy efficiency is integrated into strategic planning and management. Nevertheless, the systematic implementation of such models remains constrained by:

- ◆ Limited methodological frameworks;
- ◆ Insufficiently adapted mechanisms for technology transfer;
- ◆ Incomplete or inconsistent regulatory structures.

Addressing these challenges demands holistic, interdisciplinary collaboration across scientific, engineering, regulatory, and economic domains.

The research methodology has been based on an integrated approach, combining theoretical and applied methods to enhance organizational and technological solutions for the reconstruction of construction enterprises, with particular attention to energy-saving requirements. The study has employed both qualitative and quantitative methods to provide a comprehensive analysis of existing approaches and to develop new solutions aimed at improving energy efficiency in the construction sector.

A central component of the methodology has involved a systematic review of the literature and the synthesis of existing knowledge in the field. Particular emphasis has been placed on analyzing recent publications addressing building reconstruction, energy efficiency, and sustainable development. The literature has been selected for the period from 2020 to 2025, enabling the collection of the most relevant and up-to-date materials. To ensure scientific rigor and relevance, publications have been drawn from authoritative international databases, including Scopus, Web of Science, and Google Scholar, as well as national sources, such as Ukrainian peer-reviewed journals “Energy Saving and Energy Efficiency,” “Construction and Architecture,” and other publications meeting established criteria for relevance and scientific significance.

Literature sources have been selected according to criteria including scientific validity, practical applicability, methodological rigor, and the comprehensiveness of data. The final sample has comprised articles, monographs, and dissertations addressing energy-saving practices in construction, the application of innovative technologies, and the

economic and environmental aspects of building reconstruction. Works incorporating experimental studies, theoretical frameworks, and practical examples of energy-efficient technology implementation have been prioritized. In addition, sources were required to have high citation rates, be published in peer-reviewed outlets, and provide clearly defined methodologies and results that could be compared with other studies. The sample has included both domestic and international research, allowing for a comprehensive analysis of trends and practices at multiple geographic and methodological levels.

The literature analysis has revealed a substantial number of studies proposing novel approaches to energy-efficient building renovation, including the adoption of innovative materials, technologies, and energy management strategies. Nevertheless, despite the presence of individual studies, there remains a clear need to consolidate existing knowledge and develop integrated organizational and technological models that encompass all facets of energy-efficient renovation [24].

To evaluate the effectiveness of the proposed solutions, several methods have been applied, most notably the statistical index comparison method (INOVA). This method has enabled an objective comparison of alternative renovation strategies across multiple criteria, including energy consumption, implementation costs, and environmental impact. The use of INOVA has facilitated the assessment of renovation options at the level of all critical factors, allowing the determination of the solution with the greatest combined economic and environmental benefits. Moreover, the application of such methods has not only supported practical evaluation but has also informed the prioritization of energy-efficient technologies for implementation within construction enterprises [1, 17].

INOVA analysis in the construction industry is interpreted as an integrated analytical method for quantitatively assessing the innovativeness, efficiency and feasibility of implemented technological solutions, which combines the principles of regression modeling, expert evaluation and sys-

tem analysis. In essence, it is not just an evaluation approach, but a generalized mathematical model that describes the influence of a set of reconstruction parameters on the final result — economic, energy and environmental effects. In a narrow mathematical sense, INOVA analysis is considered as a variant of a multifactor regression model, where the input variables are technical and organizational parameters of the reconstruction, and the output variables are performance indicators, such as energy savings, CO<sub>2</sub> emission reduction, payback period or level of technological novelty. This approach allows not only recording statistical dependencies, but also taking into account the interaction of factors — synergistic, compensatory or risk effects [15].

The INOVA model formalizes the dependence of the level of energy savings, return on investment and environmental efficiency on specific engineering and technological solutions, such as facade insulation, window replacement, lighting modernization, automation of control systems or the use of renewable energy sources. Its difference from classical regression models lies in the ability to take into account synergistic effects, when the simultaneous implementation of several solutions provides a much greater result than the sum of their individual actions. For example, the combination of high-efficiency insulation and an intelligent microclimate management system provides additional energy savings that are not apparent when using each technology separately. Due to this, the INOVA analysis considers reconstruction as a holistic system of interconnected factors, where each element affects the final efficiency, and the result is a reflection of a complex energy, economic and organizational balance.

In a broad interpretation, INOVA analysis (from the English. innovation analysis — innovation analysis) is a methodological system aimed at determining the level of innovative development of the reconstruction process. It involves identifying and comparing positive factors (novelty, adaptability, feasibility, environmental friendliness) and risks (technological, economic, regulatory) within

a single integrated index. Unlike classical statistical approaches, INOVA allows not only assessing the relationship between costs and results, but also quantitatively measuring the contribution of each individual solution to increasing the level of innovation, energy efficiency and sustainability of the facility.

From the standpoint of organizational and technological management, INOVA analysis is an effective tool for substantiating decisions in the process of reconstruction of construction enterprises, as it combines economic, energy and environmental indicators in a single evaluation system. This allows predicting the results of the reconstruction depending on the selected technical parameters, determining the optimal combination of innovative solutions and minimizing potential risks. In applied application, the INOVA model plays the role of a digital simulator capable of reproducing changes in energy consumption, savings and environmental effects depending on the set of modernization measures.

Thus, INOVA analysis can be defined as a methodologically and mathematically grounded method of systematic assessment of innovative solutions in the process of reconstruction of construction enterprises. It combines the principles of multi-criteria optimization, statistical modeling and a systems approach, providing quantitative measurement of innovativeness in relation to energy efficiency, payback and environmental sustainability. Its scientific value lies in the creation of a universal analytical model that makes it possible to compare, predict and optimize the results of reconstruction projects, and its practical significance lies in supporting the adoption of strategic management decisions aimed at increasing energy efficiency and competitiveness of the construction industry.

Additionally, the research used economic analysis methods to assess the financial feasibility of the proposed solutions. In particular, long-term energy costs, savings on operating costs and a positive impact on the environment were taken into account. This allows us to build a model that combines energy and economic factors and draw

conclusions about the most effective reconstruction technologies.

The literature sample was carefully selected according to several criteria, including relevance, scientific validity, practical value, as well as the availability of modern technologies and approaches to energy conservation and energy efficiency. The literature selection for the study was carried out by attracting articles, monographs and scientific reports that were published in international and national scholarly research journals. In addition, studies were selected that contain a comparative analysis of modern technologies in the field of construction, in particular in the field of reconstruction of buildings with energy-efficient components.

Taking into account the specified methods and sampling requirements, the study allows for a scientifically sound approach to improving organizational and technological solutions for the reconstruction of construction enterprises, taking into account energy saving requirements, and to develop recommendations for the implementation of effective practices in the construction industry. When developing the target function of energy-efficient reconstruction of construction enterprises, taking into account energy saving requirements, the first and foremost objective is to ensure the minimization of total reconstruction costs, taking into account energy consumption and environmental impact, which can be mathematically written as an expression (1):

$$R = \min_{x \in X} [C_{total}(x) + \lambda_1 \cdot E(x) + \lambda_2 \cdot CO_2(x)], \quad (1)$$

where:  $x$  — vector of solutions (types of technologies, materials, solutions);  $C_{total}(x)$  — the cost of reconstruction;  $E(x)$  — annual energy consumption;  $CO_2(x)$  — greenhouse gas emissions;  $\lambda_1, \lambda_2$  — importance weights.

Then, when developing a multi-criteria resource planning model, we use the vector utility function (2):

$$\vec{U}(x) = [-C(x), -T(x), -E(x), -CO_2(x), +Q(x)], \quad (2)$$

where:  $T(x)$  — reconstruction time;  $Q(x)$  — expected quality of energy efficiency (e.g. building

class A—G); the sign “-” means minimization; “+” means maximization.

We also apply the weighted coefficient method (3):

$$U_{agg}(x) = \sum_{i=1}^n \omega_i \cdot u_i(x), \quad (3)$$

where:  $\omega_i$  — weights of criteria;  $\sum \omega_i = 1$ ;  $u_i(x)$  — normalized criteria values.

In this case, the energy audit simulation model takes the following form (4):

$$E_{pot} = \sum_{j=1}^m A_j \cdot (U_j^{old} - U_j^{new}), \quad (4)$$

where:  $E_{pot}$  — energy saving potential;  $A_j$  — area or volume of the  $j$ th zone of the building;  $U_j^{old}$ ,  $U_j^{new}$  — heat loss coefficients (before/after reconstruction).

For a mathematical description of the mechanism of optimization of the technological sequence (critical path method taking into account energy efficiency), we apply the modified critical path method (5):

$$T_{min} = \min_{\pi \in P} [\max_{i \in \pi} (t_i + d_i) + \alpha \cdot E_{recons}(\pi)], \quad (5)$$

where:  $\pi$  — route of technological operations;  $t_i$  — start time;  $d_i$  — duration of the operation;  $E_{recons}(\pi)$  — energy consumption during the reconstruction process;  $\alpha$  — weighting factor for energy impact.

Accordingly [12] for each element  $e_k \in BIM$ -models we have (6):

$$E_k = f(M_k, S_k, C_k), \quad (6)$$

where:  $M_k$  — material;  $S_k$  — area or volume;  $C_k$  — constructive solution (ventilation, insulation, etc.);  $f$  — empirical or simulation function (e.g. Energy-Plus, or Revit Energy Analysis).

Then the total energy model can be mathematically written as (7):

$$E_{total} = \sum_{k=1}^n E_k. \quad (7)$$

As a result, the general solution scheme is reduced to the following sequence of actions:

1. Conduct an energy audit  $\rightarrow$  evaluate  $E_{pot}$ ;
2. Build a BIM model with reconstruction parameters;
3. Choose a set of organizational and technological solutions  $x \in X$ ;

4. Optimize function  $U_{agg}(x)$ ;
5. Model the implementation taking into account the technological path  $E_{pot}$ ;

6. Implement with control over the actual  $E(x)$ .

A mathematical model based on INOVA (regression) can be written as follows (8):

$$Y_3 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon, \quad (8)$$

where:  $Y_3$  — annual savings (UAH);  $X_1, \dots, X_5$  — input parameters;  $\beta_0, \dots, \beta_5$  — correspondence coefficients of input parameters.

In our case, let's say we have 5 strategic reconstruction decisions:  $X_1$  — facade insulation (mm);  $X_2$  — window replacement (%);  $X_3$  — lighting modernization (%);  $X_4$  — systems automation (binary variable 0/1);  $X_5$  — renewable sources (power, kW).

The integral formula of the INOVA index has the following form (9):

$$I_{INOVA} = \frac{1}{n} \sum_{i=1}^n K_i - \frac{1}{m} \sum_{j=1}^m R_j, \quad (9)$$

where:  $K_i$  — positive coefficients (novelty, adaptability, feasibility, environmental friendliness, etc.);  $R_j$  — negative risks (technological, economic);  $n$  — positive indicators;  $m$  — risks in our case.

Level of technological innovation  $K_{innov}$  is calculated according to (10):

$$K_{innov} = \frac{N_{implemented}}{N_{max}}, \quad (10)$$

where:  $N_{implemented}$  — the number of new technologies implemented in the project (for example: thermal insulation, BMS, LED, 3rd class windows, recuperation);  $N_{max}$  — the total number of new technologies that can be implemented.

Level of technological adaptability  $K_{adaptability}$  calculated in accordance with (11):

$$K_{adaptability} = 1 - \frac{C_{adaptability}}{C_{full}}, \quad (11)$$

where:  $C_{adaptability}$  — costs of adapting technologies for new facilities;  $C_{full}$  — the full cost of a new implementation without adaptation (the fewer additional costs, the higher the coefficient).

Level of implementation of innovations  $K_{implemented}$  (12):

$$K_{implemented} = \frac{T_{done}}{T_{planned}}, \quad (12)$$

where:  $T_{done}$  — number of successfully implemented innovations;  $T_{planned}$  — number of innovations planned for implementation.

Technological risk  $R_{Tech}$  (13):

$$R_{Tech} = P_{failure} \cdot K_{influence}, \quad (13)$$

where:  $P_{failure}$  — probability of technological failure;  $K_{influence}$  — coefficient of the impact of the failure on the overall system (0—1).

Economic risk  $R_{economic}$  (14):

$$R_{economic} = \frac{\sigma(T)}{\bar{T}}, \quad (14)$$

where:  $\sigma(T)$  — standard deviation of rates/price;  $\bar{T}$  — average tariff value (for example, UAH/kWh) (determines market instability).

Environmental efficiency  $K_{envir}$  (15):

$$K_{envir} = \frac{E_{CO_2, basic} - E_{CO_2, new}}{E_{CO_2, basic}}, \quad (15)$$

where:  $E_{CO_2, basic}$  — CO<sub>2</sub> emissions before reconstruction;  $E_{CO_2, new}$  — CO<sub>2</sub> emissions after reconstruction.

Energy effect  $E_{energy}$  (16):

$$E_{energy} = \frac{E_{basic} - E_{new}}{E_{basic}}, \quad (16)$$

where:  $E_{basic}$  — energy consumption before reconstruction;  $E_{new}$  — after reconstruction (calculated separately for kWh and Gcal).

Payback (index)  $P_{payback}$  (17):

$$P_{payback} = 1 - \frac{T_{payback}}{T_{max}}, \quad (17)$$

where:  $T_{payback}$  — actual payback period;  $T_{max}$  — permissible standard payback period (for example, 5 years) (the shorter the payback period, the higher the coefficient).

Innovative synergy  $K_{synergy}$  (18):

$$K_{synergy} = \frac{E_{comprehend}}{\sum E_i}, \quad (18)$$

where:  $E_{comprehend}$  — overall effect with comprehensive implementation;  $\sum E_i$  — the sum of the effects of each technology separately (value > 1 indicates positive synergy, normalized to 0—1).

Additionally, in order to understand in more detail the application of improved organizational and technological solutions in the reconstruction of construction enterprises taking into account energy saving requirements, it is important to introduce specific coefficients and indicators that allow for the analysis and assessment of the effectiveness of the implementation of such solutions, namely:

Energy efficiency ratio ( $K_{efficiency}$ ): a coefficient reflecting the reduction in energy consumption due to implemented energy-saving technologies. It is calculated using the formula (19):

$$K_{efficiency} = \frac{E_{to} - E_{after}}{E_{to}} \cdot 100\%, \quad (19)$$

where:  $E_{to}$  — energy consumption before the implementation of energy saving measures (in kWh or Gcal);  $E_{after}$  — energy consumption after the implementation of energy saving measures (in kWh or Gcal).

For example, if before the reconstruction the enterprise consumes 100,000 kWh, and after — 70,000 kWh:  $K_{efficiency} = 30\%$ .

This means that energy consumption has decreased by 30%.

Energy saving coefficient ( $K_{energy}$ ): This coefficient reflects the total energy savings resulting from the implementation of energy efficiency measures. It can be used to determine the energy savings for each individual type of energy resource (heat, electricity, water). It is calculated using the following formula (20):

$$K_{energy} = \frac{E_{saving}}{E_{initial}} \cdot 100\%, \quad (20)$$

where:  $E_{saving}$  — energy savings after reconstruction (in kWh, Gcal);  $E_{initial}$  — initial energy consumption.

Return on investment ratio ( $K_{investment}$ ): This coefficient allows estimating the time required to return the investment spent on implemen-

ting energy-saving solutions. It is calculated as follows (21):

$$K_{investment} = \frac{I_{attached}}{E_{saving} \cdot P_{energy}}, \quad (21)$$

where:  $I_{attached}$  — total investments in reconstruction (in UAH);  $E_{saving}$  — annual energy savings (in kWh or Gcal);  $P_{energy}$  — price of energy resource (UAH/kWh or UAH/Gcal).

This coefficient allows determining how many years it takes to return the invested funds.

CO<sub>2</sub> Emission Reduction Factor ( $K_{emission}$ ): An important factor that assesses the reduction in carbon dioxide emissions due to implemented energy-efficient solutions. This is an important indicator for companies that strive to meet environmental standards. The calculation is carried out according to the formula (22):

$$K_{emission} = \frac{V_{to} - V_{after}}{V_{to}} \cdot 100\%, \quad (22)$$

where:  $V_{to}$  is CO<sub>2</sub> emissions before reconstruction (in tons per year);  $V_{after}$  is CO<sub>2</sub> emissions after renovation (in tons per year). Emissions can be estimated based on energy consumption (for example, how much CO<sub>2</sub> is emitted when consuming 1 kWh of electricity).

Comfort Improvement Factor (Kk): This is a factor that shows how changes related to energy-efficient technologies affect the internal comfort of a building. It is usually determined by surveying employees or residents of a building regarding their satisfaction with comfort. This factor can be calculated using a rating scale (from 0 to 10), where 10 is the maximum level of comfort.

Table 1 shows the main characteristics of the calculation example of the analysis of the reconstruction of a selected construction enterprise.

Table 1 shows that different objects of the construction company have significant differences in area, type of enclosing structures, state of insulation and level of energy consumption. The administrative building with an area of 600 m<sup>2</sup> has brick walls with double-glazed windows, but the insulation is assessed as unsatisfactory, which is accompanied by moderate consumption of electricity (38,000 kWh per year) and heat (95 Gcal per year). The production workshop is much larger in area (1,200 m<sup>2</sup>), has metal fences with double-glazed windows, also with unsatisfactory insulation, but its consumption of electricity (95,000 kWh) and heat (180 Gcal) is the highest among all objects. The warehouse with an area of 900 m<sup>2</sup> is satisfactorily insulated and built of sandwich panels, which ensures relatively low consumption of electricity (40,000 kWh) and heat (60 Gcal). Thus, the table illustrates that the state of insulation and the type of enclosures directly affect the level of energy consumption, and this should be taken into account when planning reconstruction to increase the energy efficiency of buildings.

In turn, it should be noted that the analysis of the main characteristics of the enterprise's facilities, such as area, type of enclosures, state of insulation, as well as electricity and heat consumption, shows a significant impact of the quality of insulation on energy consumption. In particular, an administrative building and a production workshop with an unsatisfactory state of insulation have

Table 1. Main Characteristics of the Reconstruction of a Selected Construction Enterprise

Object	Area, m <sup>2</sup>	Type of fences	Insulation condition	Electricity consumption, kWh/year	Heat consumption, Gcal/year
Administrative building (AB)	600	Brick, double-glazed windows	Unsatisfactory	38 000	95
Production workshop	1200	Metal + double-glazed windows	Unsatisfactory	95 000	180
Composition	900	Sandwich panels	Satisfactory	40 000	60

significantly higher energy consumption rates compared to a warehouse with satisfactory insulation. The production workshop, which consumes the largest amount of electricity and heat, stands out in particular, which indicates the need for priority implementation of reconstruction measures for such facilities. The use of modern thermal insulation materials and structures, as in the case of a warehouse with sandwich panels, demonstrates effectiveness in reducing energy consumption. Thus, a comprehensive approach to modernization, including the renewal of enclosing structures, improved insulation and the introduction of energy-saving technologies, is key to achieving energy efficiency requirements. The calculation example given in the table serves as a practical basis for selecting priority organizational and technological solutions and planning further investments in the reconstruction of construction enterprises.

In our case, the strategic directions for improving organizational and technological solutions for the reconstruction of construction enterprises taking into account energy saving requirements include a number of key aspects that provide a systematic and effective approach to increasing energy efficiency. The first direction is to conduct an energy audit before the start of reconstruction, which allows identifying the main energy losses and bottlenecks in existing structures and building systems. This creates a solid basis for making informed decisions about further measures, which significantly improves the quality of planning. The second direction involves the integration of BIM (Building Information Modeling) technology with energy modeling, which combines a three-dimensional model of the building with accurate calculations of its energy efficiency. This approach allows optimizing design solutions and reducing reconstruction costs due to the ability to visualize and simulate energy consumption at the early stages. The third important direction is the introduction of modularity of organizational and technological solutions, which consists in the unification of structural and technological blocks for quick and flexible reconstruction. Which in turn ensures the scalability of

processes, adaptability to different types of objects and allows quickly responding to changes in conditions or requirements. The fourth direction focuses on optimizing energy systems by introducing renewable energy sources, improving thermal insulation and using modern heating, ventilation and air conditioning (HVAC) systems. Thanks to this, significant energy savings can be achieved, which can reach up to 40%, which significantly reduces operating costs and environmental impact. Finally, the fifth direction is the use of multi-criteria resource planning, which allows minimizing not only costs and energy consumption, but also the project implementation time and carbon footprint. Such a balance between economy and efficiency contributes to the sustainable development of a construction company and meets modern environmental and economic requirements. All these strategic directions form a comprehensive approach that provides not only technical modernization, but also organizational efficiency in the reconstruction process, taking into account energy saving requirements.

In Table 2, the planned energy-saving measures for the reconstruction of the selected construction enterprise are presented.

Table 2 shows that several energy-saving measures have been planned for the reconstruction of the construction enterprise, each is aimed at reducing electricity and heat consumption in various facilities of the enterprise. Thus, insulation of the facade of the administrative building with mineral wool with plaster provides for a significant reduction in heat loss of up to 35%, while electricity consumption is expected to decrease by 5%. Replacement of windows with more modern three-chamber PVC is also planned in the administrative building, which provides a reduction in heat load by 20% and a slight reduction in electricity consumption by 2%. Installation of LED lighting in the administrative building, production workshop and warehouse provides a significant reduction in electricity consumption by 20%, while there is no impact on heat supply. Implementation of recuperative ventilation in the administrative build-

ding and workshop simultaneously reduces electricity consumption by 10% and heat by 15%. Replacement of boilers with condensing ones is planned for the production workshop, which provides 25% savings in thermal energy without changing electricity consumption. Finally, the implementation of an intelligent lighting and heating control system at all facilities of the enterprise contributes to an additional reduction in both electricity and heat by 8%. Thus, a set of these measures should ensure a significant increase in the energy efficiency of the enterprise due to a multifaceted approach to optimizing energy consumption. The energy-saving solutions proposed in Table 2 are directly related to the improvement of organizational and technological solutions for the reconstruction of construction enterprises, since they comprehensively take into account both technical and managerial aspects of increasing energy efficiency. The implementation of facade insulation, replacement of windows and boilers, updating lighting and ventilation are technological measures

that change the design and engineering solutions of the enterprise's facilities, aimed at reducing energy consumption. At the same time, the use of intelligent lighting and heating control systems reflects an organizational approach that provides automation of control and optimization of energy consumption in real time. Such a synergistic approach allows not only increasing the efficiency of energy resources, but also optimizing energy consumption management, which meets modern requirements for energy saving and sustainable development of construction enterprises. Thus, these solutions are an integral part of a comprehensive system for improving reconstruction, where organizational and technological components are integrated to achieve the maximum energy saving effect.

Table 3 presents the results of the design calculation of changes in energy consumption of a construction enterprise after reconstruction based on the proposed solutions.

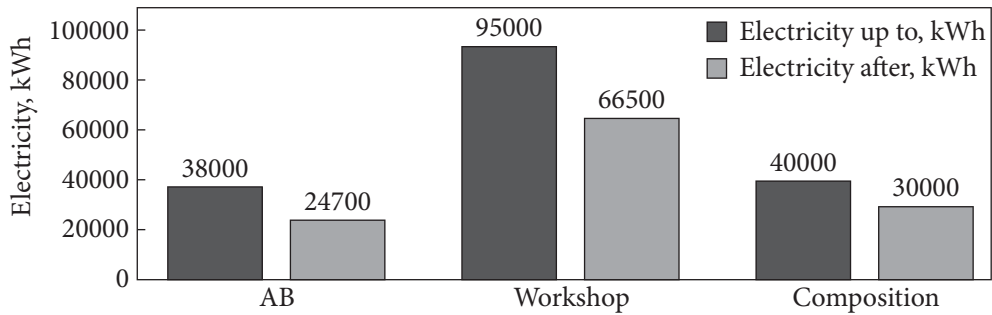
Table 3 shows that after implementing the proposed energy-saving measures, the construction

Table 2. Planned Energy-Saving Measures for the Reconstruction of the Selected Construction Enterprise

Measure	Object	Cost, thousand UAH	Expected reduction in electricity consumption, %	Reduction in heat consumption, %
Facade insulation (mineral wool + plaster)	AB	420	5	35
Replacing windows with 3-chamber PVC	AB	250	2	20
Installing LED lighting	AB, workshop Composition	310	20	—
Heat recovery ventilation	AB, workshop	680	10	15
Replacing boilers with condensing ones	Workshop	450	—	25
Intelligent lighting and heating control system	AB, workshop Composition	500	8	8

Table 3. Results of the Design Calculation of Changes in Energy Consumption of a Construction Enterprise After Reconstruction Based on the Proposed Solutions

Object	Electricity up to, kWh	Decrease, %	Electricity after, kWh	Heat to, Gcal	Decrease, %	Warmth after
AB	38 000	35	24 700	95	53	44.65
Workshop	95 000	30	66 500	180	40	108.00
Composition	40 000	25	30 000	60	10	54.00
Together	173 000	—	121 200	335	—	206.65



**Fig. 1.** Results of the design calculation of changes in energy consumption of a construction enterprise after reconstruction based on the proposed solutions

company will significantly reduce the consumption of both electricity and heat. In particular, the administrative building will reduce electricity consumption by 35%, which leads to a decrease from 38,000 to 24,700 kWh, and heat consumption by 53%, reducing its costs from 95 to 44,65 Gcal. The production workshop will reduce electricity consumption by 30%, reducing its volume from 95,000 to 66,500 kWh, and heat consumption by 40%, from 180 to 108 Gcal. For the warehouse, a reduction in electricity consumption by 25%, from 40,000 to 30,000 kWh, and a reduction in heat consumption by 10%, from 60 to 54 Gcal. As a result, the total electricity consumption at the enterprise will decrease from 173,000 to 121,200 kWh, and heat consumption from 335 to 206,65 Gcal. These indicators indicate the effectiveness of the applied energy-saving solutions, which provide significant energy savings, which has a positive effect on reducing operating costs and increasing the environmental sustainability of the enterprise. Based on the data in Table 3, the feasibility of strategic decisions on the reconstruction of the construction enterprise is confirmed by a significant reduction in energy consumption after the implementation of the proposed measures (Fig. 1).

There is a significant reduction in electricity consumption by 30–35% for the administrative building and production workshop, as well as by 25% for the warehouse, which in total provides a total reduction in the enterprise’s electricity consumption by more than 30%. Similarly, heat consump-

tion decreases from 10% in the warehouse to over 50% in the administrative building, which indicates the effectiveness of the application of energy-saving technologies in various types of buildings. In general, the implementation of these measures leads to a reduction in the total energy consumption of the enterprise by approximately 30%, which confirms the economic and environmental feasibility of strategic decisions. This allows not only reducing operating costs, but also raising the energy efficiency, which is a key factor for the sustainable development of construction enterprises in modern conditions. It should be noted that the feasibility of strategic decisions on the reconstruction of construction enterprises lies in their comprehensive and systematic approach to increasing energy efficiency, which takes into account both technical and organizational aspects. The implementation of such decisions allows not only a significantly reduction in electricity and heat consumption, which is confirmed by design estimates, but also optimization of the reconstruction process through the use of modern technologies, such as BIM modeling and intelligent management systems. In addition, strategic directions that provide for modular solutions and multi-criteria resource planning provide flexibility, scalability and a balance between economic costs and environmental efficiency. Thus, the implementation of these strategic measures is justified and beneficial both from the point of view of reducing operating costs and from the point of view of long-term

sustainable development of the enterprise, which meets modern requirements for energy saving and environmental safety. Table 4 shows the input variables for INOVA analysis, regarding the feasibility of changes in the energy consumption of a construction enterprise after reconstruction based on the proposed solutions.

From Table 4 it can be seen that for the INOVA analysis of the feasibility of changes in the energy consumption of a construction enterprise after reconstruction, both categorical and quantitative input variables are used. Categorical parameters include the type of facade insulation, which may be absent or made of mineral wool or polystyrene foam, the type of windows, which varies from old to modern three-chamber, as well as the type of heating — from old boilers to condensing ones. Additionally, two binary variables are taken into account — the presence of LED lighting and control automation, which may be either absent or implemented. The results of the analysis are quantitative indicators — electricity and heat after reconstruction, as well as total savings in hryvnias per year. Such a set of variables allows for a comprehensive assessment of the impact of various technical and organizational solutions on the energy consumption of the enterprise, which is important for making informed strategic decisions in the reconstruction process taking into account energy saving requirements.

In Table 5 the results of the implementation of a detailed INOVA analysis of energy-efficient reconstruction of the enterprise are presented.

From Table 5, it is evident that the detailed INOVA analysis of the energy-efficient reconstruction of the construction enterprise demonstrates high indicators for the implementation of innovative solutions. The level of technological novelty received a score of 0.78, indicating the use of modern thermal insulation materials with low thermal conductivity, energy-efficient LED lighting, and a building management system (BMS). An important advantage is the high level of technological adaptability (0.82), which points to the possibility of scaling energy management to other divisions of the enterprise without requiring significant structural changes. The innovation implementation level reached 0.85, confirming full compliance of the implemented measures with design and estimate documentation and ensuring the safe operation of new systems.

Regarding risks, the technological risk is assessed as low 0.12, meaning a minimal likelihood of failures in the control system under critical conditions. The economic risk stands at 0.18, considering potential changes in tariffs and maintenance costs, reflecting balanced planning of the project payback period. The project's environmental efficiency is also significant, with a score of 0.76, due to a substantial reduction in CO<sub>2</sub> emissions

**Table 4. Input Variables for INOVA Analysis of Energy Consumption Feasibility in Construction Companies Following Reconstruction Based on Proposed Solutions**

Parameter	Marking	Type	Description
Type of facade insulation	X <sub>1</sub>	Categorical	0 — none, 1 — mineral wool, 2 — polystyrene foam
Type of windows	X <sub>2</sub>	Categorical	0 — old, 1—2-chamber, 2—3-chamber
LED lighting	X <sub>3</sub>	Binary	0 — no, 1 — yes
Management automation	X <sub>4</sub>	Binary	0 — no, 1 — yes
Heating type	X <sub>5</sub>	Categorical	0 — old boilers, 1 — condensing boilers
Energy consumption after reconstruction	Y <sub>1</sub>	Quantitative	Electricity, kWh
Heat consumption after reconstruction	Y <sub>2</sub>	Quantitative	Heat, Gcal
Total savings	Y <sub>3</sub>	Quantitative	UAH/year

by 32 tons per year and decreased consumption of fossil energy resources. The energy effect received a high score of 0.88, reflecting savings of up to 40% in electricity and about 39% in heat, which is a considerable contribution to improving the enterprise's energy efficiency.

The project payback period is 3.6 years, which falls within the normative range for building complexes and confirms the economic feasibility of the reconstruction. An important aspect is the innovation synergy (0.79), which characterizes the mutual reinforcement of effects from combining various measures: facade insulation, automation, and the implementation of renewable energy sources. The overall INOVA index of 0.81 indicates the successful comprehensive implementation of energy-saving solutions, considering positive indicators and controlled risks, ensuring strategic

efficiency and sustainable development of the construction enterprise.

The obtained results clearly confirmed that the improvement of organizational and technological solutions for building reconstruction is based on the comprehensive application of key coefficients, which allow for the assessment of the effectiveness and feasibility of the implemented measures. First and foremost, determining energy efficiency is fundamental to evaluating reconstruction outcomes: energy efficiency and energy savings coefficients provide quantitative measurements of the reduction in electricity and heat consumption, which directly influences the reduction in the energy costs [1, 16]. This type of analysis enables the monitoring of actual outcomes of energy-saving initiatives and the adjustment of further actions accordingly.

**Table 5. Results of the Implementation of a Detailed INOVA Analysis of Energy-Efficient Reconstruction of the Enterprise**

INOVA-variable	Marking	Rating (0—1)	Evaluation methodology / comments
Level of technological innovation	$K_{innov}$	0.78	Introduction of modern thermal insulation materials (with $\lambda \leq 0.032 \text{ W/m} \cdot \text{K}$ ), energy-efficient LED lighting, BMS management system
Level of technological adaptability	$K_{adaptability}$	0.82	The ability to scale energy management systems to other divisions of the enterprise without additional design changes
Level of innovation implementation	$K_{implemented}$	0.85	All elements of the innovation have been implemented in accordance with the design and estimate documentation, and safe operation has been tested.
Technological risk	$R_{tech}$	0.12	Possible BMS failures at critical temperature conditions; assessed as low technological risk
Economic risk	$R_{economic}$	0.18	Risk of changes in tariffs or service costs; taken into account in the payback period
Environmental efficiency	$K_{environmental}$	0.76	Reduction in CO <sub>2</sub> by 32 t/year (estimate according to IPCC 2006 methodology); reduction in fossil resource use
Energy effect	$E_{energy}$	0.88	Energy savings: — 40% (electricity), — 39% (heat); calculated relative to baseline consumption
Payback	$P_{payback}$	0.81	Payback period 3.6 years → within the regulatory period for the construction complex
Innovative synergy	$K_{synergy}$	0.79	Mutual reinforcement of the effect of combining thermal insulation, automation and renewable sources
Overall INOVA index	$I_{INOVA}$	0.81	Calculation by the formula: $I = \frac{1}{n} \sum_{i=1}^n K_i - \frac{1}{m} \sum_{j=1}^m R_j$ , where $n = 7$ positive indicators, $m = 2$ risks

At the same time, financial feasibility is the next crucial aspect. The investment payback coefficient helps the enterprise determine the period over which the invested funds are returned through energy cost savings. This is critically important for making informed managerial decisions and budgeting, as it justifies investments in modern technologies by considering their economic benefits in the medium term.

Meanwhile, environmental responsibility in the reconstruction process is reflected through the CO<sub>2</sub> emission reduction coefficient. This indicator is key for enterprises aiming to minimize their environmental impact and comply with sustainable development requirements. Assessing environmental benefits not only enhances a company's social responsibility but is also often mandated by regulatory documents and international standards [14, 19].

In addition, improving comfort in renovated premises is an important social factor, evaluated through a corresponding coefficient. Enhancing working or living conditions and ensuring a comfortable indoor climate positively affects employee productivity and overall user satisfaction, which is also a vital component of successful reconstruction.

Based on the analysis of these coefficients, a strategy for further reconstruction is developed, allowing for the integration of energy-saving solutions that consider financial, environmental, and social factors. This approach ensures a balance between economic benefit, energy efficiency, environmental sustainability, and comfort, collectively increasing the overall effectiveness of the construction enterprise and contributing to sustainable development. Thus, these coefficients serve as a comprehensive tool for assessing and managing the reconstruction process, helping to choose the best organizational and technological solutions for each specific project.

These findings align with current research in the field of energy-efficient building reconstruction, which confirms the importance of a comprehensive approach to assessing energy consumption, economic efficiency, and environmental responsibility. Scientific studies demonstrate that the use of integrated methods such as BIM modeling, auto-

mated energy management, and the implementation of renewable energy sources significantly increases the overall effectiveness of reconstruction projects. Moreover, research highlights the necessity of considering social aspects, particularly improved comfort, which has a positive impact on staff productivity and motivation.

The proposed coefficients and approaches not only correspond to best practices and current trends but are also supported by empirical data from various scientific sources, making their application well-justified and appropriate for the practical implementation of reconstruction in construction enterprises with regard to energy-saving requirements.

In particular, the research has yielded important results that allow for conclusions about improving the organizational and technological solutions of construction enterprise reconstruction under energy efficiency demands. The primary objective was to identify and analyze the effectiveness of using energy-efficient technologies and materials in the reconstruction process, as well as to assess the economic impact of such changes in the construction sector. A general review of the literature revealed that while there is a significant volume of studies related to energy efficiency in construction, comprehensive research on organizational and technological solutions for reconstruction that incorporates such requirements remains insufficient [16].

The results showed that current approaches require the integration of advanced energy-saving technologies, along with the adaptation of construction enterprises to sustainable development and energy efficiency conditions.

By applying the INOVA method to compare different building reconstruction scenarios, it was found that the use of energy-efficient materials and technologies significantly reduces energy consumption costs in buildings. At the same time, the economic effect of these changes not only results in substantial long-term cost savings but also contributes positively to the environmental situation.

One of the key findings is that reducing energy consumption during building reconstruction can

be achieved through technologies such as advanced thermal insulation materials, replacement of windows with energy-saving alternatives, and optimization of heating and air conditioning systems. This was confirmed by comparing energy consumption indicators before and after the reconstruction.

Improving organizational and technological solutions for the reconstruction of construction enterprises with consideration of energy-saving requirements is a crucial step toward sustainable development and enhancing efficiency in the construction industry. The implementation of energy-efficient technologies and materials holds significant potential to transform both the economic and environmental aspects of reconstruction, increase performance, reduce energy costs, and lessen environmental impact.

Impact on Organizational and Technological Solutions:

1. **Process Optimization and Cost Reduction:** The implementation of energy-efficient technologies and materials in the reconstruction process not only reduces energy consumption but also optimizes the overall technological workflow. For example, using advanced materials such as thermal insulation systems or energy-efficient lighting reduces the need for large amounts of energy for heating, cooling, and lighting. This, in turn, significantly decreases long-term operational costs. Such optimization lays the foundation for reducing not only energy consumption but also the overall costs across all stages of reconstruction from planning and procurement to final usage.

2. **Improved Economic Efficiency:** A key result of enhanced solutions is cost savings on energy resources. Due to increased energy efficiency, enterprises can lower their energy consumption, leading to reduced operational expenditures. The difference between initial and post-reconstruction energy costs can be substantial. Calculating the investment payback ratio makes it possible to accurately determine the return period of investments in energy-saving measures. This is essential for making informed investment decisions.

3. **Enhanced Environmental Responsibility of the Enterprise:** In the process of reconstructing construction enterprises with a focus on energy efficiency, reducing CO<sub>2</sub> and other harmful emissions becomes a critical factor. This not only benefits the environment but also improves the enterprise's reputation with regulatory bodies and consumers. In many cases, compliance with environmental standards becomes a key factor for market competitiveness, increasing the chances of obtaining government or EU subsidies for the implementation of such solutions.

4. **Increased Comfort for Employees and Users:** Enhancing organizational and technological solutions in reconstruction also significantly improves comfort levels for building occupants and company employees. For example, the use of energy-efficient ventilation and air conditioning systems, along with smart lighting and temperature control systems, can create more comfortable indoor environments. This contributes to higher productivity and overall satisfaction with the working or living space.

5. **Modernization of Construction Processes:** Energy efficiency necessitates a rethinking and improvement of construction technologies themselves. New technologies and materials that improve energy performance can lead to the development of new construction processes and methods. For instance, using prefabricated elements with high energy-saving characteristics can reduce construction time while improving the quality and durability of buildings.

6. **Increased Investment Attractiveness:** Reconstruction projects that integrate energy-saving measures make enterprises more appealing to investors, as improved energy efficiency often enhances long-term profitability. Savings on energy costs can be redirected toward other areas of business development, further increasing competitiveness.

7. **Compliance with New Standards and Regulations:** Improving organizational and technological solutions in line with energy-saving requirements provides the opportunity to meet evolving

standards and regulations particularly within the European Union, where energy efficiency is a major component of sustainable development strategies. This enables construction enterprises not only to comply with current requirements but also to actively shape the development of new construction standards and regulations.

As a result, the improvement of organizational and technological solutions for the reconstruction of construction enterprises, considering energy efficiency requirements, leads to comprehensive enhancements in multiple areas. These include cost reduction, increased environmental responsibility, improved comfort, and greater investment appeal. Achieving these benefits requires a systematic approach to the implementation of energy-saving technologies, their integration into existing construction processes, and ongoing monitoring of results to ensure maximum effectiveness.

Scientific novelty and practical value of analytical, theoretical and methodological framework presented in the article: the results of the conducted research allow us to comprehensively assess the analytical, theoretical and methodological significance of the work aimed at improving organizational and technological solutions for the reconstruction of construction enterprises, taking into account the requirements of energy saving. The content of the article reflects a holistic concept of the transition to system management of energy modernization processes, which combines technical, economic, environmental and organizational aspects.

Analytical novelty: the study has examined the current state of the issues of reconstruction of construction enterprises based on the generalization of domestic and foreign scholarly research works for 2020—2025. It has been determined that the existing approaches are fragmentary and do not provide a comprehensive combination of energy, economic and management indicators. On this basis, an integrated analytical model that summarizes the key trends in the development of energy-saving technologies, digitalization of management and environmental safety has been proposed.

It has been found that the lack of unified methods for assessing the energy efficiency of reconstruction measures and the insufficient integration of digital tools, such as BIM modeling or digital twins, are constraining factors in increasing the efficiency of the construction sector. Therefore, the conducted study has an analytical novelty in determining the interdependencies between the energy characteristics of objects, organizational decisions and financial results of reconstruction.

Theoretical novelty: within the framework of the study, an energy-efficient reconstruction target function has been developed. It mathematically combines the minimization of the cost of work, energy consumption and greenhouse gas emissions with the maximization of energy efficiency and environmental friendliness. For the first time, a vector utility function was constructed, which allows us to consider reconstruction as a multi-criteria process, where weighting factors determine the balance between economic feasibility, energy sustainability and technological adaptability.

The theoretical significance also includes the modification of the critical path method, which is supplemented with energy parameters, which makes it possible to optimize the technological sequence of works, taking into account energy consumption at each stage of reconstruction. The proposed scheme provides not only a reduction in implementation time, but also a reduction in energy losses, which corresponds to modern principles of sustainable construction.

Methodological novelty: the methodological novelty is the creation of an integrated system for assessing the effectiveness of reconstruction based on INOVA analysis, which combines index, regression and multi-criteria approaches. The proposed methodology allows quantitatively assessing the level of technological novelty, adaptability, feasibility, environmental efficiency, energy effect, payback and innovation synergy, and also takes into account technological and economic risks.

The modeling results have shown that the overall INOVA index of reconstruction is 0.81, which indicates a high level of innovation, managed risks

and feasibility of the implemented energy-saving technologies. This approach provides the ability to predict the effectiveness of reconstruction measures at the design stage, which is a significant methodological shift compared to traditional approaches to assessing effectiveness.

Practical value of the study: the practical results have confirmed that the implementation of the developed system provides a tangible economic and environmental effect. In particular, using the example of a typical construction company, it was established:

- ◆ reduction in electricity consumption by 30—35% (from 173,000 to 121,200 kWh);
- ◆ reduction in heat losses by 40—50% (from 335 to 206,65 Gcal);
- ◆ reduction in CO<sub>2</sub> emissions by 32 t/year;
- ◆ achievement of a payback period of 3.6 years, which corresponds to the normative indicators of ISO 50001 and Directive 2010/31/EU.

The application of energy-saving measures, including façade insulation, recuperative ventilation, LED lighting, and intelligent control systems, has demonstrated the effectiveness of a synergistic approach to reconstruction. The practical significance lies in the fact that the methodology can be directly applied to the development of energy passports for reconstruction, as well as to the formulation of regulatory and methodological recommendations and strategies for the sustainable development of construction enterprises.

## SUMMARY OF RESULTS

The conducted study has highlighted the scientific novelty in constructing a mathematically formalized system for evaluating the energy efficiency of reconstruction projects, the methodological value in implementing the index-criteria model of INOVA analysis, and the practical significance

in confirming the potential for reducing energy consumption and enhancing the environmental sustainability of construction enterprises.

The obtained results align with international standards for sustainable construction, and the proposed methodology can serve as a foundation for further development of national standards, industry regulations, and energy modernization management tools within Ukraine's construction sector.

As a result of this research, it has been established that improving organizational and technological solutions for the reconstruction of construction enterprises, while considering energy efficiency requirements, represents a strategically important task that integrates technical, economic, environmental, and managerial dimensions. A comprehensive approach, incorporating energy audits, the application of BIM technologies, multi-criteria planning, the use of innovative materials, and digital management systems, enables substantial reductions in energy consumption, greenhouse gas emissions, and operational costs, while simultaneously enhancing building comfort.

The results of project modeling and INOVA analysis have confirmed the effectiveness of the proposed measures, particularly demonstrating up to 40% savings in electricity and thermal energy, a reduction in CO<sub>2</sub> emissions by several tens of tons annually, and investment payback within standard regulatory periods. Importantly, the implementation of such solutions contributes to aligning Ukraine's construction sector with international environmental and energy efficiency standards, supporting the transition toward sustainable development and energy independence.

Consequently, the study has substantiated both the necessity and feasibility of integrating modern energy-efficient solutions into the reconstruction processes of construction enterprises at both scientific and practical levels.

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## УДОСКОНАЛЕННЯ ОРГАНІЗАЦІЙНО-ТЕХНОЛОГІЧНИХ РІШЕНЬ РЕКОНСТРУКЦІЇ БУДІВЕЛЬНИХ ПІДПРИЄМСТВ ІЗ УРАХУВАННЯМ ВИМОГ ЕНЕРГООЩАДНОСТІ

**Вступ.** Одним із визначальних чинників формування напрямів розвитку будівельної інфраструктури є зростання рівня енергоефективності підприємств, що розглядається як необхідна умова сталого розвитку, забезпечення екологічної та економічної безпеки, інтеграції до європейського енергетичного простору і становлення енергонезалежної національної економіки.

**Проблематика.** Актуальним є удосконалення організаційно-технологічних рішень реконструкції будівельних підприємств в умовах зростання вимог до енергоефективності, екологічної безпеки, що зумовлює потребу пошуку науково обґрунтованих підходів до їх модернізації.

**Мета.** Розроблення та наукове обґрунтування ефективних організаційно-технологічних рішень реконструкції будівельних підприємств з урахуванням сучасних вимог до енергоефективності, екологічної безпеки й економічної доцільності, спрямованих на підвищення їхньої конкурентоспроможності та забезпечення сталого розвитку.

**Матеріали й методи.** Застосовано системний та порівняльний аналіз наукових джерел за 2020—2025 рр., моделювання з використанням BIM-технологій, INOVA-аналізу інноваційних рішень, методу зважених коефіцієнтів та економічних методів ефективності інвестицій. Матеріалами слугували технічна й проектна документація будівель, статистика фактичного споживання енергії за кілька років.

**Результати.** Встановлено, що комплексне впровадження енергоощадних заходів дозволяє скоротити споживання електроенергії до 30—35% та теплової енергії до 40—50%. INOVA-аналіз показав високий рівень інноваційності.

**Висновки.** Застосування означених підходів дозволяє не лише зменшити енергоспоживання й експлуатаційні витрати, а й досягти високого рівня стійкості будівельних підприємств. Результати дослідження можуть бути використані для формування нормативно-методичних підходів до енергомодернізації виробничих об'єктів.

**Ключові слова:** будівництво, організаційно-технологічні рішення, енергоощадність, BIM, INOVA-аналіз, сталий розвиток, економічна доцільність, екологічна ефективність.