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Possibilities of Using Prefabricated Modular Panels for Building NZEB Buildings in Earthquake-Affected Areas in Croatia – Case Study

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Abstract: This case study questions the possibility of using the prefabricated modular panels for building nZEB homes in earthquake-affected areas in Croatia. The comparison of the traditional and prefabricated construction was made in terms of construction costs and time, and energy consumption. Four cases of a ground floor family house were simulated in this research: two using modular prefabricated panels and two built traditionally with hollow brick. The energy consumption of all houses was compared to the current Croatian nZEB requirements. Furthermore, the costs, durability, and construction time of prefabricated and traditionally built houses were compared. The results showed that although prefabricated houses consume less energy, and experience lower thermal losses, they are slightly more prone to overheating in the summer. Finally, it was concluded that prefabricated houses are the best solution for current earthquake-caused situation due to their construction time which is significantly shorter compared to the traditionally built houses.

Keywords: Modular prefabricated panels, NZEB buildings, overheating, building technology, construction time & cost

1. Introduction

For decades, prefabrication has been used to improve the quality and efficiency of building [1]. The shortage of traditional building materials and/or labour is the modern reason for utilizing the prefabrication approach [2]. Prefabrication implies that the elements are made in a factory and transported either as a kit or as a complete building and the result comes from either assembling the kit or attaching the complete building to its foundation. Also, this kind of building can be designed to be energy efficient [3]. Considering buildings account for over 40% of total energy consumption and greenhouse gas emissions, the building industry is receiving increased attention from governments around the world when it comes to sustainable development initiatives [4]. That is also due to the fact that the majority of energy that is consumed while using the building comes from non-renewable sources [5]. What is more, there is a special emphasis on decreasing energy consumption since a problem that will be affecting millions of people is energy poverty. This is an issue since a lack of energy can result in a lack of essential services like cooking and heating, as well as the inability to access education, health, and important information from around the world [6]. Many countries promote energy-efficient construction by implementing national programs regarding energy usage and carbon dioxide emission. The European Directive on Energy Performance of Buildings [7] was introduced to improve the energy performance of buildings in the European Union. By the year 2020, the European Union has decided that energy consumption in buildings and greenhouse gas emissions have to be reduced by 20% [8]. Among other things, a concept

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of a ″Net Zero Energy Program″ was introduced and all new buildings must be nearly zero-energy buildings from December 31st, 2020, while all new public buildings had to be nZEB from December 31st, 2018 [7]. The European Union is committed to developing a sustainable, secure, and decarbonized energy system by 2050, and the Energy Union and the Energy and Climate Policy Framework define ambitious commitments for 2030 to reduce greenhouse gas emissions by at least 40% compared to 1990 and to increase the proportion of used renewable energy [9]. Furthermore, the European Union intends to invest in nature-based solutions (NBS) in order to preserve or improve well-being and welfare production at a cheaper cost while also providing prospective innovations. It can be said that the true benefit of NBS is dependent on how much non-renewable energy can be replaced with renewable [10, 11]. Most energy in buildings, about 85%, is used for heating, cooling, and heating domestic water. Therefore, increasing the insulation while using energy-efficient systems for heating or cooling, could save most of this energy [12]. Furthermore, insulating materials consisting of wood fibers and cellulose fibers obtained from recycled paper can be used to promote material recycling and reuse [13]. The energy efficiency of a building can also be increased by applying a special type of architecture, keeping the orientation of the building in mind, and striving for a low ratio of surface to volume [14]. A specific type of building that takes into consideration the aforementioned ways of increasing the energy efficiency of a building is a passive house. In comparison to traditional constructions, passive houses consume just 15-20% of the space heating demand while delivering increased living comfort. In comparison to the total costs of construction, the additional costs of a passive house are only approximately 10%. Total primary energy consumption makes up less than 50% than in conventional buildings while assuring comfortable indoor conditions in all seasons [15]. The concept of a passive house was developed in the 1990s by an institute founded in 1996 in Germany in the city named Darmstadt. The idea was to create a building standard that is, at the same time, energy-efficient, comfortable, affordable, and uses energy sources that are inside the building. Passive houses also have a ventilation system which supplies fresh air and therefore makes the air quality much better without draughts. When it comes to the needs of such a house, it requires less than 15kWh/m2a for heating and cooling and about 120 kWh/m2a of total energy consumption. Furthermore, the heating and cooling load is limited to 10 W/m2. Most importantly, this kind of house must be airtight which is achieved with air change rates that are not more than 0,6/h. In addition, in warmer climates, the passive home standard allows for high temperatures for 10% of the cooling period [16]. Considering the stated facts, the popularity of passive house standards across central and northern Europe is not surprising since the most of energy consumption in these regions is made up of energy required for heating. When it comes to the Mediterranean zones in southern Europe, solar energy can help by increasing the indoor temperatures in the winter but also can lead to overheating in the summer. Therefore, the use of solar gains and other passive house strategies has shown an increase in the thermal comfort of indoor spaces [17]. Various institutions in the world evaluate the efficiency of buildings and issue certificates, such as the aforementioned Passive House in Germany, BREAAM in the United Kingdom, and LEED in the United States of America [18]. Besides the mentioned institutions, the energy efficiency of a building can also be evaluated by EPC (Energy Performance Certificated) that are produced by accredited domestic energy assessors. The certificate is valid for ten years and required for the sale of a real estate property. In the process of planning and constructing new and existing energy-efficient buildings, quality monitoring and commissioning procedures are becoming increasingly important [1]. Quality control and commissioning procedures are becoming more and more important in the process of designing and constructing new and existing energy-efficient buildings [1]. Since energy efficiency entails lowering energy consumption and greenhouse gas emissions, the passive house standard serves as a foundation for the zero-energy building standard [4], and developing a structure to meet zero-energy building requirements has become mandatory. In comparison to passive building design, the zero-energy building design is a progression. It is a building that has a net energy consumption of zero in a year. Zero energy building does not mean the building consumes no energy, but the energy that is demanded for heating is reduced and so is electrical power [18]. Furthermore, this kind of building produces electrical power on itself with renewable energy sources. Solar photovoltaics can be used to generate electricity, solar thermal can be used to heat household water, wind turbines can be employed, and so on [12, 19]. The goal is to have a balance between the surpluses and the shortages of energy on an annual basis. The principle of operation of a ZNEH is usually based on a few components: photovoltaic arrays which generate electricity, an inverter for transforming the delivered direct current to alternating current, a local electric grid, a heat pump in the ground for both heating and cooling, and a steam superheater that preheats the domestic water [19].

2. Energy Poverty in Earthquake-Affected Areas in Croatia

The recent 6.4 magnitude earthquake hit about 50 km from the capital city of Croatia – Zagreb. The earthquake's epicenter was near the towns of Petrinja and Sisak, which is home to the region's major hospital, which was mostly rendered unusable due to the massive damage, and it was Croatia's greatest earthquake in 140 years. It is estimated that more than 3500 houses were completely destroyed, and it is not yet defined how many of them are not usable anymore [20, 21]. To make the situation even worse, Sisak-Moslavina County is already a poor Croatian county with homes that were previously destroyed during the Croatian War of Independence during the nineties and the whole county has not recovered since. The main indicator for this is the county development index showed in Fig. 1. Where it is visible that the Sisak-Moslavina County is included in the assisted areas.

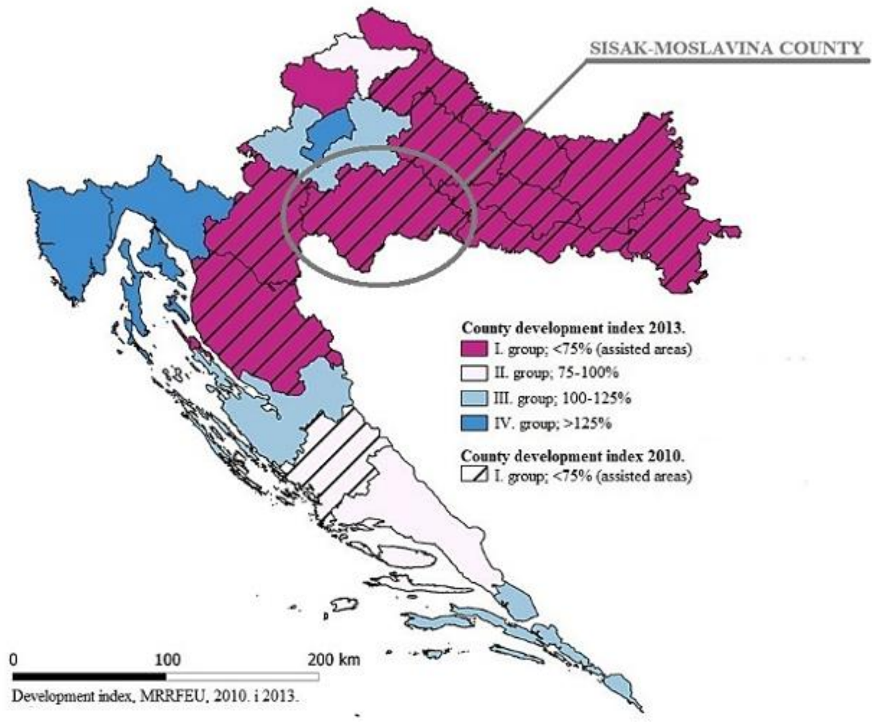


Fig. 1 - County development index [22]

The mentioned area is also the subject to the emergence of energy poverty due to the poverty of the county itself and its inability to access the energy easily available to wealthier counties in the country. As the price of energy continues to rise, an increasing number of households are having difficulty paying their energy bills and are being forced to live in energy-inadequate circumstances, causing them to downsize their living space in the winter. According to the definition of vulnerable energy customers, they are the energy consumers who, by the socio-demographic characteristics and energy indicators that are tied to their household are more likely to be energy poor than the general population. With that stated, it can be said that energy consumers of Sisak-Moslavina County are vulnerable. Field research was conducted on the area of Sisak Moslavina County in 2016. Which included 394 respondents. The results showed that the majority of respondents come from households with three or more household members (60%), mostly single-family homes built before 1990. The average living area is 72 square meters with 55 square meters heated. What worries is the fact that most of these houses have no kind of insulation since they are mostly family houses with old single windows with simple heating systems like wood furnaces (Fig. 2) [23].

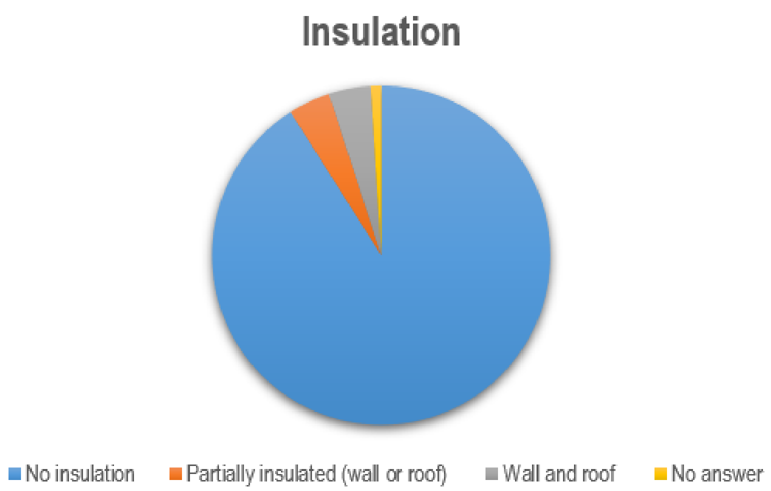


Fig. 2 - Insulation of homes included in the field research in Sisak-Moslavina County [23]

Furthermore, the field investigation revealed a substantial lack of access to essential energy services (heating, cooking, washing, cooling, and lighting), with some services being completely unavailable. In addition, 11 visited households had no electricity connection because they cannot afford it while all the household appliances, as well as lighting fixtures, are old and inefficient [23]. Considering the stated facts, it is of extreme importance to provide energy-efficient homes for those people and the plan is to build prefabricated houses since they are considered to be a fast and effective solution. Since the current regulations in Croatia demand for a new house to be nZEB, it is clear that the prefabricated homes would have to meet the current energy regulations and demands while also being earthquake resistant. With that said, it is clear that prefabricated nZEB homes would be the best solution for this unfortunate situation.

3. Comparison of Traditional and Prefabricated Building

The most common method of traditional building is cast-in-place. Even though the cost of this construction style is minimal, it has a number of flaws. Some of these are more wet work, high level of manual labor, environmental impact on the construction site, low efficiency in construction, big noise production, and serious dust pollution [19]. Traditional construction procedures are seen to be unsustainable because of the aforementioned issues. Particularly in terms of resource consumption and waste generation resulting from the use of non-sustainable materials and construction methods [24]. According to Pinto et al. [25], prefabricated modular buildings have several benefits and some of those are increased accuracy, decreased construction time and labor cost, and increased energy efficiency. Furthermore, this kind of construction minimizes waste throughout the whole life cycle of the building. Also, prefabricated construction has high efficiency in construction and prefabricated parts are of high quality [26]. Additionally, prefabricated construction has an impact on the safety aspect during construction. The reason for this is that the prefabrication increases safety on the construction site by reducing the activities at great heights and activities that are required in traffic on the site [27]. As a result of the building activities, site deliveries and traffic are decreased by up to 70% [28]. Since the materials and personnel are in a production facility, they are less exposed to bad weather conditions like wind and rain, resulting in increased safety [29]. Additionally, site management is improved because the modules were previously scheduled for delivery, requiring minimum material storage on site. When talking about traditional construction, site preliminaries may represent 12-15% of the total cost. Those preliminaries consider: costs of management, site facilities, storage, accommodation, and equipment. For fully modular buildings, the aforementioned expenses can be assumed to equal 5%, resulting in a savings of 7 to 10% over traditional construction. Not to mention that modular building saves money on commissioning and 'snagging' costs, which can be as much as 3% in traditional construction [28]. The lack of holistic and scientific analyses of prefabrication's suitability to a specific project is a disadvantage of comparing traditional versus prefabricated construction. The reason for this is that standard methods of evaluation only examine material, labor, and transportation costs, not the project's life cycle cost, health and safety, energy consumption effects, or environmental impact [30]. Finally, the mentioned characteristics of both traditional and prefabricated building are listed in table 1.

Table 1 - Comparison of characteristics of prefabricated and traditional building [24-31]

Characteristic	Traditional building	Prefabricated building
Costs	Relatively low costs	Higher costs
Labor	High level of manual labor	Reduced amount of work
Environmental impact	Environmental impact on the construction site; big noise production; serious dust pollution	Workers and materials less exposed to environmental influences
Efficiency	Low efficiency in construction	High efficiency in construction
Waste generation	High resource consumption and waste generation	Site waste highly reduced

4. Literature Review

An extensive search about the use of prefabricated panels for nZEB houses was done, but it was found that there is no literature regarding the use of them in a continental climate zone. Bioau, Bernier, and Ferron presented the models and methods for the simulation of a Zero Net Energy Home (ZNEH) with photovoltaic panels for on-site electrical production and a geothermal heat pump for heating, cooling, and pre-heating of domestic water [19]. Kalamees, Pihelo, and Kusk presented solutions for a deeply-renovated typical apartment building in 2017 [32]. The structure is made of concrete panels and was built in Estonia between 1960 and 1990. A study was conducted on the same structure to evaluate the thermal performance of prefabricated timber frame insulation elements for nZEB renovation as well as the moisture safety of nZEB restoration using prefabricated timber frame insulation wall elements [1, 33]. The aforementioned building was also the foundation for the article regarding nZEB renovation with prefabricated modular panels [34]. Hachem-Vermette, Dara, and Kane investigated the performance of container-based housing units and compared them to traditional housing. The results showed that the case study system can reduce thermal loads by about 57% comparing to the same traditional house [35]. The major findings of a research of an innovative modular prefabricated construction system are presented by Pinto et al. The system was created to meet the nZEB standards for a detached single-family home in several temperature zones throughout Portugal [25]. The mentioned paper studied the use of prefabricated panels for the construction of nZEB houses in the Mediterranean climate zone while this paper studies the use in the continental climate zone. Furthermore, the paper only studies the use of prefabricated panels while this paper compares them to the nZEB houses built with traditional and thermo brick.

5. Methodology of NZEB in Croatia

According to the Croatian regulation [36], all new buildings must be nZEB from the December 31, 2020. The Guidelines for nZEB construction were made by the Ministry of Physical Planning, Construction, and State Assets and can be divided into two sets. First, the guidelines for nearly zero energy buildings that are intended for the general public [37], and the guidelines for nearly zero energy buildings that are intended for the professional public [38]. The requirements in Croatia for a near-zero energy building are specified with:

- annually required thermal energy for heating per area unit of the usable area of the heated part of the building, Q’’H, nd [kWh / (m2·a)], does not exceed the permitted values set out in Annex B of the Regulation [36],
- annual primary energy per area unit of the usable area of the heated part of the building Eprim [kWh / (m2·a)] which, depending on the purpose, includes energy specified in Annex B of the Regulation [36] and does not exceed the other permitted values of Regulation [36] such as the maximum allowed values of heat transfer coefficient U-value [W/(m2K)],
- minimum share of delivered energy from renewable energy sources,
- and by meeting the air permeability requirement which is proven by testing on the building before the technical inspection of the building [38].

Since the emphasis in this paper is on the prefabricated family houses, according to the aforementioned guidelines, it is necessary to define the heating system, the preparation of hot water and regarding the mechanical ventilation and air conditioning system, it should be considered whether there is a system installed. Furthermore, the cooling system and the lightning system are not required to be defined for the case of a family house [38]. Also, the whole Croatia can be divided into two climate zones that are based on the mean monthly temperatures of outdoor air in the coldest month of the year at the building’s location. In this paper, the continental zone will be observed at the location of Sisak, Croatia.

6. Case Study

The case study was conducted on a family ground floor house with a net area of 76,88 m^2 in Sisak, Croatia. The medium monthly temperatures for the climate zone of Sisak are presented in table 2.

Table 2 - Medium monthly temperatures for the climate zone of Sisak, Croatia [39]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Medium monthly temperature [°C]	0,2	2,2	6,7	11,6	16,2	19,8	21,5	20,7	16,2	11,1	6,2	1,7

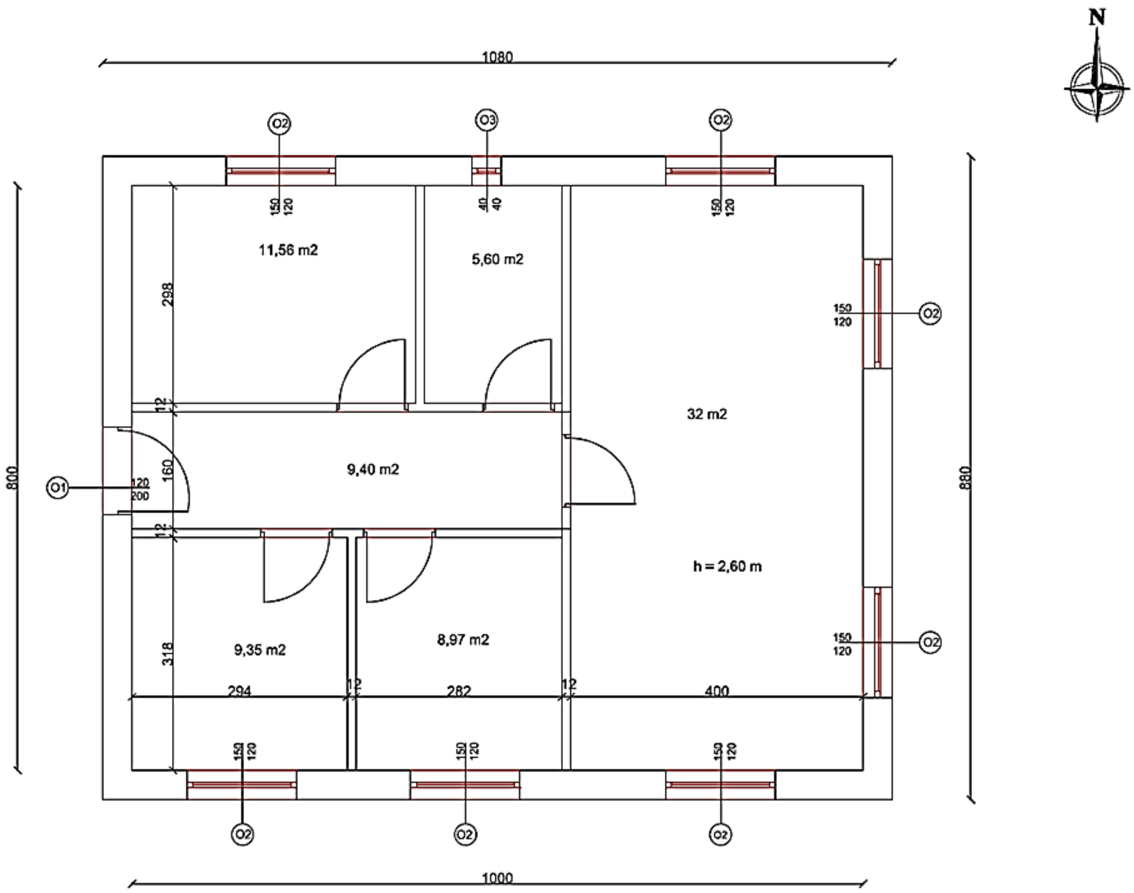


Fig. 3 - Ground plan of the family house

Four different cases i.e., house types were analyzed in this case study and they are:

- House built of Beattie Passive System prefabricated panels [40],
- House built of Lumar Passive Energy prefabricated panels [41],
- Traditionally built house with Porotherm thermo brick [42] and
- Traditionally built house with hollow clay brick.

All houses (cases) have the same ground plan seen in Fig. 3, the same story height of 2,60 m and a flat roof. The idea was to determine whether it is possible to build a net-zero energy house with prefabricated panels and to compare the two prefabricated houses with two traditionally built houses regarding their demands, energy sources costs, the cost of construction, durability of the construction, and construction time. A software using a quasi-dynamic calculation based on monthly values was used to determine the houses' energy consumption, emission of CO2, the share of renewable energy sources and the price of energy sources consumed. All of the houses have the same thermo-technical system which consists of a gas condensing boiler for space heating and preheating the domestic hot water (power 34kW), 7 radiators 1000x600x102 mm (power 2,16 kW), an electric air conditioner with an EER factor of 9,2 (power 2,64 kW) and 11 photovoltaic panels on the flat roof with dimensions 1956x992x40 mm with a 30-degree tilt to south. In the calculation of primary and delivered energy, the heating system and the preparation of domestic hot water were considered. The conversion factor from final to primary energy for gas amounts 1,095 while the conversion factor for electricity amounts 1,614.

The panels used in prefabricated houses are certificated by the PassivHaus Institute and so are the windows and doors that are the same in all four houses. Therefore, all houses have an air exchange rate of 0,6 h-1 according to the Passive House Standard [16]. The windows have roller shutters at the external side of the windows, and the ventilation of the house is performed naturally. A 3D model of the described house was made in a building performance simulation software IDA Indoor Climate and Energy (Fig. 4).

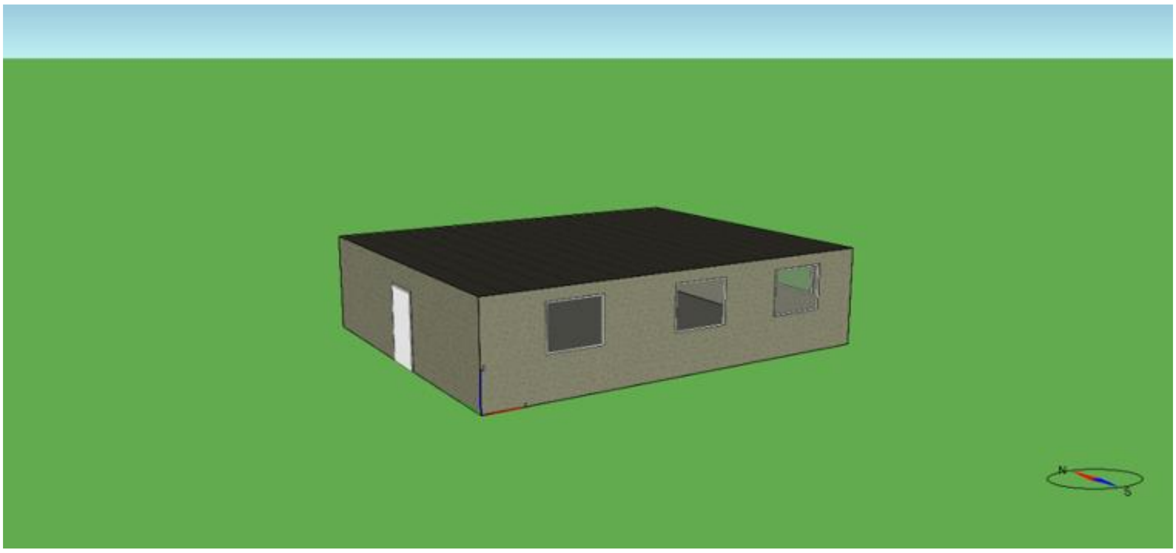


Fig. 4 - 3D model of the family house

The mentioned panels were chosen to be used during the research of the prefabricated panels market. The first system was the Beattie Passive System and its external wall panel is shown in Fig. 5 and the second one was the Lumar Passive Energy wall system shown in Fig. 6. Figs. 5 and 6 contain details regarding panels layers, materials, and their thickness.

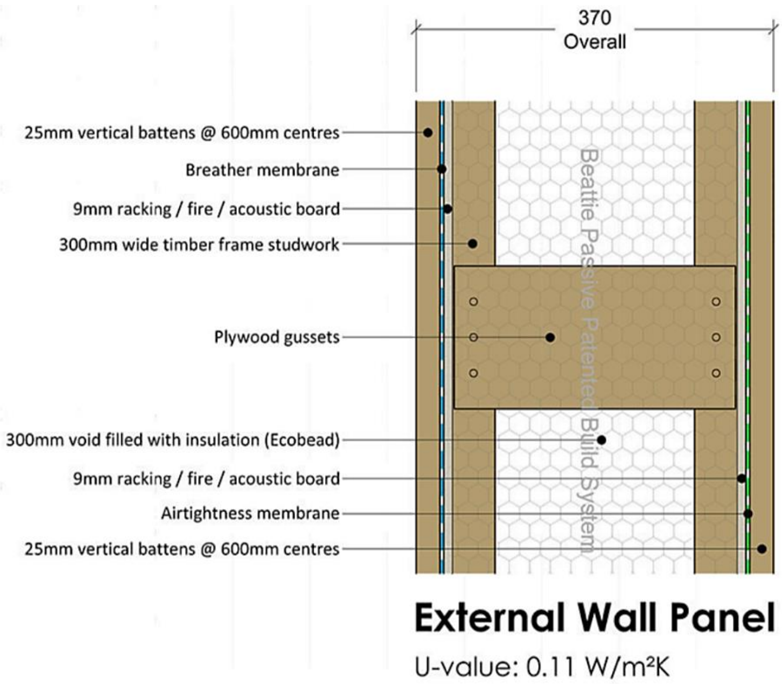
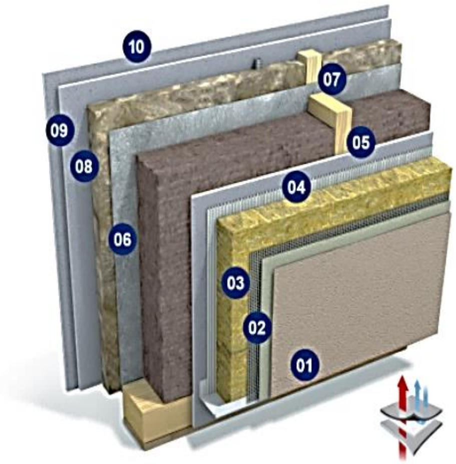


Fig. 5 - Beattie Passive System external wall panel [40]



TECHNICAL INFORMATION

01	The final layer of the facade	2 mm
02	Reinforcing mortar and mesh	5 mm
03	Facade insulation	140 mm
04	Gypsum fiberboard	15 mm
05	Wooden load-bearing structure	160 mm
	Mineral thermal and sound insulation	160 mm
06	Steam barrier	0.2 mm
07	Wooden substructure	60 mm
	Mineral thermal and sound insulation	60 mm
08	Gypsum fiberboard	15 mm
09	Gypsum fiberboard	10 mm
	WALL THICKNESS	407 mm
	INSULATION THICKNESS	**360 mm**
	Thermal conductivity through insulation	**0.106 W / m ^{2} K**
	Thermal conductivity taking into account the proportion of wood	0.120 W / m ^{2} K

Fig. 6 - Lumar Passive Energy wall system [41]

The traditional houses built with Porotherm thermo brick and with hollow clay brick were chosen for analysis in this case study because they are the most used materials for building residential buildings in continental Croatia which is shown in Fig. 7. Pictures were taken in Osijek in period from December 1st 2020 to February 1st 2021.

(a) (b)

(c) (d)

Fig. 7 - Recent construction sites in Osijek, Croatia during the last two months: (a) private residential building; (b) IT office building; (c) residential-office building; (d) private residential building

Among the four cases, the external walls, floor and flat roof were variated. In the first two cases with panels, the floor and flat roof were also made from the same manufacturer as the wall panels and in the other two cases, they were built as traditional floor and flat roof. The U-values of external walls, flat roof and floor are presented in table 3.

Table 3 - U-values of external walls, flat roof and floor in four simulated houses (cases) [40, 41]

U-values [W/m^{2}K]	External walls	Flat roof	Floor
1. case – Beattie Passive System prefabricated panels	0,11	0,11	0,09
2. case – Lumar prefabricated panels	0,12	0,14	0,09
3. case – Traditionally built house with Porotherm thermo brick	0,21	0,19	0,17
4. case – Traditionally built house	0,26	0,19	0,17

7. Results

Since the shape factor of this house is 1,59, the maximum allowed $Q''_{H,nd}$ [kWh/m^{2}a] is 75 kWh/m^{2}a and the maximum allowed E_{prim} [kWh/m^{2}a] for the climate zone of Sisak (continental part of Croatia) is 45 kWh/m^{2}a. Also, the minimum required share of renewable energy sources is 30%. So, when looking at table 4. it is clear that all the houses consume a similar amount of energy, and the energy sources cost is also very similar with prefabricated. However, prefabricated houses do show a slightly lower energy demanded for heating. Since all the houses have the same thermo-technical system, the share of renewable energy sources is around 100%. If comparing table 4. to the abovementioned requirements for an nZEB house, all four simulated cases of the house fulfill the Croatian nZEB requirements.

The value of $Q''_{C,nd}$ [kWh/m^{2}a] was included in the table, even though it is not taken into consideration when issuing an energy performance certificate in Croatia, because it shows and confirms the problem of overheating which is especially common in the case of prefabricated housing which showed a slightly higher value. Despite that, modular buildings still represent an energy-efficient solution since the value of $Q''_{C,nd}$ is not an excluding factor for the building to be nZEB. Regarding the table 4, it is important to mention that the negative values in the table obtained from the used software represent energy surpluses, i.e., the renewable energy sources do not only cover the house's energy demands, but also create a surplus of energy. Also, the energy sources cost is not only covered, but an extra amount of money is obtained if the surplus of energy is perhaps sold.

Table 4 - Energy consumption, CO2 emission, energy sources cost and share of renewable energy sources in five simulated houses

Values observed	$Q''_{H,nd}$ [kWh/m^{2}a]	E_{prim} [kWh/m^{2}a]	E_{del} [kWh/m^{2}a]	CO_2 emission [kg/m^{2}a]	Energy sources cost [€]	Share of renewable energy sources [%]	$Q''_{C,nd}$ [kWh/m^{2}a]
1. case – Beattie Passive System prefabricated panels	24,64	-44,17	-19,08	5,75	-139,53	100	24,64
2. case – Lumar prefabricated panels	24,24	-44,91	-19,67	5,66	-141,89	100	20,57
3. case – Traditionally built house with Porotherm thermo brick	39,23	-27,91	-4,09	9,15	-87,43	100	18,69
4. case – Traditionally built house	43,72	-22,78	0,60	10,19	-71,00	98	18,41

The thermal losses through ventilation, transparent parts (windows, doors) of the house and nontransparent parts (external walls, floor, flat roof) have also been analyzed for all four simulated houses (cases) and compared to the total thermal losses. They are presented in table 5.

Table 5 - Thermal losses through ventilation, transparent, nontransparent parts of four simulated houses (cases) and their share in total thermal losses

Case/Losses	1. case – Beattie Passive System prefabricated panels		2. case – Lumar prefabricated panels		3. case – Traditionally built house with Porotherm thermo brick		4. case – Traditionally built house	
Thermal loss	**[W/K]**	**Share in total %**	**[W/K]**	**Share in total %**	**[W/K]**	**Share in total %**	**[W/K]**	**Share in total %**
Ventilation	36,84	55,91	36,84	58	36,84	46,55	36,84	48,04
Transparent parts	9,57	14,52	9,57	15,07	9,57	12,09	9,57	12,34
Nontransparent	19,48	29,56	17,09	26,91	32,73	41,36	37,93	39,61
Total thermal losses	65,89	100	63,5	100	79,14	100	84,34	100

In table 5 it is visible that the ventilation losses make the most of total thermal losses in all four simulated cases. This is due to the fact that the houses have natural ventilation, which explains the same values obtained and suggests that it could be useful to install mechanical ventilation to further improve the energy efficiency and decrease thermal losses. Furthermore, the thermal losses through transparent parts are also the same since all the houses have the same windows and doors, but the thermal losses through nontransparent parts are quite lower in the case of prefabricated houses in comparison to the traditional ones.

Finally, by looking at table 6. it is visible that the price of construction and durability of construction are similar for both prefabricated nZEB houses and traditionally built nZEB houses, while the construction time is significantly shorter when it comes to prefabricated houses. Considering the fact that it is possible to build nZEB houses with prefabricated panels and with traditional construction methods, it can be concluded that prefabricated houses have an advantage when it comes to construction time since they can be built in a very short time.

Table 6 - Price of construction, construction time and durability of construction of prefabricated nZEB house and traditionally built nZEB house

Values observed	Price of construction	Construction time	Durability of construction
Prefabricated nZEB house made of panels	Comparable to traditionally built houses [40]	4-6 months [40, 41]	Comparable to traditionally built houses [41, 43]
Traditionally built nZEB house	600-800 €/m2 [44]	6-12 months [45]	70-100 years [46]

8. Conclusion

This paper examines the possibility of using modular prefabricated panels to build nZEB buildings in earthquake-affected areas in Croatia in four simulated houses(cases). During the analysis of the affected area, it was concluded energy poverty there is extremely high. Considering the stated, prefabricated houses could provide an effective and fast solution for the current situation. Prefabricated houses have many benefits such as reduced costs due to the shorter construction time regarding the labor costs, shorter environmental impact on the construction site, increased efficiency, etc. An analysis of energy consumption, CO2 emission, energy sources cost, and the share of renewable energy sources in four simulated houses (cases) was made. The results showed that the prefabricated houses have lower values of energy demanded for heating i.e., 24,24 kWh/m^{2}a. But the prefabricated houses showed a slight increase of value of energy demanded for cooling in comparison to traditionally built houses i.e., 24,64 kWh/m^{2}a. Therefore, it can be concluded that prefabricated houses have an increased risk of overheating in the summer period but still not an extremely higher risk than the traditionally built houses. Furthermore, the transmission thermal losses in prefabricated houses are slightly lower than in traditionally built houses, while the ventilation losses make up most of total thermal losses which would suggest installing mechanical ventilation in such houses. The price and durability of traditional and prefabricated houses are comparable, while the construction period of prefabricated houses can amount to one third of the time necessary to build a traditional house. Therefore, the construction period can be considered as the crucial factor in the current earthquake situation where there is the need to build a lot of homes in a short time.

Ultimately, it can be concluded that prefabricated nZEB homes can be an amazing solution addressing the current earthquake-caused situation. Recommendations for future researches would consider decreasing the possible overheating in such houses and installing mechanical ventilation.

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