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BRIDGES AND TUNNELS: THEORY, RESEARCH, PRACTICE

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N. O. DANKEVYCH

Department of Industrial and Civil Engineering, Zaporizhzhia National University,
226 Sobornyi ave., Zaporizhzhia, Ukraine, 69006, tel. +38 (098) 272 90 77,
e-mail dankevichnatali28@gmail.com, ORCID 0000-0002-7146-9303

AN INTEGRATED MODEL FOR ASSESSING THE TECHNICAL CONDITION OF BUILDINGS TO IMPROVE THEIR ENERGY EFFICIENCY AND RELIABILITY

Purpose. The study aims to assess the reliability and conduct technical diagnostics of the building, identify defects and restore the operational suitability of damaged structures, as well as to develop a comprehensive approach to improving the energy efficiency and reliability of the facility by implementing organizational, technological, and practical solutions and developing recommendations for safe further operation. **Methodology.** A comprehensive survey of the building was conducted to assess the technical condition of its structures and engineering systems and to identify defects affecting the building's reliability and energy efficiency. Based on the survey results, a list of identified defects and damages was compiled, along with recommendations for their elimination and for restoring the operational suitability of the building. Using the data obtained, a set of organizational, technological, and practical measures was developed to improve the building's energy efficiency and reliability, including thermal modernization of the building envelope, optimization of engineering systems, and planning of maintenance works. Priorities for the implementation of these measures were defined, and recommendations for the safe further operation of the building were provided. **Findings**. During the inspection of the building, a detailed list of defects was compiled, including major structural damage and recommendations for their elimination. Comprehensive measures were proposed, including thermal modernization of the building envelope, optimization of engineering systems, and organizational solutions aimed at improving the building's energy efficiency, restoring the operational suitability of damaged structures, reducing maintenance and energy costs, and increasing the reliability and safety of operation. The implementation of these measures provides significant energy savings, extends the service life of the facility, and promotes the application of modern technological and organizational solutions in construction practice. **Originality**. The originality of the study consists in the development of an integrated model for assessing the technical condition of buildings, identifying defects and damage, and substantiating organizational and technological measures aimed at improving the energy efficiency and operational reliability of building structures. **Practical value.** The proposed model makes it possible to assess the technical condition of buildings, identify defects, and plan their elimination, while the integrated approach to thermal modernization and optimization of engineering systems improves energy efficiency, extends the service life of structures, and ensures the safe and cost-effective operation of existing facilities.

Keywords: building; technical condition; thermal modernization; energy efficiency; reliability; safe operation

Introduction

The modern development of engineering systems and technologies is accompanied by increasing demands for the efficient use of energy resources. In the context of limited natural resources and heightened attention to sustainable development, the issue of energy efficiency has become one of the key directions in the modernization of engineering processes. Achieving a high level of energy savings requires a comprehensive approach that encompasses organizational, technological, and applied solutions. Organizational aspects involve the optimization of management processes and resource planning, technological aspects focus on the implementation of innovative methods and equipment, and applied aspects involve the practical implementation of energy-saving strategies in specific engineering tasks (Dankevych, 2025; Костира, & Бакуліна, 2022).

The implementation of such comprehensive measures allows not only the reduction of energy consumption but also the improvement of reliability, safety, and economic efficiency in the operation of engineering systems.

Most objects of social infrastructure, commercial real estate, and the housing stock are operated

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according to outdated structural schemes and do not meet modern quality standards. As a result, these buildings are often characterized by insufficient thermal insulation, high heat losses, and a low level of technical maintenance, which leads to excessive energy consumption and a decrease in user comfort.

Furthermore, poor technical condition and significant structural wear are the main factors contributing to the occurrence of emergency situations. The majority of incidents are caused by the expiration of the normative service life of the structures, non-compliance with scheduled preventive maintenance, and violations of operational regulations. A particularly pressing issue is the low reliability of buildings under challenging conditions of extreme natural events, which underscores the need for regular technical inspections, certification, and modernization of structures (Citadini de Oliveira, Martins Vaz, Ghisi, 2024; & Dankevych, 2025).

The procedure for technical diagnostics, certification, assessment of technical condition, as well as the preparation of technical documentation is defined by a set of laws, government resolutions, and state standards of Ukraine, which collectively establish requirements for scheduled and unscheduled inspections, qualification requirements for personnel, and the content of technical passports (Закон України, 2017; Постанова КМУ, 2025; ДСТУ 9273:2024, 2024).

The problem of assessing and predicting the safe service life of buildings in the Zaporizhzhia region, which is also relevant for Ukraine as a whole, is particularly urgent due to a wide range of adverse factors, including: an unstable economic and financial situation; insufficient funding for construction, reconstruction, and maintenance of public facilities; a high degree of physical and moral wear of building structures; limited effective service life of certain structural elements; the absence of a comprehensive and systematic program for technical inspection, monitoring of technical condition, and timely execution of repair and restoration works; as well as the complex conditions of martial law, accompanied by the risk of damage from military actions, restricted access to facilities for inspections and repairs, interruptions in energy supply and logistics, shortages of construction materials and qualified personnel, and the need to repurpose public buildings for shelter, temporary accommodation of the population, and operation of critical infrastructure (Hryhorovsky, Murasyova, & Bronevytskyi, 2023; Dankevych, 2025).

In this context, there is an urgent need for a comprehensive approach to improving the energy efficiency and reliability of buildings, which involves the implementation of organizational, technological, and applied solutions, as well as regular technical inspections and certification of structures. Research in this area will contribute to reducing energy consumption, increasing operational safety, and improving the quality of the environment for users.

Purpose

The aim of the study is to develop a comprehensive approach for enhancing the energy efficiency and reliability of a building through the implementation of organizational, technological, and practical solutions, as well as to provide recommendations for the safe continued operation of existing structures.

Methodology

The inspection of construction objects is the basis for forming quantitative and qualitative assessments of the impact of operational, mechanical, and atmospheric and climatic factors on their long-term performance. It enables the identification of cause-and-effect mechanisms of material and structural element degradation, the determination of effective methods for minimizing negative impacts, and the development of scientifically sound measures to restore load-bearing capacity (Корзаченко, Прибитько, Ганєєв, & Болотов, 2021).

The inspection practice is implemented through a sequential set of interrelated procedures, including detailed diagnostics of the actual technical condition of structures, analysis of operating conditions, and assessment of the intensity of individual adverse factors, such as corrosion of metal elements, shrinkage deformations, thermal loading, and vibration effects.

The methodological basis of inspections is founded on the principles of a systems approach and an integrated approach, which consider a building facility as an integrated system of interdependent elements, including structural joints, piping and thermal insulation systems, technological equipment, and related technological processes,

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taking into account the influence of the external environment. Such an approach enables a comprehensive assessment of the technical condition of the facility and the prediction of its future operational reliability.

The scope of work may be refined and adjusted in the course of the survey based on the analysis of interim data and the identified features of the technical condition of the facility. The information obtained during the survey should objectively characterize the degree of degradation of structures and the dynamics of the development of existing defects and damage. The scope and content of the collected data should be sufficient for a scientifically sound classification of the technical condition of the building, as well as for a reliable assessment of the cost of measures to eliminate the identified defects.

The overall assessment of the condition of the building (generalized condition indicator) is used to determine the appropriate strategy for carrying out the work necessary to ensure the required condition, as well as to assign the operating mode (Данкевич, & П'ятниця, 2021; Hryhorovsky, Murasyova, & Bronevytskyi, 2023; Бондарський, Дробишинець, Лучинець, Ротко, & Ужегова, 2023).

The technical inspection of the building «Medical Care Center, Zaporizhia» is carried out under a contract with the Customer, which specifies the elements of the facility to be inspected, as well as the tasks, objectives, and deadlines for the work (Dankevych, 2025).

The layout of the Medical Center building, intended for further normal operation, is designed as a two-story, U-shaped building. The building is provided with heating, water supply, sewage, and electricity. The structural system of the building consists of longitudinal load-bearing walls. The roof is made of reinforced concrete slabs, and reinforced concrete slabs are also used for the floor structures.

The walls are made of silicate bricks laid on cement-sand mortar. No temperature or settlement joints are provided in the building. The building has a staircase made of reinforced concrete structures. Engineering and geological surveys have been conducted, and the climatic conditions of the site have been determined. The standard depth of soil freezing is 0.8 m. The soil conditions of the construction site are classified as type II subsidence. There are no subsoil use areas within several kilometers of the land plot.

The site is rectangular in shape and is characterized by a rugged terrain with a slight slope (i=0,050). The category of complexity of the engineering and geological conditions is II. No unfavorable physical or geological processes have been identified within the survey area.

The appearance of the existing building and defects in the exterior walls are shown in the photo of the object (Figure 1).

Figure 1. Appearance of the building facade

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The classification of the technical condition of the structure is determined in accordance with ДСТУ 9273:2024.

The survey program provides for the following main activities:

- general assessment of the building and its operating conditions;
- taking measurements and preparing the necessary drawings for the survey;
- visual inspection of structures with recording of defects, damage and geometric parameters, verification of the compliance of components with regulatory requirements, as well as photographing and sketching the identified non-conformities;
- analysis of the results of visual and instrumental surveys;
- comprehensive assessment of the technical condition of the structure, with determination of the priority of operational measures.

Based on the results of the technical condition survey of the building, a list of defects is compiled with a list of identified damage and recommendations for their elimination. Based on the results of the expert assessment, an expert opinion is compiled, and at the request of the Customer, a technical condition passport is issued, which reflects the actual condition of the building at the time of the survey.

Findings

To achieve the set goal, a review and generalization of scientific publications by domestic and foreign authors were carried out, the choice of the regulatory framework was justified, and the results of field surveys of building structures operated in the Zaporizhzhia region were used.

The research was carried out using analytical and experimental methods in accordance with current regulatory documents. During the survey, a table of the main identified defects and measures for their elimination was compiled (Table 1).

The condition of the building structures is assessed as suitable for normal operation (condition category II) based on the analysis of technical documentation and visual inspection, except for the roof (condition category II), which is unsuitable for normal operation.

The final assessment of the overall technical condition of the building structures of the medical center was made based on the results of assessing the technical condition of individual elements and structures at various stages of work. Based on the analysis of technical documentation, visual and instrumental inspections, and verification calculations of the building's load-bearing capacity, the overall condition of the building is assessed as suitable for normal operation (condition category II), except for the roof, which is unsuitable for normal operation (condition category III) (ДСТУ 9273:2024, 2024; Dankevych, 2025).

Table 1

List of defects and damages

No s/n	Defect or damage characteristics	Condition category
1. Bases and foundations		
1	No defects or damage to bases and foundations affecting normal operation were found at the time of inspection	Satisfactory technical condition
2. Metal structures		
2	Destruction of the paint coating of load-bearing metal structures with corrosion damage to the metal surface up to 0,5 mm	Satisfactory technical condition
3. Roofing		
3	Numerous defects and damage to the roof affecting normal operation were not detected at the time of inspection	Satisfactory technical condition
4. Engineering networks		
4	Defects and damage to engineering networks affecting normal operation, identified at the time of inspection as preventing normal operation	Satisfactory technical condition

In order to bring the building structures into compliance with the design solutions and applicable regulatory requirements, it is necessary to implement a set of measures to eliminate the identified defects and damage. To this end, separate design and cost estimate documentation shall be developed for the reconstruction of the center's building, providing for the reinforcement of external walls, major repairs of the structures and roof, building insulation, restoration of the surrounding pavement, repair of the porch, restoration of the metal elements of the evacuation ladder on the façade, and the provision of accessibility for people with limited mobility.

All works and organizational and technical measures shall be carried out in full in accordance with the developed project documentation. In the future, the proper operational condition of the building structures shall be ensured through the

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timely detection and elimination of defects and damage in order to maintain their reliability and durability throughout the entire service life of the building.

The energy efficiency of the building was assessed based on data from the energy passport and thermal calculations, which resulted in proposals for energy efficiency measures that will reduce energy consumption by more than 50 % and ensure comfortable conditions in the premises, namely: insulation of external walls and roofs and modernization of the heat supply system with the installation of automatic heat flow control.

The development of a thermal modernization project is an integral part of a set of measures for the comprehensive modernization of the building and is aimed at increasing its energy efficiency, reducing energy consumption, improving the thermal performance of the building envelope, and ensuring proper and comfortable operating conditions (Жусь, & Гуйван, 2025; Gholamzadehmir, Pandolfi, Del Pero, Leonforte, & Sdino, 2025).

The working project provides for a set of works to strengthen and repair the structures, including

- the strengthening of external walls, masonry, and external stair slabs;
- replacement of external metal stairs;
- installation of a lift for people with reduced mobility, including foundations and modification of openings; insulation of walls and foundations;
- restoration of paving and porches; installation of canopies; reconstruction of the roof (replacement of the rafter system, roofing, thermal and waterproofing layers, drainage, sealing, and lightning protection);
- as well as partial replacement of windows and doors.

During the design process, a system for insulating the exterior walls, foundation (Figure 2), and floors was determined to meet the thermal requirements (ДБН, 2021; Dankevych, 2025).

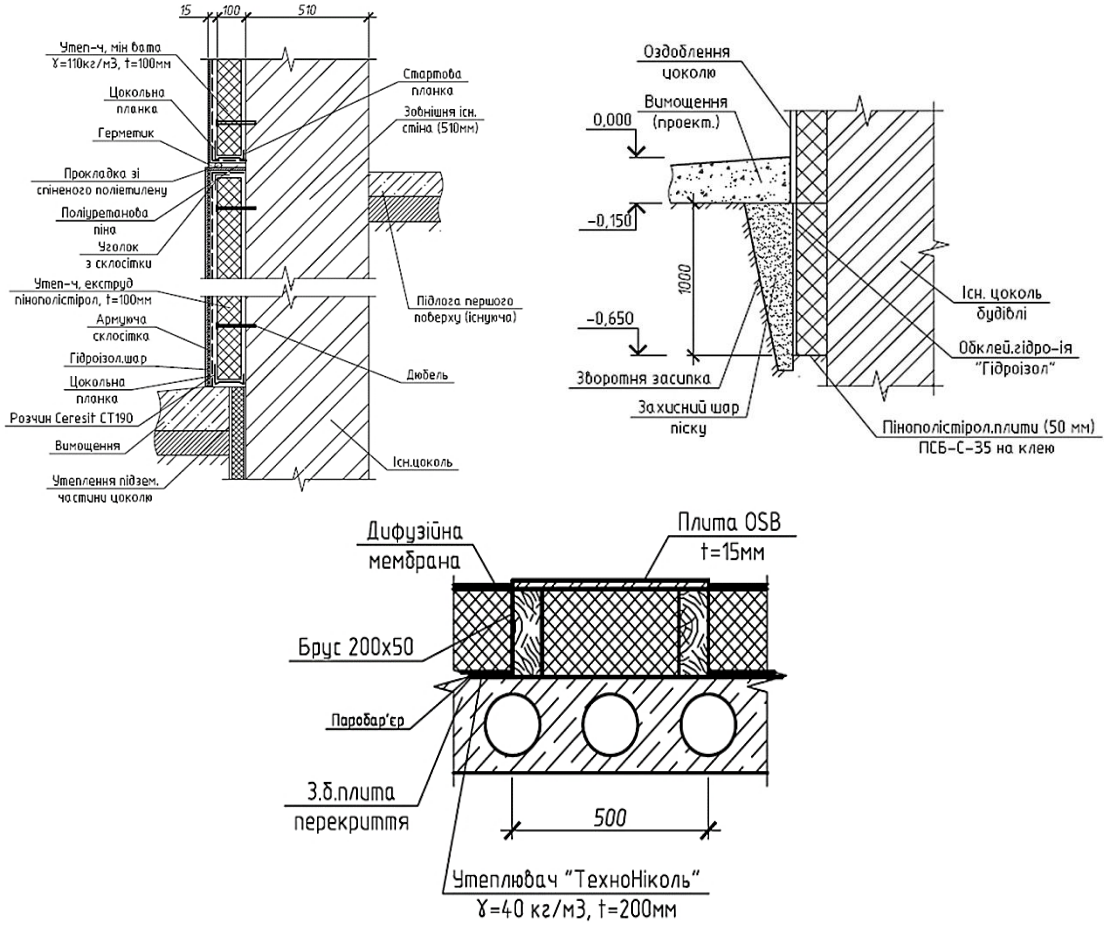

Figure 2. Approved design for insulation of exterior walls, foundations, and floor slabs

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During the work, an assessment of the energy efficiency of the existing building was conducted, encompassing a range of measures and studies to determine the building's actual energy performance and its compliance with regulatory requirements.

The criterion used to assess energy efficiency is compliance with the conditions (ДБН В.2.6-31:2021, 2021):

$$ER < ER_{\max},$$

where ER – the calculated or actual specific annual energy demand; $ER_{\max}$ – the maximum permissible value of specific annual energy demand, kWh/m² or kWh/m³.

Accordingly, for this building:

$$\frac{ER - ER_{\max}}{ER_{\max}} \cdot 100\% = \frac{58 - 37{,}5}{37{,}5} \cdot 100\% = 54{,}7\%,$$

corresponding to the energy efficiency class *F* (ДБН В.2.6-31:2021, 2021).

The results of the analysis showed that the thermal retrofit of existing public buildings is an effective way to improve their energy efficiency. In combination with other measures, it helps extend the service life of buildings and significantly reduce the maintenance costs for local communities. To achieve the maximum effect, it is important to conduct a mandatory comprehensive survey of the building before starting work, enabling more accurate prioritization of modernization measures and cost optimization. Large-scale implementation of such energy efficiency measures can yield substantial savings on energy resources, enhance the country's energy independence, and stimulate overall development of the construction industry.

Originality and practical value

As a result of the study, an improved model for systematizing technical inspection data for buildings was developed using scientific publications and current regulatory documents. Particular attention was paid to the advisability of timely capital and routine repairs, which directly affect the reliability and technical condition of buildings.

In addition, the proposed methodology provides for an assessment of the building's energy efficiency in order to determine the potential for reducing energy consumption and improving operational performance. Taking the above into account, the proposed approach allows for the systematization of survey results, simplification of the recording of identified defects, and planning of repair and restoration work.

Conclusions

In recent years, Ukraine has been actively developing a legislative framework in the field of energy efficiency and renewable energy, supporting the implementation of energy conservation programs. A significant portion of energy resources is consumed in building operations due to insufficient thermal insulation of enclosing structures, substantial heat loss, and the lack of modern microclimate control systems. Therefore, thermal modernization projects have become an important tool for enhancing the energy efficiency of buildings.

The results obtained during the study made it possible to justify technical solutions for facade insulation, select energy-saving materials and technologies, and ensure the project's compliance with current DBN and European standards. An analysis of the building's structural characteristics, regulatory framework, and energy performance allowed for determining optimal methods to improve the thermal insulation properties of the building envelope.

The use of the obtained data increased both the scientific and practical value of the work and contributed to the development of a systematic approach to planning thermal modernization measures and assessing their effectiveness. Implementing such solutions meets the current requirements for energy-efficient and environmentally safe construction and contributes to strengthening the country's energy independence and advancing the construction industry.

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Н. О. ДАНКЕВИЧ

Кафедра промислового та цивільного будівництва, Запорізький національний університет,
пр-т Соборний, 226, Україна, 69006, тел. +3 8 (098) 272 90 77,
ел. пошта dankevichnatali28@gmail.com, ORCID 0000-0002-7146-9303

ІНТЕГРОВАНА МОДЕЛЬ ОЦІНКИ ТЕХНІЧНОГО СТАНУ БУДІВЕЛЬ ДЛЯ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ТА НАДІЙНОСТІ

Мета. Дослідження спрямоване на оцінювання надійності та проведення технічної діагностики будівлі з виявленням дефектів і відновленням експлуатаційної придатності пошкоджених конструкцій, а також на формування комплексного підходу до підвищення енергоефективності та надійності об'єкта шляхом упровадження організаційних, технологічних і практичних рішень та розроблення рекомендацій щодо безпечної подальшої експлуатації. **Методика.** Проведено комплексне обстеження будівлі з оцінкою технічного стану конструкцій та інженерних систем для виявлення дефектів, що впливають на надійність та енергоефективність будівлі. За результатами обстеження складено відомість дефектів із переліком пошкоджень та рекомендаціями щодо їх усунення та відновлення експлуатаційної придатності. На основі отриманих даних розроблено комплекс організаційних, технологічних і практичних заходів, спрямованих на підвищення енергоефективності та надійності будівлі, включаючи термомодернізацію огороджувальних конструкцій, оптимізацію інженерних систем та планування робіт із обслуговування. Визначено пріоритети впровадження заходів і надано рекомендації щодо безпечної подальшої експлуатації будівлі. **Результати.** В ході проведеного обстеження будівлі було складено детальну відомість дефектів, яка містить основні пошкодження конструкцій та рекомендації щодо їх усунення. Запропоновані комплексні заходи, включаючи термомодернізацію огороджувальних конструкцій, оптимізацію інженерних систем та організаційні рішення, що дозволяють підвищити енергоефективність будівлі, відновити експлуатаційну придатність пошкоджених конструкцій, змен-

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шити витрати на обслуговування та енергоресурси, а також підвищити надійність і безпечність експлуатації. Впровадження таких заходів забезпечує значну економію енергії, продовження терміну служби об'єкта та стимулює застосування сучасних технологічних і організаційних рішень у будівельній практиці. **Наукова новизна** дослідження полягає у розробці інтегрованої моделі оцінки технічного стану будівель, виявлення дефектів і пошкоджень, обґрунтування організаційних і технологічних заходів, спрямованих на підвищення енергоефективності та експлуатаційної надійності будівельних конструкцій. **Практична значимість.** Запропонована модель дозволяє оцінювати технічний стан будівель, виявляти дефекти та планувати їх усунення, а інтегрований підхід до термомодернізації й оптимізації інженерних систем підвищує енергоефективність, подовжує термін служби конструкцій і забезпечує безпечну та економічно ефективну експлуатацію існуючих об'єктів.

Ключові слова: будівля; технічний стан; термомодернізація; енергоефективність; надійність; безпечна експлуатація

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