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Envelope Life Cycle Costing of Energy-Efficient Buildings in Ukraine

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***Abstract**: The article describes main points and characteristics of the building envelope design considering life-cycle cost and compliance with the codes for energy efficiency parameters in Ukraine. This article contains of the problem analysis of the requirements development for the energy-efficient buildings parameters in Ukraine considering life-cycle cost in the walling design. The structural concepts for the thermal insulation of building exterior walls and roof coatings and their impact on energy efficiency are considered. Designing rational structural concepts for thermal insulating envelope of energy-efficient buildings. The role of the life cycle cost criterion in making decisions on the choice of building envelope is clarified. Analysis of activities, publications and regulatory documents in Ukraine and the EU-countries for the design of rational thermal insulating building envelope considering life-cycle cost to reducing energy consumption. The requirements of regulatory documents on the design of energy-efficient buildings in Ukraine are systematized. The variants of construction solutions for building envelope are considered in terms of the life-cycle cost and energy saving requirements. The tasks of choosing optimal solutions for enclosing structures of external walls and building coatings are multicriteria of a cardinal choice of alternatives with different important measures from a finite set of feasible solutions when considering a weakly structured problem with clearly defined separated parameters. Thermal insulating building envelope using modern insulation systems should be used in all types of buildings.*

***Keywords**: Building, building envelope, coating, energy efficiency, life cycle, wall.*

I. INTRODUCTION

The energy efficiency level (an efficient use of energy reserves) in Ukraine comprises 60% of the EU countries level. About half of the entire energy is spent on the buildings' construction and operation. In 2017, the Law on the Energy Efficiency of Buildings, adopted in Ukraine, aims at reducing the energy consumption and ensuring the proper level of the buildings' energy efficiency in accordance with technical regulations, national standards, rules and regulations. This Law defines the basic principles for stimulating the reduction of energy consumption in buildings, ensuring their thermal modernization, encouraging the use of renewable energy sources. The building's energy efficiency is a feature of its thermal insulating envelope and of engineering equipment to provide during the life cycle for the person's life necessities and optimal microclimatic conditions for their stay and/or living at the statutory permissible level of energy resources consumption for heating, lighting, ventilation, air conditioning local climatic conditions [1]. Designing optimal structural concepts solutions for the building's thermal insulating envelope should promote the rational use of energy resources for heating, cooling and hot water supply, maintaining acceptable sanitary and hygienic parameters of the indoor microclimate and the statutory durability of its operation. Indicative of the building's energy durability is the specific consumption of thermal energy to create the optimal thermal conditions of the indoor microclimate per unit of its heating area or volume. The energy efficiency index (the values' interval of the thermal energy specific consumption) determines the level of energy efficiency of the building. Basic in the energy efficiency of buildings are thermotechnical laws of heat, moisture and air movement through the building envelope. Of particular importance are the building energy efficiency requirements during the building's design or thermal modernization of thermal insulation (basement enclosures, exterior walling, covering structures) and ensuring its compliance with the applicable requirements of Ukraine's National Building Code [1], taking into account the obligatory consideration of the local conditions; functional purpose, type, architectural and planning solution of the building; geometric, thermal and specific energy requirements; regulatory sanitary and microclimatic conditions of the premises; durability and reliability of the thermal insulating envelope. In the course of designing the building envelopes of energy-efficient buildings with the aim of meeting people's domestic needs and creating optimal microclimatic conditions in the premises for their living and stay, the regulations of Ukraine's National Building Code [1] set the minimum requirements as for heat engineering indicators of the thermal insulation envelope (Table 1), as well as for the buildings characteristics (Table 2), which are determined on the basis of economically justified level of their energy efficiency, taking into account the expected life cycle.

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When applying the system design principle of the building energy efficiency requirements, it is necessary to check the minimum admissible temperature of the inner surface of the building envelope, the magnitude of the difference between the temperature of the interior air and the reduced temperature of the inside surface of the building envelope, the humidity and thermal operating conditions, air permeability and indicators of thermal durability of the building envelope [2].

Table 1: The minimum admissible resistance value of heat transfer of the building envelopes of residential and public buildings, $R_{q\,\min}$

Item No.	The type of the building envelope	The values of $R_{q\,\min}$, $m^2 K./W$, for Ukraine temperature zones	
		I	II
1	Outside walls	3.3	2.8
2	Combined coatings	6.00	5.5
3	The coatings of heated attics (technical storeys) and attic type coatings	4.95	4.5
4	Attic coatings of non-heated attics	4.95	4.5
5	Coatings over driveways and non-heated ones	3.75	3.3
6	Translucent building envelopes	0.75	0.6
7	External doors	0.6	0.5

Table 2: The statutory maximum specific energy requirement for residential and public buildings EP_{max}

Item No.	Purpose of the building	Values of EPmax, $kW{\cdot}h/m^2$ [$kW{\cdot}h/m^3$], for Ukraine temperature zones	
		I	II
1	Residential buildings by the storey indication:		
	from 1 to 3	120	110
	from 4 to 9	83	81
	from 10 to 16	77	75
	17 and more	70	68
2	Public buildings and structures by the storey indication:		
	from 1 to 3	[20Λb_{ci} + 31]	[19,4Λ b_{ci} + 33]
	from 4 to 9	[38]	[40]
	from 10 to 24	[37]	[39]
	25 and more	[34]	[36]
3	Trade enterprises	[28 Λ b_{ci} + 17]	[32 Λ b_{ci} + 18]
4	Hotels		
	from 1 to 3	110	100
	from 4 to 9	75	70
	10 or more	65	60
5	Buildings and facilities of educational establishments	[28]	[30]
6	Preschool buildings and structures	[48]	[50]
7	Healthcare facilities	[48]	[50]
	Note: Λ b_{ci} – coefficient of building compactness, m^{-1}		

where $R_{\sum r}$ – reduced heat transfer resistance of the non-transparen building envelope or non-transparent part of the building envelope, reduced heat transfer resistance of translucent building envelope.

For exterior building envelopes that are heated and cooled as well as for interior building envelopes that separate the facilities, with the air temperature difference of 4°C or more, the mandatory conditions as follows are to be met:

$$R_{\sum пр} \geq R_{q\,min}, \tag{1}$$

$$\Delta T_{пр} \leq \Delta T_{сг}, \tag{2}$$

$$T_{в\,min} > T_{mim}, \tag{3}$$

$R_{q\,min}$ – the minimum permissible value of heat transfer resistance of the non-transparent building envelope or non-transparent part of the building envelope, the minimum value of heat transfer resistance of the translucent building envelope, m2K/W;

ΔT_{np} – temperature difference between the temperature of the inside air and the reduced temperature of the inside surface of the building envelope, °C;

$\Delta T_{cг}$ – the difference between the inside air temperature and the reduced inside surface temperature of the building envelope, °C, which is acceptable under the sanitary-hygienic requirements;

$T_{в\ min}$ – the minimum value of the inside surface temperature in the zones of thermal conducting inclusions in the building envelope, °C;

T_{mim} – the minimum permissible value of the inside surface temperature at the calculated values of the indoor and outdoor air temperatures, °C.

The minimum permissible values of the heat transfer resistance of non-transparent and translucent building envelopes and building doors (Table 1) depend on the temperature zone of the building operation.

According to sanitary and hygienic requirements, the admissible difference between the temperature of the interior air and the reduced temperature of the inside surface of the bulding envelope $\Delta T_{cг}$, °C, is set for buildings depending on the type of the building envelope: 4.0 °C – for exterior and interior walls; 3.0 °C – for the coverings and attic floors; 2.0 °C – for passage and cellar slabs.

The minimum adrmissible temperature of the inside surface of non-transparent bulding envelopes in zones of thermally conductive inclusions, T_{mim}, in the corners and slopes of window and door openings, as well as the minimum permissible temperature of the inside surface of the dormer windows and zenith lamps at the calculated value of the outside temperature for the zone I -22 °C and for zone II -19 °C, it should be not less than the dew point temperature tp according to the calculated values of the temperature and relative humidity of the indoor air of residential buildings $t_в$ = +20 °C and $\varphi_в$ = 55 % accordingly.

The minimum temperature on the inside surface, T_{mim}, of the translucent building envelopes at the calculated values of outdoor and indoor air temperatures and relative humidity of the indoor air thereof, will be: for cases, frames and glass strips of window and door units, as well as translucent frame zones – not less than + 6°C, but for non-transparent zones and elements, including shutters and imposts of window and door units, racks and crossbars of translucent facades, non-transparent filling of balcony doors, etc. - not less than the dew point temperature, t_p.

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II. MATERIALS AND METHODS

A. Determination of the heat transfer resistance of a non-transparent building envelope

In the cold season, in order to create comfortable conditions for people to stay in buildings, a certain amount of heat is supplied, which is a product of the utilizing different fuels and is constantly gaining in price. In order to preserve the heat energy for the heating of buildings at the stage of their design, thermal insulation coating is put in place in the form of building envelopes of basements, exterior walls and building coatings. The difference in temperature inside and outside the building or between its various parts facilitates the heat transfer from the heated premises to a cold environment, and the partition walls, floors and coatings resist some heat transfer but do not prevent it completely. The purpose of thermal insulation of building envelopes is to reduce the amount of heat transferred through them. The problem of designing external building envelopes is solved by the methods of construction heat engineering, which are based on the general theory of heat exchange and mass transfer processes in material media. For this purpose, the external building envelopes are considered in the thermodynamic process as open systems that exchange energy with the external environment by way of the heat-, moisture- and air exchange. The calculation methods of the limit states of heat transfer resistance and heat resistance of the building envelopes are laid at the basis of calculations of thermal engineering construction. This means that in the course of buildings design, as a rule, a multilayer building envelope is developed, the heat transfer supports on the main field are calculated according to the formulas given in Fig. 1, as well as the heat transfer resistance shown in Fig. 2, which is compared to the corresponding minimum values presented in Table 1. In case of failure to comply with the requirements, the structural solution of the building envelope is improved. Special attention should be paid to the additional insulation of possible thermal bypasses [3]

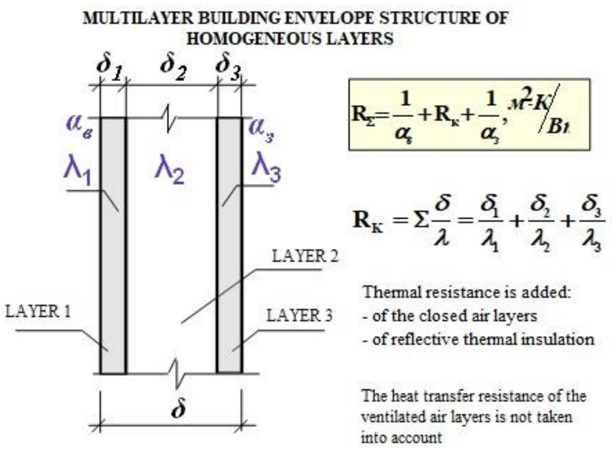

Figure 1. Calculation of the heat transfer resistance of the multilayer building envelope structure

The formula of the reduced heat transfer resistance

$$R_{\Sigma np} = \frac{F_\Sigma}{\sum_{i=1}^{I}\frac{F_i}{R_{\Sigma i}} + \sum_{j=1}^{J} k_j L_j + \sum_{k=1}^{K}\psi_k N_k}$$

F_Σ – total area of the envelope structure, m^2
$R_{\Sigma i}$ – heat transfer resistance of homogeneous sections, m^2K/W, with the area F_i
k_j – linear coefficient of heat transfer, W/(mK) at the joint's length L_i
ψ_k – point coefficient of heat transfer, W/K, number of mountings N_k

$$R_{\Sigma np} \geq R_{q\ min}$$

Figure 2. Calculation of the reduced heat transfer resistance of the multilayer building envelope structure

Energy efficiency calculations of a building are completed with the development of an energy passport - a document that contains the geometric, energy, and thermotechnical characteristics of the designed or operated buildings, their thermal insulation envelopes and determines their compliance with regulatory documents [4].

B. Design methodology for energy efficient buildings

The building is considered as an integrated energy system consisting of independent subsystems:

• the external climate as a source of energy and an object that the building must be protected from;

• the building, as a complex of engineering subsystems, interconnected with energy.

The operations research comprises: the construction of a mathematical model of forming the thermal regime of premises; the choice of the objective function that sets the conditions for the constraint and the formulation of the optimization problem; the solution of the optimization problem set. The method of determining heat consumption [5] are the following methods: seasonal or monthly, simplified hourly, and the method of detailed modeling. The method of calculation of energy consumption for heating, cooling, ventilation, lighting and hot water supply is given in Ukraine's National Code [6]. Method of calculating energy consumption for heating, cooling, ventilation, lighting and hot water. The sequence chart of calculating the energy consumption: 1) determination of boundaries of the conditioned and non-conditioned volumes and (if applicable) the division of the building into the calculation zones; 2) determination of the input values of the building thermal insulation, the conditions of the internal and external environment, the model of employment (work) and engineering systems for each zone; 3) calculation of heat transfer by transmission and ventilation for each zone of the building and every month of the year; 4) calculation of internal and solar heat inflows for each zone of the building and every month of the year; 5) calculation of energy consumption for heating, cooling, ventilation and hot water (DHW) for each zone of the building and every month of the year; 6)

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calculation of additional energy, heat losses of the systems of allocation, distribution and generation of energy for each zone of the building and every month of the year; 7) calculation of energy consumption for heating, cooling, ventilation, DHW and lighting for each zone of the building and every month of the year; 8) summarizing the results of energy consumption for the whole building for the year; 9) drafting the report for the building.

To determine the energy efficiency class of the building, the specific annual energy demand for heating, cooling and DHW is calculated according to the formula as follows:

$$EP = (Q_{H,\mathrm{nd}} + Q_{C,\mathrm{nd}} + Q_{DHW,\mathrm{nd}})/\ A_f,\ (\text{or } V) \quad (4)$$

where $Q_{H,\mathrm{nd}}$, $Q_{C,\mathrm{nd}}$ and $Q_{DHW,\mathrm{nd}}$ – annual energy consumption of the building for heating, cooling and hot water supply, respectively, kW • h, determined in accordance with Ukraine's National Code [6];

A_f, V – air-conditioned (heated) living space, m^2, or air-conditioned volume for a public building (or its part), m^3, determined in accordance with Ukraine's National Code [5].

In accordance with Table 2 the regulatory maximum specific energy requirement for the operation of the building is defined. The energy efficiency class of a building by specific energy consumption (Table 3) is determined by the difference of the calculated or actual value of the specific energy consumption of the EP and the maximum permissible value EP_{max} in percents according to the formula $[(EP – EP_{\max})/EP_{\max}]\cdot 100\%$.

Table 3: Classification of buildings according to energy efficiency

Building energy efficiency classes according to the specific energy use	Difference in % of estimated or actual value of specific energy consumption, *ER*, and the maximum admissible value, EP_{max},$[(EP - EP_{\max})/EP_{\max}]\cdot 100\%$
A	Minus 50 or less
B	From minus 49 to minus 10
C	From minus 9 to 0
D	From 1 to 25
E	From 26 to 50
F	From 51 to 75
G	76 and more

The energy efficiency class of a building according to the requirements of Ukraine's National Building Code [1] shall not be lower than "C". If this condition is not complied, it is necessary to provide for the measures to reduce the level of energy costs in terms of the energy efficiency of the building – to modernize the thermal insulation envelope and/or technical systems of the building.

According to the method of calculating energy efficiency in accordance with the Law of Ukraine on the Energy Efficiency of Buildings, it is proposed to determine the energy efficiency class by the indicator of energy consumption. Therefore, in formula (4), instead of Q_{nd}, Q_{USE} values are taken into account, which are calculated according to Ukraine's National Code [6]. The classification of buildings proposed by this method requires further clarification related to the building surface and the consideration of temperature zones of Ukraine, which are not considered in this paper.

Currently in the construction practice of Ukraine, the minimization of construction costs is a decisive factor in the customer/investor approval of the design solution of the buildings thermal insulation envelope. However, in order to maximize material resource efficiency, it is necessary to estimate the costs of the entire life cycle of the construction site. The optimization o the building life cycle should play a key role in the decision-making process since it involves an economic analysis of the construction associated costs, operation and maintenance of the construction site. The greatest effect of using the life cycle cost can be obtained at the design stage of buildings.

In the construction industry, the capital costs for construction are almost always separated from the maintenance costs. Costs for the life cycle of a building and structure and its completion are rarely considered during the design stage. The practice is to reconcile the lowest capital costs for construction and to separate the technical operation costs of the building. The typology of buildings is very diverse. Buildings and their structures have the requirements of reliability, constructive and fire safety, the required level of sanitary and hygienic features and energy conservation, taking into account the influence of the natural and climatic conditions of the area, the choice of structures that correspond to the level of their capital characteristics, cost-effectiveness of construction and operation, etc. Therefore, when designing building envelope structures it is necessary to constantly address the problems of multicriteria optimization [7].

Due to the wide nomenclature of insulating materials with different technical and cost-effective parameters, there is a need to clarify the relevant requirements that do not regulate the choice of specific types of layers, which may consist of optimal systems of envelope structures of the external walls and building coatings and taking into account the cost of their complete life cycle while ensuring the energy efficiency of the object. External walls are a complex, costly, and heavy-duty part of a building, they contribute to its durability and performance features, protection of the internal environment from external influences [8], [9]. By static function in the building system, they can be: load-bearing walls, which receive vertical loads from their own weight, wind, cover structures, slabs, stairs and transfer them through the groundwork onto the soil foundations; self-supporting walls, which receive the load only from their own weight of all the floors above the building and transfer them through their own foundations to the soil bases; non-load-bearing half-timbered walls, which receive the loads of self-weight within one floor and transfer them to horizontal load-bearing building structures (frame crossbars or floor slabs); hinged walls that receive self-weight loads within one floor or its part and transfer them to vertical load-bearing buildings structures (columns or frame crossbars, interior walls, slabs, bulk blocks) at install locations. According to the material, the walls are divided into those made of different types of stones; reinforced concrete; wooden; complex multilayered.

According to the method of construction, the walls are divided into: hand-built of natural or artificial stones, joined by mortar; monolithic walls made on the construction site of various types of concrete and reinforcement; precast walls which are mounted on large concrete blocks, reinforced concrete or sandwich panels and other precast structures.

The requirements for the external walls strength are contrary to the requirements of energy conservation – the materials that have high strength tend to have a high density and therefore a low resistance to heat transfer. Therefore, in modern constructioni to provide the minimum allowable resistance to heat transfer, the external walls are designed as multilayer ones, they have a load-bearing, a thermal insulation and an external protective layers. It is not expedient to use single-layer load-bearing exterior walls – their thickness should be irrationally large to provide a normalized thermal insulation of premises, for example, silicate bricks of more than 1.5 m. The solution to the problem of energy efficiency is the design of the multi-layered exterior walls of buildings, which separate the supporting and envelope structural elements, and to use the external non-load-bearing timber or hinged walls with load transfer to slabs, carcass columns, or transverse walls.

In modern construction industry, the load-bearing and self-supporting multilayered walls are designed with an inner bearing layer of cement-sand mortar, precast or monolithic reinforced concrete, the thickness of which is taken as a result of the calculation of strength and durability. The facades provide a thermal insulation layer of effective insulation, securely connected to the carrier, which is equipped with decorative plaster or industrial elements with a ventilated air layer. The thickness and density of the thermal insulation layer is determined by the calculation of the heat transfer resistance. Taking into account the climatic characteristics of all regions of Ukraine, when designing the building envelope structures [8], [9], [10], the facade thermal insulation of the exterior walls – the placement of the insulation on the facades (Fig. 3) has proven its best. Covering (roofing structure) is the upper structural element intended to protect the building premises from external climatic factors and influences, which performs a complex of load-bearing and enclosing functions (waterproofing and thermal insulation). The roof covering is an element of a roofing structure (roof) that protects a building from the penetration of precipitation into it. Designing of building roof covering is performed in accordance with Ukraine's National Building Code [11]. Covering of buildings and structures. The use of effective systems of thermal and waterproofing coverings can significantly reduce the energy consumption for buildings' heating.

The load-bearing structural elements of the coverings are reinforced concrete slabs or core elements, and the enveloping elements are the waterproofing and thermal insulation layers [10], [12].

In the construction of the covering the following basic layers are most frequently used: 1) protective – the roofing material, to which powder or geotextile is applied and ballast is put on top. Geotextile is a fabric made by a hydro-bonded process of polypropylene or polyester threads; 2) waterproofing – insulates the inner layers of the roof from the penetration of atmospheric moisture; 3) thermal insulation – provides a stable air temperature in the premises; 4) steam insulation – prevents the penetration of water vapor from inside the building into the roof structure; 5) the load-bearing foundation under the roof – plates, beams with filling, core elements, etc.

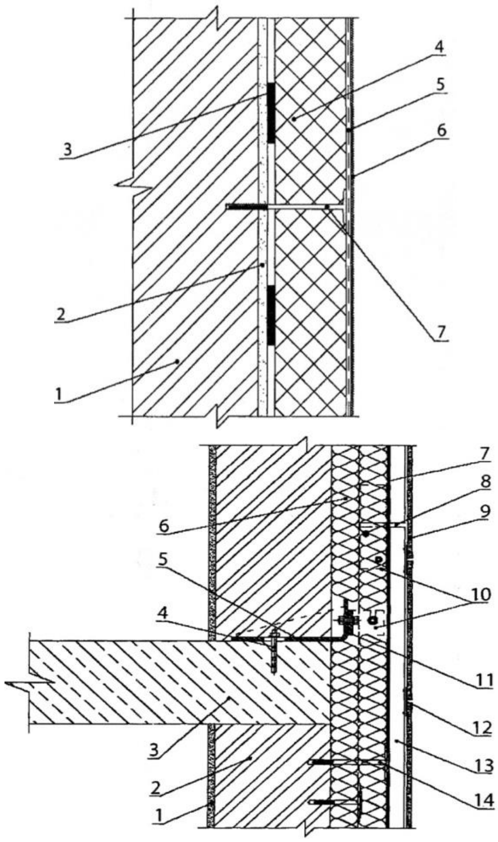

Figure 3. Constructive systems of external walls with façade thermal insulation: a – finished with light thin-layer plasters; 1 - load-bearing wall; 2 - plaster layer; 3 - adhesive coating; 4 - insulant; 5 - protective layer reinforced with fiberglass; 6 - finishing cover; 7 - element of mechanical fastening of the insulation; b - with ventilated air layer and riser fastening of external equipment with industrial elements; 1 - internal plaster; 2 - half-timbered or load-bearing wall; 3 - floor slab; 4 - wedge anchor; 5 - bracket; 6 - insulant; 7 - airtight film; 8 - air ventilated layer; 9 - industrial facing elements (ceramic tiles); 10 - connecting elements; 11 - gasket; 12 - stapler; 13 - riser; 14 - element of mechanical insulation fastening.

III. RESULTS AND DISCUSSION

According to structural solutions, the coverings are divided into: 1) trusses (frame), which are constructed with significant slopes of linear elements that form the attic; 2) reinforced concrete combined slabs, in which thermal insulation and waterproofing layers are arranged directly on the floor of the upper floor; sometimes such coverings are used to accommodate people's equipment or for their leisure – the operated and green roofs; 3) reinforced concrete partition slabs, in which a ventilated space or an attic that can be used to house engineering equipment is available between the floor slabs of the upper floor and the cover structures; 4) lofts, in which the attic space is designed for people to stay or to live.

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Industrial coverings in the mass construction of Ukraine are built mainly of reinforced concrete structures as combined flat ones (with a slope up to 15°) or with attics. In terms of temperature and humidity, the interior space of the attic coverings may be:

• cold – thermal insulation is arranged on the slab of the upper floor;

• warm – heat insulation layers are arranged on the attic floor, with waterproofing layers stacked on top or under the insulation. The last option, which provides a better protection of waterproofing layers, is referred to as an inversive one.

Building coverings are classified as follows: by volume-planning solutions – the attic coverings (with attic space) or non-attic coverings; by geometric shape and drainage conditions – the sloped and flat ones; by insulation – the cold, warm, or combined ones. In buildings over 18 m high, according to the requirements of Ukraine's National Building Code [11], the internal water drainage is planned with the flat covering design. In the framework of dense urban development and high-rise restrictions, multi-storey non-residential buildings are most commonly used with flat combined coverings. For multi-storey residential buildings according to the requirements of the Ukraine's National Building Code [13] it is recommended to design the attic flat. Atticless combined and operated coatings are designed in multi-storey residential buildings that are individually designed because modern roofing systems that utilize efficient materials and technologies make it possible to create sealed, energy-efficient and reliable structural solutions for various types of coverings [14].

Thus, while designing the building envelope structures of energy-efficient buildings it is necessary to solve multi-criteria problems taking into account technological, economic, operational and environmental requirements depending on the following: the type of functional purpose of the building; construction and structural system of the building; loads and impacts on the structure; the type of load-bearing walling or covering structure; the placement sequence and arrangement technology of the main load-bearing and protective layers of the structure; the cost of materials, assembly, operation, and their utilization (life cycle).

The best world practices show that taking into consideration the life-cycle costing when designing the thermal insulation of buildings boosts their investment attractiveness, enables to predict and accurately estimate the cost effectiveness of the construction. Calculating the life cycle cost of building envelope structures is one of the main forms of decisions effectiveness analysis performed according to [13] (Figures 4, 5). The building's energy efficiency and life-cycle requirements are also used in the Leadership in Energy and Environmental Design (LEED) – a voluntary certification developed by the US Green Building Council. Designers, engineers, builders, building owners, management companies, using modern approaches to design, taking into consideration the natural and infrastructural features of construction sites and end-users' needs, create high-quality, durable, energy-efficient and attractive construction objects.

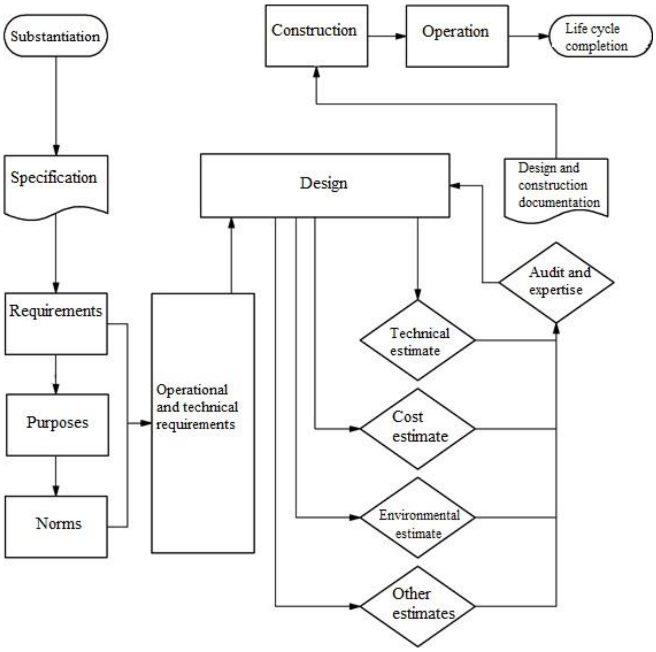

Figure 4. Operational and technical requirements in the framework of the life-cycle of designing the thermal insulation building envelope

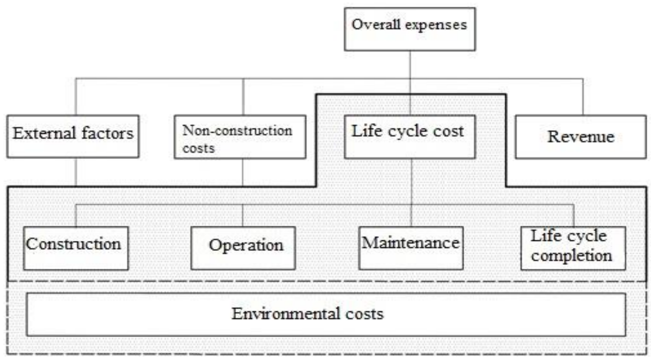

Figure 5. Costing elements of general and life cycles of thermal insulation envelope

However, the problem of choosing the optimal solution of the of the building thermal insulation envelope structures in the practice of Ukrainian design, taking into account the above life-cycle criteria, is usually not considered, and the options approval is based on the ordinal choice (a specific technical task based on the customer's previous experience, experience in the subject of the customer; his vision of the problem, involvement in the result, personal qualities, external motivation, impact of other experts' opinions, influence of responsibility for the use of expert evaluation, etc.). The general chart of decision-making in the design of building envelope structures can be described as follows (Fig. 6). Each block 1-5 of the chart needs to be specified and formalized. The task with a given set of alternatives and a principle of optimality is a general optimization problem the content of which is to identify the array of the best alternatives. Provided that the principle of optimality is given by a set of criterial functions, it is necessary to solve the problem of multicriteria optimization [15].

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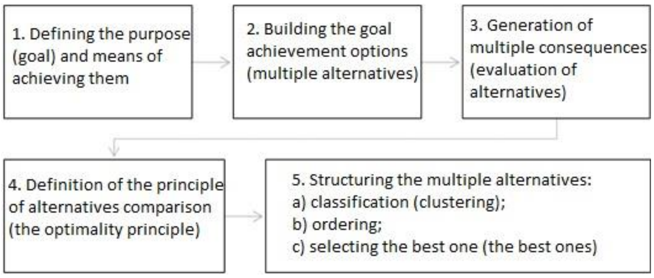

Figure 6. The general scheme of decision-making in the design of building envelope structures

Thus, the analysis of options when choosing the optimal design solution for the building envelope thermal insulation entails the task of multicriteria evaluation of alternatives. According to the classification of system analysis, all choice problems are divided into classes [14]:

• well-structured or quantitavely formulated problems in which significant dependencies are identified very well;

• unstructured or qualitatively formulated problems containing only a description of the most important resources, features and characteristics, quantitative relationships between which are unknown;

• ill-structured or mixed issues that contain both quantitative and qualitative, not fully understood indicators.

Given that the design of envelope structures of different building types is a complex process, containing both qualitative and quantitative components, the task of choosing the optimal design solutions for energy-efficient exterior walls and coverings of buildings can be attributed to poorly structured selection problems.

The most common are two groups of methods for choosing rational solutions for envelope structures: the ordinal and the cardinal ones.

The group of ordinal selection method performs the ordering of *n*-variations done by an expert team. A group score arises from their individual estimates [16], [17]. The Delphi method is usually used to obtain expert estimates with an acceptable level of accuracy – the procedure for obtaining expert opinions by conducting repeated interviews with a group of specialists. The method of expert estimates is, in fact, a universal one in relation to the solution of multicriteria selection problems, however, it actually works only with external aspects of decision-making, without touching on the procedural part of the problem.

The second group of cardinal selection methods is based on the criterial evaluation of alternatives. The classification of the selection criteria is shown in Fig. 7 [11].

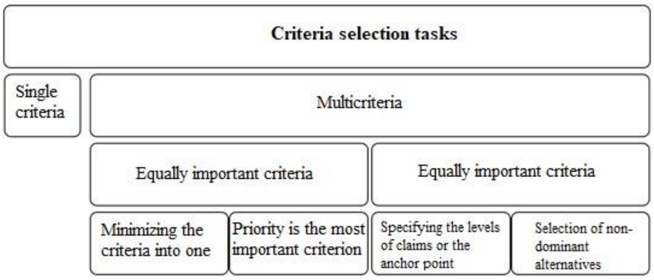

Figure 7. Classification of selection criteria

IV. CONCLUSIONS AND PROSPECTS OF FURTHER RESEARCH

Thus, the tasks of choosing optimal solutions for enclosing structures of external walls and building coatings at the designing stage of the building are are determined as the problems of multicriteria cardinal choice of alternatives with different important measures from a finite set of feasible solutions when considering a weakly structured problem with clearly defined separated parameters. It is advisable to use thermal insulating building envelope utilizing modern insulation systems [12] in all types of buildings.

The key parameters and limitations of energy efficient external walls of buildings are: 1) type of static work: a load-bearing, a self-supporting, a non-load-bearing timber or a hinged one; 2) type of bearing base of the material: a stone, a brick, a reinforced concrete, a wooden, a multilayered complex one; 3) type of construction method: a stone-built, a monolithic reinforced concrete, a precast concrete block, a reinforced concrete or sandwich panel; 4) the location of the insulation: front, inside the wall, from the part of the premises; 5) type of finishing equipment: thin or thick-plaster, brick or wall stones, with ventilated air layer and equipment with industrial elements or translucent facade; 6) fire safety requirements: REI fire resistance, flame spread M; group D of materials combustibility; 7) technological requirements: location of the building (taking into account the regionality of the materials used and their components), seasonal feature of the works; 8) life cycle cost.

Prospects for further research are thermal insulation building coatings utilizing modern insulation systems.

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