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EVALUATION OF THE NEW CONSTRUCTIVE-TECHNOLOGICAL SOLUTION OF THE FENCE STRUCTURE IN THE NON-REMOVABLE FORMWORK

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Abstract. The known constructive and technological solutions of enclosing constructions of buildings in fixed formwork with the use of qualitative, quantitative and general analysis are analyzed. Selected quantitative indicators, such as wall thickness, weight of 1 m^2 of wall, heat transfer resistance, area of premises, cost, durability, tendency to shrinkage. Qualitative indicators were used: resistance to the sun, mold, fertilization and destruction, features of delivery of building materials.

The method of multicriteria analysis is used to evaluate new structural and technological solutions of fencing structures and determine the most effective technologies. Categories of various constructive-technological decisions in a fixed timbering on the basis of economic consideration of modeling are considered.

Such modern constructive-technological decisions of enclosing constructions in a fixed timbering are selected for comparison, as: expanded polystyrene blocks; blocks with wall alignment system; polystyrene concrete blocks; concrete blocks; blocks of cement-chip material; large panels made of expanded polystyrene; three-layer reinforced expanded polystyrene panels; cement particle boards; concrete slabs; frame-monolithic formwork with cement-chipboard cladding; frame-monolithic formwork with cladding of glass-magnesium plates and technology according to the patent UA 149402.

The new design and technological solution, which has been developed and patented, is a combination of modern materials that are of great interest and demand to consumers, such as light steel thin-walled structures and expanded polystyrene concrete.

The evaluation of technological solutions by quantitative criteria on a ten-point scale, where the minimum and maximum values are assigned points 1 and 10, respectively. Graphical modeling of the summary variants, which are equalized, is performed, and the corresponding diagrams are constructed.

Keywords: structural and technological solutions, enclosing structures, multicriteria analysis, non-removable formwork.

Introduction. Individual houses occupy the second line in the housing rating, primarily due to the competitive price and tangible advantages of such a purchase compared to apartments. Fundamental changes have taken place in the field of thermal protection of buildings over the past decades. With the update of normative documents on thermal insulation of buildings, the map of temperature zones of Ukraine has changed – the number of these zones has been reduced from 4 to 2. Thus, the indicators of the minimum permissible value of heat transfer resistance have increased. Therefore, there was a need to research new economical structural and technological solutions for erecting enclosing structures of low-rise buildings in fixed formwork with high thermal performance.

Energy efficiency in residential construction is a set of measures aimed at reducing the building's energy consumption. The solution to the task of choosing an economic variant of the structural-technological solution for erecting the enclosing structures of low-rise buildings in fixed formwork will help to saturate the housing market with the availability of budget cottages with high heat-technical characteristics.

One of such structural and technological solutions is frame construction in fixed formwork. Light steel thin-walled constructions and polystyrene foam concrete are of great interest and demand among consumers of construction products. However, in modern literature there are no recommendations for determining effective construction solutions for erecting buildings from polystyrene foam concrete in a fixed frame formwork. Completing the task of choosing an effective solution for the construction of buildings will allow solving the issues of modern construction, directly related to the problem of energy and resource conservation.

Analysis of research and publications. Low-rise buildings are becoming popular due to the following advantages:

– high speed of construction and minimization of risks, the house is built faster, because there is a small volume of work and a simplified registration procedure;

– ecology and comfort, low-rise buildings are mainly built far from industrial, urban areas, closer to nature and minimum noise;

– there is more free space near the house for recreation areas, for walks and games with children, there is an opportunity to arrange a terrace or an outdoor recreation area, your own flower bed, a small garden;

– increased privacy, life in a low-rise complex is confidential [1-4].

One of the ways to solve the housing problem is the active expansion of the construction of low-rise, quickly built energy-saving houses made of highly efficient modern building materials. For the quick construction of such housing, it is advisable to use light construction technologies that do not require heavy equipment and expensive mechanisms and devices. Fast construction will also be significantly facilitated by the dry construction method (without wet technological processes).

Significant savings on heating costs have always been a very important indicator when buying houses. Quickly constructed low-rise residential buildings (1-3 floors) can be divided into frame (with a metal or wooden frame), frame-panel, panel and modular. It is worth noting that the construction of such buildings, in addition to speed and cost savings, prioritizes the environmental friendliness of buildings and the health of their residents [2].

Economic affordability is the ability to freely choose and buy housing that is affordable and inexpensive to operate; the ability to renew, characterized by flexible planning solutions that allow for economically rational reconstruction and modernization, due to which the service life of the house is significantly extended; compliance with market requirements by satisfying people's needs, taking into account changes in demographic conditions and purchasing habits of the population [3]. Especially in low-rise construction, non-removable formwork is used for enclosing structures [4-10].

Purpose and tasks. To analyze the known constructive and technological solutions of enclosing structures of buildings in fixed formwork. Compare known solutions with the developed new solution using multi-criteria analysis and determine the most effective of them.

Research materials and methodology. Modern structural and technological solutions of enclosing structures in fixed formwork [4-10] and the developed solution [11] are presented in the form of a classification (Fig. 1).

From them, 12 technologies for erecting fencing structures in fixed formwork were selected for comparison, namely:

1. Styrofoam blocks.
2. Styrofoam blocks with wall leveling system.
3. Blocks made of polystyrene concrete.
4. Concrete blocks.
5. Blocks made of cement-chip material with foam polystyrene inserts.
6. Large-sized polystyrene foam panels.
7. Three-layer reinforced polystyrene panels.
8. Cement chipboards.
9. Concrete slabs with a decorative coating.
10. Frame-monolithic formwork with cladding with cement chipboards.
11. Frame-monolithic formwork with cladding of glass-magnesium plates.
12. Constructive and technological solution according to the patent [11].

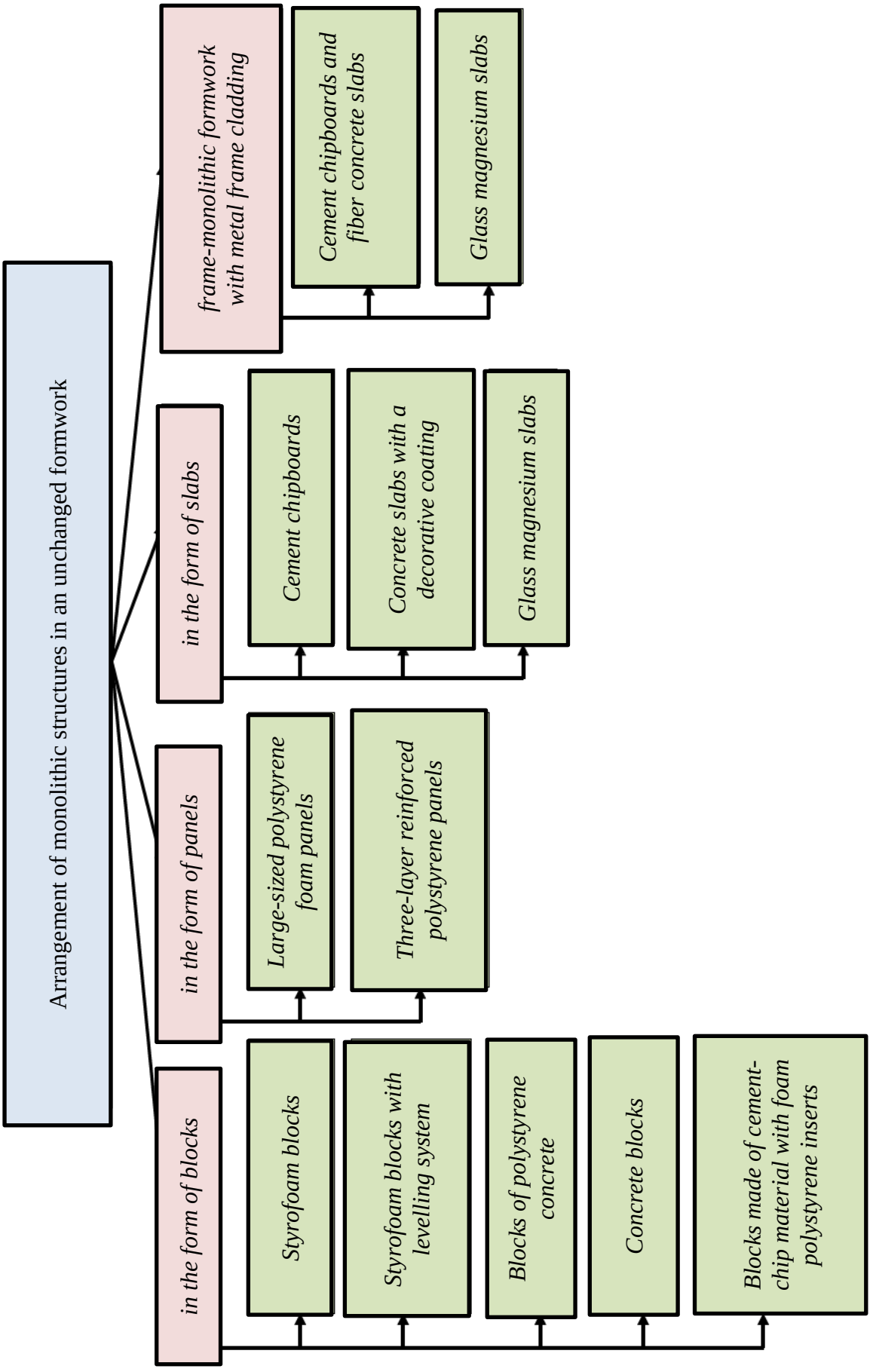

Fig. 1. Classification of monolithic structural and technological solutions in fixed formwork

The peculiarity of the developed solution is the installation, which is carried out easily and quickly, allowing to shorten the construction period, excluding the use of special machinery and equipment, which allows to reduce the cost of construction. Also, the cost of transportation of frame elements is reduced due to the lightness of structures and the linear shape of LSTS parts (light steel thin-walled structures) in comparison with traditional fittings, which enables compact packaging. Thanks to the LSTS frame, high stability is ensured not only during the pouring of polystyrene foam concrete, but also during further work.

Polystyrene concrete acts as an effective heat-insulating material. This is a light version of the traditional classic cement mortar, in which the heavy sand filler is replaced by a light polymer, as a result of which not only the weight of concrete structures is significantly lightened, but also an excellent thermal insulation material is created. It has high heat (depending on the brand of the mixture, λ is from 0.052 to 0.1 W/Mk) and sound insulation (at 500 Hz and a thickness of 5 cm is 13 dB) properties and sufficient vapor permeability (μ 8.5).

Due to the specially selected composition and physical properties of the polystyrene foam concrete mixture, namely plasticity, it is possible to concrete the wall structure for the entire floor at once, without additional technological operations to compact the concrete mixture, and the frame made of LSTS profiles prevents the expansion of the fixed formwork made of cement chipboards. Such a wall structure has the possibility of using various types and methods of finishing, from plaster to a hinged facade.

When choosing, the requirements of regulatory documents and the popularity of technologies among the population were taken into account. In order to make the optimal decision regarding the choice of structural and technological solutions of fixed formwork, it is first important to determine which characteristics will be the main ones. They can be economic, technical, environmental, social or other.

The proposed system of multi-criteria analysis for evaluating structural and technological solutions allows to characterize not only quantitative but also qualitative parameters. That is, a distinctive feature of multi-criteria analysis is the presence of several groups of criteria, each of which allows to describe in sufficient detail a specific structural and technological solution of fixed formwork, analyzing information sources.

Selection criteria can be: manufacturability, cost and construction time. Factors such as thermal insulation properties, resistance to external weather factors, reliability, durability, environmental friendliness, speed of construction, strength and weight characteristics of materials and the finished structure play an important role in this complex selection process. An equally important indicator before the construction of the object is the determination of the cost per square meter of the selected structural and technological solution of the fencing structures.

Based on the search for relevant information about the selected structural and technological solutions and for choosing the most effective of them, the following most significant evaluation criteria were adopted:

Quantitative:

• thickness of all layers of the structural and technological solution, taking into account heat transfer resistance, mm;

• the mass of all layers of the structural and technological solution 1 m^2, kg;

• the area of the premises, which is formed when the external dimensions of the buildings are 10 m wide and long, m^2;

• the cost of a constructive and technological solution;

• durability according to regulatory documents and literary sources, years;

• probability of shrinkage according to regulatory documents and literary sources, %.

Qualitative:

• prevention of decay and destruction.

Based on the analysis of information sources [1-10] and calculations of heat transfer resistance [12, 13], the thickness of enclosing structures, cost estimates of the cost of 1m^2 of erecting enclosing structures, a comparison table of structural and technological solutions according to the selected criteria was compiled. Quantitative evaluations of the criteria are given from real-time measuring devices into a single point scale. The evaluation of technologies according to quantitative criteria was carried out on a ten-point scale, in which 1 point is the minimum, and 10 is the maximum value, respectively. The rest of the points are obtained by interpolation.

Structural and technological solutions of fencing structures in fixed formwork, criteria and points assigned to them are presented in the Table. 1.

Table 1 – Criteria and points assigned to them of structural and technological solutions that are compared

No.	Evaluation criteria / Construction technologies	Thickness, mm / in points	Heat transfer resistance, $m^2 \cdot S/W$ / in points	Weight 1 m^2 of a wall, kg/in points	Area of premises, m^2/in points	Price, UAH/m^2/ in points	Durability, years/in points	Shrinkage, %/ mm/m	Prevents decay and destruction
1	Fixed formwork "Thermodim, Legodim, Izodim"	340/7	3.2/10	386/5	86.9/9	2 725/9	100/8	1/9	Stand
2	Styrofoam blocks with wall leveling system	345/7	3.2/10	395/5	86.8/9	2 760/9	100/8	1/9	Stand
3	Formwork from polystyrene concrete blocks	500/9	3.1/9	400/5	81/9	2 422/10	100/8	2/8	Stand
4	Formwork from cement-chip blocks	520/9	3.1/9	420/5	80.5/9	2 380/10	100/8	2/8	Stand
5	Movable modular formwork of the "TIBE" type	400/8	2.8/8	420/4	84.6/9	3230/9	100/8	1/9	Stand
6	Fixed formwork "Plastbau"	320/6	3.2/10	390/5	87.6/9	2 814/9	100/8	1/9	Stand
7	Fixed formwork "SOTA, 3-D reinforced panel"	550/9	3.2/10	300/6	80.2/9	3 553/9	100/8	1/9	Stand
8	Formwork from cement chipboards	640/10	3.0/9	560/2	76/8	3085/7	100/8	2/8	Stand
9	Fixed formwork "Technoblock"	350/7	3.3/10	465/4	86.5/9	3 738 /8	80/6	1/9	Processiong
10	Frame-monolithic formwork with CSP cladding	540/9	3.0/9	580/2	76/8	4 627/7	100/8	2/8	Stand
11	Frame-monolithic formwork with glass magnesite cladding	540/9	3.0/9	580/2	76/8	4 730/7	100/8	2/8	Stand
12	Patent UA No. 149402 "Wall of a building"	330/6	3.1/9	390/5	87.1/9	2 445/10	100/8	1/9	Stand

The criteria for choosing a structural and technological solution for enclosing structures in fixed formwork are indicators that most completely and objectively evaluate its leading characteristics. They include a multi-level approach to ensure the solution of numerous problems: technical, technological, operational, economic and environmental.

A "summary chart" created using Microsoft Excel was used to process multi-criteria analysis scores. This diagram is formed on the basis of a "summary table" (Table 1) for analysis, study, generalization and summarization of data from external sources. First, a summary diagram was created, which groups the values of the quantitative criteria of all structural and technological solutions (Fig. 2).

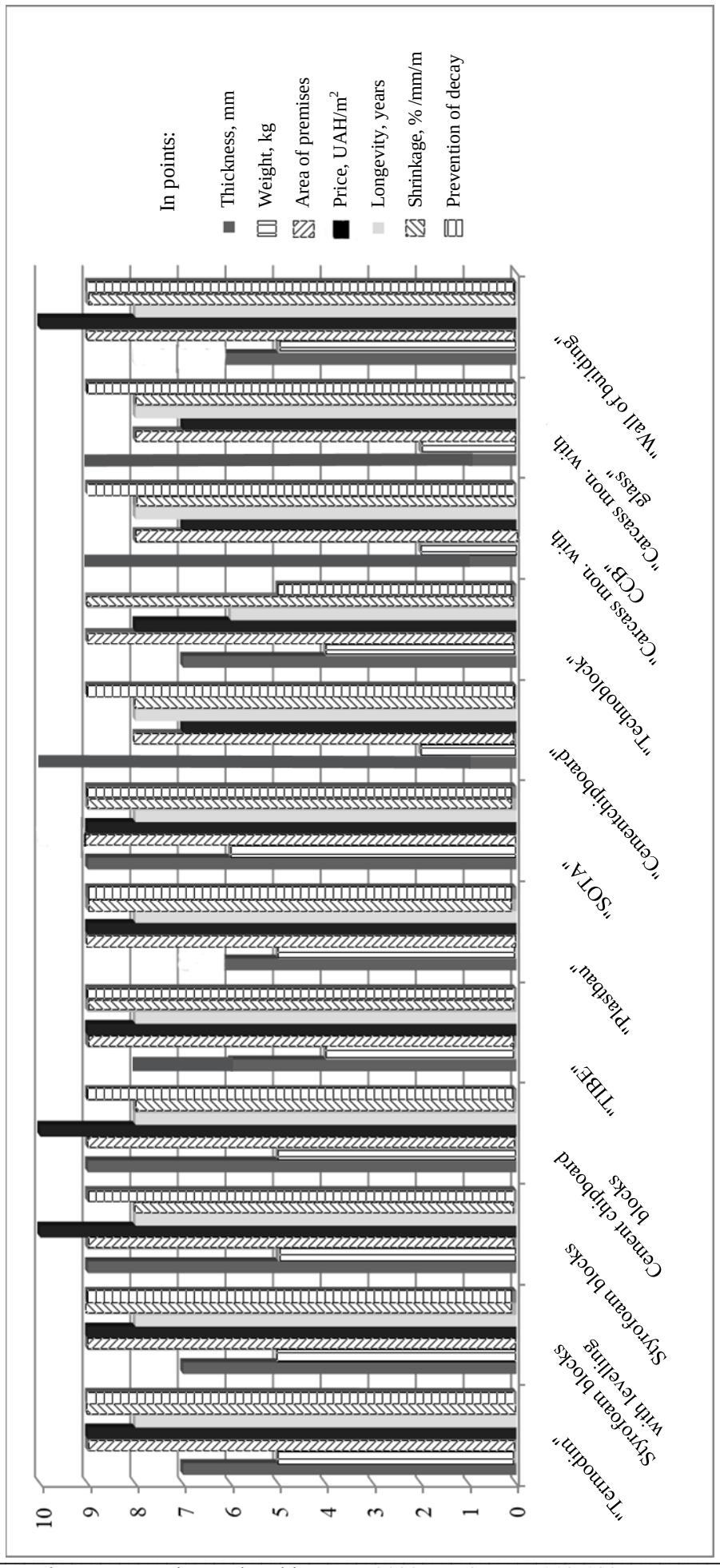

Fig. 2. Comparison of structural and technological solutions by points in the summary diagram

Analyzing the consolidated table (Table 1) of the selected structural and technological solutions, it can be seen that such a criterion as heat transfer resistance may not be considered in the future, because it corresponds to the normative value established for the II temperature zone R_{qmin}= 2,8 $m^2 \cdot S/W$, in all cases. The rest of the criteria are important when choosing a structural and technological solution for the enclosing structures of buildings in fixed formwork and were used in the subsequent comparison.

Considering the selected structural and technological solutions in the consolidated table (Table 1) and the consolidated diagram (Fig. 2), we can say that the most ineffective solution is cement chipboard with a wall thickness of 640 mm and a weight of 560 kg/m^2.

One of the main criteria is the mass of materials, which affects the cost of their delivery and the need to use additional equipment for unloading at the construction site. Also, such structural and technological solutions in fixed formwork have an additional load on the foundation.

An important advantage of modern houses is a significant increase in the usable area of the house due to a noticeable decrease in the thickness of the load-bearing walls. This advantage is especially noticeable during private construction, when the cost of the land plot is quite high. According to these criteria, in the future, we will not use constructive solution 8 "Cement chipboards" (Table 1) for selection. The rest of the structural and technological decisions in the fixed formwork are taken for further analysis with the help of summary diagrams.

The criterion of durability is the leading parameter of structural and technological solutions, which affects the quality of load-bearing structural elements (foundation and walls). During the entire life of the building, they are subject to maintenance and repair. The periodicity of these works depends on the durability of the materials from which the building structures are made, the impact of the environment and other factors.

Grouped constructive and technological solutions according to the qualitative criterion of preventing decay and destruction and comparing their technological indicators according to durability (Fig. 3), evaluated in points.

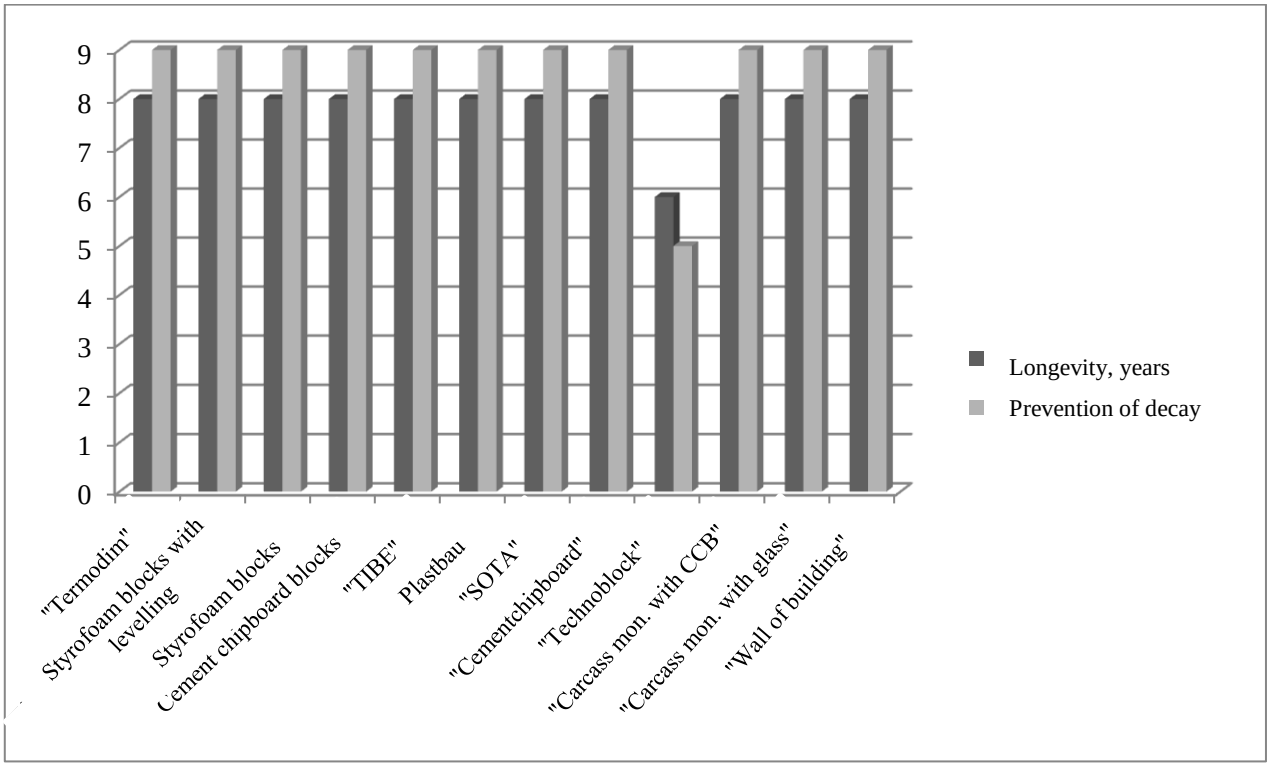

Fig. 3. Diagram of comparison of structural and technological solutions according to the criteria of durability and resistance to decay and destruction

Looking at the comparison diagram of structural and technological solutions according to the criterion of durability (Fig. 3), it is obvious that the non-removable formwork Technoblok has the lowest operational qualities. In the constructive and technological solution, Technoblok uses moisture-resistant plywood as one of the internal structural elements, which requires one-time treatment of the material with special mixtures (due to its physical properties), which reduces its service life. In addition, the cost of 1m^2 of wall according to this solution is UAH 3.738, which, compared to other options, is more than average. Therefore, constructive solution 9 (Table 1) was not taken into account in the future.

The rest of the structural and technological solutions are grouped according to the criteria of thickness and weight of the options, which respectively affect the choice of the foundation base (Fig. 4).

Analyzing the resulting diagram (Fig. 4), it can be seen that polystyrene concrete blocks, blocks made of cement-tape material, fixed formwork "SOTA", cement-chipboards and frame-monolithic formwork have a significant thickness of the finished wall structure. Therefore, solutions 3, 4, 7, 8, 10, 11 will not be taken into account in the future (Table 1).

The main of the selected criteria is the cost per 1 m^2 of the fencing structure, then we will consider the rest of the solutions according to this criterion (Fig. 5).

The diagram (Fig. 5) shows that the most expensive solutions among structural and technological solutions in fixed formwork are the following options: polystyrene blocks, TIBE and "Plastbau". Therefore, 12 solutions remain (Table 1).

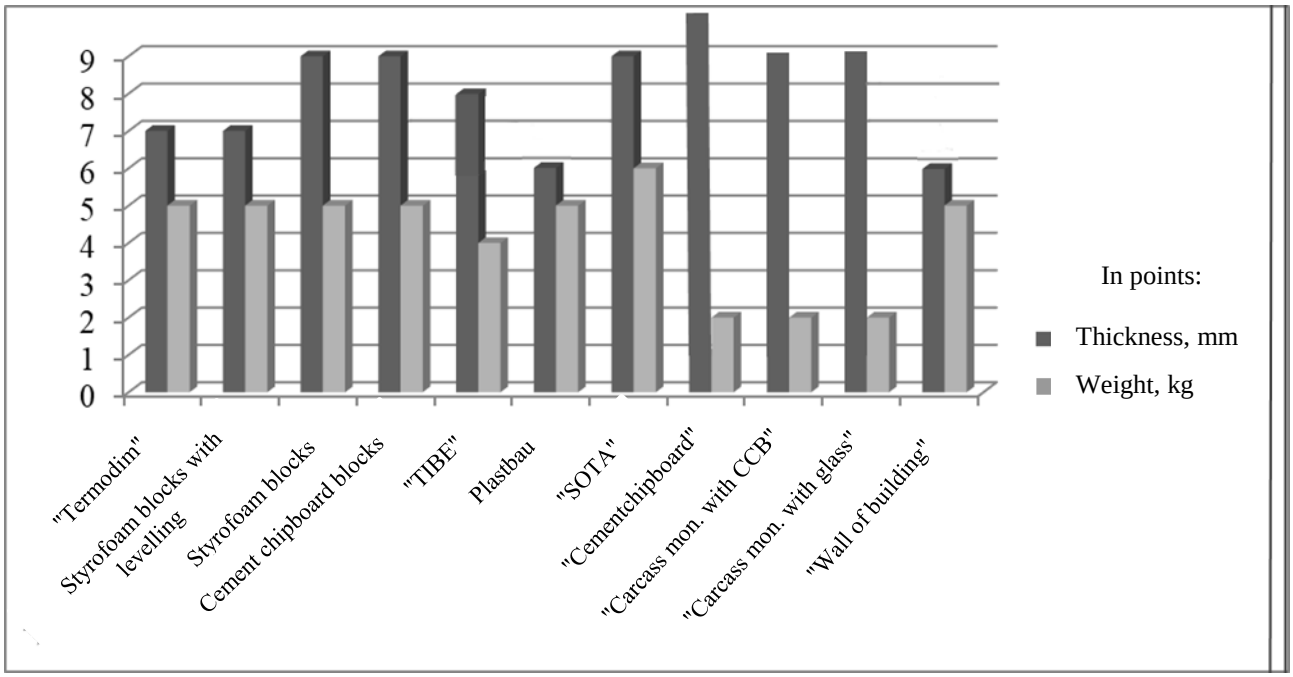

Fig. 4. Comparison diagram of structural and technological solutions in fixed formwork according to the criteria of their mass and thickness

According to the results of a comparative analysis of the structural and technological solutions of the enclosing structures of buildings in fixed formwork, the most effective is the solution according to the UA patent No. 149402 "Wall of the building" [11] with the following indicators: the cost of erecting 1 m^2 of the enclosing structure is UAH 2.445. The thickness is 330 mm and the weight is 390 kg, which provides 11% more usable area of internal premises compared to fixed formwork from blocks, with building dimensions of 10×10 m and a weight reduction of more than 1.5 times compared to frame-monolithic options. The heat transfer resistance is provided at the level of 3.1 m^2·C/W, which is higher than the normatively established 2.8 m^2·C/W for the II climate zone. Also, one of the advantages of the developed solution is the possibility of carrying out construction work at any time of the year, ensuring resistance to moisture, mold and fungal damage to the walls.

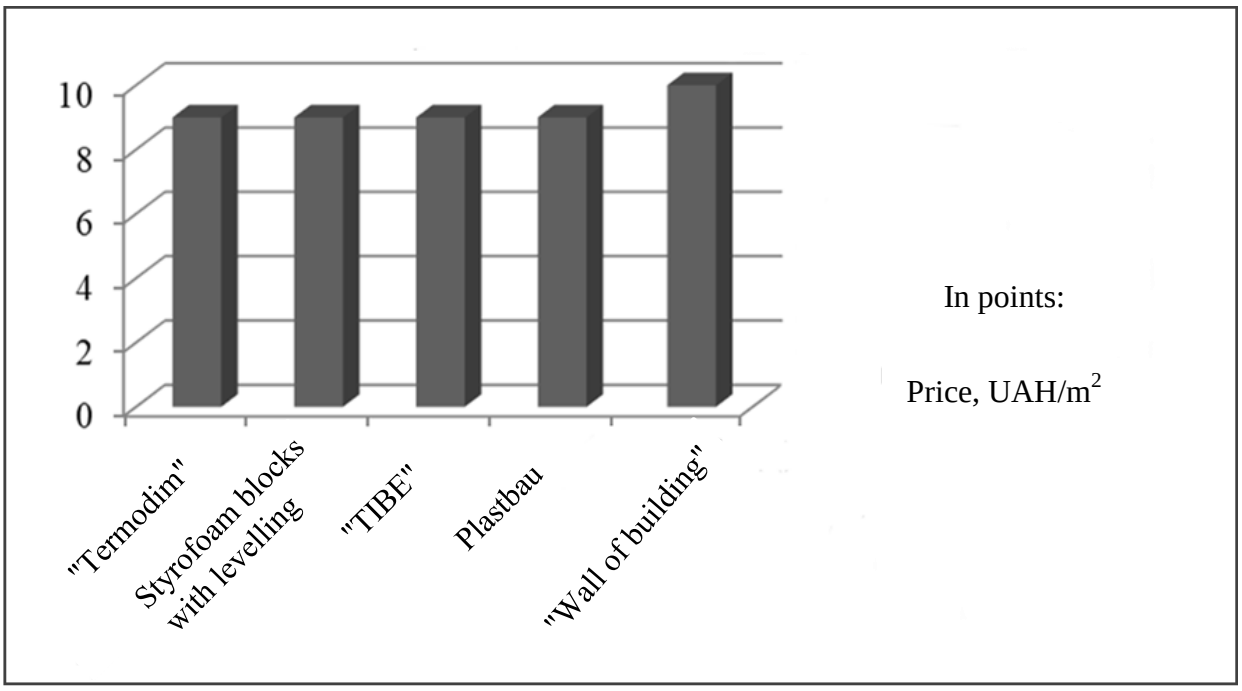

Fig. 5. Diagram of comparison of structural and technological solutions according to the cost criterion

For further research, a decision was made according to the patent [11], which provides not only heat-technical characteristics, but also economic ones.

Summary:

1. Comparison of the patented solution with 11 known solutions based on 8 criteria using Excel's "pivot tables and charts" tools, showing its advantages.

2. In order to further conduct the research, a solution developed under the UA patent No. 149402 "Wall of the building" was adopted.

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ОЦІНКА НОВОГО КОНСТРУКТИВНО-ТЕХНОЛОГІЧНОГО РІШЕННЯ ОГОРОДЖУВАЛЬНОЇ КОНСТРУКЦІЇ В НЕЗНІМНІЙ ОПАЛУБЦІ

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Анотація. Проаналізовані відомі конструктивно-технологічні рішення огороджувальних конструкцій будівель в незнімній опалубці з використанням якісного, кількісного та загального аналізу. Вибрані кількісні показники, такі як товщина стін, вага 1 м^2 стіни, опір теплопередачі, площа приміщень, вартість, довговічність, схильність до усадки. Використовувалися якісні показники: стійкість до сонця, плісняви, гноювання та руйнування, особливості доставки будівельних матеріалів.

Використаний метод багатокритеріального аналізу для оцінки нового конструктивно-технологічні рішення огороджувальних конструкцій та визначення найбільш ефективних технологій. Розглянуті категорії різних конструктивно-технологічних рішень в незнімній опалубці на основі економічного розгляду моделювання.

Підібрано для зрівняння такі сучасні конструктивно-технологічні рішення огороджувальних конструкцій в незнімній опалубці, як: пінополістирольні блоки; блоки з системою вирівнювання стін; блоки з полістиролбетону; бетонні блоки; блоки з цементно-стружкового матеріалу; великорозмірні панелі з пінополістиролу; тришарові армовані пінополістирольні панелі; цементно-стружкові плити; бетонні плити; каркасно-монолітна опалубка з обшивкою цементно-стружковими плитами; каркасно-монолітна опалубка з обшивкою скломагнієвими плитами та технологія за патентом UA 149402.

Нове конструктивно-технологічне рішення, яке розроблено та запатентовано, є поєднанням сучаснім матеріалів, які викликають великий інтерес і затребуваність у споживачів, такі як легкі стальні тонкостінні конструкції та пінополістиролбетон.

Проведена оцінка технологічних рішень за кількісними критеріями за десятибальною шкалою, в якій за мінімальне значення присвоєно 1 бал та за максимальне значення – 10 балів. Виконано графічне моделювання варіантів зведення, які зрівнюються, та побудовані відповідні діаграми.

Ключові слова: конструктивно-технологічні рішення, огороджувальні конструкції, багатокритеріальний аналіз, незнімна опалубка.

Стаття надійшла до редакції 23.11.2022