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ENSURING THE ENERGY EFFICIENCY OF HEAT SUPPLY ENERGY SYSTEMS FUNCTIONING BY JUSTIFYING THE CHOICE OF GLAZING UNITS FOR THE EXTERNAL ENCLOSING STRUCTURES OF BUILDINGS

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Summary. *The article is devoted to the further development and implementation of technologies that allow some considerable reducing energy consumption and, as a result, reduce greenhouse gas emissions. In Ukraine and abroad, a huge amount of heat is lost through the external enclosing structures of buildings. The largest specific heat losses occur through translucent enclosures, in particular, windows, the main elements of which are double-glazed windows. Today, manufacturers offer double-glazed windows, which are characterized by different costs and energy efficiency. The buyer does not know which double-glazed window to choose. We have proposed a clear and understandable method of solving this issue. For example, two different double-glazed windows were considered and a comparison was made on their cost, thermal resistance of heat transfer, and the ability to save certain amounts of heat and money for its purchase during operation. A feasibility study of additional capital investments in double-glazed windows with improved characteristics instead of conventional double-glazed ones has been carried out. Its results show that, at the current stage of the society development, the use of double-glazed windows with improved characteristics, despite their higher cost, is economically more appropriate than conventional double-glazed windows. This applies to external translucent fences of buildings of any purpose and form of ownership - both residential and industrial, public, which are on the balance sheets of local and state budgets, etc. The results of all calculations are explained in detail and presented in the form of a table. In addition, a simple and clear scheme of technical and economic substantiation of additional capital investments in a double-glazed window with improved characteristics is presented instead of an ordinary one, which can be used at the design stages of new construction or thermal renovation of existing buildings to ensure the selection of the most rational structural solutions. The materials of the article can be generalized to any other cases of technical and economic substantiation of the choice of options for technical solutions in energy-efficient projects.*

Key words: *energy efficiency, a double-glazed window, low-e glass, payback period, thermal energy.*

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Problem statement. The present military-political and economic situation in Ukraine accompanied by the changing technological order has set some new challenges for both the national energy sector and its products consumers. Our country has been in the state of a full-scale military invasion by the country-aggressor, and a considerable part of its territory has been occupied. The biggest in the last 80 years war on the European continent has significantly escalated the energy crisis caused by the long-term, regular, and purposeful damage or destruction of the generating, transforming, transporting, and distributing capacities by the country-terrorist by means of different types of rockets and drones-kamikaze. The energy industry of Ukraine has urgently needed to take a wide range of measures on repairing and modernization of the infrastructure objects of the fuel-energy complex, as well as information-communicational technologies development, and intelligent network implementation. At the same time, energy use efficiency should be increased, and clean safe technologies and processes must be implemented [1]. Thus, not only power engineering specialists should deal with the energy crisis but all energy consumers without any exception. Nowadays, a project of the European Union is being implemented in Ukraine on providing our citizens with several dozens of millions of LED lamps. Each household is able to exchange 5 old incandescent lamps for new ones free of charge. According to predictions, it will enable us to reduce the load on the energy system of Ukraine by approximately 1 GW and to reduce electrical energy consumption by the volume generated by one power-generating unit of an atomic power plant per certain period of time (as it is well-known, that the single-unit power of the vast majority of APS power-generating units in Ukraine is 1000 MW). What does it mean? An energy gap is compensated not by a generating company due to the installation and putting into operation of some extra generating capacities, but by the final consumers via the exchange of outdated lighting units for modern and considerably more energy-saving ones (approximately 7–8 times).

A similar situation happens in the case of heat production and consumption. The cost of heat energy is very high as most natural gas is used to produce it, and its price has broken all historic records in the last two years. Ukraine produces approximately half of this resource of the required amount, so we have to buy and import the rest from European countries. The consumption of heat by end-users remains largely inefficient, so large volumes of natural gas need to be purchased for its generation. Over the past 5–10 years, alternative fuels, including renewable energy sources, have also been largely used for heat generation. This makes thermal energy slightly cheaper, but it does not solve the problems of energy efficiency in the functioning of heating systems and end-users, namely the consumers of thermal energy. One of the largest consumers of heat is the heating system of buildings of various purposes - residential, public, industrial, etc. The thermal energy that reaches the heating devices of end-users leaves the room where these devices are located in the same amount through their enclosing structures – external walls, windows, the ceiling of the top floor, the floor of the bottom floor, entrance doors, etc. The external enclosures of buildings, which were constructed in different years of the 20th century, do not meet modern norms of thermal resistance of heat transfer. They do not have thermal insulation as such at all. In particular, old structures of translucent external enclosures (windows, stain-glass windows, etc.), which account for the highest specific heat losses, are also very far from compliance with modern window structures in terms of their ability to resist the penetration of thermal energy through them. Therefore, the unprecedented energy crisis that Ukraine is currently experiencing concerns not only electrical but also thermal energy, and it should be overcome not only by heat supply enterprises but also by thermal energy consumers.

In the article under consideration, we will discuss modern translucent elements of window and door units, namely double-glazed windows. Nowadays, in Ukraine, new external windows are mainly equipped with double glazing. They are also used to replace outdated single-glazed translucent structures in order to reduce heat loss during the heating period. Taking into account that double-glazed windows can have different formulas, there is a problem with choosing the best formula for the specific time and economic usage conditions.

Currently, the most recommended double-glazed windows for use in Ukraine are those of the following structures: 1) ordinary; 2) with improved characteristics. The first ones consist of three glass panes, two of which are ordinary, and the third one (internal, facing the room) is energy-saving (with a soft coating). The second ones also have three panes, though not one of them, but both (outer and inner) are energy-saving. In order to improve the heat-insulating properties, inert gas (mainly argon (for economic reasons), less often krypton or other gas (or a mixture of gases) (for the reasons of providing considerably higher thermal resistance of heat transfer, and, as a result, energy efficiency) is used instead of air in the inner chambers of both the first and second double-glazed windows. Double-glazed windows with improved characteristics, of course, have better heat-insulating properties, but their price is higher. In order not to make a mistake in choosing the formula for the double-glazed window, it is necessary to carry out a convincing technical and economic feasibility. The problem is that this issue has not been completely covered in the works of national and foreign scientists. Therefore, the article under consideration is devoted to its solution.

Analysis of the available investigation. In paper [2], the dependence of investment costs and energy savings on the glazing coefficient of the facade was determined in the case of using modern translucent structures with a thermal resistance of 0.75 m^2·°C/W, assuming that the cost of heat carriers is 375 UAH/Gcal and 1000 UAH/Gcal. However, the specific formula for the glass package is not specified in the economic calculation. It is noted that the payback period for translucent structures with a thermal resistance of 0.75 m^2·°C/W is 7–13 years, but it is unclear how the figure of 13 (years) was obtained according to the text of the study. The question of the economic feasibility of using double-glazed units with improved characteristics instead of conventional ones was not considered.

In paper [3], some recommendations were developed for the rational use of energy-efficient window structures. The article [4] discusses the numerical modeling of heat transfer through a double-glazed window. The authors of the above-mentioned works have carried out very important scientific research related to the physics of the processes that occur in double-glazed windows during their operation, but they did not consider any economic issues.

In the paper [5], the author investigated heat transfer through modern window structures. Some measures were proposed to reduce the heat consumption of an administrative building that was studied regarding the energy-efficient windows installed. According to the author, the thermal resistance value for heat transfer through single-window structures of 1 m2·°C/W can be achieved due to the implementation of the proposed innovative measures. However, the payback period or other economic indicators of these measures were not determined within the framework of this paper.

The article [6] investigates the dependence of the relative and absolute glazing area on the configuration and total area of the window opening. However, the authors did not consider the impact of these features of double-glazed units on their total cost. Based on the analysis of well-known research results, it should be noted that economic issues related to the installation of modern double-glazed units in Ukraine have not been sufficiently studied.

The aim of the work is to justify the feasibility of equipping the windows of heated buildings with double-glazed windows with improved characteristics in order to reduce heat energy expenditure on heating and increase the energy efficiency of buildings to which heat is supplied in order to maintain the desired indoor air temperature during the cold period of the year.

The problem setting. To achieve the stated goal, the following tasks need to be solved:

1. Analyze the existing methods and results of technical and economic substantiation for choosing a formula of double-glazed windows for glazing the external enclosing structures of buildings, and identify their advantages and disadvantages.

2. Perform a technical and economic comparison of two modern designs of double-glazed windows that differ in their energy efficiency level and price.

3. Propose a clear and user-friendly process scheme for technical and economic substantiation for choosing a more energy-efficient technical solution from the two cases under consideration, using a translucent external enclosure of a building as an example.

Input data and research methods. The input data for the study under discussion are the technical and economic characteristics of double-glazed windows with different levels of energy efficiency and fuel (natural gas) used to produce thermal energy. The economic feasibility of purchasing a double-glazed window with improved characteristics instead of a standard double-glazed window was determined by finding the simple payback period for additional capital investments in implementing such a technical solution and comparing it with the maximum allowable value of this indicator.

Conditions and restrictions accepted in the article. The following conditions and restrictions are accepted in the article under discussion:

1. The natural gas tariffs only from gas production companies and/or importers have been taken into consideration in the technical-economic feasibility. The cost of the "blue fuel" supply has not been included.

2. The price of thermal energy made of natural gas is influenced by a wide range of different factors (for example, electrical energy expenditure on the boiler operation and on circulation pumps drive, boilers and heat networks service and repair costs, and others). Though, only one of them has been taken into consideration in the article under discussion, namely the efficiency of a water heating boiler.

3. Any possible leakage of inert gas argon from the chambers of double-glazed windows has not been taken into account.

4. Simple payback periods for additional investments in purchasing double-glazed windows with improved characteristics instead of regular ones have been calculated. Discounting, i.e. taking into account changes in the value of money over time, will become a tool to increase the accuracy of the results in our further research.

Results of the study. The research results show that modern double-glazed windows with improved characteristics allow for a reduction in heat loss through windows by 2.2–4.2 times or more compared to single-pane windows (not to mention double-glazed wooden windows with separate panes in paired or separate casements). To achieve the maximum possible *energy efficiency* of the building's translucent facade, it is necessary to select the formula for the glass unit that provides the highest value of thermal resistance of heat transfer. Typically, this is a double-glazed unit with two energy-efficient glass panes and a third (middle) pane made of ordinary glass, with the cavities (chambers) filled with the inert gas krypton and the thickness of these chambers is the maximum possible (the largest thickness of the spacer frames of glass units known to the authors of this article is 24 mm). To minimize initial *capital costs*, it is necessary to stop at a double-glazed unit with one energy-efficient glass pane and two ordinary panes whose cavities (chambers) are filled with argon. However, if future *operating costs* for the purchase of heat for heating or fuel from which this heat is generated are taken into account, then, perhaps, the best option to choose will be something between maximum energy efficiency and the minimum price of a double-glazed unit. To confirm or refute this assumption, a detailed technical-economic comparative analysis of two types of double-glazed windows – ordinary and with improved characteristics (Table 1) will be carried out.

The heat loss per time unit through a double-glazed window are determined by the formula

$$Q = \frac{1}{R_{\text{o}}} \cdot F \cdot (t_{\text{in}} - t_{\text{out}}), \text{ W}, \tag{1}$$

where R_{o} – thermal resistance of the heat transfer to a double-glazed window, (m^2·°C)/W;
F – the glazing area, m^2;
t_{in} – air temperature in the room where a double-glazed window is installed, °C;
t_{out} – the average temperature of external air during the heating period °C.

We assume that a double-glazed window area is equal to F=1 m^2, the temperature of internal air t_{in}=+18 °C, the average temperature of external air during the heating period t_{out}=0,5 °C (this value corresponds to the average statistical data of meteorological observations in Ternopil city).

The heat loss (in Joules) per time unit (a second) through an ordinary double-glazed window of the area F=1 m^2:

Table 1

Technical and economic characteristics of double-glazed windows

№	Type of a double-glazed window	The formula of a double-glazed window *	The thermal resistance of the heat transfer to a double-glazed window R_o, $(m^2\cdot°C)/W$**	Cost of a double-glazed window B_c, UAH/m^2***
1	A double-glazed window ordinary	$4M_1$-10Ar-$4M_1$-10Ar-4*i*	0,71	2075
2	A double-glazed window with improved characteristics	4*i*-10Ar-$4M_1$-10Ar-4*i*	1,07	2225

Notes: *The formula of a double-glazed window, for example, $4M_1$-10Ar-$4M_1$-10Ar-4*i*, is decoded in a flowing way: 4 – the glass thickness, mm; M_1 – ordinary transparent window float-glass; 10 – the thickness of a distance frame (a spacer), мм; Ar – argon (gas filling the chamber of a double-glazed window); *i* – energy-saving glass with soft cover; 4+10+4+10+4=32 mm – the thickness of a double-glazed window; the order of glazing – from the external surface.
**Information about the thermal resistance of a double-glazed window heat transfer is borrowed from the following source: DBN V.2.6.–31:2006 with amendment №1 of July the 1st 2013. Construction of buildings and structures. Heat insulation of buildings.
*** Information about the cost of a double-glazed window is borrowed from the following source: the cost of a double-glazed window, UAH/m², VAT included, and using the glass of 4 mm thickness. The company «GLASS LLC» (Kyiv region, Vyshneve town). URL: https://www.busel.ua/ua/catalogs/14/14/41/144/2_____________________.pdf (date of application: 15.02.2023).

$$Q_1 = \frac{1}{R_{o1}} \cdot F \cdot (t_{\text{in}} - t_{\text{out}}) = \frac{1}{0{,}71} \cdot 1 \cdot \big(18 - (-0{,}5)\big) = 26{,}056 \approx 26 \ \text{W}. \qquad (2)$$

Heat losses per unit of time through a double-glazed window with improved characteristics of the area F=1 m^2:

$$Q_2 = \frac{1}{R_{o2}} \cdot F \cdot (t_{\text{in}} - t_{\text{out}}) = \frac{1}{1{,}07} \cdot 1 \cdot \big(18 - (-0{,}5)\big) = 17{,}897 \approx 18 \ \text{W}. \qquad (3)$$

Heat losses through a double-glazed window of the area F=1 $м^2$ during the heating season of τ =180 days:
a) a double-glazed window ordinary:

$$E_1 = Q_1 \cdot \tau = 26 \cdot (180 \cdot 24) = 112320 \ \text{W} \cdot \text{h} \approx 112 \ \text{kW·h}; \qquad (4)$$

b) a double-glazed window with improved characteristics:

$$E_2 = Q_1 \cdot \tau = 18 \cdot (180 \cdot 24) = 77760 \ \text{W} \cdot \text{h} \approx 78 \ \text{kW·h}. \qquad (5)$$

The use of a double-glazed window of the area F=1 m^2 with improved characteristics instead of a double-glazed window ordinary of the same area during a heating season that lasts τ =180 days will allow us to save the following amount of heat energy:

$$E = E_1 - E_2 = 112 - 78 = 34 \text{ kW·h}. \quad (6)$$

One of the most popular kinds of fuel for heat production in Ukraine is natural gas, as it is a low calorie and convenient in use energy. In January 2023, for example, in Ternopil region the combustion heat of natural gas *lower* was approximately Q_{gl}=8299 kcal/m^3=34746 kJ/m^3=9,652 kW·h/m^3 (Ukrainian section of the gas pipeline @Urenhoi – Pomary – Uzhhorod@) [quality indices of natural gas. URL: https://drive.google.com/file/d/1fWuztiF6tOAiJnjhERbDA3ebODfKfJxu/view (date of application: 15.02.2023)]. Amount of heat energy produced by a hot-water boiler of 1m^3 of natural gas of the following quality:

$$Q_{\text{b}} = Q_{\text{gl}} \cdot \eta = 9{,}652 \cdot 0{,}9 = 8{,}6868 \text{ kW·h/m}^3. \quad (7)$$

In formula (7) η=0,9 is the boiler efficiency.

According to the tariff plan «All inclusive» (for small businesses) of the gas supplying company «Naftogas», the average price of 1 m^3 of natural gas for the last 12 months has been (March 2022 – February 2023 included)

$$C_{\text{г1}}=(42{,}0+43{,}806+49{,}104+40{,}056+30{,}996+36{,}09+49{,}9896+ \\ +46{,}50+34{,}998+42{,}0+34{,}5+25{,}068)/12=39{,}5923 \text{ UAH/m}^3 \approx 4{,}10198 \text{ UAH/(kW·h)}. \quad (8)$$

[*source:* tariff plans GC «Naftogas». URL: https://gas.ua/uk/business/tariffs (date of application: 15.02.2023)].

According to the tariff plan «Fixed» (for individuals) of the same gas supplying company the average price for one m^3 of natural gas for the last 12 months has been (March 2022 – February 2023 included) $C_{\text{г2}}$=7,95689 UAH/m^3=0,82438 UAH/(kW·h) (the same source of information).

In the case of using the natural gas bought by the tariff plan «All inclusive» and a hot-water boiler of the efficiency η=0,9 the produced heat energy cost will be equal to $C_{\text{т1}}=C_{\text{г1}}/\eta$=4,10198/0,9=4,55778 UAH/(kW·h).

In the case of using the natural gas bought by the tariff plan "Fixed" and a hot-water boiler of the efficiency η=0,9 the cost of the produced heat energy will be equal to $C_{\text{т2}}=C_{\text{г2}}/\eta$=0,82438/0,9=0,91598 UAH/(kW·h).

The use of a double-glazed window of the area F=1 m^2 with improved characteristics instead of a double-glazed window ordinary of the same area during a heating season that lasts τ =180 days will allow us to save the following sum of money (due to the savings of heat energy that was produced of the natural gas bought by the tariff plan «All inclusive»):

$$B_1 = E \cdot C_{\text{т1}} = 34 \cdot 4{,}55778 \approx 155 \text{ UAH}. \quad (9)$$

In the case when for heat production the natural gas is used that was bought by the tariff plan «Fixed», the money savings will be as follows:

$$B_2 = E \cdot C_{\text{т2}} = 34 \cdot 0{,}91598 \approx 31 \text{ UAH}. \quad (10)$$

The payback period of extra investments for buying a double-glazed window with improved characteristics of thickness 32 mm (two *e*-glasses, the gap filler is argon) instead of an ordinary double-glazed window of the same thickness (one *e*-glass, the gap filler is argon) in the case of using the natural gas bought by the tariff plan «All inclusive» for heat energy production:

$$T_1 = \frac{(B_{c2}-B_{c1})}{B_1} = \frac{(2225-2075)}{155} = 0{,}968 \approx 1\ year. \quad (11)$$

In the case of using the natural gas bought by the preferential tariff plan «Fixed» for heat energy production, the payback period of extra investments will be as follows:

$$T_2 = \frac{(B_{c2} - B_{c1})}{B_2} = \frac{(2225 - 2075)}{31} = 4{,}839 \approx 5\text{ years.} \quad (12)$$

In formulae (11) and (12) B_{c1} and B_{c2} are the prices of 1 m^2 of an ordinary double-glazed window and a double-glazed window with improved characteristics respectively (table. 1).

The main results of calculations, carried out above, are given in tabl. 2. To understand the process of technical-economic substantiation of choosing the more energy-efficient technical solution from the two ones under consideration as well as possible, its scheme is shown in fig. 1.

Table 2

Technical and economic comparison of double-glazed windows with different energy efficiency

№	Technical and economic indices	Symbols	Units of measurement	Ordinary double-glazed window	Double-glazed window with improved characteristics	Extra investments and energy efficiency
1	2	3	4	5	6	7
1	Specific value of double-glazed windows	B_c	UAH/m^2	2075	2225	**150** (extra specific investments)
2	Specific losses of thermal power through double-glazed windows	Q	W/m^2	26	18	8 (instant energy effect)
3	Specific losses of thermal power through double-glazed windows during a heating season	E	kW·h/(m^2·year)	112	78	34 (annual energy effect)
Technical and economic indices of fuel (natural gas), energy converter (hot-water boiler), heat energy, extra specific investments for double-glazed windows with improved characteristics installation instead ordinary ones						
4	Combustion heat of natural gas lower	Qg_l	kW·h /m^3	9,652		
5	Efficiency of a converter of chemical energy of natural gas into heat (hot-water boiler)	η	dimensionless quantity	0,9		
6	Amount of heat energy produced by a boiler of 1m^3 of natural gas	Q_b	kW·h m^3	8,6868		

The end of the table

1	2	3	4	5	6
7	Specific value of natural gas (gas tariff)	$C_г$	UAH /(kW·h)	4,10198 (tariff plan "All inclusive")	0,82438 (tariff plan «Fixed»)
8	Specific value of heat energy (heat tariff)	$C_т$	UAH /(kW·h)	4,55778	0,91598
9	Annual savings on heat energy production or buying when calculating per 1m^2 of a double-glazed window area	B	UAH/(m^2·year)	**155**	**31**
10	Payback period (simple) of extra investments	T	years	0,968	4,839

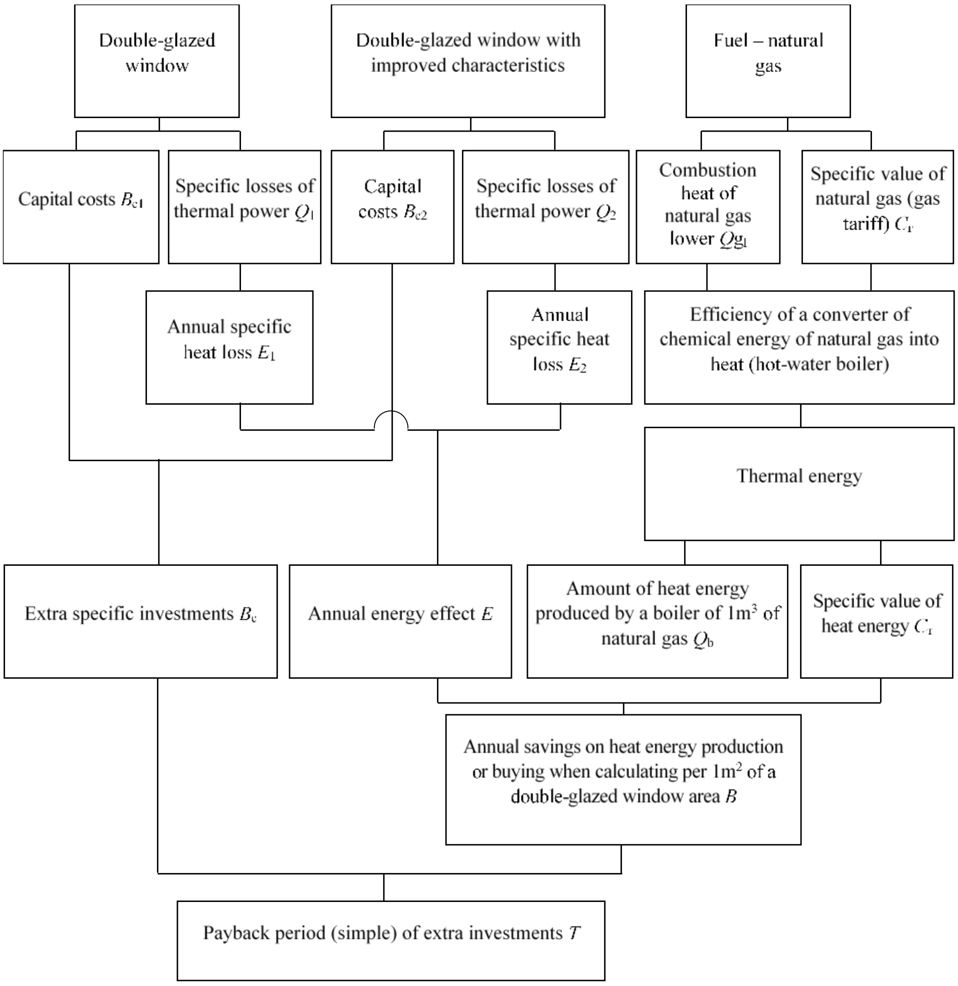

Figure 1. Schematic representation of the process of technical and economic substantiation of the choice of a more energy-efficient technical solution from the two under consideration, using a translucent external enclosure of a building as an example

The obtained values of T1 and T2 have proved, that investing in the purchase of double-glazed windows with improved characteristics is economically beneficial both for both the businesses and budget organizations, and for individuals. Moreover, the expected rise in energy prices promises to increase this benefit significantly.

In the vast majority of cases, it is economically feasible to implement a project when its simple payback period T ≤ Tmax = 5 years. However, for projects that solve global problems, such as reducing carbon dioxide emissions, an individual approach is needed to choose Tmax. It should take into account not only the economic but also the ecological component. The authors of this article are aware of a thermal power plant project that uses the heat of geothermal water-bearing layers instead of fuel for its operation. Its estimated payback period is 40 years. It has been recently implemented in one of the European Union countries. As for the external enclosures of buildings, modern window constructions, in particular, are characterized by high durability, namely several decades, and in case of careful handling, they will serve for half a century and even more. Therefore, during the techno-economic sustantiation of the choice of energy-efficient double-glazed windows, Tmax = 10 years can be accepted without any hesitation. During the first 10 (or fewer) years, they will work off the funds spent on their purchase, and the next 10–30 (and this is not the limit) years they will save the budgets of private households, enterprises, institutions, and organizations on the purchase of thermal energy or fuel for its generation. The use of external translucent enclosures, which are characterized by high values of thermal resistance of heat transfer, also allows us to reduce CO_2 emissions into the atmosphere significantly due to the corresponding reduction in thermal energy generation, and in this way to accelerate the transition of the national economy to a model of sustainable development, which ensures not only economic progress, but also the growth of economic efficiency social justice provision, as well as environmental protection.

Scientific novelty. The economic feasibility of using double-glazed windows with improved characteristics instead of ordinary double-glazed windows in new construction and in the case of replacing morally outdated single-glazed structures has been mathematically proved. An illustrative and understandable scheme of the process of technical and economic substantiation for choosing a more efficient energy-saving technical solution aimed at reducing heat consumption for heating purposes has been created from two proposed options.

Conclusions. A detailed technical -economic comparative analysis of two modern double-glazed window designs has been conducted, which are currently most commonly recommended by manufacturers and their representatives for glazing the external enclosing structures of buildings – a regular double-glazed window and a more energy-efficient double-glazed window with improved characteristics. The question of which of these designs to choose for a specific location and under current economic conditions is a matter to which we could not find a sufficiently convincing and argumentative answer. The same applies to any other type of double-glazed windows.

A technical – economic comparison of the two designs of modern double-glazed windows described in point 1 was carried out under real operating conditions (air temperature in the room – «+18 °C», average outside air temperature during the heating period – «-0.5 °C», duration of the heating period – 180 days). The simple payback period of additional capital expenditures in purchasing a more energy-efficient (by 50.7%) and slightly more expensive (by 150 UAH/m^2 or 7.2%) double-glazed window was determined. If natural gas is used for heat production at the average annual price of 39.5923 UAH/m^3 (for small businesses), the payback period is slightly less than 1 year. In the case of a gas price of 7.95689 UAH/m^3 (for households), the payback period is 4.8 years, which is less than the maximum allowable value of 5 years. Therefore, from an economic point of view, the use of a more energy-efficient double-glazed window with improved characteristics in both gas price scenarios is more reasonable than using a regular double-glazed window. The main results of the techno-economic comparison of double-glazed windows are presented in tabular form for convenience.

A scheme for the process of technical-economic substantiation for choosing a more energy-efficient technical solution from the two ones under consideration has been developed, using the example of translucent external enclosing structures of a building. The input parameters include the technical and economic characteristics of the double-glazed windows and the primary energy source used to produce thermal energy (natural gas). The output parameter is presented by the simple payback period. The scheme allows us to understand the process of technical-economic substantiation as well as possible for choosing a more energy-efficient technical solution, and in this way, to avoid any probable mistakes at any stage of the process.

The materials of this article are important not only from a technical and economic point of view, but also from an ecological perspective, as they open up opportunities for significant (as shown in the example given in this study – by 1.5 times) reduction in carbon dioxide emissions into the atmosphere by reducing the volume of thermal energy generation for buildings heating.

The methods and approaches to solving the problem of choosing an energy-efficient technical solution for the external building enclosure proposed in this paper can be generalized to any other cases of technical and economic substantiation of energy-efficient projects.

The prospects for further research in this direction lie in more detailed technical and economic substantiation of the choice of the formula for double-glazed units for glazing the external enclosure structures of buildings, taking into account more factors.

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ЗАБЕЗПЕЧЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ФУНКЦІОНУВАННЯ ЕНЕРГЕТИЧНИХ СИСТЕМ ТЕПЛОПОСТАЧАННЯ ШЛЯХОМ ОБҐРУНТУВАННЯ ВИБОРУ СКЛОПАКЕТІВ ДЛЯ ЗОВНІШНІХ ЗАГОРОДЖЕНЬ БУДІВЕЛЬ

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Резюме. *Стаття присвячена подальшому розвитку і втіленню в життя технологій, які дозволяють знижувати споживання енергії і внаслідок цього зменшувати викиди парникових газів. В Україні та за її межами величезна кількість тепла втрачається через зовнішні загороджувальні конструкції будівель. Найбільші питомі втрати тепла мають місце через світлопрозорі загородження, зокрема вікна, основними елементами яких є склопакети. На сьогодні виробники пропонують склопакети, які характеризуються різною вартістю й енергетичною ефективністю. Покупець або інша зацікавлена особа не знає, на якому склопакеті зупинити свій вибір. Ми запропонували чіткий і зрозумілий метод вирішення цього питання. Для прикладу, розглянуто два різні склопакети й виконано порівняння їх вартості, термічного опору теплопередавання та здатності заощаджувати ті чи інші обсяги тепла й коштів на його закупівлю у процесі експлуатації. Виконано техніко-економічне обґрунтування додаткових капіталовкладень у двокамерний склопакет з покращеними характеристиками замість звичайного двокамерного. Його результати показують, що на сучасному етапі розвитку суспільства використання двокамерного склопакета з покращеними характеристиками, не зважаючи на більшу вартість, з огляду економіки є доцільнішим у порівнянні зі звичайним двокамерним склопакетом. Це стосується зовнішніх світлопрозорих загороджень будівель будь-яких призначень і форм власності – як житлових, так і промислових, громадських, які перебувають на балансах місцевих і державного бюджетів та ін. Результати всіх розрахунків детально пояснено і викладено у формі таблиці. Крім того, представлено просту й зрозумілу схему техніко-економічного обґрунтування додаткових капіталовкладень у двокамерний склопакет з покращеними характеристиками замість звичайного двокамерного. Вона може бути використана на етапах проектування нового будівництва або термореновації існуючих будівель для забезпечення вибору найраціональніших конструктивних рішень. Матеріали статті можуть бути узагальнені й на будь-які інші випадки техніко-економічного обґрунтування вибору варіантів технічних рішень у енергоефективних проєктах.*

Ключові слова: *енергоефективність, двокамерний склопакет, і-скло, термін окупності, теплова енергія.*

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