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ENERGY AUDIT OF A RESIDENTIAL BUILDING AS AN ENVIRONMENTAL PROTECTION TECHNOLOGY USING THE EXAMPLE OF A HOTEL – ECOLOGICAL, ENERGY AND ECONOMIC EFFECTS: A CASE STUDY

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Abstract

In the article, which shows the results of the authors' own research, the purpose of which was determination of energy, ecological and economic effects of implementing the proposed measures based on the results of an energy audit of a residential building using the example of a hotel in conditions of armed aggression and in the perspective of the post-war reconstruction of critical infrastructure and the economy of our country, the following tasks have been consistently solved: performing the analysis of the research output data; performing the building description; performing the calculations of the building's energy efficiency indicators before implementing the suggested technical solutions; proposing the technical solutions to increase the energy efficiency of the building; performing the calculations of the building's energy efficiency indicators after implementing the suggested technical solutions; drawing conclusions based on a comparative analysis of the building's energy efficiency indicators, identified energy, ecological and economic effects of implementing the proposed measures. Problem of the study is the lack of the required number of building energy auditors in the labor market, given the prospects for the post-war reconstruction of critical infrastructure facilities, buildings and structures for industrial, office and residential purposes in terms of implementing sustainable development goals and the requirements of relevant legislation, including those regarding ecological safety. Idea of the study is to conduct an energy audit of a residential building using the example of a hotel, propose technical solutions and determine the energy, ecological and economic effects of their implementation in order to reduce energy consumption in conditions of armed aggression and in the perspective of the post-war reconstruction of the critical infrastructure and economic of our country. Object of the study is energy efficiency indicators of existing and designed buildings for various purposes. Subject of the study is methods for calculating the object of study and factors that influence their numerical values. Scientific novelty of the results obtained is the approach to determining the energy, ecological and economic effects of implementing technical measures to increase energy efficiency based on energy audit data for hotel-type buildings has been further developed. Practical value of the results obtained is the applying regulatory methods to other objects described above will allow the practical implementation of the results of such calculations in the official activities of divisions and units of the SES of Ukraine, with existing workplaces for employees, places for placing fire-fighting and emergency rescue equipment, taking into account the peculiarities of operational duty by rescuer crews.

Key words: environmental protection technologies, ecological safety, technogenic and ecological safety, buildings and structures, energy efficiency, energy audit, ecological effect, economic effect, energy effect, armed aggression, post-war reconstruction.

Statement of the problem and analysis of the sources

Currently, the implementation of measures to conduct an energy audit of existing and designed buildings and structures, in particular those housing divisions and units of the State Emergency Service of Ukraine (SES of Ukraine), with existing workplaces for employees, places for placing fire-fighting and emergency rescue vehicles etc., complies with both provisions of the Order of the SES of Ukraine No. 618 dated 20.09.2013 "On Approval of the Regulations on the Organization of Environmental Support of the SES of Ukraine" [1], i.e. it is relevant at the departmental level, and the provisions of the Decree of the President of Ukraine No. 722/2019 dated 30.09.2019 "On Sustainable Development Goals of Ukraine for the Period up to 2030" [2], i.e. it is relevant from the point of view of the state development strategy.

Regarding the practical use of the results of the completed task both in times of armed aggression and in the conditions of post-war reconstruction of critical infrastructure facilities, buildings and structures for industrial, office and residential purposes, this is determined by the compliance of the research topic with the provisions of the Resolution of the Cabinet of Ministers of Ukraine No. 476 dated 30.04.2024 "On approval of the list of priority thematic areas of scientific research and scientific and technical developments for the period until December 31 of the year following the termination or abolition of martial law in Ukraine" [3]. In terms of ensuring regulatory compliance with the indicators of the level of technogenic and ecological safety in the design, repair, modernization and exploitation of the specified type of buildings and structures, it should be noted that the topic of the task is relevant as it corresponds to the points of the Specialty Passport 21.06.01 "Environmental Safety", approved by the Resolution of the Presidium of the Higher Attestation Commission of Ukraine No. 33-07/7 dated 04.07.2001 [4]. When searching for options to ensure energy autonomy of the specified types of buildings and structures in emergency situations and blackouts, the main solution is to equip them with electric generators based on reciprocating internal combustion engines, which can be converted to consume pure or mixed motor fuels of biological origin as a renewable alternative energy resource, which will allow fulfilling the requirements of the Law of Ukraine No. 3769-IX dated 04.06.2024 "On Amendments to Certain Laws of Ukraine Regarding the Mandatory Use of Liquid Biofuels (Biocomponents) in the Transport Sector" [5]. At the same time, the legislative basis for conducting an energy audit is the Law of Ukraine No. 1818-IX in the current version dated 01.01.2025 "On Energy Efficiency", the Law of Ukraine No. 2118-VIII in the current version dated 15.11.2024 "On Energy Efficiency of Buildings" and DSTU 9190:2022 "Energy Efficiency of Buildings. Method for calculating energy consumption during heating, cooling, ventilation, lighting and hot water supply" [6-8]. At the same time, the research topic also corresponds to the content of the Topics of Scientific Research and Scientific and Technical (Experimental) Developments for 2025-2029, approved by Order of the MIA of Ukraine No. 326 dated 21.05.2024, namely: item 25 "Modeling and Forecasting of the State of the Environment, Technologies for Overcoming Negative Impacts on It". In accordance with the Priority Areas of Scientific Activity of the University, the research topic corresponds to area 2 "Problems of increasing the efficiency of ensuring fire safety of objects, processes, etc.", item 2.5 "Methods for determining the characteristics of fire equipment, automation, signaling, other products and fire protection systems". The text of the Civil Defense Service Oath (Civil Defense Code of Ukraine in the current version of September 12, 2025, Article 108) states: I swear to courageously and resolutely protect the lives and health of citizens, the property of Ukraine, and its natural environment from emergencies.

Purpose of the study. Determination of energy, ecological and economic effects of implementing the suggested measures based on the results of an energy audit of a residential building using the example of a hotel in conditions of armed aggression and in the perspective of the post-war reconstruction of critical infrastructure and the economy of our country.

Problem of the study. Lack of the required number of building energy auditors in the labor market, given the prospects for the post-war reconstruction of critical infrastructure facilities, buildings and structures for industrial, office and residential purposes in terms of implementing sustainable development goals and the requirements of relevant legislation, including those regarding ecological safety. **Idea of the study.** Conducting an energy audit of a residential building using the example of a hotel, proposing technical solutions and determining the energy, ecological and economic effects of their implementation in order to reduce energy consumption in conditions of armed aggression and in the perspective of the post-war reconstruction of the critical infrastructure and economic of our country.

Object of the study. Energy efficiency indicators of existing and designed buildings for various purposes. **Subject of the study.** Methods for calculating the object of study and factors that influence their numerical values. **Methods of the study.** Analysis of specialized scientific and technical, reference, patent and regulatory literature, regulatory methods for calculating energy efficiency indicators of buildings for various purposes, regulatory methods for using control and measuring equipment, regulatory methods for designing elements of buildings for various purposes.

Tasks of the study are the following points.

1. Performing the analysis of the research output data;
2. Performing the building description.
3. Performing the calculations of the building's energy efficiency indicators before implementing the proposed technical solutions.
4. Proposing the technical solutions to increase the energy efficiency of the building.
5. Performing the calculations of the building's energy efficiency indicators after implementing the proposed technical solutions.
6. Drawing the conclusions based on a comparative analysis of the building's energy efficiency indicators, identified energy, ecological and economic effects of implementing the proposed measures.

Scientific novelty of the results obtained is as follows. The approach to determining the energy, ecological and economic effects of implementing technical measures to increase energy efficiency based on energy audit data for hotel-type buildings has been further developed.

Practical value of the results obtained is as follows. Applying regulatory methods to other objects described above will allow for the practical implementation of the results of such calculations in the official activities of divisions and units of the SES of Ukraine, with existing workplaces for employees, places for placing fire-fighting and emergency rescue equipment, taking into account the peculiarities of operational duty by rescuer crews.

The results of the study were **used and implemented** in the educational process of a higher education institution of the IV level of accreditation in the preparation of applicants for higher education at the third (educational and scientific) level in the specialty G2 "Environmental Protection Technologies".

Description of the building

External walls.

1. Expanded clay concrete 380 mm (density 1600 kg/m^3).

2. Cement-sand mortar, 50 mm. We can not neglect the excellent material between the windows.

Entrance door is metal, uninsulated, the door thickness is 60 mm.

The *windows for places of common use* are double-glazed and have a low-emission coating, filled with argon, a 5-chamber plastic frame, 60 mm thick.

Floor of the building is an unheated basement. *Ceiling*: reinforced concrete (220 mm), cement-sand screed (50 mm), expanded clay gravel, with a density of 300 kg/m^3 (50 mm).

Attic is unheated. *Ceiling* is made of reinforced concrete panels (220 mm), mineral wool with spatula fiber (100 mm), covered with a cement screed (50 mm).

Windows and doors dimensions:

– A – 1.0 m × 1.50 m (small windows);

– B – 1.60 m × 1.50 m (medium windows);

– C – 1.1 m × 1.50 m + 0.8 m × 2.1 m (balcony windows and doors);

– D – 2.0 m × 1.50 m (large window);

– E – 0.8 m × 1.50 m (windows for places of common use);

– entrance door – 3.0 m × 2.2 m.

Window and door materials.

North facade:

– all entrance doors – metal, uninsulated;

– all windows for places of common use – metal-plastic (with double glazing and low-emission coating, filled with argon);

– 8 small windows – metal-plastic (with triple glazing and low-emission coating, filled with argon);

– other windows – wooden.

South facade:

– all windows and balcony doors (with double glazing and low-emission coating, filled with argon).

Heating system.

– heating source – own boiler room on natural gas, non-condensing boiler, power 200 kW;

– manual adjustment, takes place in the boiler room;

– internal heating system is single-pipe;

– no thermostatic regulators;

– automatic balancing valves on the heating system risers are absent.

Other relevant data.

The house is located in Lviv. The house stands alone, there is no shading (other buildings and trees). Exterior and interior views of building are at Fig. 1–4. Heated water supply is provided by a gas boiler. There is no cooling system. There is natural ventilation. The tariff for thermal energy is 2700 UAH/Gcal.

Figure 1 – Exterior view of the hotel building

a b

Figure 2 – Entrance doors and windows of the stairwells of the hotel building

A b

c d

Figure 3 – Basement and attic of the hotel building

a b c

d e f

Figure 4 – Windows and entrance doors of the hotel building

Analysis of literary data

In the scientific literature, with the exception of publications of a specifically scientific nature as [20, 21], there is a known approach that involves conducting an energy audit and developing a set of measures and recommendations based on its results to obtain energy, economic and environmental effects for a specific technical object, and in some cases, solving a certain variable research problem is envisaged [22–39].

This approach was also used in this study, namely: an energy audit was performed for a hotel-type building, while a comparative calculation study was performed on the options of the proposed technical solutions.

1. Replacement of wooden windows with metal-plastic windows and their insulation

1.1. General characteristics of the building

In the spatial-planning solution, the residential building is a 3-story building which has a 1-level basement and a simple shape in plan – a rectangle with sides of 48.57 m × 10.4 m (see Fig. 5), oriented with the entrance doors of 3 entrances to the north.

The planning scheme provides for the location of the entrances to the residential building from the side of the house territory with lawns, sidewalks and a driveway along the longer side of the building.

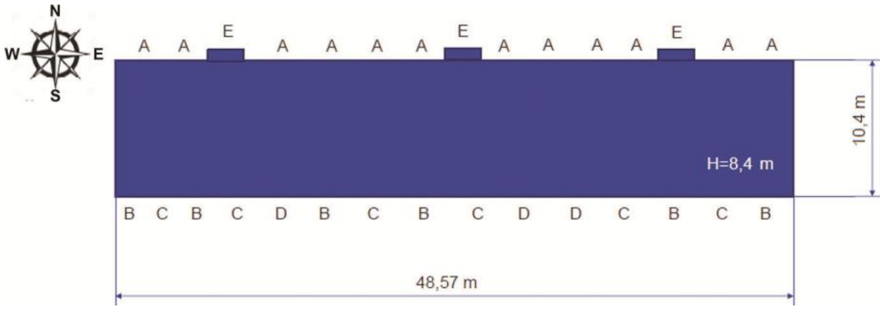

Figure 5 – Window placement and dimensions of the hotel building

There are no elevators in the building, but there are stairwells in each entrance, which are not adapted for people with limited mobility.

The residential floors are equipped with 1-room, 2-room and 3-room apartments. Staircases are provided for moving between the residential floors.

The layout of the apartments and planning solutions are designed to ensure a comfortable stay for their tenants.

The total number of hotel apartments is:

– 1-room – none,

– 2-room – none,

– 3-room – 1 apartment per floor per entrance × 3 floors × 3 entrances = 9 pcs;

– 4-room – none,

– 5-room – 1 apartment per floor per entrance × 3 floors × 3 entrances = 9 pcs;

– total number of apartments – 18 pcs.

The hotel is designed in a simple plan and has overall dimensions of 48.57 m × 10.4 m × 12.75 m.

The basement floor, located in the dump, provides for the placement of non-residential premises, as well as technical premises, in particular: electrical panels, water inlet and metering units.

The roof of the house is provided with a gable roof. Rainwater drainage from the roof is provided by external standard means.

The heat and humidity regime is adopted in accordance with current regulatory documents.

The house is provided with a convenient entrance from the side of the entrance door, as well as fire bypasses from 3 sides.

The project also provides for the landscaping of the adjacent territory.

A playground, a sports ground and a playground for adults are located in the courtyard behind the hotel. The orientation of the building is shown in Fig. 5.

1.2. Initial data for calculation

The designed building belongs to the II degree of fire resistance. Structural scheme is with longitudinal and transverse load-bearing walls made of concrete panels. The spatial rigidity of the building is provided by the existing structures of the external, internal walls, transverse walls of the staircase, and interfloor ceilings.

According to engineering and geological conditions, the foundations are provided with strip foundations made of rectangular concrete blocks.

The walls of the building above the level of 0.000 are provided with prefabricated expanded clay concrete blocks, the wall thickness is from 380 mm with a density of 1600 kg/m^3.

There is no thermal insulation layer on the walls of the building, the initial layers are cement-sand, 50 mm thick.

The floor of the building is an unheated basement, the ceiling is reinforced concrete (220 mm), cement-sand screed (50 mm), expanded clay gravel, with a density of 300 kg/m^3 (50 mm).

The stairs are designed individually from monolithic reinforced concrete and prefabricated reinforced concrete of factory production.

The lintels are made of prefabricated reinforced concrete according to the current series.

The roof is designed with a slope of metal tiles on wooden rafters.

The unheated attic has a ceiling made of reinforced concrete panels (220 mm), mineral wool from spatula fiber (100 mm), covered with cement screed (50 mm).

Porches, ramps are made of monolithic concrete in accordance with the drawings.

Entrance doors are metal, uninsulated, door thickness is 60 mm.

Fire protection of metal structures shall be carried out in accordance with the instructions on the drawings by specially trained workers who have permission to perform these works.

Translucent structures – windows for places of common use with double glazing and low-emission coating, filled with argon, 5-chamber plastic frame, thickness 60 mm.

Dimensions of windows and doors (see Fig. 5):

1. A – 1.0 m × 1.50 m (small windows), frame width 0.1 m. There are 12 such windows/floor on the northern facade, i.e. 36 in the basement, 8 of which are metal-plastic (with triple glazing and low-emission coating, filled with argon, glass block formula 4i-10Ar-4-10Ar-4i), the remaining 28 are wooden (glass block formula 4-50-4).

2. B – 1.60 m × 1.50 m (middle windows), frame width 0.1 m. There are 6 such windows/floor on the southern facade, i.e. 18 pieces in the basement – metal-plastic (with double glazing and low-emission coating, filled with argon, glass block formula 4i-16Ar-4).

3. C – 1.1 m × 1.50 m + 0.8 m × 2.1 m (balcony windows and doors), frame width 0.065 m. There are 6 such elements/floor on the southern facade, i.e. 18 pieces in the building – metal-plastic (with double glazing and low-emission coating, filled with argon, glass block formula 4i-16Ar-4).

4. D – 2.0 m × 1.50 m (large window), frame width 0.1 m. There are 4 such windows/floor on the southern facade, i.e. 12 in the building – metal-plastic (with double glazing and low-emission coating, filled with argon, glass block formula 4i-16Ar-4).

5. E – 0.8 m × 1.50 m (windows for places of common use), frame width 0.1 m. There are 2 such windows/staircase on the northern facade, i.e. 6 in the building – metal-plastic (with double glazing and low-emission coating, filled with argon, glass block formula 4i-16Ar-4).

6. Entrance door – 3.0 m × 2.2 m. There are 1 such element in the building/entrance on the northern facade, i.e. 3 in the building – metal, uninsulated.

The area of translucent structures meets the standards of natural lighting according to DBN V.2.5-28.

The insolation regime of the apartments meets the requirements of DSP 173-96.

The building has water heating, hot water supply, the source of heat supply to the apartments is its own boiler room on natural gas, the boiler is not condensing, the capacity is 200 kW, manual regulation, takes place in the boiler room, the internal heating system is one-pipe, there are no thermostatic regulators, there are no automatic balancing valves on the risers of the heating system. The tariff for thermal energy is 2700 UAH/Gcal. There is no cooling system for the premises.

The ventilation of the premises is natural. The air flow into the residential apartments is not organized through windows or transoms. The air flow into the kitchen is provided by window air inlet valves. Air removal from the kitchen, toilet or from the combined sanitary unit is provided by means of an individual vertical exhaust duct. Individual exhaust ducts and prefabricated ventilation shafts are made in building structures. Air removal from bathrooms is natural using individual exhaust ducts.

The use of renewable and alternative energy sources is not provided. Energy storage during hours of minimum energy consumption is not provided.

1.3. Determining the parameters of the existing windows

In the specified building, we have:

A. 8 pcs of type Aa windows – 1.0 m × 1.50 m (small windows), which are metal-plastic (with triple glazing and low-emission coating, filled with argon), which do not require replacement:

– glass block formula 4i-10Ar-4-10Ar-4i;
– frame width 0.1 m;
– glazing area of 1 window is 1.0 m × 1.50 m = = 1.5 m^2;
– total glazing area of these windows is 8 pcs × × 1.5 m^2 = 12 m^2;
– perimeter of the frame contour of 1 window is 2 × 1.0 m + 2 × 1.50 m = 5 m;
– total perimeter of the frame contour of these windows is 8 pcs × 5 m = 40 m.

B. 28 pcs of windows of type Ab – 1.0 m × 1.50 m (small windows), which are wooden:

– glass block formula 4-50-4;
– frame width 0.1 m;
– glazing area of 1 window is 1.0 m × 1.50 m = = 1.5 m^2;
– total glazing area of these windows is 28 pcs × × 1.5 m^2 = 42 m^2;
– perimeter of the frame contour of 1 window is 2 × 1.0 m + 2 × 1.50 m = 5 m;
– total perimeter of the frame contour of these windows is 28 pcs × 5 m = 140 m.

C. 18 pcs of type B windows – 1.60 m × 1.50 m (medium windows), which are metal-plastic (with double glazing and low-emission coating, filled with argon), which can be replaced with similar ones with triple glazing:

– glass block formula 4i-16Ar-4;
– frame width 0.1 m;
– glazing area of 1 window is 1.6 m × 1.50 m = = 2.4 m^2;
– total glazing area of these windows is 18 pcs × × 2.4 m^2 = 43.2 m^2;
– perimeter of the frame contour of 1 window is 2 × 1.6 m + 2 × 1.50 m = 6.2 m;
– total perimeter of the frame contour of these windows is 18 pcs × 6.2 m = 111.6 m.

D. 18 pcs of windows of type Ca – 1.1 m × 1.50 m (balcony windows), which are metal-plastic (with double glazing and low-emission coating, filled with argon), which can be replaced with similar ones with triple glazing:

– glass block formula 4i-16Ar-4;
– frame width 0.1 m;
– glazing area of 1 window is 1.1 m × 1.50 m = = 1.65 m^2;
– total glazing area of these windows is 18 pcs × × 1.65 m^2 = 29.7 m^2;
– perimeter of the frame contour of 1 window is 2 × 1.1 m + 2 × 1.50 m = 5.2 m;
– total perimeter of the frame contour of these windows is 18 pcs × 5.2 m = 93.6 m.

E. 18 pcs of windows of type Cb – 0.8 m × 2.1 m (balcony doors), which are metal-plastic (with double glazing and low-emission coating, filled with argon), which can be replaced with similar ones with triple glazing:

– glass block formula 4i-16Ar-4;

– frame width 0.1 m;

– glazing area of 1 window is 0.8 m × 2.1 m = = 1.68 m^2;

– total glazing area of these windows is 18 pcs × × 1.68 m^2 = 30.24 m^2;

– perimeter of the frame contour of 1 window is 2 × 0.8 m + 2 × 2.1 m = 5.8 m;

– total perimeter of the frame contour of these windows is 18 pcs × 5.8 m = 104.4 m.

F. 12 pcs of type D windows – 2.0 m × 1.50 m (large window), which are metal-plastic (with double glazing and low-emission coating, filled with argon), which can be replaced with similar ones with triple glazing:

– glass block formula 4i-16Ar-4;

– frame width 0.1 m;

– glazing area of 1 window is 2.0 m × 1.50 m = = 3.0 m^2;

– total glazing area of these windows is 12 pcs × × 3.0 m^2 = 36.0 m^2;

– perimeter of the frame contour of 1 window is 2 × 2.0 m + 2 × 1.50 m = 7.0 m;

– total perimeter of the frame contour of these windows is 12 pcs × 7.0 m = 84.0 m.

G. 6 pcs of type E windows – 0.8 m × 1.50 m (windows for places of common use), which are metal-plastic (with double glazing and low-emission coating, filled with argon), which can be replaced with similar ones with triple glazing:

– glass block formula 4i-16Ar-4;

– frame width 0.1 m;

– glazing area of 1 window is 0.8 m × 1.50 m = = 1.2 m^2;

– total glazing area of these windows is 6 pcs × × 1.2 m^2 = 7.2 m^2;

– perimeter of the frame contour of 1 window is 2 × 0.8 m + 2 × 1.50 m = 4.6 m;

– total perimeter of the frame contour of these windows is 6 pcs × 4.6 m = 27.6 m.

The reduced heat transfer coefficient of the window is determined by the following formula:

$$Uw = (\Sigma(A_g \cdot U_g) + \Sigma(A_f \cdot U_f) + \Sigma(l_g \cdot \psi_g)) / (\Sigma A_g + \Sigma A_f).\ \mathrm{W/(m^2 \cdot K)}. \quad (1.1)$$

where A_g is the area of the window glass unit, m^2; U_g is the reduced heat transfer coefficient of the window glass unit, $W/(m^2 \cdot K)$; A_f is the area of the profile elements of the window frame, m^2; U_f is the reduced heat transfer coefficient of the profile elements of the window frame, $W/(m^2 \cdot K)$; l_g is the length of linear heat-conducting inclusions in the area of the glass unit abutting the frame, m; ψ_g is the linear heat transfer coefficient of the distance frame, W/(m·K).

The heat transfer resistance for the window is determined by the following formula:

$$R_{pr} = 1 / U_w.\ \mathrm{m^2 \cdot K/W}. \quad (1.2)$$

The value of the reduced heat transfer coefficient of the glass package is given according to the manufacturer SLI-DOOR LLC from its website in Fig. 5 [14].

For windows that are metal-plastic (with double glazing and low-emission coating, filled with argon, glass block formula 4i-16Ar-4i) we have the value of the reduced heat transfer coefficient of the glass package U_g = 1.12 $W/(m^2 \cdot K)$, while for windows that are metal-plastic (with triple glazing and low-emission coating, filled with argon, glass block formula 4i-10Ar-4-10Ar-4i) U_g = 0.826 $W/(m^2 \cdot K)$. In the case of windows that are metal-plastic (with triple glazing and low-emission coating, filled with argon, the glass block formula is 4i-20Ar-4-20Ar-4i) U_g = 0.519 $W/(m^2 \cdot K)$. For a double-glazed window installed in a wooden frame and having the formula 4-50-4 (without coating, the gap is filled with air), we have the value U_g = 2.732 $W/(m^2 \cdot K)$.

The value of the heat transfer coefficient of the profile elements of the window frame, given according to the manufacturer of metal-plastic structures [14], is U_f = 1.163 $W/(m^2 \cdot K)$, and for a more advanced profile of the manufacturer of REHAU LLC – U_f = 0.790 $W/(m^2 \cdot K)$ [15] and article [16], and for frames made of wood, namely pine wood, the fibers are placed along, according to Alta Profil LLC [17], U_f = 0.18 $W/(m^2 \cdot K)$.

The value of the linear heat transfer coefficient of the distance frame according to DSTU B EN ISO 10077-1:2016 “Thermal properties of windows, doors and blinds. Calculation of the heat transfer coefficient. Part 1. General conditions” [18] (see Table 1) for the case of existing triple-glazed units with a PVC frame is ψ_g = 0.08 W/(m·K), for the case of existing double-glazed units with a PVC frame is ψ_g = 0.06 W/(m·K), for the case of existing double-glazed units with a wooden frame is ψ_g = 0.08 W/(m·K).

To establish the values of U_w and R_{pr} of the building's windows, as well as to identify the corresponding energy, economic and ecological effects of implementing the proposed technical solution – replacing windows with wooden frames with double-glazed windows in metal-plastic frames, as well as replacing existing double-glazed windows with triple-glazed windows, as well as replacing existing and planned triple-glazed windows with the formula 4i-10Ar-4-10Ar-4i with triple-glazed windows with the formula 4i-20Ar-4-20Ar-4i, a calculation study was performed in this work using the free-access spreadsheet editor WPS Office.

The study options are as follows:

– Variant No. 1 “BASIC” – all windows are in the same condition as in the initial data before the task, the calculation results for other variants will be compared with this variant;

– Variant No. 2 “WITHOUT WOOD” – only windows that were in wooden frames were replaced with double-glazed units with low-emissivity coating, filled with argon, glass block formula 4i-16Ar-4i;

– Variant No. 3 “BEST GLASS PACKAGE” – all windows were replaced with triple-glazed units with low-emissivity coating, filled with argon, glass block formula 4i-20Ar-4-20Ar-4i.

The results of the calculation study are shown in Tables 2–5. Analysis of the results of the study for Variants No. 1–3 will be presented in Section 2.

2. Determination of the building's energy efficiency class of the building, energy, economic and environmental effects of the proposed technical solutions

2.1. Determination of the energy efficiency class of the building

The energy efficiency class of a residential building is determined according to DSTU 9190:2022 "Energy efficiency of buildings. Method for calculating energy consumption during heating, cooling, ventilation, lighting and hot water supply" [8]. The main indicator of the energy efficiency class of a residential building is the numerical value of the specific energy consumption of the building in kWh/m^2 – see Table 5.

The energy efficiency class of a residential building according to DSTU 9190:2022 "Energy efficiency of buildings. Method for calculating energy consumption during heating, cooling, ventilation, lighting and hot water supply" [8] is determined by the formula (2.1).

$$EP_{use} \le EP_p. \text{ kW·h/m}^2. \quad (2.1)$$

where EP_{use} is the annual calculated or actual value of the total specific energy consumption of the building for heating and cooling, kWh/m^2; EP_p is the limit value of the specific energy consumption of the residential building for heating and cooling, kWh/m^2 (see Table 5).

Since the building is equipped with its own natural gas boiler room with a non-condensing boiler with a power capacity of 200 kW, we will assume that this value of the boiler power was chosen based on the results of calculations regarding the energy audit of this building at the design stage, with the expectation that the maximum boiler power should be expected in winter on days with the lowest ambient air temperatures outside the building with a safety factor of 0.10, i.e. the boiler should develop 90 % of the nominal power, namely 200 kW · 0.90 = 180 kW, with the existing parameters of windows and doors.

With constant boiler operation in this regime, the following amount of thermal energy will be released per day (24 hours): 24 h · 180 kW = 4320 kWh/day. A non-leap year contains 365 days, therefore, when the boiler operates in this mode, 365 days/year · 4320 kWh/day = 1576800 kWh/year will be released. However, the heating period in the city of Lviv in the 2024/2025 heating season began on October 28 and ended on April 14, which amounted to 169 days, or 169/365 = = 0.463 parts of the year, i.e. the energy release for this period will be of 0.463 · 1576800 kWh/year = = 730058.4 kWh/season.

The heated area of the house is (see Fig. 5) for 3 heated floors (the attic and basement are unheated) with unheated staircases, each floor contains 3 identical compartments in plan behind 3 entrances, each compartment contains:

a) 9 living rooms with the following areas: 11.6 m^2, 16.3 m^2, 11.1 m^2, 18.5 m^2, 13.1 m^2, 8.9 m^2, 7.8 m^2, 7.7 m^2, 8.9 m^2, total 103.9 m^2;

b) 2 vestibules with different areas: 8.7 m^2 and 8.2 m^2, total 16.9 m^2;

c) 2 storage niches with different areas: 1.0 m^2 and 0.9 m^2, total 1.9 m^2;

d) 2 bathrooms with the same areas: (1.1 + 2.2) m^2, total 6.6 m^2.

Thus, the total heating area of 1 compartment of the 1st floor is 103.9 m^2 + 16.9 m^2 + 1.9 m^2 + 6.6 m^2 = = 129.3 m^2/compartment. Then the heating area of the 1st floor is 3 compartments · 129.3 m^2/compartment = = 387.9 m^2/floor. So, the total heating area of all 3 floors is 3 floors · 387.9 m^2/floor = 1163.7 m^2.

Therefore, when the boiler operates in the described mode around the clock and, in the first approximation, the allocated thermal energy is fully used for the needs of the building, i.e. to fully cover the energy needs of the building, the specific energy demand of the building in kWh/m^2 is: 4320 kWh/day / 1163.7 m^2 = = 3.712 kWh/m^2/day. For the heating season, this value is 169 days · 3.712 kWh/m^2/day = = 627.3 kWh/m^2/season.

This corresponds to energy efficiency class D.

2.2. Determination of the energy effect of implementing the proposed technical solutions

As it can be seen from the tables of calculation results presented in Tables 3–5 and with initial data from Tables 6–8, in Variant No. 1 "BASIC" we have, with a total glazing area of 200.34 m^2, the thermal energy capacity transmitted to the environment at an outside temperature of –27 °C, an inside temperature of +23 °C, i.e. a temperature head of 50 °C, 14.725 kW, which is 8.2 % of the capacity of the thermal energy source – a gas boiler at its operating regime described above.

Table 1 – Values of the reduced heat transfer coefficient of the glass unit [14]

Total thickness of the glass unit. mm	Glass unit formula	Heat transfer coefficient U_q			
		Ordinary glass. chambers filled with air	Single energy-saving glass. chambers filled with air	One glass is energy-saving. the chambers are filled with argon	Two energy-saving glasses. chambers filled with argon
24	4-16-4	2.732	1.360	1.120	-
32	4-10-4-10-4	1.981	1.395	1.138	0.826
40	4-12-4-16-4	1.835	1.076	0.873	0.638
42	4-15-4-15-4	1.803	1.098	0.890	0.604
44	4-16-4-16-4	1.779	1.056	0.859	0.575
48	4-20-4-16-4	1.747	1.033	0.850	0.549
52	4-20-4-20-4	1.714	1.018	0.864	0.519
Cold glass units					
Energy-saving glass units					
Highly efficient energy-saving glass units					

Table 2 – Values of the linear heat transfer coefficient of the distance frame [18]

Frame material	Estimated thermal conductivity coefficient for different types of glazing ψ_g	
	Double-glazed window with two or three layers of glass. uncoated glass. the inter-glass space is filled with air or gas	**Double-glazed window with two* or three** layers of low-emissivity glass. the inter-glass space filled with air or gas**
Wood or PVC	0.06	0.08
Metal with thermal insulation	0.08	0.11
Metal without thermal insulation	0.02	0.05

*with a single glass in a double-glass unit **with two glasses in a triple-glass unit

Table 3 – Results of the calculation study for Variant No. 1 “BASIC”

Indicator	Measuring unit	Magnitude							
Window type	–	**Aa**	**Ab**	**B**	**Ca**	**Cb**	**D**	**E**	**Σ**
Number of windows	–	8	28	18	18	18	12	6	
Length of the glass unit	**m**	1	1	1.6	1.1	0.8	2	0.8	
Height of the glass unit	**m**	1.5	1.5	1.5	1.5	2.1	1.5	1.5	
Frame width	**m**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Frame material	–	PVC	Wood	PVC	PVC	PVC	PVC	PVC	
Glass unit window formula	–	4i-10Ar-4-10Ar-4i	4-50-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	
A_g	**m²**	1.5	1.5	2.4	1.65	1.68	3	1.2	
U_g	**W/(m²·K)**	0.826	2.732	1.12	1.12	1.12	1.12	1.12	
A_f	**m²**	0.5	0.5	0.62	0.52	0.58	0.7	0.46	
U_f	**W/(m²·K)**	1.163	0.18	1.163	1.163	1.163	1.163	1.163	
l_g	**m**	5	5	6.2	5.2	5.8	7	4.6	
p_{sig}	**W/(m·K)**	0.08	0.08	0.06	0.06	0.06	0.06	0.06	
U_w	**W/(m²·K)**	1.110	2.294	1.252	1.274	1.285	1.242	1.298	
R_{pr}	**m²·K/W**	0.901	0.436	0.799	0.785	0.778	0.805	0.770	
Θ_{in}	**°C**	23	23	23	23	23	23	23	
Θ_{out}	**°C**	-27	-27	-27	-27	-27	-27	-27	
$\Delta\Theta$	**°C**	50	50	50	50	50	50	50	
ΣA	**m²**	12	42	43.2	29.7	30.24	36	7.2	**200.340**
W_w	**kW**	0.666	4.817	2.704	1.892	1.943	2.235	0.467	**14.725**
t	**h**	24	24	24	24	24	24	24	
	s	86400	86400	86400	86400	86400	86400	86400	
Q_w	**MJ**	57.6	416.2	233.7	163.5	167.9	193.1	40.4	**1272.253**
	kWh	15.988	115.618	64.904	45.408	46.631	53.639	11.216	**353.403**

Table 4 – Results of the calculation study for Variant No. 2 “WITHOUT WOOD”

Indicator	Measuring unit	Magnitude							
Window type	–	**Aa**	**Ab**	**B**	**Ca**	**Cb**	**D**	**E**	**Σ**
Number of windows	–	8	28	18	18	18	12	6	
Length of the glass unit	**m**	1	1	1.6	1.1	0.8	2	0.8	
Height of the glass unit	**m**	1.5	1.5	1.5	1.5	2.1	1.5	1.5	
Frame width	**m**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Frame material	–	PVC	PVC	PVC	PVC	PVC	PVC	PVC	
Glass unit window formula	–	4i-10Ar-4-10Ar-4i	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	4i-16Ar-4	
A_g	**m²**	1.5	1.5	2.4	1.65	1.68	3	1.2	
U_g	**W/(m²·K)**	0.826	1.12	1.12	1.12	1.12	1.12	1.12	
A_f	**m²**	0.5	0.5	0.62	0.52	0.58	0.7	0.46	
U_f	**W/(m²·K)**	1.163	1.163	1.163	1.163	1.163	1.163	1.163	
l_g	**m**	5	5	6.2	5.2	5.8	7	4.6	
p_{sig}	**W/(m·K)**	0.08	0.06	0.06	0.06	0.06	0.06	0.06	
U_w	**W/(m²·K)**	1.110	1.281	1.252	1.274	1.285	1.242	1.298	
R_{pr}	**m²·K/W**	0.901	0.781	0.799	0.785	0.778	0.805	0.770	
Θ_{in}	**°C**	23	23	23	23	23	23	23	
Θ_{out}	**°C**	-27	-27	-27	-27	-27	-27	-27	
$\Delta\Theta$	**°C**	50	50	50	50	50	50	50	
ΣA	**m²**	12	42	43.2	29.7	30.24	36	7.2	**200.340**
W_w	**kW**	0.666	2.690	2.704	1.892	1.943	2.235	0.467	**12.597**
t	**h**	24	24	24	24	24	24	24	
	s	86400	86400	86400	86400	86400	86400	86400	
Q_w	**MJ**	57.6	232.4	233.7	163.5	167.9	193.1	40.4	**1088.409**
	kWh	15.988	64.550	64.904	45.408	46.631	53.639	11.216	**302.336**

Table 5 – Results of the calculation study for Variant No. 3 "BEST GLASS PACKAGE"

Indicator		Measuring unit	Magnitude							
Window type		–	**Aa**	**Ab**	**B**	**Ca**	**Cb**	**D**	**E**	**Σ**
Number of windows		–	8	28	18	18	18	12	6	
Length of the glass unit		**m**	1	1	1.6	1.1	0.8	2	0.8	
Height of the glass unit		**m**	1.5	1.5	1.5	1.5	2.1	1.5	1.5	
Frame width		**m**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Frame material		–	PVC	PVC	PVC	PVC	PVC	PVC	PVC	
Glass unit window formula		–	4i-20Ar-4-20Ar-4i	same	same	same	same	same	same	
A_g		**m^2**	1.5	1.5	2.4	1.65	1.68	3	1.2	
U_g		**W/(m^2·K)**	0.519	0.519	0.519	0.519	0.519	0.519	0.519	
A_f		**m^2**	0.5	0.5	0.62	0.52	0.58	0.7	0.46	
U_f		**W/(m^2·K)**	0.79	0.79	0.79	0.79	0.79	0.79	0.79	
l_g		**m**	5	5	6.2	5.2	5.8	7	4.6	
p_{sig}		**W/(m·K)**	0.08	0.08	0.08	0.08	0.08	0.08	0.08	
U_w		**W/(m^2·K)**	0.787	0.787	0.739	0.776	0.794	0.722	0.816	
R_{pr}		**m^2·K/W**	1.271	1.271	1.353	1.289	1.260	1.386	1.226	
Θ_{in}		**°C**	23	23	23	23	23	23	23	
Θ_{out}		**°C**	-27	-27	-27	-27	-27	-27	-27	
$\Delta\Theta$		**°C**	50	50	50	50	50	50	50	
ΣA		**m^2**	12	42	43.2	29.7	30.24	36	7.2	**200.340**
W_w		**kW**	0.472	1.652	1.596	1.152	1.200	1.299	0.294	**7.665**
t		**h**	24	24	24	24	24	24	24	
		s	86400	86400	86400	86400	86400	86400	86400	
Q_w		**MJ**	40.8	142.7	137.9	99.5	103.7	112.2	25.4	**662.251**
		kWh	11.329	39.652	38.303	27.644	28.808	31.174	7.048	**183.959**

Table 6 – Building energy efficiency classes [8]

No.	Building type (reference buildings)	Limit value of specific energy consumption of buildings for heating and cooling EP_p. kWh/m^2 (kWh/m^3). for the temperature zone of Ukraine	
		I	II
1	Residential buildings (number of floors)		
	from 1 to 3	120	110
	from 4 to 9	85	75
	from 10 to 16	75	70
	17 and more	70	65
2	Public buildings (storeys)		
	from 1 to 3	[38Λinitial + 15]	[34Λinitial + 13]
	from 4 to 9	[30]	[25]
	10 and more	[25]	[20]
3	Certain types of public buildings		
3.1	Hotel buildings	[57Λinitial + 60]	[50Λinitial + 55]
3.2	Educational institution buildings	[55Λinitial + 24]	[52Λinitial + 23]
3.3	Preschool education buildings	[32]	[28]
3.4	Buildings of healthcare institutions	[30]	[26]
3.5	Commercial buildings	[33Λinitial + 17]	[26Λinitial + 15]

Table 7 – Climatic zones of Ukraine (in the original language) [12]

Region	Climatic zone	Region	Climatic zone	Region	Climatic zone
Vinnytska	I	Kirovohradska	I	Kharkivska	I
Volynska	I	Luhanska	I	*Khersonska*	II
Dnipropetrovsks	I	Lvivska	I	Khmelnytska	I
Donetsks	I	*Mykolaivska*	II	Cherkasska	I
Zhytomyrska	I	*Odeska*	II	Chernivetska	I
Zakarpatska	II	Poltavska	I	Chernihivska	I
Zaporizhzhska	II	Rhivnenska	I	*AR Krimea*	II
Ivano-Frankivska	I	Sumska	I		
Kyivska	I	Ternopilska	I		

Table 8 – Normative values of reduced heat transfer resistance [13]

Enclosing structures of the building		Heat transfer resistance for temperature zone	
		I	II
1	Exterior walls	4.0	3.5
2	Combined coatings bordering the outside air	7.0	6.0
3	Covering heated attics (technical floors). Mansards. Attic floors of unheated attics	6.0	5.5
4	Ceilings bordering the outside air and above unheated basements	5.0	4.0
5	Translucent fencing structures	0.9	0.8
6	Skylights	0.8	0.7
7	Exterior doors	0.7	0.6

At the same time, in 1 day, i.e. 24 hours or 86400 s, a total of 1272.250 MJ or 353.404 kWh of thermal energy is lost through all windows.

When implementing Variant No. 2 “WITHOUT WOOD”, that is, when replacing all wooden windows in the building with double-glazed windows with low-emission coating, filled with argon, the glass block formula is 4i-16Ar-4i, we have a thermal energy capacity that is transmitted to the environment under the same conditions of 12.597 kW, which is 14.5 % less than in the basic Variant. At the same time, in 1 day, a total of 1088.410 MJ or 302.336 kWh of thermal energy is lost through all windows.

When implementing Variant No. 3 “BEST GLASS PACKAGE”, that is, when replacing all wooden windows in the building with triple-glazed windows and low-emission coating, filled with argon, the glass block formula is 4i-20Ar-4-20Ar-4i, we have a thermal energy capacity that is transmitted to the environment under the same conditions of 7.665 kW, which is already 47.9 % lower than in the basic Variant. At the same time, in 1 day, a total of 662.251 MJ or 183.959 kWh of thermal energy is lost through all windows.

2.3. Determination of the economic effect of implementing the proposed technical solutions

With the thermal energy tariff of 2700 UAH/Gcal provided in the initial data, which corresponds to the value of 645.3 UAH/GJ, or 0.6453 UAH/MJ, so we have that in 1 day the total energy is lost through all windows:

– in Variant No. 1 “BASIC” by 820.60 UAH,

– in Variant No. 2 “WITHOUT WOOD” by 702.02 UAH, i.e. by 14.5 % less than in the basic option, the daily savings are 118.58 UAH,

– in Variant No. 3 “BEST GLASS PACKAGE” by 427.15 UAH, i.e. by 47.9% lower than in the basic Variant , the daily savings are 393.45 UAH.

2.4. Determination of the environmental effect of the implementation of the proposed technical solutions

The lower calorific value of natural gas is 47,000 kJ/kg, or 47.0 MJ/kg, as known from reference data [19]. Thus, the loss of thermal energy through all windows in Variant No. 1 “BASIC” corresponds to the complete combustion of 27.1 kg of natural gas and the release of such a quantity of complete combustion products according to the formula:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (2.3)$$

The molar mass of methane is

$$\mu(CH_4) = \mu(C) + 4\,\mu(H) = 12 + 4 \cdot 1 = 16 \text{ kg/mol},$$

the molar mass of carbon dioxide is

$$\mu(CO_2) = \mu(C) + 2\,\mu(O) = 12 + 2 \cdot 16 = 44 \text{ kg/mol}.$$

In the redox reaction (2.3), 1 mol of the burning reducing agent (fuel, methane) requires 2 mol of the oxidizing agent (oxygen from the air) and produces 1 mol of carbon dioxide and 2 mol of water vapor. That is, for 1 mol of CH_4, 1 mol of CO_2 is released during its combustion, which is a marker of the carbon footprint and is a greenhouse gas.

Accordingly, 27.1 kg CH_4 = 1.694 mol CH_4, and therefore 1.694 mol CO_2, which corresponds to 74.525 kg CO_2. In Variant No. 2 “WITHOUT WOOD”, CO_2 should be emitted 14.5 % less than in the baseline, i.e. 63.719 kg. In Variant No. 3 “BEST GLASS PACKAGE», CO_2 should be emitted 47.9 % less than in the baseline, i.e. 38.828 kg.

Conclusion

Thus, based on the results of the research, reflected in the sections of this work, the following general conclusions can be drawn.

1. Some energy efficiency indicators of the building have been analyzed.

2. Two variants for technical solutions have been proposed to increase the energy efficiency indicators of the building:

a) replacing all wooden windows in the building with double-glazed and low-emissivity glass units filled with argon, glass block formula 4i-16Ar-4i;

b) replacing all wooden windows in the building with triple-glazed and low-emissivity glass units filled with argon, glass block formula 4i-20Ar-4-20Ar-4i.

3. The energy efficiency class of the building was established in a first approximation.

4. Based on the analysis of the results of the performed calculation study, the energy, economic and ecological effects of the implementation of the proposed technical solutions to increase the energy efficiency indicators of the building operation have been determined.

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At the same time, the materials from the VCU library system have been used, including electronic versions of journals and other materials, databases, interlibrary subscription as part of participation in Non-Resident Academic Associates program co-sponsored by the College of Humanities and Sciences at Virginia Commonwealth University (VCU) and the Davis Center for Eurasian Studies at Harvard University in 2024–2025 academic year.

The subject of the study is fully consistent with the main points of the Presidential Decree No. 722/2019 of 30.09.2019 “About the Sustainable Development Goals of Ukraine for the period up to 2030” [2], “Regulation on the Organization of Environmental Support of the SES of Ukraine”, approved by Order No. 618 of

20.09.2013 [1], Specialty passport 21.06.01 "Ecological Safety", approved by the resolution of the Presidium of the Higher Attestation Commission of Ukraine No. 33-07/7 dated 04.07.2001 [4], Resolution of the Cabinet of Ministers of Ukraine No. 476 dated 04/30/2024 "On approval of the list of priority thematic areas of scientific research and scientific and technical developments for the period until December 31 of the year following the termination or abolition of martial law in Ukraine" [3] and Law of Ukraine No. 3769-IX of 04.06.2024 "On Amendments to Certain Laws of Ukraine Regarding the Mandatory Use of Liquid Biofuels (Biocomponents) in the Transport Sector" [5].

In the study, there have also been used the results of the authors 'completion the course on the educational online platform "Progresylny" "Big Course «About AI in Education" (26.05–09.06.2025, 1.5 ECTS credits, Certificates No. VKShIO-1754, VKShIO-1773), the course on the educational online platform "Zrozumilo!" "Training of Energy Auditors of Buildings and Designers (TEAD"» (23.06–23.07.2025, 3.76 ECTS credits, certificate, members of the Public Organization "Progresylny", Certificates No. 1625/25, 1649/25) and full-time participation in the training program "Academy of Mentoring" of the Public Organization "Progresylny" (14–18.08.2025, 1.0 ECTS credits, Certificate 012/AM dated 17.08.2025).

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ЕНЕРГОАУДИТ ЖИТЛОВОЇ БУДІВЛІ ЯК ТЕХНОЛОГІЯ ЗАХИСТУ НАВКОЛИШНЬОГО СЕРЕДОВИЩА НА ПРИКЛАДІ ГОТЕЛЮ – ЕКОЛОГІЧНИЙ, ЕНЕРГЕТИЧНИЙ ТА ЕКОНОМІЧНИЙ ЕФЕКТИ: ТЕМАТИЧНЕ ДОСЛІДЖЕННЯ

У цій статті наведено результати власного дослідження авторів, метою якого було визначення енергетичних, екологічних та економічних ефектів від впровадження запропонованих заходів на основі результатів енергетичного аудиту житлового будинку на прикладі готелю в умовах збройної агресії та в перспективі післявоєнної відбудови критичної інфраструктури та економіки нашої країни, послідовно вирішувалися такі завдання: виконання аналізу вихідних даних дослідження; виконання описання будівлі; виконання розрахунків показників енергоефективності будівлі перед впровадженням запропонованих технічних рішень; розробка технічних рішень для підвищення енергоефективності будівлі; виконання розрахунків показників енергоефективності будівлі після впровадження запропонованих технічних рішень; формулювання висновків на основі порівняльного аналізу показників енергоефективності будівлі, виявлення енергетичних, екологічних та економічних ефектів від впровадження запропонованих заходів. Проблемою дослідження є відсутність необхідної кількості енергетичних аудиторів будівель на ринку праці, враховуючи перспективи післявоєнної реконструкції об'єктів критичної інфраструктури, будівель та споруд промислового, офісного та житлового призначення з точки зору реалізації цілей сталого розвитку та вимог відповідного законодавства, зокрема щодо екологічної безпеки. Ідея дослідження полягає в проведенні енергетичного аудиту житлової будівлі на прикладі готелю, пропонуванні технічних рішень та визначенні енергетичного, екологічного та економічного ефектів від їх впровадження з метою зниження споживання енергії в умовах збройної агресії та в перспективі післявоєнної реконструкції критичної інфраструктури та економіки нашої країни. Об'єктом дослідження є показники енергоефективності існуючих та проектованих будівель різного призначення. Предметом дослідження є методи розрахунку об'єкта дослідження та фактори, що впливають на їх числові значення. Наукова новизна отриманих результатів полягає в тому, що набув подальшого розвитку підхід до визначення енергетичного, екологічного та економічного ефектів від впровадження технічних заходів щодо підвищення рівня енергозбереження на основі даних енергоаудиту для будівель типу готель. Практична цінність отриманих результатів полягає в тому, що застосування методів аудиту та проєктування до інших, описаних вище, об'єктів дозволить практично впровадити результати таких розрахунків у службову діяльність підрозділів та частин ДСНС України, з існуючими робочими місцями для працівників, місцями для розміщення пожежного та аварійно-рятувального обладнання, з урахуванням особливостей оперативного чергування рятувальними загонами.

Ключові слова: технології захисту навколишнього середовища, техногенно-екологічна безпека, будівлі та споруди, енергоефективність, енергоаудит, екологічний ефект, економічний ефект, енергетичний ефект, збройна агресія, повоєнна відбудова.

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