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ANALYSIS OF THE EXPERIENCE FOR CLIMATE MODERNIZATION OF ENGINEERING SYSTEMS IN BUILDINGS

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ABSTRACT

In this paper, an analysis of solutions for adapting existing buildings to changing operating conditions, climate and technological requirements is fulfilled. Dynamic modernization allows the sustainable operation of buildings, taking into account modern standards for engineering systems. The projects under consideration use flexible engineering solutions that allow according to response changes in load, and prospects for ensuring the stability of automation while taking into account user comfort. The main objective in the considered examples of building modernization is to study the experience of work on the modernization of engineering systems of buildings, on the basis of which approximate economic and environmental assessments were obtained that correspond to similar projects.

1. INTRODUCTION

EU environmental plans envisage that most countries will achieve climate neutrality and almost 100% renewable energy supply by 2050 [1].

Achieving this goal for the construction industry means renovating existing buildings with significant financial investments [2].

A typical object requiring energy reconstruction is residential buildings in which combined gas boilers are used as a source of thermal energy, which does not ensure the climate neutrality of buildings, which implies the rejection of gas and oil.

Therefore, the transition to climate neutrality is inextricably linked with the optimization of investments and the development of comprehensive concepts for the energy reconstruction of buildings, which can use a dynamic approach and the implementation of partial solutions [3].

The use of a dynamic approach involves not simply technical re-equipment, but the implementation of a flexible, manageable strategy for improving the energy efficiency of buildings, which includes sequential stages that take into account the adaptation of new technologies, budget optimization, and user involvement.

Approaches and methods for implementing climate modernization using a dynamic approach require further development and elaboration (especially for residential and civil buildings), and work aimed at analysing the practical experience of energy reconstruction of building projects makes an important contribution to the development of the methodology for dynamic modernization of buildings.

Analysis of completed energy renovations allows us to obtain the first rough estimates of the effectiveness of the adopted technical solutions.

This allows for the selection of rational research directions to ensure the greatest possible flexibility of projects and can serve as a guideline for the modernization of construction projects and is of practical interest to developers of climate-neutral buildings.

2. EXPOSITION

Traditionally, heat and energy supply systems for buildings have been developed based on the nominal (maximum design) load, while over-consumption and the origin of fuel and energy resources, as a rule, have not been the subject of close analysis.

A key distinction in constructing a climate-neutral thermal energy system for a building is its long-term focus, considering the building's life cycle and its phased implementation. Therefore, it makes sense to divide the modernization process into several stages (Fig. 1).

The result of the first stage of modernization, the energy audit is the energy balance of the object, which can be presented in the form of a mathematical model of the type according to equation (1),

$$\begin{aligned}&\sum Q_i+\sum Q_{G_i}+\sum Q_{F_i}+\sum N_i=\\&=\sum Q_j+\sum Q_{G_j}+\sum Q_{F_j}+\sum N_j\end{aligned}\tag{1}$$

here Q_i and Q_j are the heat flows entering and leaving the object with the flows of substances G_i and G_j;

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Q_{Gi} and Q_{Gj} are heat flows supplied to the object and removed from it by heat carriers circulating in closed circuits;

Q_{Fi} and Q_{Fj} are the heat flows supplied and removed through enclosures (walls, windows, floors, building ceilings, etc.);

N_i and N_j are the supplied and used electrical energy.

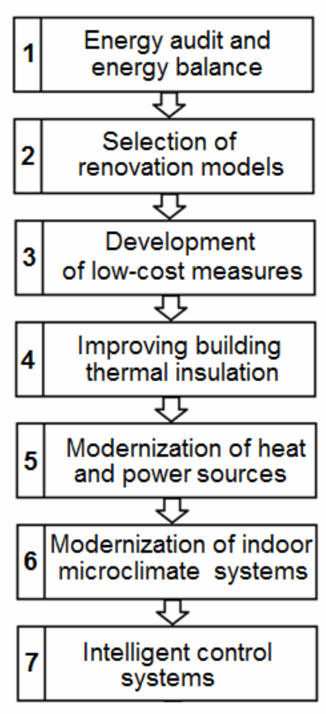

Fig. 1. Stages of energy modernization of buildings

Analysis of the energy flow model makes it possible to plan modernization paths. As a rule, energy modernization of buildings is carried out in the form of a comparison of several modernization models of the object under study (building or group of buildings).

The developed models of energy modernization of the facility are checked according to the criteria of cost-effectiveness (costs of modernization $C_i \to min$) and environmental friendliness (number of pollutants $W_i \to min$) [4].

Considering a number of developed projects for the energy modernization of buildings of various construction volumes (small, medium, and complexes of buildings) with the aim of increasing climate neutrality some examples are shown.

Fig. 2 shows a residential 6-apartment building with an area of 350 m^2 located on a separate plot of land.

To transition to alternative energy sources in low-rise construction, air-to-water heat pumps are widely used [5].

The building is in good technical condition; modern energy-saving windows have been installed, and thermal insulation of the enclosing structures has been completed in accordance with regulations.

The house is heated by gas boilers installed in each apartment. To ensure climate neutrality and the transition to alternative energy sources, an energy audit of the building was conducted and an energy balance was compiled.

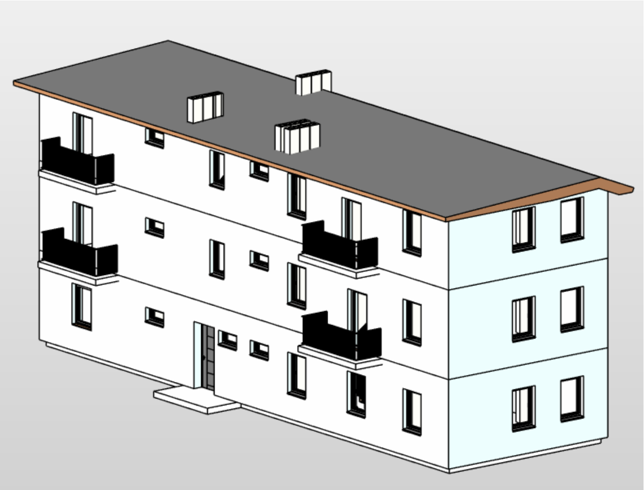

Fig. 2. A residential 6-apartment building

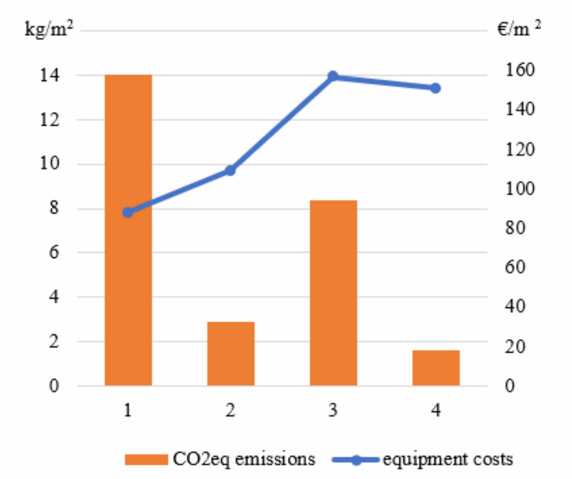

Fig. 3. Investments and CO$_{2eq}$ reduction for the conversion of 1 m^2 of space in a 6-apartment building

Three reconstruction models are proposed for the building in question:

- for heating in each apartment, use air-to-water heat pumps connected to the existing heating system, provide hot water supply using solar water heaters on the roof, install photovoltaic systems on the roof and southern facade of the house;
- use a hybrid solar installation and photovoltaic systems for heating and hot water supply of the house;
- use a pellet boiler and photovoltaic systems for heating and hot water supply of the house.

The second and third models involve the reconstruction of heating and hot water supply systems.

Calculations of profitability, considering indexation to assess the economic efficiency of proposals over the service life (20 years) of the building's engineering systems, showed significant advantages of the first model with air-to-water heat pumps.

This modernization model offers greater flexibility and the potential for dynamic, phased modernization. Therefore, it was chosen for practical implementation.

A comparison of specific investment costs (for heat sources) for equipment and expected CO$_{2eq}$ emissions allows to evaluate the environmental and economic impact of the developed models and the existing heat supply option with a gas boiler. Fig. 3 illustrates these differences among the analyzed heat supply options.

To calculate the heat demand for heating, the building's energy consumption was determined by monitoring the building's energy consumption after thermal modernization under the building's operating meteorological conditions - southern Ukraine. The heat demand for heating the residential building is approximately 65 kWh/m², which corresponds to benchmark values for residential buildings in EU countries.

For energy-efficient products, lighting equipment should be purchased at different prices, with a minimum requirement of 20%.

The following average coefficients were used for calculating international CO_{2eq} emissions (for external exports to Ukraine): 215 grams of CO_{2eq} per kWh for natural gas and 280 grams of CO_{2eq} per kWh for electricity.

The start of the building's refurbishment was limited by the low capacity of the supply electrical network and the impossibility of backing up an additional electrical input.

Therefore, at the first stage, it was proposed to implement partial solutions (using the Pareto principle [4]) that would reduce gas consumption.

To improve the dynamization and flexibility of the modernization project, the following was proposed:

- rational organization of the living space;
- improved operation of the existing heating system;
- optimization of thermal energy use;

Rational organization of living space involves precise zoning of apartments with the definition of "desired comfort" zones and zones with acceptable microclimate parameters.

To improve operation, it is planned to reinstall the control thermostat (gas boiler) in the "desired comfort" zone, which will ensure more precise operation of the heating system, and to reduce the power of the radiators, taking into account the zoning of the rooms and optimization of the thermal mode of operation by the heating devices. During these activities, it is necessary to ensure the highest possible efficiency of the existing heating system.

An example of the implementation of a dynamic approach and partial solutions in the energy modernization of medium-sized buildings is an office center with an area of 3,200 m^2. Fig. 4 presents the building used as the case study.

Fig. 4. Office center

The building has five floors and is heated by four gas boilers located on the first and third floor. The building's windows and enclosing structures were modernized in the early 2000s.

Following an energy audit and energy balance, the following modernization models were proposed to improve the building's climate neutrality:

- Heating (heating, ventilation, and some hot water) will be provided by brine-to-water heat pumps installed in place of the gas boilers. The roof can withstand the additional load, so solar hot water systems and photovoltaic panels are installed on it;
- for heat supply (heating and ventilation and partially hot water supply) use a pellet boiler, for hot water supply solar installations and photovoltaic panels are installed;

Based on economic calculations and the selection of the main model of energy modernization with flexibility and dynamism (considering the capacity of photovoltaic systems), a combined model was adopted for implementation, namely:

- heat pumps cover 50% of the heat load and 50% is covered by a pellet boiler, solar installations for hot water supply and photovoltaic panels.

Fig. 5 compares the specific investment costs for heat source equipment and the expected CO_{2eq} emissions for the analysed heating options.

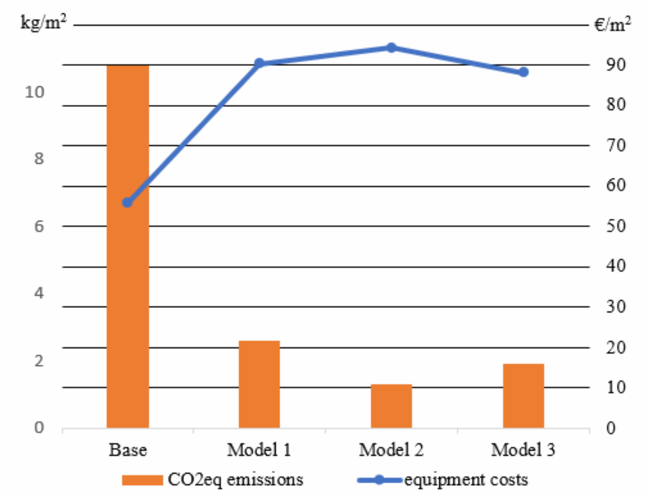

Fig. 5. Investments and CO_{2eq} reduction for the conversion of 1 m^2 of office center space

Energy-efficient systems rely on external storage of equipment (20% uncertainty).

Coefficients for calculating net CO_{2eq} (Ukraine) are provided: 215 grams of CO_{2eq} per kWh for natural gas and 156 grams of CO_{2eq} per kWh for electricity.

For the office center, the heat requirement for heating was determined based on actual indicators after thermal modernization under the meteorological conditions of the building's operation – southern Ukraine – and is approximately 40 kWh/m^2. The specific heat consumption figures for heating the building correlate well with those of modernised buildings in various EU regions.

To improve the efficiency of the existing heating system, its operation was optimized. The following optimization criteria were adopted:

- minimization coolant flow rate (G_i) from the calculated values (G_{ir}) across all circuits in the system. The optimization criterion, denoted as G_{min}, is mathematically expressed in Equation (2):

$$G_{min} = \sum_{i=1}^{n} \left(G_i - G_{ir}\right)^2 \qquad (2)$$

- the second optimization criterion focuses on minimization of squared deviations of the actual thermal power of radiators (Q_i) from the calculated values (Q_{ir}) across all radiators in the system. This criterion, denoted as Q_{min}, is mathematically expressed in equation (3):

$$Q_{min} = \sum_{i=1}^{n} \left(Q_i - Q_{ir}\right)^2 \qquad (3)$$

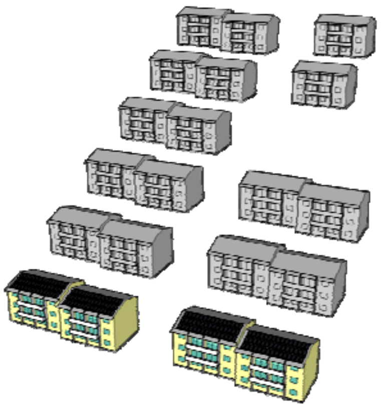

Fig. 6. Residential complex

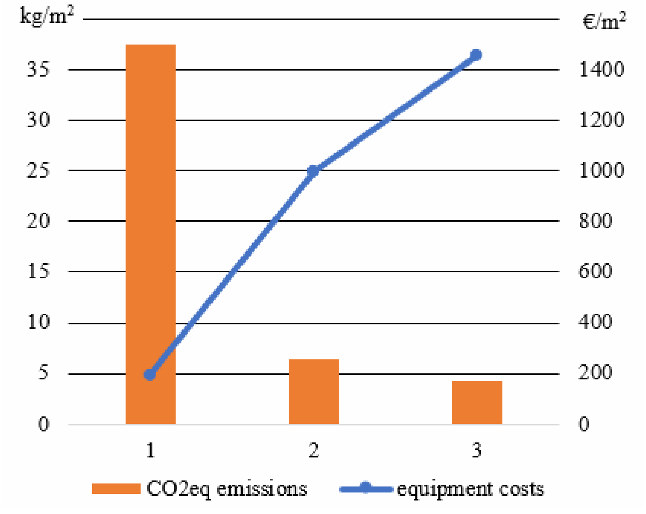

Fig. 7. Rough costs for implementation of energy supply and thermal renovation options for residential complex

Thermographic examination of radiators demonstrated the effectiveness of the measures taken to optimize the heating system.

The energy modernization models discussed above can be scaled up for groups of buildings. In the context of the energy progressive group, buildings are called residential complexes, consisting of apartment buildings with a total area of about 9,000 m^2 (Fig. 6).

To ensure flexibility in modernization of energy sources, two reconstruction models have been proposed according to [6]:

- first model: installation of separate air-to-water heat pump systems. This option is complemented by roof covering and photovoltaic modules.
- the second model: installation of a hybrid brine-water heat pump system that uses deep wells as a heat source. The photovoltaic system will be installed in the same volume as in the first model.

Fig. 7 provides a basis for comparing investment costs and CO_{2eq} emission reductions, allowing a direct comparison of different retrofit models. Describe energy was scaled by CO_{2eq} factor (156 g/kWh).

The costs of upgrading the engineering systems of a residential complex for model 1 are less than in model 2.

However, to select a rational solution, it is necessary to consider the design features of the equipment. Using air-to-water heat pumps (model 1) is more energy-intensive when operating in cooling mode than brine-to-water heat pumps (model 2).

Therefore, the final choice of the modernization path can be made in favor of model 2.

Both modernization models have a certain flexibility, which allows for work to be carried out in stages, taking into account financial and technical capabilities.

The economic and environmental aspects of the physiological complex should be discussed by a group of engineers and builders.

3. CONCLUSION

The examples provided demonstrate that constructing climate-neutral thermal energy systems for buildings requires a change in traditional design principles.

A dynamic approach to energy modernization of buildings can be implemented by dividing the renovation process into possible individual stages and measures, using the Pareto principle.

The introduction of partial low-cost solutions into the modernization plan allows for the selection of more flexible financial instruments for the implementation of adopted technical solutions.

During renovation, special attention should be paid to microclimate systems due to their inherent energy consumption.

The modernization models discussed are versatile and can be used in the renovation of buildings of various types and climates.

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