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ASSESSMENT OF THE VALIDITY OF INVESTING IN ENERGY-EFFICIENT SINGLE-FAMILY CONSTRUCTION IN POLAND - CASE STUDY

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The article raised issues related to the design and execution of low-energy objects in Polish conditions. Based on the designed single-family house, adapted to the requirements of the National Fund for Environmental Protection and Water Management ("NF40" standard), the tools to assist investment decisions by investors were shown. An economic analysis and a multi-criteria analysis were performed using AHP method which had provided an answer to the question whether it is worthwhile to bear higher investment costs in order to adjust to the standards of energy-efficient buildings that fulfil a minimal energy consumption's requirements contained in Polish law. In addition, the variant of object that had optimal characteristics due to the different preferences of investors was indicated. This paper includes analysis and observations on the attempts to unify that part of the building sector, which so far is considered to be personalized, and objects in accordance with the corresponding idea are designed as "custom-made".

Keywords: energy-efficient construction, NF40 standard, economic analysis, multi-criteria analysis, analytic hierarchy process, light wood-frame construction

1. INTRODUCTION

The systematically rising energy costs determine an increasingly grater load on the budget of buildings' users. We calculate what is more profitable: the incurrence of grater capital costs and reducing space heating operating, or building "traditionally", fulfilling only the basic legislature's requirements. Decision-making is becoming repeatedly difficult, requires also more and more

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knowledge. Technological progress creates new opportunities in construction, which is manifested not only in the development and implementation of new design solutions, but also more effective energy systems for buildings.

Depletion of non-renewable energy resources, as well as the need for greater care for the environment, necessitated the introduction of energy savings in the residential sector. An additional justification for the appropriateness of the topic taken is the connected with changes introduced in the Polish national law, in requirements of energy efficiency of construction, in response to adopted Directive 2010/31/EU, the so-called "Recast EPBD". This direction of policy after the year 2021 will lead to mandatory requirement for the design and execution of the objects, currently referred to as low-energy building (here: with nearly zero energy consumption).

The aim of the study is to assess the economic viability of investments in the energy-efficient single-family residential sector. In addition, the analysis is undertaken to indicate the answer to the question of whether previous technical knowledge and available materials allow building in a way that respects the principles of sustainable development under Polish conditions. This paper contains observations concerning the attempts of unification of energy-efficient construction under Polish conditions and establishment of general guidelines to comply with the requirements for each time a low energy buildings is in demand and to comply with the interests of investors.

2. METHODOLOGY OF ANALYSIS

The case study includes technical and economic analysis of two structural and materials' variants of the energy-saving building with reference to the variant of this facility fulfilling basic requirements for thermal insulation of building's partitions, included in the Polish legislation. Also the installations which have a direct impact on energy consumption in building are evaluated.

Economic evaluation of each variant has been made using global cost method. This method involves adding up the initial investment and the discounted annual operating costs during the period of computation. In the case of residential house, this period shall be 30 years.

In addition, popular economic indicators - simple and dynamic payback time on investment were used. The estimated operating costs for each variant associated with work of the heating and ventilation installations and hot water preparation systems, were designated on the basis of a draft drawn up the energy performance of the building. In a similar way, CO_2 emissions were also determined and included in the simplified environmental assessment.

The final stage of the evaluation of the variants was the multi-criteria analysis using Analytic Hierarchy Process, which took into account the technical, economic and socio-environmental aspects of the proposed investment. The simulation carried out with different weights listed aspects allows choosing the best option depending on the attitude of a potential investor to key parameters of the investment item.

3. DESCRIPTIONS OF BUILDING'S VARIANTS

The analyzed object was a detached family house with a usable area of less than 150 m^2 and designed for 5 people. It's located outside of the centre of Cracow, in the third climatic zone with computational external air temperature equal to -20°C.

The building was designed as a two-storey, without basement with partially reduced level of premises from the north, where the boiler-room, storage and garage (unheated room) were located. Due to the large glazing the building is open to the southern side, which allows using solar energy for space heating. All variants of the construction have the same architectural arrangement of spaces.

3.1. CONSTRUCTION VARIANTS

The essential elements which distinguish the individual variants of the house are the design and materials of structural partitions (Table 1 shows the summary of the most important of them). Structural partitions of the 1st variant are designed in such a way as to comply with the basic requirements contained in the text of the Decree of the Minister of Transport, Construction and Maritime Economy [32]. The 2nd and the 3rd variant's partitions have been designed in accordance with the requirements of the National Fund for Environmental Protection and Water Management (hereafter: NFEP&WM) for objects in NF40 standard [8].

In energy efficient variants despite a variety of design, partitions are designed to be comparable of heat transmissions. Moreover, treatments to minimise thermal bridges, such as extra insulation at the height of the ceiling and walls' connections or warm and tight fitting of windows and doors using consoles and steam-tight and steam-permeable tapes.

To illustrate the quality of the thermal enclosure of an object, the results of thermo-humidity analysis as heat conduction coefficients for external divisions, are presented in Table 2.

Table 1 . Summary of design solutions and materials of external building partitions in analysed variants

Element of the envelope	**1st variant**	**2nd variant**	**3rd variant**
	compatible with WT2014 [32]	compatible with NF40 standard	
Exterior walls' construction	built of porous ceramic bricks Porotherm 25 P+W	built of porous ceramic bricks Porotherm 25 P+W	lightweight timber frame stiffened from the outside by OSB-3 boards
Exterior wall's thermal insulation	polystyrene EPS 70-040 12 cm thickness	sheeting mineral wool 22 cm thickness	mineral wool 15 cm thickness and glass wool 15 cm thickness between construction
Foundation	concrete foundation benches	concrete foundation benches	slab foundations
Foundation's thermal insulation	polystyrene EPS 100-038 10 cm thickness	polystyrene EPS 100-038 20 cm thickness	polystyrene EPS 100-038 20 cm thickness
Ceiling	Teriva II	Teriva II	wooden beams stiffened by OSB boards
Roof's construction	100x200 mm rafters in spaced every 120 cm	100x200 mm rafters in spaced every 120 cm	50x200 mm rafters in spaced every 60 cm
Roof's thermal insulation	glass wool 20 cm thickness between the rafters	glass wool 20 cm thickness between the rafters and 20 cm thickness below	glass wool 20 cm thickness between the rafters and 20 cm thickness below

Table 2. Summary of heat transfer coefficients for external partitions for each variant [$W/(m^2 \cdot K)$]

Element of the building envelope	**1st variant**	**2nd variant**	**3rd variant**
Exterior wall	0,249	0,149	0,148
Wall between dwelling and garage	0,294	0,149	0,148
On the ground floor/base plate	0,299	0,152	0,153
The ceiling over a loft	0,198	0,118	0,118
The roof on wooden structure	0,198	0,118	0,118

The necessity to comply with the requirements for the thermal insulation of the two above-mentioned guidelines, in practice, comes down to the use of double-glazed windows and a standard door in the first variant and triple-glazed windows and doors with enhanced thermal insulation in the second and the third option. Table 3 lists the coefficients of heat transfer of used joinery.

Table 3. Heat transfer coefficients of windows and door in each type of variants [W/(m²· K)]

The type of joinery	The basic variant's solutions	The energy-saving variants' solutions
Windows, doors and unopenable transparent surfaces	1.2 to 1.25	0,9 to 0,95
Roof window	1.4	1.0
Exterior doors and the doors between heated and unheated rooms	1.4	1.3
Garage doors in unheated rooms	1.4	1.4

3.2. INSTALLATION VARIANTS

An integral part of the evaluated variants of object are two installation variants, respectively: fulfilling the basic requirements included in the Polish legislation and energy-efficient. In both cases, the installations having a direct impact on the energy intensity of the object were designed in a way that is adapted to their conditions of work and to eliminate the generation of additional costs associated with oversizing their constituent elements. Installations in the basic version have been adapted to the object to be analyzed in such a way as to meet the demand for primary energy requirements limit (from a year of 2014 equal to 120 kWh/(m^2· year)). Technical parameters and guidelines to design for the 2nd and 3rd variant were taken from the NFEP&WM's documentation of requirements for technical equipment of objects in NF40 standard [8]. Table 4 shows the main features and parameters of the above-mentioned installation.

Table 4. Overview of the most important components and parameters of the installation of heating, ventilation, and hot water preparation

Type of system	Installation of the basic variant	Installation of energy-efficient options
HEATING SYSTEM		
The heat source	pellet boiler + wood burning fireplaces with water jacket	gas condensing boiler + wood burning fireplace with water jacket
Type of heat exchangers	plate heaters, 75/55/20 °C	under-floor heating, 55/45/20 °C
VENTILATION SYSTEM		
Type of ventilation	controlled ventilation with heat recovery	controlled ventilation with heat recovery
Thermal efficiency of heat recovery	up to 75%	up to 95%
DOMESTIC HOT WATER PREPARATION SYSTEM		
The heat source	flow-through electric heaters	gas condensing boiler + system of flat solar panels
Accumulation tank	-	bivalent, 300 dm^3 volume

4. THE BUILDING ENERGY BALANCE EVALUATION'S RESULTS

Following the adoption of the assumptionsregardging the future facility usage as intended hot water consumption, the climate zone which the object will be located in or internal temperature of the heating, a building's energy performance for each of the variants were calculated. The results of the analyses are determining the demand for usable, final and primary energy (respectively: EU, EK, EP indicators) for energy installations work (see: Table 5).

Table 5 . The building energy balance evaluation's results with highlighting of key parameters due to design requirements [kWh/(m^2·year)]

Type of system parameter	1st variant	2nd variant	3rd variant
Heating and ventilating	52,43	15,36	12,02
Preparation of hot water	21,74	21,74	19,76
The EU indicator	**74,17**	**37,10** (-50,0%)	**32,78** (-55,8%)
The EK indicator	**100,29**	**60,18** (-40,0%)	**52,63** (-47,5%)
The EP indicator	**119,51**	**43,23** (-63,8%)	**44,58** (-62,7%)

Highlighted value of the usable energy demand associated with the provision of appropriate thermal-humidity and ventilation conditions for the 2nd and the 3rd variant, respectively at 15,36 and 12,02 kWh/(m^2· year), attest to the fulfilment of the requirements for the NF40 standard objects. The limit value of usable energy in this case is equal to 40 kWh/(m^2·year). Moreover, designated value of EP indicator confirms, that the mandatory requirement to limit the final energy consumption for residential buildings are met in each of the analysed variants [32]. The undertaken analysis also provides information which allows drawing conclusions about the conditions of the internal climate of the object at the stage of the operation of the building. Nearly twice the lower heat capacity of lightweight partitions in the 3rd variants' object in relation to the 1st and the 2nd variant afford a much lower thermal inertia of the object, and also to the larger dynamics of temperature change in this object. In practice, this allows for easier control of the internal thermal conditions, but during the summer can easily lead to overheating of the premises with large glazing. To eliminate this unwanted phenomenon from the southern façade and roof glazing larger canopies, blinds or shutters are installed or more advanced solutions are used, as internal cladding containing phase-change materials or construction of the massive walls of the room. These treatments allow reducing the energy consumption of air conditioning systems and refrigeration. Yet it is worth to refer to construction resources that we have and what we are going to have as a society [4].

Fig. 1 shows the background for assessment results obtained proposed energy alternatives and expected effects of limitations of energy consumption. Energy-efficient houses consume nearly twice less energy in relation to typical newly built or upgraded objects in order to meet the current standards and legislation. The further part of the paper will show how this effect is reflected in operating costs of these facilities.

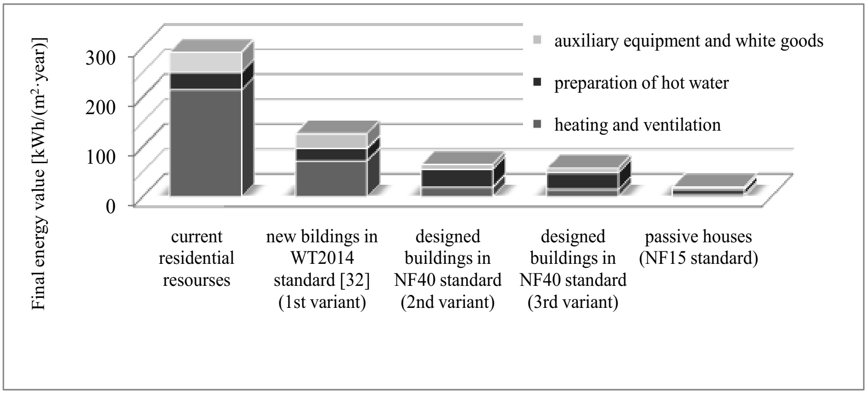

Fig. 1. The final energy requirement analysed against the background of the variants of existing housing stock and passive objects (own development on the basis of [4])

On the basis of the data relating to the indicators of CO_2 emissions volume [9], related to the processing of different types of energy sources and the volume of demand for the various types of energy, it is possible to estimate the degree of reduction of the environmental load associated with improving the systems to be equipped with the proposed variants. This allowed analyzing the investment objectives under an additional aspect associated with protecting the environment, which is described in Fig. 2.

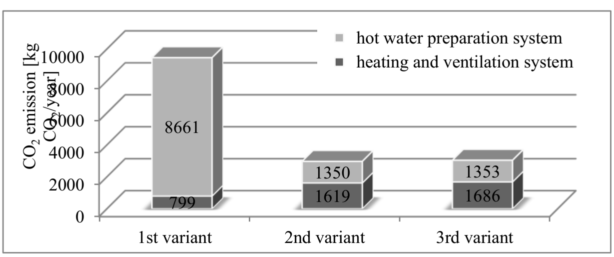

Fig. 2. The annual emissions of CO_2 during operation of objects [kg CO_2/year]

5. THE EVALUATION OF ECONOMIC VENTURES OF INVESTMENT

5.1. INVESTMENT COSTS

Important and often decisive factors in making investment decisions are the initial costs related to the implementation of the project. In this case, additional financial costs associated with the adjustment proposed object to energy-efficient standards will be calculated. The calculation results of the costs related to the elements influencing the energy consumption of a building and the total investment costs will be used to assess the economic viability of the planned investment in the housing sector with reduced power consumption.

On the basis of the average prices of materials, labour and equipment used for work in 2014, gross investment costs, taking into account the 8% of VAT was designated. To prepare an estimate of investment cost NORMA PRO - Educational Version 4.45 was used. Bill of quantities and costs associated with heating system was made automatically based on installation projects in the Kan SDG 2.1. The cost of mechanical ventilation with heat recovery has been determined on the basis of individual calculation by several companies involved in assembling and adjusting this type of installation. Table 6 shows the results of calculations for items of investment and execution.

Table 6. Comparison of gross investment costs of items directly affecting on energy consumption and the total investment costs among all the variants [PLN]

Investment item	1st variant	2nd variant	3rd variant
Heating and ventilation system	63 721,02	67 128,54	67 628,58
Hot water preparation system	2 106,57	17 596,82	17 096,78
Windows and doors	23 146,97	38 097,16	36 874,47
Building envelope	240 411,77	263 736,04	267 378,53
The sum from above	**329 386,33**	**386 558,57** (+ 17.4%)	**388 978,36** (+ 18.1%)
Total investment costs	**370 071,98**	**427 088,88** (+ 15.4%)	**429 670,83** (+ 16.1%)

5.2. OPERATING COSTS

The results of the assessment of energy facilities in the form of final energy indicators for individual systems, allowed estimating the expected operating costs of analyzed objects per year (Table 7). For this purpose, the real unit prices for each type of energy and electricity used in each system were taken into account. In addition, operating costs are included in the fixed monthly subscription fees for electricity and natural gas. The unit prices of energy and energy carriers for individual customers come from price lists of distributors operating in the southern Poland.

Table 7. Comparison of the estimated annual gross operating costs for the variants [PLN/year]

Type of system	**1st variant**	**2nd variant**	**3rd variant**
heating and ventilating	1 959,2	474,4	546,1
preparation of hot water	1 749,7	697,4	698,4
auxiliary equipment	413,4	411,0	443,5
The sum from above	**4 122,3**	**1 519,3** (-63,1%)	**1 623,5** (-60,6%)

5.3. ECONOMIC EVALUATION OF PROJECTS

Each investment process focused on generating economic profits should be subject to a thorough analysis. This is particularly important in the case of investment processes, which the subject of investment profits is distributed over a large period of time, such as, inter alia, in the construction industry. An economic analysis provides information which determines whether the project is cost effective and if the proposed solutions are commercially viable.

In the current practice we can find many examples of use of the economic analysis as making investment decisions' support [13, 16, 26, 27]. In this paper to assess and evaluate the effectiveness of proposed investments, indicators such as simple and dynamic payback time of additional expenditure on investment (SPBT and DPBT) as well as the net present value (NPV) were used. To determine value of the two first indicators, evaluation of the effectiveness of investments involved additional initial costs associated with the adaptation the 1st variant, in accordance with the basic requirements of the WT2014 [32], to requirements placed energy-saving objects in the NF40 standard (the 2nd and the 3rd variant). Analyzed cash flows within a given time interval are differences in operating costs calculated analogously to the way described above, set out in section 5.2 (treated as profits). DPBT indicator differs from the indicator of SPBT that the calculations adopt a model based on the time value of money. Calculation model requires in this case, taking into account additional information such as estimated increase in the price of energy sources i.e. gas - 4.8%/year, wood/pellet - 3.6%/year and electricity - 3.8%/year [7], and the inflation rate at the level of the long-term objectives of 2,5%.

Cost flow analysis (NPV) for each variant was carried out separately under the assumption that initial costs as well as operating costs distributed over time, discounted at the moment of carrying out of calculations, are negative flows (expenditures). Therefore, the best option will have the greatest rate of NPV (Table 9). The calculation has only taken into the account costs associated with items that have a direct impact on the energy consumption of the objects.

Table 8. The value of a simple and dynamic payback time of additional initial costs for individual items of energy-saving investments in relation to the basic variant [years]

Investment item	**SPBT**		**DPBT**	
	2st to 1st variant	3rd to 1st variant	2st to 1st variant	3rd to 1st variant
Plane solar collectors	11.8	11.8	10.8	10.8
Preparing hot water system	14.7	14.3	13.2	12.8
Heating and ventilation system with external partitions	26.9	30,8	22.4	25.2
Total investment cost	22.0 (14.3)	23.8 (15.8)	18.9 (12.9)	20.3 (14.1)

Table 9. The value of NPV for the 30-year life time of the objects in accordance with the proposed variants [thousand PLN]

Indicator	**1st variant**	**2nd variant**	**3rd variant**
NPV_{30}	-486,7	-444,6 (-424,6)	-451,0 (-431,0)
Difference to the 1st variant	-	-8.7% (-12.8%)	-7,3% (-11.4%)

In the two above tables data contained in brackets relate to the calculation, taking into account the payments from the funds of NFEP&WM to complying with the requirements of the NF40 standard. The real amount of subsidies, taking into account of interest rates on necessary loan, the cost of obtaining the loan and the required income tax, is reduced from 30 thousand PLN gross to less than 20 thousand PLN [28]. This amount does not cover all additional expenditures to adapt objects to set of higher standards of energy efficiency, but positively affects economic ratings. In practice, this can be an additional argument to convince undecided investors.

The most viable part of the whole investment was the purchase of solar panels which are an additional source of renewable energy. These investments, despite the considerable investment costs, are characterized by short payback time, nearly equal to the half of the estimated life time of the installation. Such solutions are determined in the literature [26] as a technically and economically feasible. However, it should be noted that working conditions have been created for the purpose of giving the minimum values of DPBT and SPBT indicators and in the case of cost-effectiveness evaluation purchase and operation cost of a solar panel in a basic solution uses energy with the highest unit price. In all other cases that use a cheaper source of the energy in reference variant, mentioned-above indicators will grow and the profitability of investments decrease.

6. MULTI-CRITERIA ANALYSIS USING AHP METHOD

A multitude of factors to be taken into account when decisions are made, forces investors to make use of the analytical tools that are able to include inter alia, irrational or qualitative parameters which numerical values are difficult or impossible to determine [19, 20]. One of the most widely used solutions to this problem is multi-criteria analysis using the Analytic Hierarchy Process, enabling the decomposition of the complex decision making and the creation of the final ranking for a finite set of variants [17, 18]. For the analysis of the problem a hierarchical structure of decision-making (Figure 3) was created by a selection of evaluation criteria, important from the investor's point of view, grouped into three categories.

The first step of the analysis contains an assessment of the variants within each category of criteria taking into account the designated weight of criteria (Table 10). In the next step, the simulation was made on the assumption different sets of weights for three categories of criteria to the representation of the various preferences of investors (Table 11).

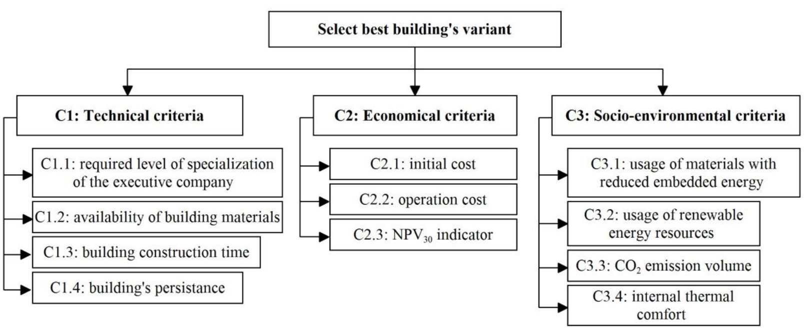

Fig. 3. A hierarchical structure for the multi-criteria analysis

This multi-criteria analysis was based on the expertise gained during interviews conducted among architects, representatives of companies and individual investors. In situations that make up the contradictions in the assessment, experience and knowledge of the authors of this study were used.

Evaluation of variants in relation to the three categories of criteria (Table 10), did clarify which of the variants is the best. The answer to this question was provided by the second step of the analysis (Table 11) - in 8 out of 9 cases the highest rating in the analysis of multi-criteria acquired the 2nd variant.

This option, although it has deteriorated in the assessment missed features in relation to the other options, for this situation is optimal according to general investors preferences. Second place in the analysis acquired the 3rd variant, confirming that the analyzed cases of buildings with reduced energy consumption have a raison d ' être.

Table 10. Evaluation of variants in relation to the sub-criteria and in relation to each category of criteria

The sub-criteria	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**3.3**	**3.4**
The weight of the sub-criteria	0,199	0.094	0,427	0,281	0.094	0,627	0,280	0.138	0,373	0,184	0,305
1st variant	0,726	0,545	0,472	0,285	0,683	0,072	0,167	0,101	0,111	0,091	0,099
2nd variant	0,172	0,273	0,402	0,498	0.200	0,491	0,500	0.226	0,444	0,469	0,527
3rd variant	0,102	0,182	0,126	0,217	0,117	0,438	0,333	0,674	0,444	0,440	0,374
1st variant	0,477				0,155			0,102			
2nd variant	0,371				0,466			0,444			
3rd variant	0,152				0,378			0,454			

Table 11. The results of the multi-criteria analysis of the variants in the simulation of different investors approaches in weights of the category criteria with detailing the optimal variants for each approach

Approach	**C1**	**C2**	**C3**	**1st variant**	**2nd variant**	**3rd variant**
#1	50%	30%	20%	0,305	**0,414**	0,280
#2	30%	50%	20%	0,241	**0,433**	0,326
#3	20%	30%	50%	0,193	**0,436**	0,371
#4	60%	20%	20%	0,338	**0,405**	0,258
#5	20%	60%	20%	0,209	**0,443**	0,348
#6	20%	20%	60%	0,188	**0,434**	0,378
#7	80%	10%	10%	**0,407**	0,388	0,205
#8	10%	80%	10%	0,182	**0,454**	0,363
#9	10%	10%	80%	0,145	**0,439**	0,416

7. CONCLUSIONS

Studies made it possible to ascertain that the designed energy-efficient house, together with the required installations in accordance with the 2nd and the 3rd variant; meet the given requirements at the design stage. It is therefore right to fill out postulates of main ideas contained in the NFEP&WM's guidelines [8]. Deliberate activity of the minimization of energy losses associated with various types of phenomena related to the building's physics and the maximization of the efficiency of installation systems, processing the energy supplied to the buildings at the stage of their operation, allows reducing the energy consumption of the proposed single-family houses by nearly a half. More efficient use of energy derived from non-renewable sources allows them for sustainable land use, as well as a significant reduction in carbon dioxide emissions into the atmosphere. In addition, the current technical knowledge provides benefits from additional sources of renewable energy in economical way, which in turn reduces operating costs related to the fulfilment of such tasks as the preparation of hot water. Before applying in practice, the recommendations of the program conducted by the NFEP&WM, it is worth noting that the presented guidelines necessary to meet the requirements of the objects in the NF40 standard, must lead to a kind of oversizing of the solutions for improving the energy consumption of buildings. These guidelines are likely to be the first such detailed and at the same time an attempt at unification that part of the building sector, which is still considered in each case on an individual basis. Achievement of the assumed, respectively, the low level of energy performance required in any case to carry out detailed analyses in specific climatic conditions for the planned location of the item, for a given project, often the individual geometry and at the individual manner of the use of the building. Such a state of affairs in the field of energy-efficient building led to the popularization of "custom-made" objects which each applied an element in bears the optimal solutions for the conditions. Such solutions are optimal in the assessment of the cost-effectiveness and additional investment in the whole object will be payback within several years.

The most reliable assessment of the economic analysis of investment efficiency allows declaring that the parsed variant of the light wooden structure is less cost-effective for a potential investor than a variant based on the massive structure. Without certain treatments, objects with such a structure does not allow for the full use of external and internal heat gains. When external partitions are well thermally insulated, these profits have a significant share of the energy used to ensure adequate climatic conditions inside the object. However, it should be pointed out that the solution using wood as the main building material allows to apply a total prefabrication of structure. This solution is in line with the principles of sustainable development, as significantly reduces energy built-in facility construction and minimizing waste causes difficult-to-land.

In general, the analysis undertaken show key issues and factors to be taken into account when making investment decisions, particularly in the construction sector, of which this work is concerned. In addition, this shows how important is it is to educate in this regard, all participants in the construction process, because there are many solutions, materials or equipment, which the use of in practice today doesn't have any economic justification. We hope, however, that popularization of the idea of energy efficiency, which slowly begins to find its reflection in the legal regulations, will in future lead to greater competitiveness on the market of goods used in low-energy consumption objects, and thus it become easier to erect objects with optimized energy potential.

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LIST OF FIGURES AND TABLES:

Tabela 8. Wartości wskaźników prostego i dynamicznego czasu zwrotu dodatkowych nakładów inwestycyjnych dla poszczególnych elementów inwestycji wariantów energooszczędnych w odniesieniu do wariantu podstawowego [lata]
Table 9. The value of NPV for the 30-year life time of the objects in accordance with the proposed variants [thousand PLN]
Tabela 9. Wartości wskaźnika NPV dla 30-letniego okresu eksploatacji obiektów zgodnych z projektowanymi wariantami [tys. PLN]
Table 10. Evaluation of variants in relation to the sub-criteria and in relation to each category of criteria
Tabela 10. Ocena wariantów względem poszczególnych kryteriów oraz względem poszczególnych kategorii kryteriów
Table 11. The results of the multi-criteria analysis of the variants in the simulation of different investors approaches in weights of the category criteria with detailing the optimal variants for each approach
Tabela 11. Wyniki analizy wielokryterialnej wariantów w symulacji różnych podejść inwestorów do wag kategorii kryteriów wraz z wyszczególnieniem wariantów optymalnych dla danego podejścia

OCENA ZASADNOŚCI INWESTOWANIA W ENERGOOSZCZĘDNE BUDOWNICTWO JEDNORODZINNE W POLSCE - ANALIZA PRZYPADKU

Słowa kluczowe: budownictwo energooszczędne, standard NF40, analiza ekonomiczna, analiza wielokryterialna, metoda AHP, lekkie budownictwo szkieletowe drewniane

STRESZCZENIE

W artykule poruszono tematykę związaną z projektowaniem i wykonawstwem obiektów niskoenergetycznych w warunkach polskich. Na przykładzie projektowanego domu jednorodzinnego, dostosowanego do wymogów Narodowego Funduszu Ochrony Środowiska i Gospodarki Wodnej (standard NF40), przedstawiono narzędzia wspomagające podejmowanie decyzji inwestycyjnych przez inwestorów. Wykonana analiza ekonomiczna oraz wielokryterialna metodą AHP pozwoliła odpowiedzieć na pytanie, czy warto ponosić większe koszty inwestycyjne na dostosowanie do standardów energooszczędnych obiektów pierwotnie spełniających jedynie w minimalny sposób polskie wymogi dotyczące energochłonności. Ponadto wskazano wariant projektowanego obiektu, który wykazywał cechy optymalne ze względu na różne preferencje inwestorów. Praca zawiera analizy i spostrzeżenia dotyczące prób unifikacji tej części budownictwa, która do tej pory uznawana jest za indywidualną, a obiekty zgodne z odpowiadającą mu ideą projektowane są "na miarę".

Studium przypadku obejmuje analizę techniczno-ekonomiczną dwóch wariantów konstrukcyjno-budowlanych jednorodzinnego budynku energooszczędnego, tj. o konstrukcji murowanej z ceramiki poryzowanej, posadowionego na ławach fundamentowych (wariant II) oraz o konstrukcji lekkiego szkieletu drewnianego, posadowionego na płycie fundamentowej (wariant III), w odniesieniu do wariantu tego obiektu spełniającego podstawowe wymagania zawarte w polskim prawodawstwie w zakresie izolacyjności przegród budowlanych (wariant I). Ocenie poddawane są również instalacje mające bezpośredni wpływ na energochłonność obiektu.

Integralną częścią ocenianych wariantów obiektu są dwa warianty instalacji – odpowiednio: spełniający podstawowe wymagania zawarte w polskim prawodawstwie i energooszczędny. W obu wypadkach instalacje mające bezpośredni wpływ na energochłonność obiektu zaprojektowane zostały w sposób dostosowany do warunków ich pracy i eliminujący generowanie dodatkowych kosztów związanych z przewymiarowaniem ich elementów składowych. Instalacje w wersji podstawowej zostały dostosowane do analizowanego obiektu w taki sposób, aby spełniał on graniczne wymagania zapotrzebowania na energię pierwotną (od 2014 r. jest to 120 kWh/(m^2·rok)).

Ocenę ekonomiczną wariantów obiektu budowlanego dokonano metodą kosztów globalnych. Metoda ta polega na sumowaniu początkowych nakładów inwestycyjnych oraz zdyskontowanych rocznych kosztów eksploatacyjnych w okresie obliczeniowym (w przypadku obiektów jednorodzinnych okres ten wynosi 30 lat). Ponadto posłużono się popularnymi wskaźnikami ekonomicznymi - prostym i dynamicznym czasem zwrotu inwestycji oraz wartością zaktualizowaną netto. Szacunkowe koszty eksploatacyjne dla każdego wariantu, związane z pracą instalacji ogrzewania i wentylacji oraz przygotowania ciepłej wody, zostały wyznaczone na podstawie sporządzonej projektowanej charakterystyki energetycznej budynku. W podobny sposób wyznaczono również wielkość emisji CO_2 uwzględnionej w uproszczonej ocenie środowiskowej wariantów.

Na podstawie sporządzonych projektowanych charakterystyk energetycznych stwierdzono, że na etapie projektowym zastosowanie wytycznych NFOŚiGW dla standardów NF40 pozwala na ponad 40%-ową redukcję wskaźników zapotrzebowania na energię końcową budynku w wariancie II i III w stosunku do wariantu I. Poprawienie jakości

i szczelności obudowy termicznej a także zmiana systemów grzewczych i wentylacyjnych oraz przygotowania ciepłej wody użytkowej wraz z zastosowaniem kolektorów słonecznych pozwoliło na teoretyczną redukcję rocznych kosztów eksploatacyjnych w wariantach energooszczędnych o ponad 60% w stosunku do wariantu referencyjnego. W tym zakresie jednak działania te wiążą się ze wzrostem kosztów inwestycyjnych o ponad 17%. Podstawę analiz stanowiły wyliczone koszty pomniejszone o realne wielkości dopłat do projektowanych wariantów budynku energooszczędnego, z programu prowadzonego przez NFOŚiGW.

Ostatnim etapem oceny wariantów była analiza wielokryterialna metodą AHP (ang. *Analytic Hierarchy Process*), w której uwzględniono aspekty techniczne, ekonomiczne i społeczno-środowiskowe projektowanej inwestycji, łącznie 11 kryteriów. Przeprowadzona w drugim kroku analizy symulacja opierająca się o różne zestawy wag istotności wymienionych aspektów pozwoliła na wybór najlepszego wariantu w zależności od nastawienia potencjalnego inwestora do czynników kształtujących kluczowe parametry przedmiotu inwestycji. Na każdym etapie analizy korzystano z wiedzy eksperckiej zgromadzonej podczas wywiadów przeprowadzonych wśród architektów, przedstawicieli firm wykonawczych oraz inwestorów indywidualnych, zaś w sytuacjach tworzących sprzeczności w ocenie posłużono się doświadczeniem i wiedzą autorów niniejszego opracowania.

Przeprowadzone analizy pozwoliły na stwierdzenie, że przedstawione projekty domu energooszczędnego wraz z wymaganymi instalacjami zgodnie z wariantem II i III, na etapie projektowym spełniają stawiane im wymagania. Racjonalne jest zatem zrealizowanie postulatów i głównych idei zawartych w wytycznych NFOŚiGW. Celowe działania polegające na minimalizacji strat energii towarzyszących różnego typu zjawiskom związanym z fizyką budowli oraz maksymalizacji sprawności instalacji przetwarzających energię dostarczaną do obiektów budowlanych na etapie ich eksploatacji, pozwoliło na obniżenie energochłonności projektowanych domów jednorodzinnych o blisko połowę. Sprawniejsze wykorzystywanie energii pochodzącej ze źródeł nieodnawialnych pozwala na bardziej racjonalne zagospodarowanie jej oraz na znaczne ograniczenie emisji dwutlenku węgla do atmosfery.

Przed zastosowaniem w praktyce zaleceń programu prowadzonego przez NFOŚiGW warto mieć na uwadze, że przedstawione wytyczne konieczne do spełnienia wymogów stawianych obiektom w standardzie NF40, muszą prowadzić do swego rodzaju przewymiarowania zastosowanych rozwiązań w zakresie poprawy energochłonności budynków. Wytyczne te prawdopodobnie są pierwszymi tak szczegółowymi i zarazem stanowią próbę unifikacji tej części budownictwa, która nadal traktowana jest w każdym wypadku w sposób indywidualny. Osiągnięcie zakładanego, odpowiednio niskiego poziomu charakterystyki energetycznej wymaga w każdym wypadku przeprowadzenia szczegółowych analiz w specyficznych warunkach klimatycznych dla planowanej lokalizacji przedmiotu przedsięwzięcia, dla danej, często indywidualnej geometrii oraz przy indywidualnym sposobie użytkowania budynku. Taki stan rzeczy w sektorze budownictwa energooszczędnego doprowadził do popularyzacji obiektów „na miarę”, w których każde zastosowane rozwiązanie nosi znamiona rozwiązań optymalnych dla danych warunków. Takie też rozwiązania są optymalne w ocenie efektywności ekonomicznej, a dodatkowe nakłady inwestycyjne w skali całego obiektu zwracają się na przestrzeni kilkunastu lat.