TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO
1-B/2016

DOI: 10.4467/2353737XCT.16.072.5421

ALENA TAŽIKOVÁ*, MÁRIA KOZLOVSKÁ*, ZUZANA STRUKOVÁ*

TECHNOLOGICAL AND ECONOMICAL ANALYSIS OF SELECTED WOOD-BASED CONSTRUCTION SYSTEMS

ANALIZA TECHNOLOGICZNYCH I EKONOMICZNYCH WYBRANYCH SYSTEMÓW NA BAZIE DREWNA

A b s t r a c t

The aim of the paper is to present the results of a comprehensive analysis of three selected wood-based construction systems from design, technological and economical point of view. The selected construction systems imply the stick frame construction system, the structural insulated panels and the standard panel construction system. The optimal construction system from the perspective of a customer is evaluated on the basis of the multi-criteria optimization method. The typified design of the family house Largo 85 served as a model to present and analyze the parameters such as construction cost, construction time, heat transfer coefficient of external walls and air soundproof of walls. The mentioned criteria are the most significant for a customer when making a decision about the most suitable wood-based construction system.

Keywords: *wood-based buildings, construction cost, construction time, structural insulated panels, frame construction system*

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

Celem pracy jest przedstawienie wyników kompleksowej analizy trzech wybranych systemów budowlanych na bazie drewna z projektowego, technologicznego i ekonomicznego punktu widzenia. Wybrane systemy konstrukcyjne oznaczają: system konstrukcji szkieletowej, izolowane panele strukturalne oraz standardowy system konstrukcji paneli. Optymalny system konstrukcji z punktu widzenia klienta jest oceniany na podstawie wielokryterialnej metody optymalizacji. Charakterystyczna konstrukcja rodzinnego domu Largo 85 służyła jako model do przedstawienia i analizy parametrów takich jak: koszt budowy, czas budowy, współczynnik przenikania ciepła ścian zewnętrznych i dźwiękoszczelne powietrza ścian. Wymienione kryteria są najbardziej znaczące dla klienta przy podejmowaniu decyzji o systemie budowy na bazie drewna.

Słowa kluczowe: *budynki na bazie drewna, koszt budowy, czas budowy, strukturalne panele izolowane, system konstrukcji szkieletowy*

* Ph.D. Ing. Alena Tažiková, Prof. Ph.D. Eng. Mária Kozlovská, Prof. Ph.D. Eng. Zuzana Struková, Faculty of Civil Engineering, Institute of Construction Technology and Management, Technical University of Košice.

1. Introduction

Nowadays, the public interest in healthy living, healthy housing, fast construction and low operating cost housing increases. Current trends in construction reflect it and natural construction materials as wood and materials from natural sources are being used more often. Application of wood into construction has a long tradition in all European countries. Much attention has been paid to development and improvement of wooden construction [1]. Currently, there are available and preferred several wood-based construction systems. The systems differ by structure, composition of materials as well as by appearance [2].

Given the stability, durability and renewability of wooden materials, as well as the targets for a greener, sustainable and low-carbon construction industry, a big potential to increase the use of wood in house construction has been identified [3]. Wood as a building material is seen to have low impacts from the perspective of low water pollution, low green house gas emissions, low air pollution and low solid waste compared to concrete and steel [4]. Several building industry professionals has described industrialized wood building methods as promising for various reasons as dry pre-fabrication increased quality, speed of on-site assembly, requiring less personnel on site [5, 6]. In Slovakia, prefabricated wood-based building systems are the most preferred and expanded from all the modern methods of construction. The constant expansion of wood construction in architecture coincides with the development of new building materials and new building systems. One of the advantages of wood houses is the variability of structures and composition of the walls, which can be designed as a low cost, low energy and passive models.

2. Materials and Methodology

In the study, presented in the paper, three wood based construction systems were compared with one another. The systems include:
- the panel construction system – variant 1
- the structural insulated panels (SIPs) – variant 2
- the stick frame construction system – variant 3

2.1. The panel construction system and the stick frame construction system

The wooden house is built of large panels, manufactured in a factory and assembled on site. The wall sections in the stick frame construction system are identical with the panels of the panel construction system. The thermo-technical and acoustic characteristics of the structures are also identical. The panel construction system is characterized by the factory production and assembly on site, the stick frame construction system is characterized by necessary on-site carpentry work. This is reflected in the construction time, construction cost and in demands of machines and equipment. Three selected construction systems were compared by the mentioned parameters (construction time, construction cost, and demands of mechanization) point of view. The external panels provided with basalt thermal insulation are faced by fibre gypsum boards Fermacell and have windows installed in the factory.

2.2. SIPs – The structural insulated panels

The construction system SIPs is characterized by modern sandwich panel provided with the hardened polystyrene in the core and faced by oriented strand boards (OSB). Unlike the conventional wooden construction, the panel does not involve any wooden frame.

2.3. Characteristics of the family house and selection of wood based construction systems

The typified family house Largo 85 (Fig. 1) served as the reference house for comparison of selected construction systems. In order to reveal an optimal variant for the potential customer, the three variants of the reference house, characterized by the three construction systems, were designed. The reference house Largo 85 is a single-storey house with sloping gabled roof. The dimensions of the house are: 11 m (length) and 7.7 m (width) and the usable area is 70.73 m^2. In the next part of the paper the thermo-technical and acoustic parameters of the house are presented, as well as the total construction cost, the time schedule and the total construction time of the house in three selected (above mentioned) construction systems. Based on the multi-criteria optimizing method, the optimal construction system for the potential customer has been determined. The results of the study are presented in the next parts of the paper.

Fig. 1. The reference family house Largo 85

3. Results and Discussion

3.1. The thermo-technical parameters

The thermo-technical assessment of the building involves the course of isotherm, the course of temperature and assessment of water vapour diffusion. Moreover, the thermal resistance and the heat transfer coefficient of the structure were estimated. The estimation, based on the standards STN EN ISO 6946 and STN 73040, was made by the software Area 2010 and Teplo 2010. The external temperature is –15°C and the internal temperature is +20°C.

The boundary conditions R_{si} = 0.13 m²·K/W; R_{se} = 0.04 m²·K/W. The calculation value of the thermal resistance R = 7.67 m²·K/W. The calculation value of the heat transfer coefficient U = 0,127 W/m²·K, and the amount of diffusing water vapour Gd = 2.861·10⁻⁹ kg/m²s (Table 1). From the estimation it is clear that there is no water vapour condensation of the structure in the specified design temperature. The calculation value of the thermal resistance of the SIPs construction system R = 7.500 m²·K/W. The calculation value of the heat transfer coefficient U = 0.130 W/m²·K and the amount of diffusing water vapour Gd = 2.6·10⁻⁹ kg/m²s (Table 2). From the estimation it is clear that there is no water vapour condensation of the structure in the specified design temperature.

Table 1

The composition of the external wall of panel and stick frame construction system

No.	Type of the layer *from interior to exterior*	Thickness d [m]	λ [W/m·K]
1	Fibre gypsum board Fermacell	0.015	0.320
2	Wood frame + insulation Isover	0.060	0.036
3	Vapour barrier – Tyvek sheet	0.0002	0.350
4	Wood frame + insulation Isover	0.120	0.036
5	Fibre gypsum board Fermacell	0.015	0.130
6	Bonding mortar Baumit	0.003	0.800
7	Polystyrene EPS	0.100	0.040
8	Bonding mortar Baumit + glass fibre mesh lep. malta+sk.sieťka	0.003	0.800
9	Silicone plaster Baumit	0.002	0.700

Table 2

The composition of the external wall of SIPs construction system (EUROPANEL manufactory)

No.	Type of the layer *from interior to exterior*	Thickness d [m]	λ [W/m·K]
1	Fibre gypsum board Fermacell	0.015	0.320
2	Air space + CD profile	0.030	0.147
3	Vapour barrier – Tyvek sheet	0.0002	0.350
4	Oriented strand board – Europanel	0.015	0.130
5	Polystyrene EPS – Europanel	0.180	0.040
6	Oriented strand board – Europanel	0.015	0.130
7	Bonding mortar Baumit	0.003	0.800
8	Polystyrene EPS	0.100	0.040
9	Bonding mortar Baumit + glass fibre mesh	0.003	0.800
10	Silicone plaster Baumit	0.002	0.700

3.2. The acoustic characteristics

The value of theoretical airborne sound insulation of external wall is 47.6 dB in both, panel and stick frame construction system. In SIPs construction system it is 38.8 dB.

3.3. The construction time

The construction time is also one of important parameters in selecting an optimal construction system. The time schedules of all three variants were prepared, the results of the schedules are presented in Fig. 2. The construction time of the house (only framework structure, without finishing processes) in the variant of the panel construction system is 11 days. The construction time of the house (only framework structure, without finishing processes) in the variant of the stick frame construction system is 32 days. The construction time of the house (only framework structure, without finishing processes) in case of the SIPs construction system is 26 days.

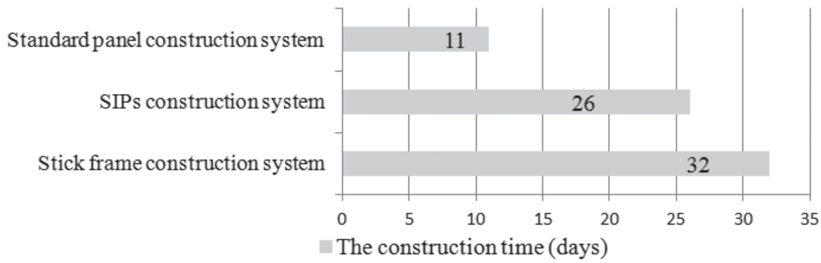

Fig. 2. The construction time of the house in three different construction systems

3.4. The cost analysis

In order to compare the construction cost of the house in three different variants, the cost calculations were prepared. The construction cost involves the cost of the frame structure, facade and windows installation. The cost of three different variants (panel construction system, SIPs construction system and stick frame construction system) are similar. The construction of external and indoor walls is different due to different construction systems. The roof structure and the facade are the same. The construction costs of the house include: a) material cost, b) labour cost, c) site equipments cost and d) cost of material transport into site. The results are presented in Fig. 3.

The stick frame construction system – the main items in the cost calculation of external and indoor walls are: timber, insulation material and fibre gypsum boards Fermacell as the cost of material and the cost of wood-based frame structure erecting and facing. The different items in the cost calculation, divided into material cost, labour cost, site equipments renting cost and transport cost are in Fig. 3 presented in percentages. In the stick frame construction system, the material cost is 66.8% of the total construction cost and the labour cost is 30.39% of the total construction cost. The remaining 2.81% of the total construction cost responds to material transport cost and cost of site equipments renting. The total construction cost of the house (without finishing processes) is 31.505 Eur.

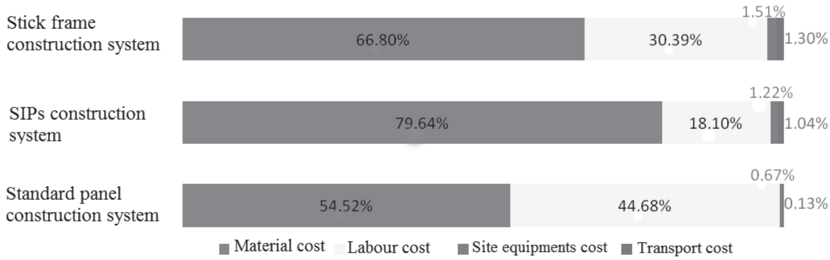

Fig. 3. Comparison of the construction cost of three different construction systems

The standard panel construction system – it is surprising that the labour cost is almost 45% of the total construction cost**.** That is because the cost includes the operating cost of manufacturer (automatic production line, rental cost etc.). The cost of material is 55% of the total construction cost. The total construction cost of the house in this variant of construction system is 33.568 Eur.

The SIPs construction system – the main items of the external walls and indoor walls are represented by the structural insulated panels (SIPs), manufactured by Europanel Manufactory. The cost of material is almost 80% of the total construction cost and the labour cost is a little more than 18% of the total construction cost. While the labour capacity of this construction system is low, the cost of material (Structural Insulated Panels) is excessively high. The total construction cost of the house in the variant of the SIPs construction system is 34.379 Eur.

Table 3

The values of the total utility of three different variants

Conjunction of nominal scale of optimising criteria and corresponding index coefficient K_{ij}								Total utility
	C1	C2	C3	C4	C5	C6	C7	
Stick frame construction system	0.1400	0,20515	0.05974	0.00136	0.00095	0.00074	0.4000	0.80794
SIPs construction system	0.11412	0.2100	0.07396	0.00169	0.00108	0.00086	0.36656	0.76827
Standard panel construction system	0.1400	0.20515	0.1750	0.0025	0.0025	0.0025	0.37541	0.90307

Based on the multi-criteria optimization method, the optimal wood-based construction system for a potential customer is defined and the order of the construction system variants is determined. The scales of the criteria of decision making method: the designing criteria 35%

(i.e. C1 – acoustic characteristics 40% and C2 – thermo-technical characteristics 60%), the technological criteria 25% (i.e. C3 – construction time 70%, C4 – total labour capacity 10%, C5 – demands on site equipments 10%, C6 – transport of materials 10%) and the cost criteria 40% (i.e. C7 – the total construction cost of the house without finishing processes 100%). In Table 3 the results of determining the total utility of three different construction systems are presented (stick frame, SIPs and standard panels). The method of index coefficients was applied. Based on the results, the optimal variant is the one with the highest value of the total utility.

Based on the results, the highest rate of the total utility of the construction system from the presented criteria point of view is in the variant of the standard panel construction system (0.90307). Under these conditions, the standard panel construction system presents the optimal variant of the wood-based house for a potential customer. The SIPs construction system is the system with the lowest total utility (0.76827).

4. Conclusions

The three selected wood-based construction systems are analyzed in the paper from technological, design and economic point of view. Based on the multi-criteria optimising method, the optimal variant of wood-based house from the perspective of a potential customer is determined. The three different variants were assessed and compared in terms of construction cost, construction time, thermo-technical parameters and acoustic characteristics. These construction parameters play an important role in deciding for the most suitable type of the construction system of the house. Based on the results, the standard panel construction system, with the highest total utility, was determined as the optimal one.

The article presents a partial research result of project VEGA – 1/0677/14 Research of construction efficiency improvement through MMC technologies.

References

[1] Mačková D., Spišáková M., *STEKO wood modular construction system*, Improving the efficiency of construction through MMC technologies: Proceedings of scientific papers 2014, Košice 2014, 55–62.

[2] Kozlovská M., Švajlenka J., *Comparative analysis of selected assembled construction of wood-based and traditional brick system*, Improving the efficiency of construction through MMC technologies: Proceedings of scientific papers 2014, Košice 2014, 109–116.

[3] Huang C.P., Wei C., Wang S.Y., Lin F.C., *The study on the carbon dioxide sequestration by applying wooden structure on eco-technological and leisure facilities*, Renewable Energy, Vol. 34, 2009, 1896–1901.

[4] Liu Y., Zhang J.X., Zhou B.G., Huang Z.Z., *Modern wood construction architecture and its possibilities in China*, Jiangsu Architecture, Vol. 3, 2005, 5–8.

[5] Roos A., Woxblom L., Mc Cluskey D., *Architects, and Building Engineers, and Stakeholders Perceptions to Wood in Construction – Results from a Qualitative Study*, Berg seng E., Belbeck G. and Hoen H. (ed.). Scandinavian Forest Economics, No. 42, 2008, proceedings of the biennal meeting of the Scandinavian Society of Forest Economics, Lom, Norway, 2008, 184–194.

[6] Sirochmanová L., *MMC methods in context of sustainable buildings*, Improving the efficiency of construction through MMC technologies: Proceedings of scientific papers 2014, Košice 2014, 63-70.