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EFFICIENCY OF OPERATION OF EXTERNAL THERMAL INSULATION SYSTEMS FROM THE POSITION OF THE EXPEDIENCY OF REPAIR WORK

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Abstract. As a result of the research, it was found that in the construction industry, when insulating external enclosing structures, in most cases, their effective operation over time takes a special place. In modern conditions, the issue of obtaining an economic effect from the operation of insulated buildings is of great importance. Insulation of building facades is carried out mainly by external thermal insulation systems with plaster finishing, and to a lesser extent, systems are used in which cladding is carried out by industrial elements with a ventilated air layer. For thermal insulation systems, it is important that the level of operational efficiency is not lower than the calculated one or is maintained within acceptable limits throughout the entire service life. It was established that when assessing economic efficiency according to the first option for short-lived technical systems, the condition must be met under which the cost of the new system would not exceed the cost of the outdated one. Since thermal insulation systems are structures of long-term operation, such a condition is difficult to fulfill due to the fact that the replacement of the layers of the system, as a rule, occurs after a certain specified time, which can reach up to 30 years. In this case, it is necessary to fulfill the requirement that the ratio of the cost of a new structure with the costs of performing the replacement to the designated service life would be less than the ratio of the cost of an outdated structure with the costs of its operation to the actual service life. It has been established that in order to make a rational decision on the further operation of the thermal insulation system, along with traditional methods of assessing the technical condition and developing recommendations for its further operation, it is necessary to perform an assessment of the economic effect when adopting a particular method of repair or restoration.

Keywords: enclosing structures, transparent facade systems, installation cost, selection criteria, expert evaluation method.

Relevance and statement of the problem. Thermal insulation of building facades is one of the main tasks of our time. The urgent need for mass insulation of building facades contributes to the creation of a separate direction in the construction industry of our country [1]. This is due to the complete non-compliance with regulatory requirements and world standards regarding the heat transfer resistance of the external structures of the majority of both public and residential buildings built since the middle of the last century and at the beginning of the current one [2-3]. Therefore, more and more attention should be paid to the problems of thermal insulation of modern buildings. Since in the conditions of an unstable economic situation there is an urgent need to promptly adjust the cost of both the insulation works themselves and the entire project as a whole [4-5]. Over the past decade, the park of enclosing structures used in new construction and thermal modernization has changed significantly. In addition, the

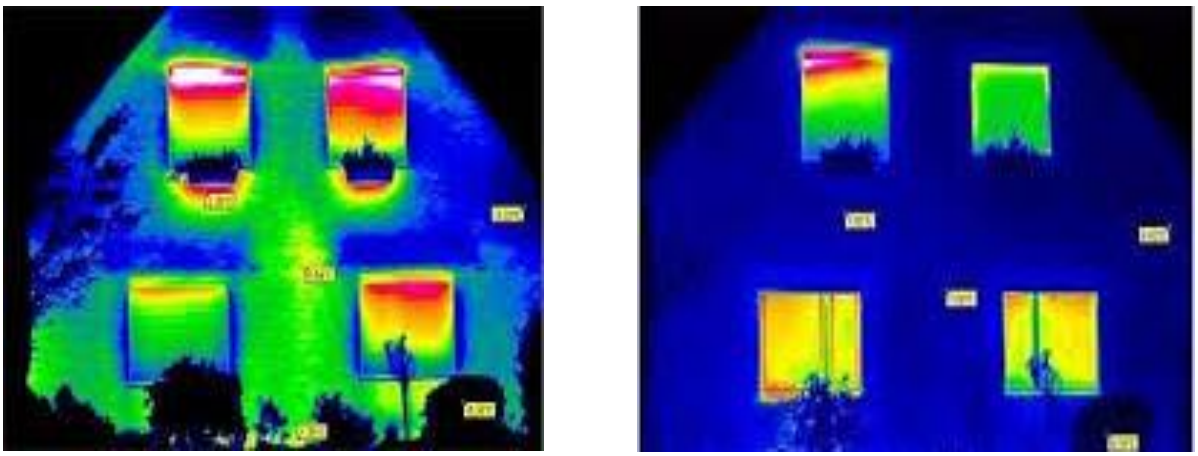
restoration of the external protective and decorative layer is part of the process of repairing insulated facades in order to ensure an attractive appearance of the building and protect the thermal insulation layer from the influence of external climatic factors. It should be especially noted that the repair of insulated facades maintains the effectiveness of the thermal insulation coating, ensures durability and improves the appearance of the building [6, 7].

Thermal modernization and repair of walls of residential buildings in operation is the most urgent problem of today and, probably, will be relevant for more than one year. Solving this problem requires a systematic approach with the involvement of state programs, for example, especially for buildings built from the middle of the last and at the beginning of the new century.

For insulation and thermal modernization of external walls of buildings in operation, the following technological solutions should be used: external insulation, insulation from the inside of the premises and insulation in the thickness of the enclosing structure, Fig. 1. However, each of these solutions requires certain operating conditions and subsequent costs for their repair. Therefore, before using a particular insulation system, it is necessary to clearly understand the operational cycle of each of them.

Fig. 1. Scheme of selection of thermal insulation systems for insulation and thermal modernization of facades

In modern conditions, the issue of obtaining an economic effect from the operation of insulated buildings is of great importance. However, it should be noted that houses that are in operation do not bring profit directly in monetary terms. Therefore, determining the profit that results from the operation of houses with effective thermal insulation that meets regulatory requirements is a difficult task. The approach to determining the efficiency of the operation of houses with facade thermal insulation systems should be based on the interpretation of the reduction in costs from the thermal insulation system that is in a state of "failure" as a conditional profit for the thermal insulation system that is in operation (excluding capital investments in its arrangement). Hence, when assessing the economic effect, the losses for bringing the thermal insulation system to a working condition should not exceed the reduction in profit losses from when the system is in a state of failure (Fig. 2), or the heat transfer resistance of the external enclosing structure has significantly decreased during operation.



a) b)

Fig. 2. Thermograms of the external wall of the house: a) the thermal insulation system of the house in a state of "failure" (light color indicates insufficient thermal insulation or its failure); b) the thermal insulation system of the house, which meets the requirements of regulatory documents (blue gradients show low surface temperature, which indicates good thermal insulation)

Analysis of recent research and publications. Recently, pre-project modeling of organizational and technological solutions has been considered interesting and necessary in order to reduce the cost of performing repair work on thermal insulation systems [5]. These and other problems in building insulation are the subject of the works of domestic scientists Farenyuk G., Meneylyuk O., Sokha V., Savyovsky V., Savytsky M., Shalenny V., Serdyuk V., Dudar I., Babii I., etc. Studies are being conducted on the dependence of technical and economic indicators of projects on the insulation of building facades [6, 9]. Various projects aimed at thermal modernization of existing buildings are being created and financed by state programs within the framework of supporting a sufficient level of energy efficiency. In our country, the insulation of building facades is carried out mainly by external thermal insulation systems with plaster finishing, for which the name of the bonded thermal insulation system (SSTI) is most often used. To a lesser extent, facade insulation, due to its higher cost, is carried out by cladding with industrial elements with a ventilated air layer, the so-called hinged ventilated facades (HVF) [10, 11]. However, these projects are not always effective, because not all optimization possibilities have been fully explored, both in the organization of projects and in the selection of technological solutions. This gives rise to scientific interest in researching these systems and their comparative analysis in determining the total cost of facade insulation, their operation and repair over time. In Ukraine, more than 256 million square meters of facade insulation have been completed since the beginning of the 21st century. However, as is known, the operational efficiency of facade systems is 20-25 years, depending on the type of insulation system [12]. Therefore, many facade systems currently require repair work. Moreover, this must be done both due to the end of the period of repair-free operation, and the need to repair the facade due to the loss of integrity and, as a result, the failure of the facade thermal insulation.

It is known that the reasons that determine the thermal modernization and repair of facade systems are various factors. Thus, based on the analysis of the results of the research, the following four types of failures in the thermal regime of building envelopes and the reasons for their occurrence have been established [13]:

1 – design (structural) failures, which are caused by imperfection or violation of design standards, which led to an unjustified choice of the level of thermal insulation of the elements of the thermal insulation shell, failure to analyze the structural features of the enclosures and, as a result, condensation on their inner surface or the accumulation of moisture in their thickness during the cold season, insufficient consideration of factors that affect the operational properties of structures or incorrect selection of design parameters of enclosure materials;

2 – technological (production) failures, which are caused by imperfection in the manufacture and installation of structures and, as a result, the influence of random factors (deviations from the design density of the thermal insulation layer, non-compliance with design solutions for sealing the butt joints of panels, elements, etc.) on the operational properties of the thermal insulation shell as a whole;

3 – operational (failures due to improper handling), which are caused by a decrease in the power of heating and ventilation systems, accidental soaking of structures, etc.;

4 – conceptual (system) failures, which are clearly associated with the imperfection of the regulatory framework, which establishes inadequate regulatory calculations of thermal indicators for modern structures and does not clearly regulate the rules and parameters of their assessment, design without establishing thermal reliability requirements for the main elements that form the thermal and humidity regime, and which can be eliminated only after reforming the regulatory framework for the design of thermal insulation structures of buildings [10].

Purpose and tasks. The purpose of the work is to determine the efficiency of operation of external thermal insulation systems from the standpoint of the feasibility of repair work. The main tasks are determined:

– to determine the criterion for the feasibility of repair or partial replacement of the main structural elements;

– to establish the costs associated with the replacement of the structure and its further operation.

– to determine the annual economic effect of the costs of complete replacement of the thermal insulation system or its repair.

Materials and methods of research. The research was carried out with the extensive use of systems analysis methods and statistical research, as well as field observations. The proposed methods made it possible to identify and build empirical dependencies.

Research results. It can be noted that most facade thermal insulation systems are those that can be repaired and restored. For such systems, the economic effect, according to [14, 15], is determined by two options:

– the economic effect of continuing the efficiency of the operation of the facade system;

– the economic effect of improving the quality of the facade system installation.

In the first option, the economic effect is associated with the replacement of the layers of the facade system and structures that are in a state of "failure" [8] with new ones. In the second option, high-quality modern materials and repair technologies are used. In order to assess which of the two options for repairing facade thermal insulation systems of operated structures is more effective and which one to take into action, it is necessary to determine the costs for both options, compare them and make a decision on the further operation of the system.

The criterion for the feasibility of replacing the system, according to [2], is the following expression:

$$\Delta E = (l_f - \sum_{i=1}^{n} \frac{C_{r_i}}{T_{es_i}}) \geq 0,$$

where ΔE – specific efficiency index;

l_f – specific (per accepted unit of time) possible losses due to «failure» of the thermal insulation system;

n – number of elements/layers of the structure to be replaced;

C_{r_i} – cost of replacing the i-th structural element, including the cost of performing the work and the cost of the element;

T_{es_i} – effective service life of the i-th structural element.

In the case of replacing a structure in a state of failure with a new one, the specific efficiency index must be higher than zero. This means that the new thermal insulation system must meet increased requirements for the quality of performance and the duration of its service life, i.e. contribute to the extension of the durability of the entire structure.

An indicator of the quality of the external thermal insulation system can be the ratio of the intended effective service life of the new thermal insulation system to the actual service life of the structure being operated.

$$Q = \frac{\mathrm{T_1}}{\mathrm{T_o}},$$

where $\mathrm{T_1}$ – is the intended service life of the new thermal insulation system;

$\mathrm{T_o}$ – is the actual service life of the outdated thermal insulation system.

When assessing the economic efficiency according to the first option for short-lived technical systems, the condition must be met under which the cost of the new system would not exceed the cost of the outdated one. Since thermal insulation systems are structures of long-term operation, such a condition is difficult to fulfill due to the fact that the replacement of the layers of the system, as a rule, occurs after a certain specified time, which can reach up to 28 years. In this case, it is necessary to fulfill the requirement under which the ratio of the cost of the new structure with the costs of performing the replacement to the intended service life would be less than the ratio of the cost of the outdated structure with the costs of its operation to the actual service life.

$$\frac{\mathrm{C_1}}{\mathrm{T_1}} \leq \frac{\mathrm{C_0}}{\mathrm{T_o}},$$

The costs associated with replacing the structure and its subsequent operation are determined by the following formula:

$$\mathrm{C}_r = \left[\mathrm{K}_l^0 + \sum_1^t \frac{\mathrm{C}_t}{(1+S_{dt})^t} \geq 0\right] \times k_{rs}\ ,$$

where K_l^0 – one-time costs for replacing system layers;

t – period in years since the production of the replacement structure;

$\frac{\mathrm{C}_t}{(1+S_{dt})^t}$ – total depreciation deductions for the new design taking into account the deferral of costs at t = 28 years;

k_{rs} – number of system repairs made.

As is known, reliability is characterized by reliability, maintainability and preservation. For thermal insulation systems, it is important that throughout the entire service life the level of operational efficiency is not lower than the calculated one or is maintained within acceptable limits. And here the failure-free operation of the structure is of great importance. There are two ways to maintain the required level of reliability. First, during operation, the appearance of defects and damage should be minimal, which is associated with the quality of the design. Secondly, it is necessary to timely eliminate defects and damage by carrying out repairs, and also strive to increase the repair intervals. The criterion for the feasibility of repair or partial replacement of the main structural elements is the following expression:

$$\Delta\mathrm{C} = C_n - \mathrm{C}_f - \sum_{i=1}^n \frac{C_{r_i}}{\mathrm{T}_{p_i}} \geq 0,$$

де $\Delta\mathrm{C}$ – specific costs for restoring the working condition of all elements of the thermal insulation system.

The costs associated with the repair and restoration of facade thermal insulation systems and their further operation are determined by the formula:

$$\mathrm{C}_f = \left[\mathrm{K}_\mathrm{o}^\mathrm{y} + \sum_1^t \frac{\mathrm{C}_t}{(1+S_{dt})^t} \geq 0\right] \times S_{rf},$$

where $\mathrm{K}_\mathrm{o}^\mathrm{y}$ – one-time costs for the repair of the thermal insulation system;

t – period in years from the moment of the repair, which limits the summation of costs;

C_t – annual operating costs, including depreciation and standard costs for the current repair of the thermal insulation system;

S_{dt} – standard for reducing costs at different times, which is taken at 0.08 [15];

S_{rf} – percentage of the total area of repaired thermal insulation of facades.

After considering the options for operating the building, a comparison of the costs for the complete replacement of the thermal insulation system or its repair is performed. The option with lower costs is selected, and the annual economic effect is determined as the difference in costs.

$$\mathrm{E}c_{ef} = C_r - C_f.$$

The above are the main provisions for determining the economic effect of the operation of facade thermal insulation systems. When performing such a calculation in detail, multiple factors are taken into account that affect the process of both complete replacement and repair of the system.

Conclusions. Based on the above, we can conclude that in order to make a rational decision on the further operation of the thermal insulation system, along with traditional methods of assessing the technical condition and developing recommendations for its further operation, it is necessary to also assess the economic effect when adopting a particular method of repair or restoration. This approach will significantly increase operational efficiency and extend the period of repair-free operation of facade thermal insulation systems, and will also allow for the targeted use of funds that are annually allocated to maintain them in working condition.

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ЕФЕКТИВНІСТЬ ЕКСПЛУАТАЦІЇ ЗОВНІШНІХ СИСТЕМ ТЕПЛОІЗОЛЯЦІЇ З ПОЗИЦІЇ ДОЦІЛЬНОСТІ РЕМОНТНИХ РОБІТ

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Анотація. У результаті досліджень встановлено, що в будівельній галузі при утепленні зовнішніх огороджувальних конструкцій у більшості випадків особливе місце займає їх ефективна експлуатація в часі. У сучасних умовах велике значення має питання отримання економічного ефекту від експлуатації утеплених будівель. Утеплення фасадів будівель здійснюється переважно зовнішніми теплоізоляційними системами з обробкою штукатурками, та в меншому об’ємі використовуються системи, в яких здійснюється облицюванням індустріальними елементами з повітряним шаром, що вентилюється. Для систем теплоізоляції важливо щоб протягом усього терміну служби рівень експлуатаційної ефективності не був нижчим за розрахунковий або зберігався в допустимих межах. Встановлено, що при оцінці економічної ефективності за першим варіантом для недовгочасних технічних систем має дотримуватися умова, за якої вартість нової системи не перевищувала б вартості застарілої. Оскільки системи теплоізоляції є конструкціями тривалої експлуатації, таку умову виконати важко через те, що заміна шарів системи, як правило, відбувається через певний визначений час, який може сягати до 28 років. У такому разі, необхідне виконання вимоги при якому відношення вартості нової конструкції з витратами на виконання заміни до призначеного терміну служби було б меншим від відношення вартості застарілої конструкції з витратами на її експлуатацію до фактичного терміну служби. Встановлено, що для прийняття раціонального рішення щодо подальшої експлуатації системи теплоізоляції, поряд з традиційними методами оцінки технічного стану та розробкою рекомендацій щодо її подальшої експлуатації, необхідно виконувати і оцінку економічного ефекту при прийнятті того чи іншого способу ремонту чи відновлення.

Ключові слова: огороджувальні конструкції, теплоізоляція фасадів, економічна ефективність, ремонт фасадів, вартість влаштування.

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