Expanded polystyrene as the bearing building material of low energy construction

P Mesaros¹, M Spisakova¹, L Kyjakova¹ and T Mandicak¹
¹Technical University of Kosice, Civil Engineering Faculty, Kosice, Slovakia

E-mail: tomas.mandicak@tuke.sk

Abstract. Sustainability of buildings is a really important issue for the construction industry. Sustainable buildings are characterized by the lower construction costs for energy consumption and operations, they are environmentally friendly, able to save natural resources and they are comfortable and healthy for their users. The European Union supports this trend through its Strategy 2020, respectively with document Energy Roadmap 2020. The strategy 2020 sets greenhouse gas emissions 20% lower than 1990, 20% of energy from renewable and 20% increase in energy efficiency. It manifests itself in introduction of modern technologies of house building. One potential for the energy saving is construction of low-energy buildings using modern materials. This paper focuses on the analysis of the low-energy buildings made by expanded polystyrene as the bearing building material. The paper analyzes their design and describes the benefits of this modern but unusual type of construction technology for houses. The examples from abroad clearly indicate that this technology has potential in modern architecture. The success and exploration of this technology potential in the conditions of Slovak construction sector is closely related to interest of investors and users of further sustainable houses which are design according the Strategy 2020 conditions.

1. Introduction
The increasing environmental impact from the construction becomes a serious problem that can cause significant damage, not only to ecosystems but also to the health and wellbeing of field workers and nearby residents of building sites [1]. Therefore, it is necessary to approach and continuous effort within the industry in order to achieve the objectives sustainable construction and reducing of the environmental impacts of construction.

The authors Shen and Zhang [2] suggest that the impacts of construction activities on the environment include: (i) competition for land with other activities such as agriculture; (ii) adverse effect on the plots of land which are developed, and their environment, such as changing their ecological characteristics; (iii) consumption of substantial volumes of physical resources, both renewable and non-renewable; (iv) production of substantial volumes of wastes; (v) consumption of large amounts of energy during the processing of materials, the construction process and in the use of constructed items; (vi) contribution to air pollution from the dust and substances, including some toxic ones, which are released during the production and transportation of materials, and in some construction operations; (vii) disruption of the lives of the people living in the vicinity of the project through traffic diversions, noise pollution and others.

Considering this, the construction industry has a significant environmental footprint, especially in terms of greenhouse gas emissions and energy consumption. The European Commission estimates that 35% of all of Europe's greenhouse emissions come from buildings. On the other hand, the climate
change and energy sustainability presents one of the five targets for the European Union in 2020. The construction sector provides many opportunities for achieving of strategy 2020 targets. One of them is optimize of the design and management of constructions based on modern methods of construction using the unusually and innovative environmentally friendly construction materials - expanded polystyrene as the bearing building material.

2. Sustainability in affordable housing

Housing is one of the most basic human needs and is a key competent in the sustainable development of a community. Sustainability has been defined as economic growth that meets the current generation compromising the opportunity and the potential for future generation needs [3]. In general, sustainable development is divided into three interacting sectors: economic, environmental, and social [4] which resent three pillars of sustainable development [5].

Sustainable construction can influence the short and long term economic targets. The cost reduction is possible thought the using of local suitable materials (lower transportation costs); the energy efficiency of sustainable construction (lower economic demands of realization and operation of construction), etc.

Social sustainability focuses on the people using the building. Their current and future needs influence the design, which aims to create a highly-flexible plan that allows the building to be easily re-purposed as needs change by the design. A flexible design means the structure can be used longer, preventing the negative impact involved in tearing down an old building and rebuilding a new one.

Measures to address environmental sustainability can include increasing a building's energy efficiency, finding ways for the building to produce its own energy or heat, installing water-reduction measures, finding ways to reduce waste and using of “green” and local building materials. Even the location and orientation of a building can make it more environmentally friendly.

![Figure 1. Three pillars of sustainable development [5].](image)

Environmentally preferable products have less negative effects on human health and the environment when compared with competing products that serve the same purpose. In the design phase of construction is necessary to consider the selection of construction technology and building materials and products and prioritize environmentally-friendly forms. It is necessary to think about the theoretical and real sustainable development in the practice [5]. As seen in Figure 1, the individual pillars of sustainable development have different height pillars (influence) at present; therefore, it is necessary to do particular steps to balance their perception. The sustainability must be supported by the strong and the same high pillars in all three areas by the selection appropriate method of construction and construction material within the sustainable design and management of construction.
One of the possible ways of sustainable construction is the application of modern methods of construction (MMC).

3. Modern methods of construction

The majority of constructions are still constructed using traditional technology (masonry, concreting). On the other hand, the last few years it has been increased use of modern methods of construction (MMC) for housing, driven by a range of factors including demands for faster construction, skills shortages and sustainability of construction.

The modern methods of construction primarily involves the manufacture of constructions in factories, with potential benefits such as faster construction, fewer housing defects, reductions in energy use and waste [6] and offer significant potential to minimise construction waste [7] and construction safety risks [8]. The MMC is reasonably common in building construction but are less often used in civil engineering. For civil engineering projects, MMC can include use to pre-cast (prefabricated) components or preassembled structure. MMC can result in changes to on-site practice and may require different teams of specialist contractors; for example, compare operational needs on site to place large precast concrete components (handling areas, cranes and operators) with the demands of cast in – situ concrete (erection and striking of shuttering, temperature monitoring/control of large pours). The authors of study [7] divided the MMC products into these categories: (i) volumetric modular; (ii) timber frame and steel frame flat packs; (iii) prefabricated kitchen and bathroom pods; (iv) composite/insulated/sandwich (non load-bearing) panels; (v) light steel frame systems; (vi) pre-cast structural panels; (vii) pre-cast hollow-core flooring; (viii) structural insulated panels; (ix) pre-cast concrete cladding; (x) tunnel form construction; (xi) insulating concrete formwork. The wide range of MMC products has various applications in construction practice.

Many of the benefits of using MMC for housing are as yet unproven or contentious. On the other hand, the advantages and disadvantages are closely related to drivers and barriers of prefabrication use [9]. We can divide the main advantages of MMC [6] according the three pillars of sustainable development:

- economic – MMC houses typically have fewer defects and can be built more quickly, components provide a better quality and standards, the construction process can be speeded up by the mass production of prefab components in the factories,
- social – there may be fewer accidents and less impact on local residents during construction, reduces labour intensive activities and provides a safer working environment, designers from different disciplines can work closely together in the early design state to help to reduce abortive work,
- environmental – the houses can be more energy efficient, may involve less transport of materials, and produce less waste.

Typically MMC involves the manufacture of construction parts offsite in a specially designed factory. The two main products of MMC are:

- panels – including ready-made walls, floors and roofs. These are transported to the site and assembled quickly, often within a day. Some panels have wiring and plumbing already inside them, making construction even faster,
- modules – ready-made rooms or their parts, which can be pieced together to make a whole house or flat but are used most frequently for bathrooms or kitchens, where all the fittings are added in the factory. Also known as ‘pods’.

A range of materials is used for MMC, the most common being wood, steel and concrete. One of the latest trends in the field of MMC is application of expanded polystyrene as the bearing building material.
4. Expanded polystyrene house

The Japanese company Japan Dome House Co. inspired by the development of its model Inuit tribe [10], which throughout the ages build their homes out of ice blocks. This fact was the basis of the concept of production similar dwellings, except that the ice blocks replaced polystyrene.

The concept of polystyrene was associated mainly with the production of disposable beverage cups, trays and containers for food from fast food. Even using polystyrene insulating boom in Japan acted as massive as in our country. Therefore, were and still are new houses made of such material – expanded polystyrene at the center of attention investors and users.

In Europe, in 2008, at the peak of the real estate market boom and later started the trend “fashion” of energy efficient buildings, engineers Pacura and Rogula [10] searched cheaper construction methods, that would be energy efficient and they came up with the idea of using expanded polystyrene as the bearing building material for the whole house.

Meantime, the use of foamed polystyrene in building industry has been limited to thermal insulations, filling technological spaces and protection of construction products during transportation. Thus, only compressive forces are present in the structure of the building that allow distribution of internal loads connected with the objects operational use and external loads connected with snow and wind [10].

![Figure 2. Basic shape the house of expanded polystyrene [11].](image)

4.1. Technology and specifications of expanded polystyrene house

Based on the research [10], it was developed an innovative house design in the modern methods of construction – the expanded polystyrene in the form of prefabricated elements, which is supporting structure and thermal insulation of walls, as well as. Low specific gravity of material facilitates transportation, unloading and joining individual elements into the structure. All structural elements are delivered to the building site in the form of prefabricates that are joined together with the use of simple technological operations. An important thing is the innovative use of the heat-insulating material (foamed polystyrene) that is characterised by very low thermal conductivity, eliminating heat leakage bridges and any timber roof is not used. Roofing materials, for example roofing sheets, are fastened directly to the structure of the building. No expensive foundations are necessary, either. Due to low weight of the material the building can be erected on reinforced concrete slab with thermal and damp insulation. Moreover, low building cost is the advantage of the solution. The result is an energy efficient house, where energy use index stays within 50-60 kWh/ (m²·year), whereas the index in for buildings built by the traditional methods of construction exceeds 100-120 kWh/ (m²·year).
Walls of a building, made of foamed polystyrene, accumulate heat, and at the same time – through recuperation – maintain optimal ventilation of rooms ensuring constant inflow of fresh air. Polystyrene used to building houses is an environmentally friendly material. During the production stage is used pure energy. During the using stage, the polystyrene does not decompose and is resistant to aging. These are the facts [11] which are confirmed by independent appraisers and research institutes based on many years of observation of behaviour polystyrene in all possible applications in the construction industry. In general, the aging becomes visible when the material is suitable for use, or in the subsequent decomposition [11].

This technology has some advantages, which are: short construction duration (2 - 3 months), high structural strength, very good heat insulation characteristics. The presented study will consider to a comparison of three variants of the constructions – modular construction, masonry construction and polystyrene construction on the basis of economic and time parameters.

4.2. Comparison of economic and time parameters of construction

The base for comparative analysis of time parameters are schedules prepared for three variants of construction. The time duration was selected with approximately the same building volume 428 m$^3$ considering the construction schedule. The results of schedule for all 3 construction technology are presented on the Figure 4. Modular construction is characterized by the significant shorter construction time; construction time of polystyrene construction is 90 days ad tradition methods of construction (masonry) presents 188 days. The construction duration of polystyrene is shorter than half that masonry construction, but longer than modular construction.

![Figure 4. Comparison of overall construction duration for selected construction variants (in days).](image)

The background for comparative analysis of economic parameters is prepared budgets of these three variants. Total costs were divided into the following groups: foundation, bearing structural system, windows and doors, interior partitions, heating, staircase and roof. The Figure 5 shows only the total construction costs. The graph presents the clear confirmation of efficiency of modular construction in economic indicators. The total cost of the house, realized by modular construction opposed to masonry construction, are lower by 20 650 EUR. The graph shows clearly the effectiveness of modular construction in economic indicators. The total cost of the house, realized by modular design unlike masonry structures are below 20 650 EUR. Polystyrene construction is one of the latest building technologies, the cost of this design compared to masonry construction and modular construction are higher in 19%. In spite of increased cost have polystyrene construction advantages. Among the best
include short construction cycle (from 2 to 3 months), high structural strength and very good heat insulation characteristics what should reduce the operating cost for construction in future.

![Comparison of total cost of selected construction variant (in EUR).](image)

**Figure 5.** Comparison of total cost of selected construction variant (in EUR).

5. **Conclusion**

The results of a comparative analysis of polystyrene, modular and masonry construction shown that modular construction provide the better economic and time parameters. In spite of increased cost have polystyrene construction advantages. The examples from abroad [11] clearly indicate that this technology has potential in modern architecture. The success and exploration of this technology potential in the conditions of Slovak construction sector is closely related to interest of investors and users of further sustainable houses which are design according the Strategy 2020 conditions.

**Acknowledgements**

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

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