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Research Article

Energy efficiency in the architecture of prefabricated modular houses

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Abstract – The article presents a theoretical and practical study of the analysis of the energy efficiency of traditional urban and rural buildings in addition to modern innovative ones. It briefly presents and analyzes the steps and actions of the responsible authorities in the targeted field, reflects the importance and possibilities of improving the housing stock situation, which the whole society must be aware of. It specifies the current state policies for promoting a healthy and safe environment and proposes energy efficiency strategies.
In addition, it presents activities carried out both in the context of forming new principles of sustainable and energy-efficient construction and encourages respect for environmental protection through conceptual projects aimed at reducing excessive human consumerism.
In addition, it highlights the role of local changes in international energy efficiency of buildings and state policies, and for the Republic of Moldova, several application projects in the targeted field are developed with the help of the European Union.
Examples and recommendations of energy efficiency of prefabricated modular house models are provided, which meet the requirements of the 21st century.

Keywords – Energy Efficiency, Innovation, Prefabricated Modular Homes, Sustainability.

I. INTRODUCTION

Today in the 21st century, the ecological issue, along with global warming, is a very important one, and we observe the consequences in the degradation of ecosystems, the energy crisis, the resource crisis, harmful emissions, a situation to which the whole society must be aware. Likewise, the field of construction architecture contributes to environmental pollution, by depleting natural resources, energy resources, etc., but by approaching the principles and methods of sustainable architecture, solutions and answers can be found in relation to human needs and the continuous development of the built environment. In Moldova, in construction architecture, energy-saving technologies were introduced more intensively into construction practice from 2006-2012, after the adoption of legislation on energy efficiency [1].

Urban buildings represent the main range of constructions operated in our country from the so-called energy-inefficient structures built of prefabricated concrete and local materials, whose thermal performance deteriorates during operation, either due to low-quality construction or due to improper operation [2].

Therefore, rural housing, built using outdated traditional techniques is also a problem, which is not addressed to a satisfactory extent, but is nevertheless an acute one for the Republic of Moldova. In addition, these techniques have proven to be costly in their use and do not meet modern standards of energy efficiency and sustainability.

The housing stock in operation in the Republic of Moldova is represented by small buildings, and this share exceeds 30% of the total volume of housing built in small urban areas and in rural areas. Being attractive from an ecological point of view, low-rise buildings have a significantly higher specific characteristic of thermal energy consumption for heating and ventilation, compared to high-rise buildings. In order to improve and assist the Republic of Moldova by the European Union in remediating the energy efficiency of buildings, several studies have been carried out on improving the energy efficiency of residential buildings, carried out within the framework of international projects in recent years (1997-2025), such as: *Citrus Partners LLP, Improving energy efficiency in the residential sector of the Republic of Moldova* [3].

Today, in 2025, the issue of energy efficiency in buildings in the Republic of Moldova is even more acute, with the increase in natural gas prices, which requires large investments from the state and beneficiaries. The Ministry of Energy of the Republic of Moldova aims to improve the energy efficiency of public buildings in the Republic of Moldova, carrying out several actions, such as: *The Energy Efficiency Project for Buildings in the Republic of Moldova* [4]; The *Energy Efficiency Rehabilitation Project for Educational Institutions in Local Communities in the Republic of Moldova* [5]. In the above, we mention that the Guide for the Implementation of Energy Efficiency Measures and the Use of Renewable Energy Sources for Public Sector Buildings [6] was also adopted.

With the support of the European Union and the Ministry of Energy of the Republic of Moldova, a large project was opened by the public institution, the National Center for Sustainable Energy, which launched the Financing *Program for the Energy Efficiency Fund in the Residential Sector of Moldova* (FEERM), approved by the Government of the Republic of Moldova at the meeting of April 10, 2024 [7].

Therefore, taking into account the fact that today the housing sector is in constant numerical growth and taking into account the fact that most of the residential buildings in the city are heated in the winter with the help of natural gas, which the Republic of Moldova is forced to import from international partners, which puts the country's government and the beneficiaries of services in a complicated economic situation.

So, we can mention that the Republic of Moldova needs some reconsiderations and changes in terms of how the processes of building construction are carried out, especially residential ones, and the energy efficiency standards applied to both individual and shared housing. One solution is thermal rehabilitation, a process of restoring the thermal insulation of a building, so that it can function more energy efficiently, but this does not reduce the necessary impact.

The Republic of Moldova, being a country with its own independence for 30 years, being one of the former USSR member republics, faces the same problems of emigration, lack of innovations and adoption of new technologies, becoming an obstacle to the development of the general standard of living, the transition from a production economy to a service economy, etc. At the same time, the needs of the country's population are in continuous growth, especially in the real estate market, for individual housing, which are closely linked to the history and folk traditions. An individual residential house is becoming a goal for many Moldovans, but not all of them can afford the financial coverage. Addressing the problem of architects, builders, engineers can be solved by changing the techniques, materials of construction and installation of buildings for the housing stock of the Republic of Moldova [8].

Describe The theoretical study of the situation in the field of construction and energy efficiency, of the statistics of traditional materials used in the construction of buildings, etc., allowed us to establish the

typology of residential buildings in high demand from the population, practical, sustainable, functional and energy-efficient models such as prefabricated modular houses.

Therefore, to develop the proposed study project and solve the problem investigated, an extensive research was carried out that includes a set of scientific research methods such as: documentation, analysis of scientific sources, SWOT analysis of the architectural ensemble regarding the construction techniques used, negative factors of energy inefficiency of buildings, photofixations, investigation, case study, comparison and interpretation of results in future constructions, oriented towards achieving the predetermined objectives.

II. RESULTS AND DISCUSSION

Improving energy efficiency in apartment buildings in the Republic of Moldova is essential for reducing energy consumption and protecting the environment. Currently, energy-efficient building and structure designs are successfully used in Canada, the USA, most European countries, as well as in countries with a tropical climate. In Moldova, energy-saving technologies have been more intensively introduced into construction practice since 2006, after the adoption of legislation on energy efficiency [9].

The development of the construction field and the transition towards a more energy-efficient and sustainable home, architects have found an answer by implementing prefabricated modular homes, residential and non-residential buildings.

An example of the efficiency of this method can serve as an individual house - Montana House, designed by Baragaño Architects in the Asturias region, Spain from prefabricated elements (Figure 1) [10]. The project of the house consisting of three modules is carried out on two levels, with a simple program that groups the installations and the metal staircase, the central element of the house, which connects all the areas. The simplicity of the construction, materials and interior equipment, the assembly of the building, the opening to the outside, the increased volume of natural lighting, the realization in type, all these result in the prefabricated modular house, sustainable and ecological. All these ways of designing a house, the prefabricated modular house, is a high-quality product, which allows for a future growth of the building offers a way to use the space in a much more dynamic, versatile and rational way.

Figure 1. Montana House, designed by Baragaño Architects in the Asturias region, Spain [10]

The main advantage of these methods of prefabricated modular houses, have a great impact on the traditional ones, which involve more time, multi-stage working techniques, materials and time of exception.

The typology of urban and rural architecture offers a wide range of sustainable solutions and materials that with minimal costs will cover the housing supply. This process has brought to the attention of architects a series of diverse problems, whose solutions have substantially modified the general vision regarding what constitutes the creation of architecture, namely quality architecture, alternative architecture.

In recent years, we have seen a significant growth in the prefabrication industry of residential and non-residential buildings, engineering structures or their elements that are found in a new functionality. The main advantage of these methods over the traditional one is the constructive form and accessible materials, but also minimal investments.

Combining the concept of sustainable architecture for the increased demand for housing and public spaces, but also with a high level of energy efficiency, are the models of modular and prefabricated passive houses

The range of products in the form of modular, prefabricated passive houses, a concept that offers innovative solutions for an ecological and energy-efficient home, solves not only the problem of affordable individual housing in construction, but also the problem of its maintenance.

The modular house represents an innovative and modern solution in residential construction. It offers high comfort and energy efficiency, allowing owners to personalize their home and reduce their impact on the environment.

The prefabricated modular house has a number of advantages compared to traditional concrete, stone, and clay house constructions (Figure 2) [11]:

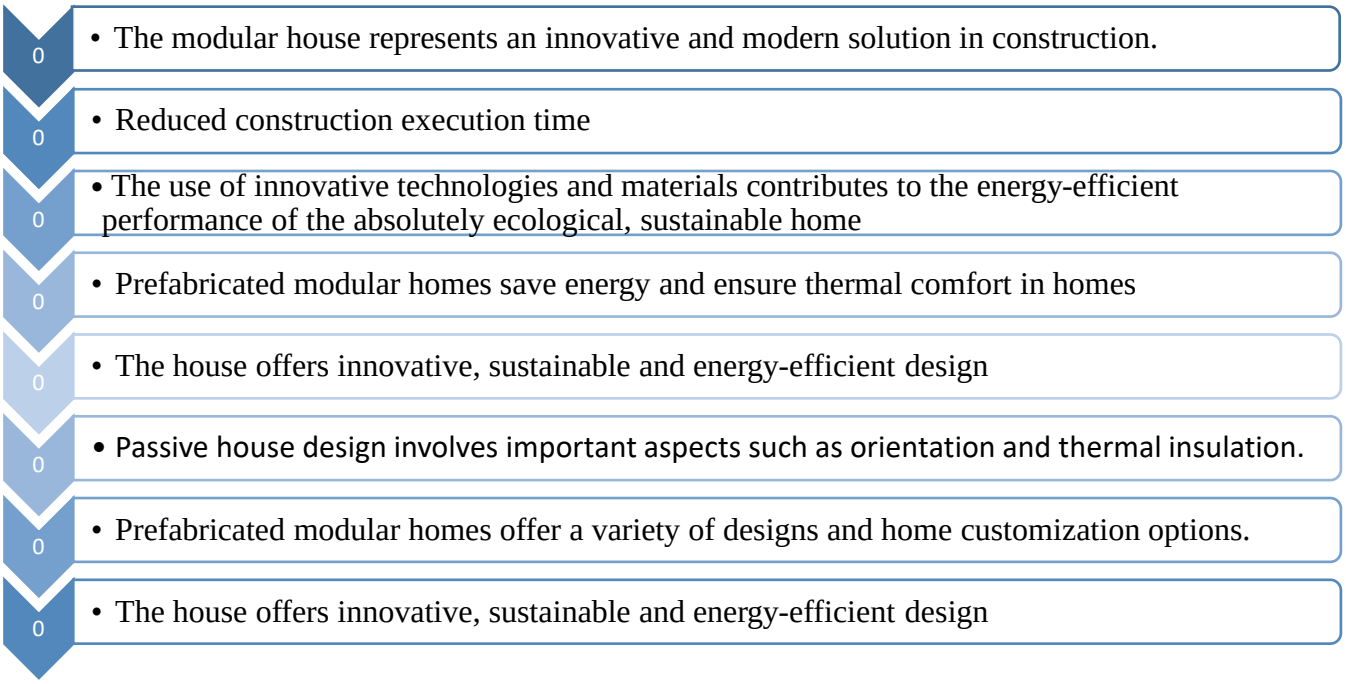

Figure 2. Advantages of prefabricated modular homes [10]

A prefabricated modular house, passive house is a house that has been designed and built to be extremely energy efficient. These houses are designed to minimize energy consumption and minimize the impact on the environment. Starting from the traditional house built of dry bricks, clay mixture with straw, the floor laid on the ground, it has many weak points, the lack of thermal insulation of the construction, reduced hardness over time and several negative factors that affect the health of the inhabitants. Similarly, Soviet urban houses meet the same lack of energy efficiency. An alternative for sustainable and energy efficient housing is the modular house - residential construction consisting of prefabricated modules that are assembled on site, thus forming a complete house. This modern construction method represents an efficient and versatile alternative to traditional constructions (Figure 3) [11].

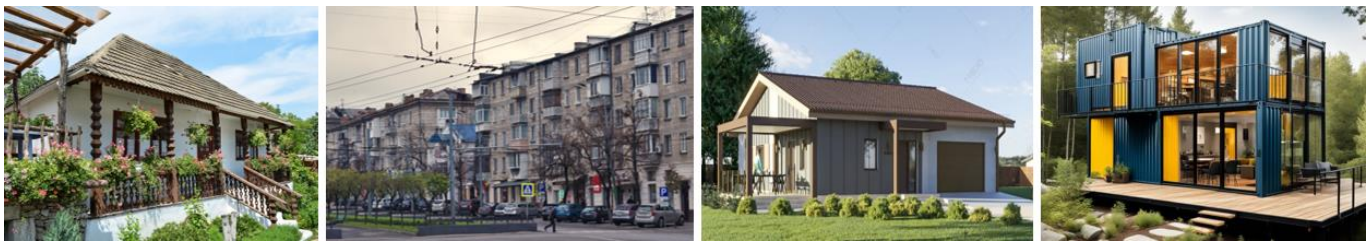

Figure 3. Traditional rural, urban and prefabricated modular houses [11]

The energy-efficient prefabricated modular house is characterized by the following:

- ❖ High-performance thermal insulation to reduce heat loss or cooling;
- ❖ Adequate sealing of the building to prevent heat leakage;
- ❖ Controlled ventilation, which ensures a healthy and comfortable indoor environment;
- ❖ Use of renewable energy sources to reduce dependence on traditional energy sources;
- ❖ Intelligent planning and design of the building, depending on the orientation to the sun, shade and wind direction;
- ❖ Prefabricated modules are made in a nearby factory and then transported to the construction site;
- ❖ Prefabricated modules are assembled on site, thus forming the final structure of the house;
- ❖ The modular house allows customization and modification of the design according to the owner's preferences;
- ❖ Thanks to prefabricated modules, the construction of a modular house is much faster and more efficient;
- ❖ The modular house is designed to meet energy efficiency, thus contributing to reducing energy consumption.

Prefabricated modular house constructions offer the opportunity to create a modern interior and exterior design that is adaptable to all the demands of the day. The stylistic development of residential house concepts has gained momentum through the program of open and minimalist spaces, the use of ecological materials, the integration of smart home technology, transforming the home into a unique and pleasant space. Thus, the stylistic approach of the prefabricated modular house follows the following trends (Figure 4):

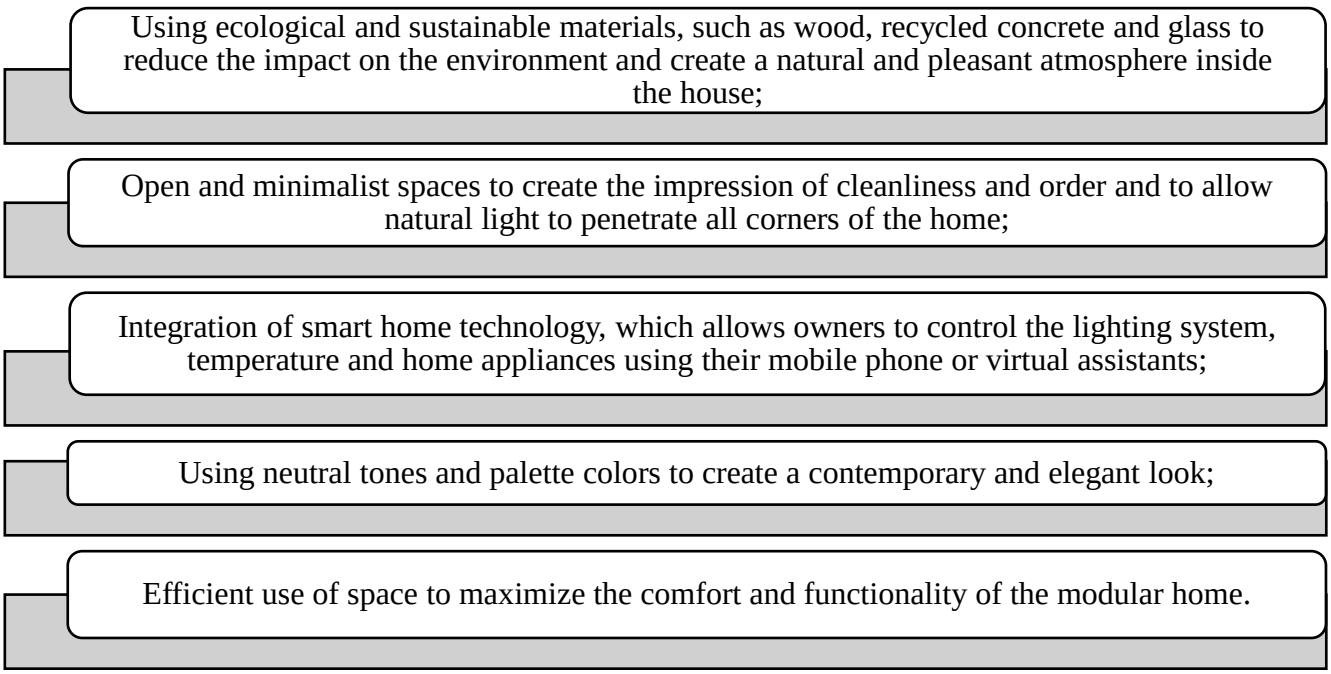

Figure 4. The opportunities of the stylistic approach of the prefabricated modular house

Sustainable energy systems that ensure comfort and energy sustainability in the modular home can include solar panels for the production of electricity or heat, heat pumps that use energy from the environment to heat or cool the home, and the domestic hot water recirculation system. These important elements transform the modular home into an energy-autonomous one and reduce the impact on the environment, with minimal reductions in home maintenance costs, contributing to the creation of a more

sustainable and environmentally friendly environment. By using prefabricated modules and the on-site assembly method, the modular home offers a quick and easy to customize construction.

III. CONCLUSION

In conclusion, we note that the prefabricated modular house presents a contemporary, energy-efficient, sustainable option compared to traditional construction. Listing the advantages and benefits of the prefabricated modular house, it offers multiple benefits to owners through home comfort, energy efficiency and flexibility, smart home, savings on payment rates, etc. Through its modern design and the integration of innovative construction techniques, the prefabricated modular house is a viable and attractive alternative in residential construction, the modular house stands out as a valuable investment and a viable option for a modern and sustainable life.

CONFIRMATION

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