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TECHNICAL-ECONOMIC RESEARCH FOR PASSIVE BUILDINGS FOUNDATION

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The Energy Performance of Buildings Directive (EPBD) per the 2010 directive of the European Parliament requires all new public buildings to become near-zero energy buildings by 2019 and will be extended to all new buildings by 2021. A passive house is something more than just an energy-saving house. This concept involves sustainable, high-quality, valuable, healthy and durable construction. Foundation is one of the most essential elements of a house. The type of foundation for a private house is selected considering many factors. The article examines technological and structural solutions for passive buildings foundation. The technical-economic comparison of the main structures of a passive house revealed that it is cheaper to install an adequately designed concrete slab foundation than to build strip or pile foundation and the floor separately. The comparison of the main envelope elements efficiency by multiple-criteria evaluation methods showed that it is economically feasible to install concrete slab on ground foundation.

Keywords: Passive house, Technological solutions, Multiple criteria evaluation.

1 INTRODUCTION

A passive house is not a new method of construction. It differs from ordinary houses by good thermal insulation, high-quality windows and heat regenerating ventilation system. All these features lead to the lower demand for thermal energy. The Energy Performance of Buildings Directive (EPBD 2010) requires all new public buildings to become near-zero energy buildings by 2019 and will be extended to all new buildings by 2021. A passive house becomes a standard for energy efficient buildings (nearly zero, plus energy). The problem in modelling a passive house occurs when investment into construction is estimated and the payback period for investment is calculated. The payback period depends on thermal energy price, which is difficult to forecast. Therefore, a house of lower energy efficiency class is a less risky investment for an individual builder (Audenaert and De Cleyn 2010).

This article examines technological and structural solutions for passive buildings foundation.

2 ALTERNATIVE SOLUTIONS FOR PASSIVE HOUSE STRUCTURES

2.1 Alternative Solutions for Foundation

Foundation is one of the most essential elements of a house. The type of foundation for a private house is selected considering many factors. The main factors are: type of the ground, ground water level, frost line in the region, presence or absence of the basement, type of bearing walls, architectural decisions, financial resources. To choose the correct foundation type for the house the builder must have the results of engineering and geological surveys, the final design of the building and calculations of loads.

2.1.1 *Strip foundation*

Strip foundation is made of assembled concrete blocks or monolithic concrete. It is built under the bearing walls and partitions. This method requires land excavation, concrete element assembling and concrete pouring work. Construction of strip foundation is not cheap, but it is the most appropriate foundation for a house with a basement.

Monolithic strip foundation provides a more rigid framework, but the installation is longer compared to the foundation made of assembled concrete blocks. Monolithic strip foundation is recommended when the house is built on expanding soil.

Strip foundation is recommended when the house walls are made of heavier materials, for more than one-story houses and it is not needed to build other type foundations (e.g., pile foundation), which is necessary while building a house on weak, expanding or watery soil. Strip foundation is generally selected due to simple construction method, regardless the longer time required to build it.

2.1.2 *Pile foundation*

Pile foundation distribute the load of the building via pile cap and sides, therefore the stress propagates across the big volume of soil. Pile foundations do not sink much and have a high load bearing capacity; thus, they are suitable for buildings that are sensitive to subsidence.

As the piles are driven deep into the ground, it is impossible to fully insulate the entire foundation. Thermal bridges occur at the pole and grade beam joints and they deteriorate the heat conservation capacity of the building.

2.1.3 *Monolithic slab*

A monolithic slab is a one-piece load bearing foundation structure. Concrete is poured into special polystyrene foam forms that completely isolate the foundation slab from direct contact with the soil. It is the single type of foundation where the load bearing monolithic slab has no contact with the soil and has the highest thermal resistance value. The thermal resistance value R of this foundation may be as high as 9.7 (R = 9.7 m^{2}K/W) and higher. Thus, thermal bridges, frost and foundation deformations are avoided. The monolithic slab bears the load of the building across the entire plane rather than individual segments. The monolithic slab has from 3 to 20 times bigger supporting area compared to conventional foundations. For this reason, it is less susceptible to movement, is firm and stable.

All traditional foundation structures create thermal bridges because there are no structural possibilities to avoid them. Monolithic slab is the only exception where the entire concrete slab can be thermally insulated at 100 %. A properly installed slab has no thermal bridges and the main advantage of this foundation is high thermal resistance and tightness.

Estimate calculations of strip, pile and monolithic slab foundations are done. A private two-story house is selected for the calculation. The calculated foundation area is 112 m^2. Labor, materials, machinery and total costs for foundation installation are calculated.

3 EVALUATION METHODS

Design solutions in construction can be evaluated by using different methods. According to the number of criteria they are divided into single-criteria and multiple-criteria evaluations. In single-criteria evaluation of construction design solutions construction costs of implementing alternative design solutions are calculated. The most effective alternative is selected according to this criterion (Juodis 2005). However, construction projects and processes are multifaceted, complex and complicated. For this reason, they are analyzed by means of multiple-criteria decision-making. Construction projects and processes are multifaceted, complex and complicated. For this reason, they are analyzed by means of multiple-criteria decision-making.

The following criteria were used in our case:

- Technical: structural reliability of the system, noise level, universality of the building, degree of construction process mechanization.
- Legal environmental issues, occupational safety.
- Economic: building site size, construction process duration, expenses productivity.
- Social: forms of labor organizations, motivation level.

In this paper two evaluation methods were chosen: cost-benefit analysis and COPRAS method. Structures of energy efficiency Class A house and passive house are compared. The main criteria for the evaluation of building structures are:

- Economic (construction price, length).
- Technological (complexity of technology, quality assurance level).
- Thermal parameters of the structures (thermal resistance, thermal bridges).

3.1 Cost Benefit Analysis

In this analysis, qualitative characteristics are measured by an expertise method while giving the scores in the grading scale 1 – 10. 10 is the best score. The criteria are not equally important, therefore the importance of one criterion with respect to another criterion is considered. All calculations and data are presented in a matrix table. The alternative with the highest cost-benefit value *N* is selected. This method enables one to compare the analyzed alternative in a simple and fast manner (Juodis 2005, Ginevicius and Podvezko 2008, Miniotaite 2016).

The first step is to select criteria for selected options. Criteria of economic, technological and thermal parameters were selected in order to evaluate different structures. Economic criteria include the cost of material, labor costs, cost of machinery and construction time. Technological criteria include the complexity of construction technology and quality assurance. Thermal parameters of the structures include the thermal resistance of a structure and elimination of thermal bridges.

The second step is to measure the weight (importance) of different criteria. In this paper, the best options of technical-economic solutions for a passive house and Class A house are analyzed, therefore the biggest significance is given to construction price and thermal parameters of the structures.

The third step is to find the utility values of different options and evaluated them by scoring from 1 to 10. Explanation of utility values (from 1 to 10).

The forth step is the calculation of efficiency values taking into consideration the criterion importance. Utility values of different options are multiplied by criterion importance in Eq. (1).

$$b_{ij} = q_i \cdot x_{ij} \ , \ \ i = \overline{1,m} \ ; \ \ i = \overline{1,n} \qquad (1)$$

where: x_{ij} is criterion i value for solution j; m is the number of criteria; n is the number of compared options; q_i is criteria significance.

In the fifth step efficiency values of different criteria for all options are summed up in Eq. (2):

$$N_j = \sum_{i=1}^{m} b_{ij} \ , \ \ i = \overline{1,m} \ ; \ i = \overline{1,n} \tag{2}$$

where: N_j is the efficiency value of the solution option.

The best option is selected in the sixth step. The best variant is found after comparing the efficiency values among the options. The option with the highest efficiency value is the best solution.

3.2 COPRAS Method

Goal setting, design and construction processes together with the final construction product and the subsequent operation process form one entity. When separate processes (solutions) of a project improve or deteriorate, the viability of the remaining solutions as well as stakeholders' satisfaction level change accordingly. Therefore, a precise evaluation and calculation of the effect of all changes on the eventual outcome is important. To this end a Complex Proportional Assessment (Miniotaite 2016) method is used. Meanwhile, the priority and significance of analyzed options directly and proportionately depends on the system of adequately describing criteria, criteria values and significant values. The criteria system is selected and criteria values as well as initial significance is calculated by experts. Stakeholders (contractor, users etc.) may modify all this information according to their goals and present circumstances. Therefore, evaluation of the options present in detail the initial data provided jointly by the experts and stakeholders. The priority and significance of analyzed alternatives is calculated in four steps.

(1) A normalized decision matrix D is drawn. The goal of this step is to obtain dimensionless (normalized) estimated values from the compared criteria. When normalized estimated values are known, all indicators measured in different units can be compared. The calculation is done by using the formula in Eq. (3):

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}} \ , \ \ i = \overline{1,m} \ ; \ i = \overline{1,n} \tag{3}$$

where: x_{ij} is criterion i value for solution j; m is the number of criteria; n is the number of compared options; q_i is criteria importance.

The sum of normalized estimated values j_i d of each criterion x_i is always equal to the importance q_i of that criterion in Eq. (4):

$$q_i = \sum_{j=1}^{n} d_{ij} \ , \ \ i = \overline{1,m} \ ; \ i = \overline{1,n} \tag{4}$$

The analyzed criterion importance value q_i is distributed proportionally to all alternatives a_j with respect to their values x_{ij}.

(2) The sums of normalized estimated minimizing (the lower value is better, e.g., Price) criteria S_{-j} and maximizing (the higher value is better, e.g., Quality) criteria S_{+j} that describe the alternative j the best is calculated from Eq. (5):

$$S_{+j} = \sum_{i=1}^{m} d_{+ij} \;;\; S_{-j} = \sum_{i=1}^{m} d_{-ij} \quad i = \overline{1,m} \;;\; i = \overline{1,n} \tag{5}$$

In this case S_{+j} and S_{-j} values express the level of achieving the goals of the stakeholders of each alternative project. In any case the sums of "pluses" and "minuses" of all alternative projects is always equal to the sums of all maximizing and minimizing criteria values.

(3) The relative significance (effectiveness) of compared options is found from their positive ("pluses" of the project) and negative ("minuses" of the project) characteristics. The relative significance Q_j of each variant a_j is found from Eq. (6):

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}} \;, \quad j = \overline{1,n} \tag{6}$$

(4) The evaluated options are prioritized. The higher is the Q_j value, the more effective the option is. The method allows to easily evaluate and then select the most feasible solution with a clear physical view of the process. A generalized (reduced) criterion Q_j directly and proportionally depends on the relative influence of the compared criteria values x_{ij} and importance q_i for the final result.

4 RESULTS AND DISCUSSION

The comparison of different foundation options revealed that strip foundation is the most feasible for houses with basements build on very good soil conditions. Drilled piles are currently the most common foundation type due to economy and fast installation. However, the biggest disadvantage of this foundation for a passive house is the unavoidable thermal bridge at the pole and grade beam joints. Thermal insulation of these spots is almost impossible and it is a doomed thermal bridge that should be avoided in a passive house.

A monolithic slab is the most appropriate foundation for passive houses due to its closed insulation circuit. Another advantage is suitability for different soil types. Besides, water supply and sewerage systems, power cables, heating system and subfloor, or sometimes even the normal floor, are installed together with the pile foundation. To this end very precise drawings of the house are required with all engineering and utility systems planned in advance. No significant changes of the house design are possible at later stages of construction. This disadvantage is eliminated by good planning and deliberations about the future use of the house. A monolithic slab becomes the most economic variant after the price of ground floor installation is added to the strip or pile foundations. It is 75 % cheaper than pile foundation with ground floor installation and twice cheaper than strip foundation with ground floor installation.

In the comparison of the efficiency among foundation options, the analyzed options of a passive house foundation structures are as following:

- F1P: strip foundation together with the first story floor;
- F2P: pile foundation together with the first story floor;
- F3P: concrete slab floor.

And the analyzed options of efficiency Class A house foundation structures are as following:

- F1: strip foundation with first story floor;
- F2: pile foundation with first story floor;
- F3: concrete slab floor.

The obtained results are presented in the Figure 1.

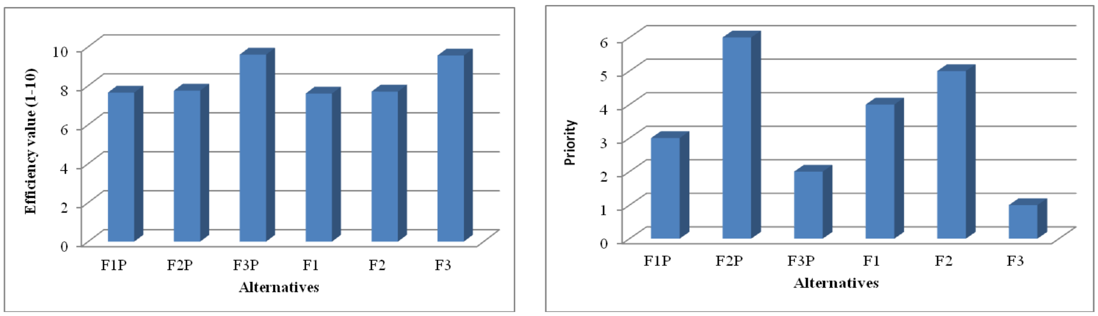

Figure 1. Comparison of the efficiency among foundation options.

The comparison of utility values among the foundation options showed that concrete slab floor received the highest scores both in a passive house and in efficiency Class A house. Efficiency values of concrete slab floor options were much higher compared to strip or pile foundations. The reason is much higher thermal parameters of the concrete slab floor compared to strip or pile foundation. The floor is installed together with the foundation slab and thus reduces the total price of the house. The analysis has shown that the best foundation option for energy efficient houses is a concrete slab floor.

5 CONCLUSIONS

According to the passive house standard an energy efficient house is a building where energy is saved by architectural, structural and technological solutions. To meet the passive house standard requirements the house must be tight, use renewable energy, employ various energy saving methods, the planning done with respect to orientation.

The technical-economic comparison of the main structures of a passive house revealed that it is cheaper to install an adequately designed concrete slab foundation than to build strip or pile foundation and the floor separately.

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