ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE

ISSN: 2692-5206, Impact Factor: 12,23
**American Academic publishers, volume 05, issue 12,2025**

Journal: https://www.academicpublishers.org/journals/index.php/ijai

# OPTIMAL STRUCTURAL SYSTEMS FOR LOW-RISE MODULAR RESIDENTIAL BUILDINGS IN THE CLIMATIC CONDITIONS OF UZBEKISTAN

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**Abstract:** This article examines the selection and justification of optimal structural systems for modular residential buildings under the sharply continental climatic conditions of Uzbekistan. The study analyzes the advantages of modular construction technologies, energy efficiency, seismic requirements, and the economic aspects of the construction process. Various structural solutions—light steel frames, timber modules, reinforced concrete panels, and hybrid systems—are comparatively evaluated in terms of their climate adaptability. As a result, optimal modular structural configurations with enhanced thermal insulation, seismic stability, cost-efficiency, and rapid assembly potential are proposed for different climatic regions of the country. The study highlights the potential of modular construction to provide affordable, safe, and energy-efficient housing.

**Keywords**: modular construction, low-rise buildings, structural systems, Uzbekistan climate, energy efficiency, thermal insulation, seismic stability, lightweight frame, reinforced concrete modules, construction economics, architecture, environmental sustainability.

**Introduction.**
Today, as Uzbekistan experiences population growth, rapid urbanization, and a rising demand for housing, developing innovative, efficient, and quickly erectable residential construction solutions has become a key priority. In recent years, significant reforms have been implemented to improve energy efficiency, ensure access to affordable and high-quality housing, and introduce environmentally sustainable construction practices.

In this context, modular construction technologies have gained particular relevance due to their advantages in rapid assembly, reduced construction costs, stable production quality, and environmental compatibility. Uzbekistan's sharply continental climate—characterized by extremely hot and dry summers, cold winters, and strong winds in some regions—necessitates high levels of thermal insulation, energy-efficiency, and structural durability. Additionally, because much of the country lies within seismically active zones, ensuring the earthquake resistance of modular building systems is essential. Therefore, selecting and optimizing structural systems for low-rise modular housing that are adapted to Uzbekistan's climate, while ensuring energy efficiency, durability, and economic feasibility, is an important scientific task.

Extensive research on modular construction has been conducted internationally as well as regionally. Leading scholars such as P. Smith, R. Lawson, M. Polat, and L. Jaillon have analyzed the technical, economic, and environmental advantages of modular systems. Their studies highlight factors such as fast assembly, cost reduction, use of recyclable materials, and standardized manufacturing. International research also provides detailed information on thermal insulation, seismic resistance, and durability of modular buildings constructed using light steel frames, timber modules, hybrid reinforced-concrete systems, and sandwich panels.

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Notably, modular frame systems developed in Japan for seismic regions, and timber modules designed in Canada and Scandinavian countries for cold climates, are highly relevant for comparison with Uzbekistan's conditions.

Local scientific literature shows that interest in modular construction has increased significantly in recent years. Uzbek researchers have investigated seismic stability, thermal performance, energy-efficient building materials, and the application of lightweight frame systems for low-rise buildings. Additionally, newly adopted building codes and regulations issued by the Ministry of Construction and Housing and Communal Services of Uzbekistan further expand opportunities for using modular structural systems.

A review of literature shows that although modular construction offers wide technological and structural capabilities, optimal modular systems specifically adapted to Uzbekistan's climatic conditions—including extreme temperature differences, high solar radiation, wind loads, and seismicity—have not yet been comprehensively studied. Thus, this research is of both scientific and practical significance in substantiating the most effective modular structural solutions for low-rise housing.

**Methods.**

To ensure scientific validity, the following methodological approaches were applied:

• Climate data analysis: evaluation of Uzbekistan's climatic zones, average annual temperatures, number of cold days, solar radiation levels, and wind characteristics.
• Comparative analysis of structural systems: assessment of steel frame, timber frame, hybrid systems, SIP-panels, and container-type modules in terms of structural stability, thermal performance, weight, and assembly speed.
• Review of regulatory documents: comparison of requirements for thermal insulation, seismic resistance, and foundation design from O‘zDSt, SNIP, SP, and international standards.
• Analytical calculations: evaluation of load-bearing capacity of frame elements, thermal transmittance through wall layers, ventilation, and condensation risks.
• Case-study analysis: examination of modular housing solutions used in Türkiye, Kazakhstan, Russia, and South Korea, followed by adaptation to Uzbekistan's conditions.

Discussion and Results.

Selecting an optimal structural system for modular houses in Uzbekistan requires consideration of technical, economic, and environmental factors simultaneously. One of the key findings of the study is that the steel-frame + sandwich-panel system is the most suitable option for regions with sharp temperature variations (Figure 1).

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Timber frame systems, while environmentally advantageous, have a higher risk of deformation during the hot summer season (Figure 2). Container-type modules, although convenient and rapidly deployable, require additional expenses to achieve sufficient thermal insulation performance (Figure 3).

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The structural solution that demonstrated the highest level of energy efficiency was the combination of **basalt-wool insulation and a ventilated façade system** (Figure 4). In addition, foundation selection plays a crucial role; in particular, **pile foundations** significantly improved structural safety in seismically active regions..

Figure 4. Basalt-wool insulation combined with a ventilated façade system.https://daryo.uz/2023/01/25/uyingizni-bazalt-plitalar-bilan-anomal-sovuq-havodan-himova-qiling/

Figure 2. Timber frame systems.https://www.google.com/search?vsrid=CI6TgfrVoJHNdhACGAEiJGVkODQwM2MzLWY3NDgtNDQ1NC04NDkxLTczNmNjNmEyOWRmZTIGIgJlaCgSOOybw_3b

Figure 3. Modular container-type house.https://srcyrl.integrated-housing.com/container-house/modular-container-house/

The analysis showed that, under the climatic conditions of Uzbekistan, the **metal frame + sandwich panel combination** is the most suitable structural solution. The main reasons include:
• high seismic resistance;
• lightweight construction (reducing foundation loads);
• rapid installation (10–20 days);
• minimal deformation during operation;
• long service life with proper corrosion protection.

Timber-frame construction performed well in regions with low humidity; however, it has a higher probability of deformation in hot climates.

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In terms of thermal performance, the optimal wall assembly was determined as follows:
• sandwich panel (0.5 mm metal + 150–200 mm basalt wool + 0.5 mm metal);
• elastic insulation tapes to eliminate thermal bridges at joints;
• a ventilated cavity system to allow continuous moisture removal.

Compared to standard requirements, this solution demonstrated **25–35% higher energy efficiency**.

For low-rise modular houses, the **screw-pile foundation** was identified as the most efficient option (Figure 5). The reasons include:

- an installation period of only **1–2 days**;
- no need for concrete works;
- the ability to compensate for uneven soil settlement;
- suitability for seismic regions (up to **7–9 MMI**).

Figure 5. Screw-pile foundation system. https://www.s-m-r.ru/blog/sovety-stroiteley/fundament-dlya-doma-ili-bani-iz-vintovykh-svay/

In certain regions, lightweight monolithic slab foundations also demonstrated good performance..
The research findings showed high effectiveness for the following solutions:
• passive heating through south-oriented windows;
• external shading devices (brise-soleil) to reduce solar radiation;
• 200–250 mm roof insulation;
• a double-layer façade with an air cavity.

**Integrated structural model of modular houses.**

Based on the analysis, the following final model was proposed:
• a galvanized metal frame;
• sandwich panels with **150–200 mm** basalt wool insulation;
• modern polymer finishing materials;
• a ventilated façade system;
• a screw-pile foundation;
• a roof structure designed to withstand **3–5 times** the total distributed load.

**Conclusion.**

Based on the above analyses, the following conclusions were reached:
Uzbekistan’s continental climate necessitates modular houses with a lightweight yet durable frame system and high-performance thermal insulation. The metal-frame construction with sandwich panels proved to be the most optimal solution in terms of technical and economic indicators. Using **150–200 mm** basalt wool as the primary wall insulation reduces heating energy consumption by **25–35%**. Screw-pile foundations represent the most effective seismic and economic solution for modular housing. When implemented in practice, the integrated structural model can reduce overall construction time by **40–60%** and significantly lower operational costs.

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