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Research paper

Investigation of the Factors Affecting Technical and Economic Indicators of Thermal Insulation of External Walls of Buildings

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Abstract

The technology of insulation of enclosing constructions of buildings and constructions is characterized. The method of technological design on the basis of integrated production of technological processes, estimation and influence of organizational and technological reliability of building production depending on methods, technologies and constructive decisions is given.
The data collection for the energy certificate of the building is shown. Energy certificate of the building is a document containing the geometrical, energy and heat engineering characteristics of the building being designed or operated, as well as the characteristics of the heat insulation. This document also establishes the compliance of the building with the requirements of regulatory documents. The energy passport of the building is not intended to be used to make payments for utility or other services provided to homeowners, tenants and apartment owners.
Energy assessment of the building - energy efficiency of buildings should be determined on the basis of estimated or actual annual energy consumption necessary to meet various needs associated with its typical use in the building. These needs should include the energy consumption for heating and cooling to maintain the desired temperature, as well as hot water supply.

Keywords: *energy efficiency, insulation, heat transfer, system insulation.*

1. Introduction

In present-day conditions of socio-economic development of Ukraine, the cost and amount of energy directed to heating of buildings, is very important. The main indicator of energy efficiency for heating is the specific fuel consumption per 1 m^2 of heated space. Comparison of this indicator with the best values, achieved in other countries similar to Ukraine on climatic conditions, allows us to state that we have 2 ÷ 2.5 times overexpenditure of energy in objects of civilian property. Due to current realities, the use of energy-saving technologies is relevant not only in Ukraine but also in most countries of the world, especially in countries with cold climatic conditions. The modern system of building operation requires advanced technologies.
Analysis of research and publications. The issues of improvement of technical and technological decisions concerning buildings reconstruction and revitalization, in particular, when arranging external thermal insulation are widely covered in the works of V.K. Chernenko [1], OI Menelyuk [2], Ye.K. Karapuzov, V.G. Sokha [3], VV Saviwski [4, 5] and other scholars. But, at the same time, some aspects of the influence of factors of different content and properties on the technical and economic parameters of construction works, especially the ones concerning simulation of the labour intensity and duration parameters, remain incomplete. The analysis of practical experience and research results on the arrangement of thermal insulation of external fencing structures of buildings allows us to conclude that, despite the high intensity of research, these issues need further study.

Aim: to establish regularities regarding the degree of organizational and technological factors influence on the work parameters when performing thermal insulation of underground wall structures using the expert evaluation method.
Objectives of the study:
- analysis of organizational and technological solutions of the arrangement of walls insulation and their impact on the work efficiency;
- study of the work efficiency parameters when performing thermal insulation of the walls;

2. Main material

Main materials and results. The transition of the economy to the market conditions set the task of radical reorganization of the approach to the issues of heat consumption. Changing conditions gave rise to the changes of regulatory requirements for external enclosing structures.
The rational increase of the heat-protective properties of the external enclosing structures of buildings cannot be achieved by increasing their thickness. This issue requires other approaches like using of modern technologies and effective insulation materials. Approximately from the mid-1990s modern heat-insulating materials, technologies and approaches began to appear on the domestic market. Investors initially were reluctant to invest in buildings insulation, but economic realities have made it necessary.
Taking into account the results of previous studies, the calculations of the thermal resistance of the external wall with a layer of insulation on the section of 1 m high were made. Calculations were made for the heat-insulating system with different methods

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of applying glue solution: with open and closed air layers. Verification calculations were carried out in accordance with the instructions of DBN B.2.6-31:2016 "Thermal insulation of buildings" according to the formula

$$R\sum пр= 1/\alpha в+ \sum \delta i/\lambda i +1/\alpha н , \quad (1)$$

In this formula, the values of the thermal resistance of the closed air layer and the layer of the adhesive solution were used as the thermal resistance of the i-th layer of the construction. The index of thermal conductivity of the adhesive solution is assumed to be

$$\lambda = 0.7 (W / (m K) , \quad (2)$$

On the basis of calculations, the charts showing correlation between the thermal resistance of the heat-shielding system and the method of applying the glue solution to the insulation were made. The analysis of the obtained correlation shows that the method of glue solution application, that is, the technological methods of thermal insulation, allows to optimize the structural design of the thermal insulation system and increase the efficiency of the thermal insulation by 4.2%. This requires the development of a suitable methodology. It is also important to take into account the temperature and properties of the soil (Fig. 1).

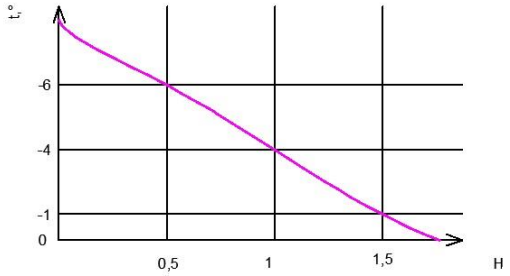


Fig. 1: Graph showing the dependence of the foundation depth on the temperature.

Analysis of the conditions for the implementation of works, design and executive construction documentation on the installation of thermal insulation of a number of buildings showed that the effectiveness of work is significantly affected by the features of objects that can be attributed to the destabilizing factors [5, 6, 7]. As a result of the presence of these factors, the technical and economic parameters of the work can significantly increase. In order to determine the range of destabilizing factors, studies of design and budget documentation as well as experience of thermal insulation installation were conducted. On the basis of the selected list, factors were ranked applying expert evaluation method. As expert groups, the following specialists were involved:

- the sum of ranks of each factor was determined, aij;
- deviations from the average sum of ranks d was determined.

$$d = \Sigma aij – T, \quad (3)$$

where T is the average sum of ranks;

- the squares of deviations from the average sum of the ranks and the sum of the squares of these deviations were determined:

$$S (d2) d = \Sigma d2 = 361, \quad (4)$$

- a certain level of consistency among the expert groups regarding the importance of the selected factors was determined. The degree of consistency of experts on the ranking of indicators is estimated by the coefficient of concordation W:

$$W = S(d2)/1/12 m2(n3 – n) – m \Sigma T, \quad (5)$$

$$T = 1/12\Sigma(t3j – tj), \quad (6)$$

where tj is the repetition of each rank in the jth row. After inserting the value in formula (4), the obtained value of the degree of consistency equals W = 0.42. The estimation of the significance of the coefficient of concordation is determined by the distribution of $\chi 2$ with the number of degrees of freedom D = n-1:

$$\chi 2 = S(d2)/ 1/12 mn(n + 1) – 1/n-1 \Sigma Ti \quad (7)$$

The value of $\chi 2$ is 98.4 and is compared to the table values by the 5% level of consistency, $\chi 2$ table.= 14.07. Since

$$\chi 2 table.< \chi 2, \quad (8)$$

Consequently, with the probability of about 95% it can be assumed that the consistency of expert opinions regarding the degree of influence of the proposed factors on the parameters of the work on the installation of thermal insulation of wall underground structures is established [8].

Subsequently, several objects were analyzed and a set of measures that lead to lower energy consumption was proposed.

Public buildings built in ukraine in the past do not meet the modern requirements for efficient use of energy resources. In particular, the consumption of heat energy for heating buildings in ukraine far exceeds the standards of developed countries. The main reasons for this are the use of outdated materials and technologies in buildings construction industry. This leads to excess fuel consumption for thermal energy production and, as a consequence, to excess greenhouse gas emissions. Building projects made before 2000 have energy efficiency class f, in 2000-2006 class d, later - class c. There are cases when individual energy efficiency classes may differ due to individual design solutions.

After studying the state of the house and consumption of energy resources it can be concluded that the existing indicators are very different from the reference in accordance with DBN в.2.6-31:2016. Therefore, it will be urgent to propose energy-efficient measures, which will not only reduce heat energy consumption, but also improve the conditions of comfortable stay indoors.

Each building is unique, so each project must be individually considered in order to identify specific opportunities for increasing energy efficiency. In order to obtain a calculated saving and payback period, all proposed measures must be implemented in a comprehensive manner.

By the concept of energy-efficient building, one should understand a building in which effective energy consumption is achieved by means of various innovative solutions, economically justified, technically applicable and acceptable from social and environmental points of view.

The actual measures for the considered civilian object that will bring saving of thermal energy and improve the conditions of stay are:

Warming down the basement (including the base)

The total floor area is 3222.99 m² and it is suggested to insulate the base and the floor.

Existing reduced thermal resistance is 0.71 (m² • k) / w, it is proposed to reach the value of 4.05 (m² • k) / w. Insulation is offered:

Constructive type 1. The floor with total area of 3222.99 m², insulation of 100 mm thickness; as the floor insulator it is offered to use boards of extruded polystyrene foam with density of not less than 35 kg / m³ and thermal conductivity coefficient of 0,03 w / (m • k) [9].

The base with total area of 224 m², insulation of 80 mm thickness, boards of extruded polystyrene foam with density of not less than 35 kg / m³ and thermal conductivity coefficient of 0.03 w / (m • k) are offered as the insulator.

below there are two most common methods of cellar or technical basement insulation. The first method is recommended for buildings without basements.

At the stage of working design, it is necessary to re-examine the options for insulation and choose the most suitable option that meets modern design requirements.

1-method: increase of thermal insulation of the wall by 0,5 m and insulation of the basement from the inside increases the path of the heat flow and, respectively, reduces the heat loss.

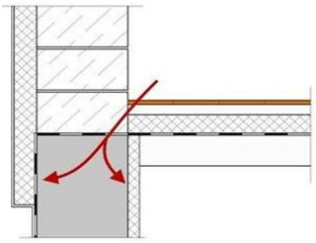


Fig. 2: Increase of the thermal insulation of the wall.

2-method: The thermal isolation of the walls is performed at 1 m below the ground (in accordance with DBN B.2.6-31:2016), with the insulator of smaller thickness in this part. With this method of insulation, the base will be slightly lower in relation to the wall, which will protect it from atmospheric precipitation.

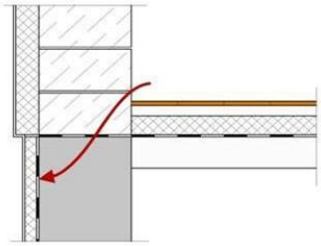


Fig. 3: The thermal insulation of the wall is carried out at 1 m below the ground level.

Table 1: Characteristics of basement warming

The total floor area	3222.99	m²
Resistance before/after insulation	0.71 / 4.05	(m² · K) / W
Savings	346.14	Gcal / year
		thousand UAH / year
Effective lifetime	40	years

Walls thermal insulation.

The total area of the walls to be insulated is 3117.9 m², the area of window slopes is 311.4 m². The resulted (average) thermal resistance of the existing walls is 0.81 (m² · K) / W and does not meet the requirements. It is proposed to achieve a value of 3.41 (m² · K) / W by means of walls insulation.

Insulation of the walls is proposed to be performed applying the technology of external insulation "wet facade". This system is quite simple to implement and reliable in operation, it should also be noted that this method is the most widespread in Europe. Mineral wool is used with thickness of 120 mm, density of 150 kg/m³ and heat transfer coefficient of 0.046 W / (m · K).

At the stage of working design, it is necessary to re-examine the options for insulation and choose the most suitable option that meets the modern design requirements [10]. The prices for the implementation of energy-efficient measures are indicative, the final prices will be known after the drafting and approval of its expertise, then the recalculation has to be made.

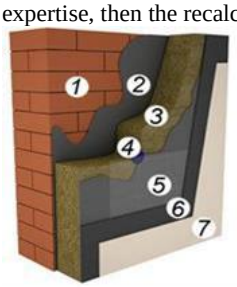


Fig. 4: Wall warming: 1 wall, 2 adhesive layer, 3 insulation, 4 plate dowel

5 reinforcing glass netting, 6 adhesive layer, 7 decorative protective layer.

Table 2: Heat insulation of walls

Area of the wall	3117.9	m²
Thermal resistance of the wall before/after the implementation of the measure	0.81 / 3.41	m²
Savings	229.34	Gcal/year
		thousand UAH/year
Effective lifetime	40	years

Replacing windows

The total area of the windows is 2363.8 m². The reduced resistance of the heat transfer of existing windows is 0.4 (m² · K) / W and does not meet the requirements. It is offered to install modern PVC windows, made of metal-plastic profile and equipped with three-chamber glass windows with energy-saving glass. The heat transfer resistance of such windows is 0.75 (m² · K) / W, which meets the regulatory requirements.

The total area of the windows whose thermal characteristics do not meet the standards are 1528.08 m² (65%). After the analysis it was decided to replace all windows that do not meet the regulatory requirements.

PVC windows have high airtightness and virtually no air in the closed position, which in turn violates the air exchange and subsequently contributes to the accumulation of carbon dioxide, vapors, the formation of fungus and mold. In order to avoid all of the above problems, it is proposed to perform reconstruction of the supply and exhaust ventilation system with the use of air recuperation.

It is also possible to purchase windows with ventilation grill (built-in ventilation valve), but with due attention to their certification, which confirms that the windows are made in accordance with the requirements.

At the stage of working design, it is necessary to re-examine variants of double-glazed windows and choose the most suitable type, which will meet modern requirements at the time of designing. The prices for the implementation of energy-efficient measures are indicative, the final prices will be known after the drafting and approval of its expertise, then recalculation has to be made.



Fig. 5: PVC window cut profile.

Table 3: Characteristics of insulation with the replacement of windows

Total area of window constructions	2363.8	m²
Area of window constructions to be replaced	1528.08	m²
Thermal resistance of the wall before/after the implementation of the measure	0.4 / 0.75	(m² K) / W
Savings	64.68	Gcal / year
		thousand UAH / year
Effective lifetime	40	years

Insulation of the roof (soft roof system)

the total area of the roof that needs to be insulated is 4724.7 m² (insulation of the entire roof).

the reduced (average) thermal resistance of the roof is 0.96 (m²· k) / w and does not meet the requirements. it is proposed to achieve a value of 6.02 (m² · k) / w by insulation and waterproofing of the roof.

we offer to apply a double layer insulating system (soft roof).

mineral wool with a density of 190/110 kg / m³ and a thermal conductivity coefficient of 0.039 w / (m · k) is used as insulator, thickness of the layer of insulator is 200 mm. roofing material with a density of 600 kg / m³ and a heat conductivity coefficient of 0.17 w / (m · k) is used as waterproofing material.

thickness of the insulator layer:

constructive type 1 - 200 mm;
it should also be noted that high-quality waterproofing will eliminate the need for constant ongoing repairs, which will further save money. At the stage of working design, it is necessary to re-examine the insulation options and choose the most suitable option that will meet the modern requirements at the moment of design work. the prices for the implementation of energy-efficient measures are indicative, the final prices will be known after the drafting and approval of its expertise, then recalculation has to be made.



Fig. 6: An example of a constructive solution of heat insulation.

1. Waterproofing, 2. Hydro isolation, 3. Insulator, 4. Insulator, 5. Vapor barrier, 6. Telescopic mounting, 7. Profile sheet (optional), 8. Double-side scotch.

Table 4: Characteristics of roof insulation

Total area of the roof	4724.7	m²
Thermal resistance of the roof before/after the implementation of the measure	0.96 / 6.02	(m² · K) / W
Savings	516	Gcal / year
		thousand UAH / year
Effective lifetime	30	years

Table 5: The resulting table on energy saving measures

The heating area of the house	9881	m²
The basic annual consumption of thermal energy for carrying out the complex of works on thermo-sanitation	2394.98	Gcal
	281.9	kWh / m²
Prospective annual consumption of thermal energy after conducting thermosanance complex of works	1100.5	Gcal
	129.53	kWh / m²
Annual heat energy saving for heating needs	1294.48	Gcal
	152.37	kWh / m²
Project life expectancy	30	years

3. Conclusion

Environmental protection.
Heat protection should provide comfort in the room both in winter (protection from the cold) and in summer (overheating protection). The importance of thermal protection under conditions of energy saving is really high. Mineral resources are being exhausted. Oil, gas, and coal are scarce as they are not reproduced. They need to be saved.
Also, we should mention the importance of thermal protection under the conditions of environmental protection. The less fuel is burned, the less are the emissions of harmful gases (carbon dioxide co2, carbon monoxide, nitrogen oxides and sulfur oxides). Together with atmospheric moisture, they form acids that, in the form of acid rain, destroy nature, buildings and structures. Therefore, thermal protection is also an important aspect of environmental protection.
Energy-efficient measures on the consumer side have a direct impact on emissions through the entire grid. Emissions from the energy production system are caused by the combustion of fossil fuels.
Carbon dioxide is not poisonous gas. It is harmless to life and environment at normal concentrations in the atmosphere, but it is considered to be one of the main gases that have an impact on climate change.
Nitrogen oxides are formed in the process of combustion at high temperatures by oxidizing part of nitrogen, which is found in the atmospheric air. Under the general formula of nox usually the sum of no and no_2 is meant. Nitrogen oxide n_2o. N_2o accounts for 1% of all greenhouse gases, but it causes the greenhouse effect to be 300 times stronger than CO_2.
Conclusions. Thus, the development of solutions aimed at improving the efficiency of work on the installation of thermal insulation, includes two components: improvement of technical and economic indicators can be achieved through the provision of effective engineering work preparation. At the stage of developing projects for the execution of works or the development of investment plans, the most important aspect is the consideration of factors that could negatively affect the effectiveness of the process as a whole; improvement of organizational, technological and constructive solutions in general allows to improve the energy-protective shell of buildings. The results of such solutions can be effective not only in the process of construction work, but also in the further exploitation of the objects.

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