UDK: 624.011.1:620.9

Review paper

DOI: 10.5937/greenb24024L

CHALLENGES IN RESIDENTIAL BUILDING CONSTRUCTION: ENERGY-EFFICIENT PREFABRICATED LIGHTWEIGHT TIMBER-FRAME HOUSES

Bojana Lević[1], Bojana Zeković[2], Nikola Miletić[3]

Abstract *The need for residential building construction is globally increasing, and the energy efficiency of houses and the ecological footprint they leave behind are becoming increasingly relevant issues. The need to reduce energy consumption for heating is one of the major requirements in residential building construction in Serbia. To address that issue, it is important to choose appropriate building materials that are highly energy-efficient and environmentally friendly. This paper presents the possibilities of using energy-efficient, prefabricated, lightweight timber-frame houses. Wood is a renewable building material of natural origin, abundant in Serbia. The paper discusses the energy efficiency of both construction systems and their environmental impact. The paper aims to investigate the advantages and limitations of prefabricated lightweight timber-frame construction compared to traditional masonry construction, which is still the predominant system in residential building construction in Serbia nowadays.*

Key words: *energy efficiency, prefabrication, timber-frame construction, residential building construction*

IZAZOVI U IZGRADNJI STAMBENIH OBJEKATA: ENERGETSKI EFIKASNE PREFABRIKOVANE LAKE MONTAŽNE DRVENE KUĆE

Apstrakt *Potreba za izgradnjom stambenih objekata globalno raste, a energetska efikasnost kuća i ekološki otisak koji one ostavljaju postaju sve aktuelnija pitanja. Potreba za smanjenjem potrošnje energije za grejanje je jedan od glavnih zahteva u stambenoj izgradnji u Srbiji, pa je važno odabrati odgovarajuće građevinske materijale koji su visoko energetski efikasni i ekološki prihvatljivi. Ovaj rad predstavlja mogućnosti primene energetski efikasnih, prefabrikovanih, lakih montažnih kuća od drveta. Drvo je obnovljivi građevinski materijal prirodnog porekla kojim Srbija obiluje. Rad prikazuje prednosti i mane prefabrikovane lake drvene konstrukcije u poređenju sa tradicionalnim zidanim sistemom gradnje, koji je i dalje dominantan sistem u stambenoj izgradnji u Srbiji. Rad razmatra energetsku efikasnost oba sistema gradnje i njihov uticaj na životnu sredinu. Cilj rada je istražiti prednosti i ograničenja prefabrikovane lake drvene konstrukcije u poređenju sa tradicionalnim zidanim sistemom gradnje.*

Ključne reči: *energetska efikasnost, prefabrikacija, drvena ramovska konstrukcija, stambena gradnja*

[1] Ms, Teaching Assistant, University of Belgrade – Faculty of Architecture, bojana.levic@arh.bg.ac.rs, ORCID 0000-0002-6431-4979

[2] PhD, Assistant Professor, University of Belgrade – Faculty of Architecture, bojana@arh.bg.ac.rs

[3] Ms, Teaching Assistant, University of Belgrade – Faculty of Architecture, nikola.miletic@arh.bg.ac.rs, ORCID 0009-0007-9052-499X

1. INTRODUCTION

The construction of single-dwelling residential buildings is constantly increasing in Serbia. According to statistical data, in the last decade, the number of newly built single-family residential buildings has been significantly higher than the number of newly built multi-family residential buildings [1]. These newly built residential buildings need to adhere to conditions set by the current energy efficiency regulations. As defined in the Rulebook on Energy Efficiency of Buildings, newly constructed buildings and elements of their thermal envelope must meet the performance standards of energy-efficient building, have heat transfer coefficients within a defined range and belong to energy performance class C, at least. [2]. In addition to the issue of building's energy efficiency and reducing the required energy for heating, the issue of reducing CO_2 emissions is becoming increasingly important. In order to achieve carbon neutrality by 2050, Serbia has committed, by signing the Green Agenda for the Western Balkans, to adhere to the guidelines of the European Green Deal by implementing strict energy policies. One of the measures of energy policy relates to reducing greenhouse gas emissions in all sectors [3]. In residential building construction, these policies can be applied to the selection of environmentally friendly and highly energy-efficient building materials. In addition to the choice of building materials, the construction method used in building construction affects the carbon footprint. The focus of this paper is to demonstrate the possibilities of applying prefabricated lightweight timber-frame panels in residential building construction to achieve highly energy-efficient thermal envelope performance and reduce the carbon footprint.

1.1. Prefabricated lightweight timber-frame assemblies

Prefabrication technology involves the formation of complex assemblies composed of several different materials and elements, which are connected in the factory as a whole and transported as finished assemblies to the construction site to be mounted [4]. The advantages of prefabrication compared to traditional construction include time savings in the construction process, minimizing errors in work execution, reducing construction waste, and reducing noise on the construction site because the majority of the construction process takes place in the factory.

There is significant potential for the application of renewable and natural materials in Serbia. Natural and regionally available materials are the optimal choice for modern, sustainable, and efficient construction. These materials do not require complex processing or long-distance transportation, and they can be easily reused, recycled, or left to biodegrade without harmful environmental effects. Compared to artificial materials, natural materials generally have better properties when it comes to their impact on human health, not only during their use and maintenance phase but throughout the entire material lifecycle.

Serbia is a country abundant in timber. According to statistical data, the average volume of harvested timber in 2019. amounted to around 3.4 million m^3. The majority of this timber volume, approximately 1.6 million m^3 (49%), was used as firewood [5]. If this wood were used as a construction material instead of for heating, the benefits would be manifold. Heating energy requirements would decrease, considering that prefabricated lightweight panels have excellent thermal characteristics, and harmful gas emissions would decrease [6].

Lightweight prefabricated wooden constructions consist of cross and longitudinal wooden beams within the frame structure. For external and internal surfaces, various wood-based products are used, including oriented strand boards (OSB) for dry construction, plywood, etc. The filling of the assemblies is mostly made of stone wool. [7].

Of all materials, wood is the best material to use in prefabricated construction because it allows for the highest level of pre-production and fast assembly. The key characteristics of wood are that it is durable, natural, and a vapor-permeable material. It does not emit any harmful substances into the environment and is the only renewable construction material with an exceptionally clean life cycle. It has the best ratio of thermal insulation to heat preservation, thus reducing heating costs. It enables easy installation and is easy to process. It has low density and weight, and it is a natural regulator of the indoor atmosphere and contributes to ventilation as well as air filtration and cleaning [8].

Stone wool is one of the most common natural thermal insulation materials on the market today. Stone wool is a natural material of mineral origin that is non-combustible, resistant to high temperatures, water-repellent, chemically neutral, and easy to install [9].

1.2. Typical freestanding single-family residential building in Serbia constructed since 2013

The focus of the research is on new residential building construction, specifically single-family residential buildings in Serbia constructed since 2013. In Serbia, mandatory energy certification for new buildings came into force at the end of 2012. This legal requirement represents compliance with minimum energy efficiency standards in buildings. Over time, there has been an increasing emphasis on achieving higher levels of energy efficiency [10].

Based on the classification in the National Typology of Residential Buildings in Serbia Constructed since 2013, a typical single-family residential building has only a ground floor or ground floor with an attic, without a basement. If there is an attic, it is heated. A typical building is heated by a central heating system with a low-temperature gas heater. The windows in the building are individual and occupy a relatively small area on the facade. A building has a sloping roof. All positions of the thermal envelope are insulated. The walls are made of lightweight concrete blocks or hollow clay blocks, externally covered with polystyrene insulation, and plastered with a contact facade. The windows are PVC profiles, with thermal insulation glass and plastic external shutters. The intermediate floor construction is semi-prefabricated, filled with hollow clay blocks [10].

2. RESEARCH METHODOLOGY

The paper analyzes a case study of a typical single-family residential building, which, according to general characteristics, corresponds to the type H1 established in National Typology of Residential Buildings in Serbia Constructed since 2013 [10].

The research focuses on analyzing the thermal envelope of the house and the possibilities of using lightweight prefabricated construction instead of traditional masonry construction. The paper examines energy savings through the implementation of environmentally friendly construction assemblies and conducts a comparative analysis with traditional construction techniques. The calculation of energy characteristics is performed using Knaufterm commercial software, which is the most commonly used tool for calculating energy performance and determining the energy class of buildings in Serbia.

2.1. Energy performance of a freestanding single-family residential building in Serbia constructed since 2013

The selected building has a ground floor and an attic (Figure 1). Both floors are heated. The house has a sloped roof. There is no basement in the house.

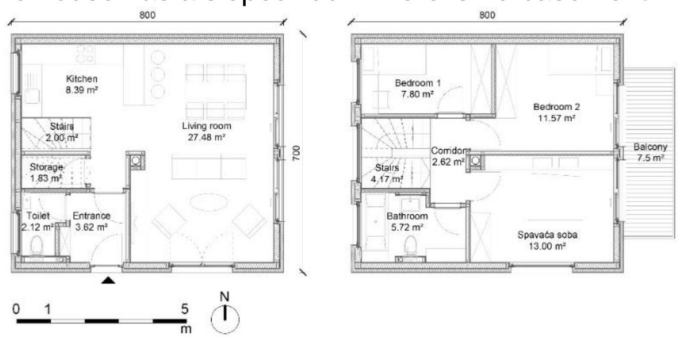
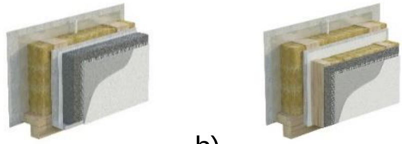


Figure 1. Ground floor and attic of the selected single-family residential building

The thermal envelope of the building consists of the facade wall, windows, external door, sloped roof, and ground floor. The facade wall is the most dominant element of the surface area of the building's thermal envelope.

When comparing the structure of the mentioned elements of the thermal envelope between traditional masonry construction systems and prefabricated lightweight assembly systems, it can be concluded that the most significant difference lies in the structure of the facade wall. The sloped roof in both construction types has a similar structure, with a timber structure ($U=0.121W/m^2K$). The ground floor in both construction types is typically made as a reinforced concrete foundation slab ($U=0.259W/m^2K$). Windows ($U=1W/m^2K$) and doors ($U=1.5W/m^2K$) are components implemented in the system. Therefore, this research focuses on modifications only to the facade wall, while the other elements of the thermal envelope remain unchanged. The structure of the thermal envelope elements is adopted from the Typology [10]. The study presents two common types of facade walls in traditional masonry construction: hollow clay block wall and lightweight concrete block wall, as well as prefabricated lightweight timber-frame wall as a new type of construction. For each type of wall, two types of thermal insulation are being considered: XPS, which is of synthetic origin and highly environmentally harmful, and stone wool, which is of natural origin and more environmentally friendly (Figure 2). Then, the thickness of thermal insulation is varied through three thickness variants, aiming for the building to reach energy class C (Table 1).



a) b)

Figure 2. 3D view of the prefabricated lightweight timber-frame wall with external thermal insulation of a) XPS and b) stone wool

Table 1. Variations in the type and thickness of thermal insulation across different types of walls and the achieved energy results

Type of construction	Structural material of the wall	Thermal insulation with thermal conductivity	Thickness of thermal insulation	U (W/m^2K) of the wall	Qh,an (kWh/m^2) of the building	Energy performance class of the building
Traditional masonry construction	Hollow clay block wall	XPS λ = 0.038 W/mK	10 cm	0.299	69.63	D
			12 cm	0.259	66.58	D
			15 cm	0.215	63.23	C
		Stone wool λ = 0.034 W/mK	10 cm	0.274	67.73	D
			12 cm	0.236	64.83	C
			15 cm	0.195	61.70	C
	Light weight concrete block wall	XPS λ = 0.038 W/mK	10 cm	0.269	67.34	D
			12 cm	0.236	64.83	C
			15 cm	0.199	62.00	C
		Stone wool λ = 0.034 W/mK	10 cm	0.248	65.74	D
			12 cm	0.217	63.38	C
			15 cm	0.182	60.71	C
Prefabricated lightweight construction	Timber-frame construction	XPS λ = 0.038 W/mK	10 cm	0.139	57.43	C
			12 cm	0.129	56.67	C
			15 cm	0.117	55.75	C
		Stone wool λ = 0.034 W/mK	10 cm	0.133	56.97	C
			12 cm	0.123	56.21	C
			15 cm	0.111	55.29	C

3. RESULTS AND DISCUSSION

Based on the obtained results, it can be concluded that using stone wool achieves better energy performance compared to XPS insulation for the same thickness of insulation (Table 1). This result confirms that it is preferable to use stone wool as a natural and environmentally friendly material instead of synthetic and environmentally unfriendly XPS insulation. Furthermore, when considering the structural part of the wall, the hollow clay block wall exhibits the poorest energy results. This wall has a thickness of 25 cm, requiring an additional 15 cm of XPS thermal insulation or 12 cm of stone wool to reach energy class C. The wall made of lightweight concrete blocks has a thickness of 30 cm, thus requiring a lesser thickness of thermal insulation compared to the previously described wall. For this wall, 12 cm of XPS insulation or stone wool is needed. The prefabricated lightweight timber-frame wall demonstrates the best results. This wall has a structural part with a thickness of 19 cm, comprising a 14 cm thick timber-frame structure, covered with double gypsum plasterboards on both sides. In all three thickness and type variants of insulation, this wall achieves favorable results. For this wall, the external thermal insulation can be less than 10 cm to reach energy class C (Table 1).

4. CONCLUSION

The research shows that by implementing prefabricated lightweight timber-frame assemblies in the construction of new buildings, exceptional energy performance can be achieved. Furthermore, the use of environmentally friendly materials such as wood and stone wool contributes to reducing CO_2 emissions, aiming to promote sustainable and energy-efficient architecture.

REFERENCES

[1] Statistical Office of the Republic of Serbia, Statistical yearbook 2022, https://publikacije.stat.gov.rs/G2022/Pdf/G20222055.pdf [27.4.2024.]

[2] Ministry of Environmental Protection, Government of the Republic of Serbia, Rulebook on energy efficiency of buildings, Official Gazette of RS. 61/2011. from https://www.paragraf.rs/propisi/pravilnik_o_energetskoj_efikasnosti_zgrada.html [27.4.2024.]

[3] Regional Cooperation Council, Sofia Declaration on the Green Agenda for the Western Balkans, 2020. https://www.rcc.int/docs/546/sofia-declaration-on-the-green-agenda-for-the-western-balkans [27.4.2024.]

[4] McGraw-Hill Construction: **Prefabrication and modularization: increasing productivity in the construction industry**. Smart Market Report, McGraw-Hill Construction, New York, NY, USA, 2011, //www.nist.gov/system/files/documents/el/economics/Prefabrication-Modularization-in-the-Construction-Industry-SMR-2011R.pdf [27.4.2024.]

[5] Statistical Office of Republic of Serbia, Forestry, Timber Harvesting in 2019, https://www.stat.gov.rs/sr-latn/vesti/20200528-seca-drveta-2019/ [27.4.2024.]

[6] Lević, B. Đukanović, L. Radivojević, A. Dimitrijević, B.: **Potentials for a complex and integrated refurbishment of post-war housing stock of Serbia**. *Energy Efficiency*, 16, 93, 2023. https://doi.org/10.1007/s12053-023-10171-z

[7] Popovac, M. Kitek Kuyman, M. Miščević, Lj.: **Natural and Regionally Available Materials for a Sustainable Future - Reviving Tradition in Contemporary Construction**. Sustainable and Resilient Building Design, Approaches, Methods and Tools. *TU Delft Open*. p. 185-201, 2018.

[8] Ivanović Šekularac, J.: **Drvo u savremenoj arhitekturi**. Arhitektonski fakultet Univerziteta u Beogradu, Beograd, 2017.

[9] https://www.knaufinsulation.rs/proizvodi/naturboard-venti [27.4.2024.]

[10] Jovanović Popović, M. Ignjatović, D. Đukanović, Lj. Nedić, M. Stanković, B. **National Typology of Residential Buildings in Serbia Constructed since 2013**. *Faculty of Architecture, University of Belgrade*, GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit. Belgrade, 2016.