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PREFABRICATION AS THE CONSTRUCTION SYSTEM OF PASSIVE HOUSE – COST ISSUES

PREFABRYKACJA JAKO SYSTEM BUDOWNICTWA PASYWNEGO – ZAGADNIENIA KOSZTOWE

A b s t r a c t

As a response to the growing need for cheaper and more energy-efficient buildings, this paper presents a building system based on a heavy timber frame. The cost analysis to build a wall which meets the requirements for a passive building concludes that a prefabricated heavy timber frame is at the forefront of cost minimization. The recognized advantages of prefabrication can prove that this method of constructing single-family homes, with a positive impact on temperature and humidity, may become an alternative to existing technologies.

Keywords: prefabrication, passive housing, cost analysis

S t r e s z c z e n i e

Prezentowany w artykule system budownictwa prefabrykowanego może być odpowiedzią na rosnące zapotrzebowanie na tańsze i energooszczędne budynki. Przeprowadzona analiza kosztowa wybudowania ściany spełniającej wymagania dla budynku pasywnego lokuje element prefabrykowany oparty na ciężkim szkielecie drewnianym w czołówce pod względem najniższych kosztów. Istniejące zalety prefabrykacji mogą sprawić, że ten sposób budowy domów jednorodzinnych może stać się alternatywą dla istniejących technologii.

Słowa kluczowe: prefabrykacja, domy pasywne, analiza kosztowa

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1. Introduction

The ongoing years of active promotion of the idea of passive construction continually bring in new solutions in building systems. The essence of passive construction is to reduce energy consumption as well as pollution. For a building to be considered passive, a number of certain criteria must be met. Consumption of end-use energy at 15 kWh/m^{2}year, consumption of primary energy at 120 kWh/m^{2}year; the U value for walls $U < 0.15$ W/m^{2}K (for detached houses in Poland the recommended $U = 0.1$ W/m^{2}K) and the air-tightness of the building at $n50 = 0.6$ 1/h [2].

Many Polish publications refer to aspects of passive construction [1, 3–6], however, despite intense promotion, numerous subsidies, grants and assistance in design, relatively few people decide to build their houses in a passive standard. Multiple problems, the level of complexity and the cost of construction increased by approximately 15–20% does not convince potential investors, even if the building will use minimal amounts of energy to function during the next 20 years [7].

It is for those reasons that the search for solutions to allow for reduced construction costs continues. One possibility is the use for prefabrication. Financial aspects of using prefabrication in passive construction is the subject of this paper.

2. Prefabrication technology

Prefabrication involves an earlier fabrication of finished building elements in a particular factory and their subsequent transport and assembly at the building site. The greatest developments in prefabrication took place in Poland in the 60s and 70s of the last century [10]. What was valued then was minimalism, high functionality of the building and the simplicity of structure. Prefabrication seemed an ideal solution, due to the capability of producing modular elements which allowed to construct a symmetrical and uniform-looking building. In Poland, despite good designs, execution failed.

The article presents wooden prefabrication which can be used in passive buildings. This solution is relatively new on the Polish market and the technology was imported from Austria and Germany which, in turn, followed the trends in the American building industry.

3. Prefabrication technology based on heavy timber frame [9, 10]

The basis of this prefabrication are wooden beams glued together longitudinally or transversely. The completed wooden frame is boosted from inside with OSB panels and then filled up with hard and heavy mineral wool. The total thickness of insulation amounts to 16 cm, as beams of this thickness are used for prefabrication. Having filled the frame up with mineral wool, the structure is closed by another OSB panel. The outer side of the wall is covered with vapour-proof membrane ensuring air-tightness which is required for every passive building. Plasterboard panels make up the inside first layer which secures the membrane and gives an aesthetic finishing to the interior. The finished construction of the wall has to be appropriately insulated. Such a finished wall (Fig. 1), covered with plaster on the outside and plasterboard on the inside, is stored vertically with the rest of the partitions of similar size.

Finished walls and ceilings are transported to the building site, where foundations have already been constructed. The outer and inner wall lines are drawn and marked with washers which fit the washers placed on wall elements. Additionally, a separation layer is placed under the walls to prevent contact between wood and concrete. Subsequently, ceilings have to be attached to the finished walls of a particular storey. The ceilings are, like the walls, prefabricated elements brought to the building site. Finished ceiling panels arrive in the form of the constructional layer consisting of beams and mineral wool closed between OSB panels. The remaining layers of the floor are assembled on the site. The indispensable tightness of the partitions is ensured by the continuity of the vapour-proof membrane in the walls and ceilings. The membrane is folded on the edges of all window openings and doorways and its edges are glued to the reveal. 20–30 cm of the membrane are left at the edge of each partition, which is then glued to the membrane of the neighbouring partition. This solution ensures high air-tightness of the building.

The last element of the building is the roof or flat roof. The flat roof is produced like inter-storey ceilings. However, the most frequent solution in Poland is the classic double- or multi-sloping roof. A simple shape of the building, that is rectangular or similar to rectangular, allows to use a prefabricated roof construction, in which the ready-made structure is then laid with roof covering.

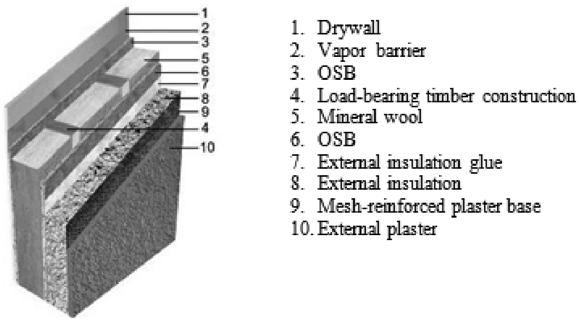

Fig. 1. Cross-section of the prefabricated heavy timber frame wall construction. Source: [9]

4. Cost analysis

The aim of the economic analysis was to compare the costs of constructing a prefabricated vertical partition with other solutions. For this purpose, various construction layers of the wall and thermal insulation layers were used. The following materials were utilized:

- for the constructional layer: prefabricated timber frame and aerated concrete, slag concrete, silicate, ceramic,
- for thermal insulation layer: polystyrene and mineral wool. For insulation with mineral wool vapour-proof membrane had to be added to ensure appropriate insulation by the material.

To make cost comparison for 1 m^2 of a wall possible, it was necessary to set such thickness of the insulation layer that the partition received an appropriate *U* coefficient. Three various values of the coefficient for the partitions were studied: $U = 0.1$; $U = 0.15$; $U = 0.3$ [W/m^2*K]. To determine thermal insulation layer thickness, the formula for R_T – total thermal resistance according to PN-EN ISO 6946: 2008 "Building components and building elements – Thermal resistance and thermal transmittance – Calculation method" is used. The necessary technical parameters of materials have been adopted from the manufacturer's Technical Cards.

The calculated thickness of a thermal insulation layer necessary for the constructional material to provide the appropriate *U* coefficient is presented in Table 1.

Table 1

The calculated thickness of a thermal insulation

	The constructional material					
The thermal insulation	Prefabricated heavy timber frame wall*	Aerated concrete block Thermalica 36.5	Silicate block Silka E24	Silicate block N24	Ceramic block MAX 220	Slag block Alfa 1/1
The thickness of thermal insulation [m] necessary to provide $U = 0.1$ [W/m^2*K]						
Polistyrene	0.13	0.26	0.41	0.41	0.39	0.40
Mineral wool	0.12	0.24	0.39	0.39	0.37	0.38
The thickness of thermal insulation [m] necessary to provide $U = 0.15$ [W/m^2*K]						
Polistyrene	0.00	0.11	0.27	0.26	0.24	0.25
Mineral wool	0.00	0.10	0.25	0.25	0.23	0.24
The thickness of thermal insulation [m] necessary to provide $U = 0.30$ [W/m^2*K]						
Polistyrene	0.00	0.00	0.12	0.12	0.09	0.11
Mineral wool	0.00	0.00	0.11	0.11	0.09	0.10

* prefabricated wall element presented in chap. 2.1. includes 16 cm thermal insulation (mineral wool).
Source: own study

The table 1 reveals that, in the case of the prefabrication analysed, an additional layer of insulation is necessary only to ensure $U = 0,1$ [W/m^2*K]. Considering the remaining types of walls, the smallest thickness of insulation is required for the wall constructed from Aerated concrete block Thermalica 36.5. On the other hand, in comparison to other solutions, the silicate walls need the thickest insulation layers to meet the parameters assumed.

In the next step of the analysis, the financial data planned were used to calculate the direct costs of wall construction (without plaster). The cost calculation involves only direct costs, that is: labour, materials and the work of the equipment needed to construct 1 m^2 of a wall.

The standards of material consumption, labour and equipment are in accordance with the books on standard expenditures: KNR, KNNR, KNNR.

Financial basis adopted for the estimate calculation: labour – 16.25 zł/r-g; prices of materials and required equipment taken from the market and the publication "The prices of factors of production RMS", Sekocenbud for the fourth quarter of 2013. Costs of purchases of materials are included in the prices of materials.

Table 2 summarizes the costs of constructing a 1 m^2 wall for the variants adopted previously.

Table 2

The cost of the walls in different variants [PLN/1 m^2]

The thermal insulation	The constructional material					
	Prefabricated heavy timber frame wall*	Aerated concrete block Thermalica 36.5	Silicate block Silka E24	Silicate block N24	Ceramic block MAX 220	Slag block Alfa 1/1
Costs [PLN] of a 1 m^2 wall with the U = 0.1 [W/m^2*K]						
Polistyrene	193.74	208.98	280.37	273.35	292.86	253.57
Mineral wool	225.10	300.07	449.68	441.05	449.04	415.80
Costs [PLN] of a 1 m^2 wall with the U = 0.15 [W/m^2*K]						
Polistyrene	155.07	175.38	198.54	192.52	219.14	173.11
Mineral wool	155.07	239.22	301.49	294.67	315.52	275.52
Costs [PLN] of a 1 m^2 wall with the U = 0.30 [W/m^2*K]						
Polistyrene	155.07	96.66	108.32	102.29	128.91	85.88
Mineral wool	155.07	96.66	138.09	131.26	152.11	112.11

* prefabricated wall element presented in chap. 2.1. includes 16 cm thermal insulation (mineral wool).
Source: own study

The analysis of the results presented in Table 1 and 2 reveals that the prefabricated heavy timber frame wall requires the lowest construction costs. Additional wall insulation is necessary only when the U coefficient is to reach the 0.1 [W/m^2*K] value. The greatest difference in costs in relation to the prefabricated heavy timber frame wall is shown by the wall constructed from silicate blocks Silka E24.

The construction costs of the walls when the U coefficient is to reach the 0.1 [W/m^2*K] value are shown in Fig. 2.

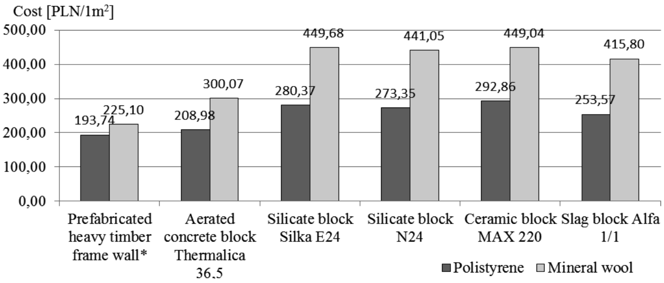

Fig. 2. The costs of constructing a 1 m^2 wall for the variants when U = 0.1 [W/m^2*K]. Source: own work

5. Conclusions

The economic analysis of outer walls in the single-family house proves that, in comparison to various variants that had been proposed, the prefabricated heavy timber frame wall involves relatively low costs.

The prefabricated construction on a heavy wooden structure is worth considering by the potential investors who would like to build passive houses, as it ensures the required high value of the U coefficient with relatively low costs.

The other advantages of the prefabricated heavy timber frame system are: short construction time resulting from utilizing ready-made prefabricated elements and high air tightness of the building achieved by the vapour-proof membrane in every partition, end-joined and glued with a binder.

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