PREFABRICATED STRUCTURAL SYSTEM FOR PASSIVE HOUSES

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Abstract
According to www.passivhausdatenbank.at, Romania is listed with 6 passive buildings certified by Passivhaus Institut Dr. Wolfgang Feist (Darmstadt-Germany), buildings built from 2004 until 2011. These buildings represent deviations from the generally accepted building tradition in Romania. Buildings designed according to the standard can significantly reduce heating, ventilation or air conditioning costs and can lessen the building sector environmental impact. The Passive House standard is a basic premise for achieving the United Nations, the European Commission and the European Parliament objectives to reduce greenhouse gas emissions with 25-40% by 2020. This paper presents the Passive House and a structural system that allows passive houses to be built at costs similar to conventional ones. It was necessary to conceive a system that simplifies and shortens the execution period by using prefabricated elements, using materials available on the national market, in order to achieve an economical solution that could be applied in Romania.

Keywords: metal structure, wooden panels, insulation, economics, environment

INTRODUCTION
The Passive House Energy Standard is one of the leading standards for energy-efficient design and construction. Positive feedback from inhabitants has confirmed that energy costs can be drastically reduced and the comfort of living significantly increased by using an energy efficient house. Such houses can be made using specific construction techniques, using prefabricated steel frame buildings and the prefabrication of certain building elements. Products suitable for passive houses have been developed in Romania, are produced locally and can be used for this type of house. This article treats the aspects of a theoretical economic solution for an energy efficient building. The information presented in the next pages is summarized from the main address master’s thesis (Passive House made with prefabricated metal structure).

MATERIALS AND METHODS
1. Perimetral and partitioning walls
Energy efficient materials are used for thermal insulation. Materials that can reduce the insulating layer thickness, the wall’s weight and help ease the installation process. The building’s insulation is based mainly on cellulose flakes, vapour and anti-condensation barriers.

The building is designed to reduce the use of inefficient building materials and to eliminate thermal bridges.

The walls are manufactured as lightweight systems, using wood and cellulose flakes as insulating materials, thus resulting in a non-load-bearing structure (similar to curtain walls).

The perimetral wall structure and assembly order, from right to left, are detailed in figure 1.
The perimetral wall elements can be seen in figure 2, wall consisting of: 13-exterior wood panel; 9-cellulose insulation; 10-wooden planks; 11-interior wall panel and vapour barrier foil; 12-interior ceiling panel and vapour barrier foil.

The exterior panels (image 1.a) are made out of wooden microfibers and natural resins: panels of 2,7 m by 1,2 m and 2,5 cm in thickness, insulating material (λ = 0.053 W/mK) [2]. The panels are mounted with screws on the walls wooden frame and help stiffen the wall (as example see image 1.a). Airtightness is achieved by applying waterproofing to the outdoor panels joints, thus achieving a greater protection from the relevant climatic factors.

The ready-made interior wall panels (image 1.b), indoor use only, are made from wood fibres and natural resins and have characteristics similar to those of the exterior panels [3]. The panel’s dimensions vary depending on the application area: 3 m x 0,6 m x 0,012 m for the wall and 1,8 m x 0,3 m x 0,012 m for the ceiling. Panels can be finished with four types of layers and a colour gamut of 30 nuances offered by the manufacturer. These panels are used for the entire indoor wall fitting, are installed using staples and require no additional finishing costs.
Cellulose insulation flakes are among the most environmentally friendly solutions used for thermal and sound insulation. The material is rarely used in Romania because of the related wall structure constraints and economic factors. Cellulose flakes are obtained by a modern process that uses only 5% of energy used to produce the same amount of traditional insulation material, namely mineral wool [4]. Because of the way the thermal insulation is applied, the dry version, thermal inefficient materials are removed and walls can be easily made. Due to the thermal insulation properties (density up to 80 kg/m$^3$, variable thickness, dry or wet installation), cellulose flakes make a remarkable material that can be used in lightweight metal structures. In the case of dry injection, the wooden walls need to have fitted on their inside face a vapour barrier foil and after that the cellulose flakes can be inserted into the desired space. An example of wall thermal insulation can be seen in image 2 (does not represent exactly the proposed solution).

Image 2. Example of wall thermal insulation [5]

2. The roof system

To allow adequate roof isolation it was necessary to introduce distancing and mounting elements on which the prefabricated plates are installed. The area where thermal insulation will be inserted can be seen in image 3 (the specific positioning of the secondary beams is necessary in order to achieve the insulating layer thickness).

Image 3. The thermal insulation zone [1]

All the secondary I-beams have U-profiles mounted at their lower flanges (seen in image 3), U8 for IPE160 and U10 for IPE140 (metal profiles cut and welded in the workshop). They are positioned in this way, as shown in image 3, in order to allow the mounting of the wooden bars (from 30 cm to 30 cm), bars on which the ceiling panels are fitted. The roof insulation is done in the same way as the perimeter wall system. The roof covering support is made out of wooden bars that are supported on the main and secondary steel beams (as shown in image 4).

Image 4. The roof support [1]
3. The prefabricated steel structure

“Prefabrication is the main route of construction work industrialization, ensuring the rapid conversion of building production into a process of assembly and installation of prefabricated elements, made possible by mechanizing the work process.” [6]

By using specific methods for the building’s production process the construction period can be shortened by typifying its elements. The building’s geometry (an octagon inscribed in a circle with a radius of 6 m), double symmetrical, allows modular composition of the steel structure and its components. This helps reduce the range of means used and takes advantage of the structure repeatability to reduce execution time, cost and manufacturing errors. The building’s system is exclusively designed for this type of construction and is based on the theory of lightweight structures (see [7]). By the way the metal structure is assembled and the way the roof system is designed, the space generated by the main beam height can be filled with insulating material. In this way the walls can be composed without being constrained by the specific requirements of conventional buildings. IPE profiles are used for the prefabricated structural elements and joining is made with high-strength screws (see image 5 for a better perspective of the load-bearing steel structure, every element type is depicted in a different color).

The structural elements can be transported to the construction site (prefabricated elements manufactured in a controlled environment) with nonspecific machinery. The relatively lightweight elements can be installed using only conventional machinery.

The steel frame manufacturing particularities are presented, in general, in the next paragraphs. Placing the steel columns in the positions marked in image 6 is required in order:
- to reduce beam stress,
- to simplify the montage process,
- to lower manufacturing costs,
- to reduce foundation costs and
- to allow the use of lightweight perimetral wall systems (eliminating thermal bridges and allowing easier building partitioning).

![Image 5. The load-bearing steel structure](image1)

![Image 6. The columns](image2)
The main girder montage is done in two steps: step 1 (image 7), mounting the main girder on axes 4 and 2 and step 2 (image 8), mounting the main girder on axes 1 and 3. Handling is mechanized and joints are made with high-strength screws. The central joining element (prefabricated octagonal piece used to join the main girders) is mounted only after the provisional mounting of step 1 elements. Corrections are made for columns, girders and the central joint and after fixing those in their position the joints can be finalized (performed for each step).

![Image 7. Step 1](image)

![Image 8. Step 2](image)

The perimetral beams installation is mechanized. The main and perimetral beams are fitted with joining elements (made in the workshop, screws are used in order to join them), figure 3 illustrating the elements (the perimetral beams are featured in yellow, image 9).

![Fig. 3. Perimetral beam joint](image)

![Image 9. Perimetral beams](image)

The coupled beams mounting will be done in four steps: fitting the type A segments-Step 1 (image 10), fitting the type B segments-Step 2 (image 11), fitting the type C segments-Step 3 (image 12), fitting the type D segments-Step 4 (image 13).

In order to reduce the fitting time the two parallel beams are linked together with steel flat-bars that assist in transporting, handling and in the installation process.

Figure 4 shows how the coupled beams are joined with the main girder (the mounting holes and the high-strength screws are purposely unrepresented).

![Fig. 4. The coupled beams](image)
Metal plates are welded at the upper flanges of the coupled I-beams, thus resulting a U shape that grips the main beam upper flange (fitting done in the workshop). These help to guide and fix the elements into position.

The coupled beams mounting will be done in the following order: lifting the segments at the mounting site, positioning them into the main beams plane, sliding them until the vertical steel flat-bars make evenly contact with the main beams web and fix them by introducing temporary clamps to prevent the segments from sliding.

After temporarily positioning the first element it is proceed to the next one, done in the order shown in figure 5.

In order to permanently join two elements of the same type, that are side by side and aligned, the steel flat-bars and the web of the main beam are drilled together and fixed with screws.

Fig. 5. The mounting order [1]

After fitting all the elements of the same type the next ones can be installed. In image 10, 11, 12, 13 one can see these elements (the coupled beams) installed in stages. The first two stages can be done manually (two workers) and the rest mechanized.
RESULTS AND DISCUSSIONS

The chosen system reduces foundation costs, reduces the buildings execution time, removes energy inefficient materials, allows for an unconstrained thermal insulation dimensioning (if desired to improve the initial solution).

The buildings efficient insulation and airtightness reduces energy loss through its envelope and reduces the heating energy requirement.

The chosen system reduces thermal bridges, both from the wall and from the floor level and has a U-value that is less than 0.15 W/(m²K).

Also, walls do not require plastering and painting (using wood for facade finish), rehabilitation interventions can be made locally and at low costs, walls have no load-bearing role and therefore they don’t condition the planning or execution of the load-bearing structure.

Due to the precision at which the metallic structure is contrived the wall elements can be more diversely prefabricated, thus offering more alternatives for transportation, storage and execution.

After a cost estimation, which includes only the costs for materials, the 230 €/m² price is achieved (a built area of 107.40 m², the prices are those given by manufacturers and online stores, prices valid from 02.06.2011 until 13.06.211) [1].

Also the following parts are integral part of the system (and are not taken into account in the cost estimation): the ventilation system, the air to air heat exchanger, the ground to air heat exchanger, the rainwater collection system and the alternative sources of electricity.

CONCLUSIONS

The building sector is increasingly influenced by people’s lifestyles, by the current climatic changes, by systemic economic problems and by international political conditions.

Therefore, systems that can reduce the time and costs of execution, that can lessen environmental impact and are overall beneficial to society, should stand at the base of building design and management.

Using the current technologies, specialised buildings can be made, buildings having characteristics that are relevant to site location and priced as a traditional house.

Also, the use of environmentally conscious design techniques may provide a solution for the pressing ecological, economic and political issues of the country’s housing sector.

Due to changing environmental, social and economical policies, these types of buildings may be accepted in countries in which buildings are predominantly conventional.

The presented system, to the extent at which it was developed, may reduce execution and maintenance costs to a level at which passive houses become widely available.
REFERENCES


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