COMPARISON OF A WOODEN HOUSE AND A POROUS CONCRETE MASONRY HOUSE

Pavol ĎURICA¹, Silvia BAĎUROVÁ^{1*}, Peter ČASNOCHA¹

Abstract

This paper deals with an evaluation of an existing wooden panel house and its comparison with alternative material composition (porous concrete masonry house). The criteria for evaluation are the energy performance, size of the usable area, environmental impact and final costs.

Address

¹ University of Žilina, Research Centre, Faculty of Civil Engineering, Department of Building Engineering and Urban Planning, Univerzitná 8215/1, 010 26 Žilina, Slovakia

* **Corresponding author:** silvia.badurova@rc.uniza.sk

Key words

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- porous concrete house,
- environmental indicators OI3,
- building energy balance,
- final costs.

1 INTRODUCTION

There is a boom in worries related to climate change as well as the continual increase in the cost of energy all over the world. Currently, the only solution for decreasing energy consumption is to build constructions that at least to passive standards. The fact that a building is energy-saving does not mean that it is also suitable for the environment. The significant criterion is the use of ecological building materials which have a very low impact on the environment during their whole life cycle. The most favourable alternative is the choice of sustainable materials which naturally regenerate or which are abundant, i.e. – products from photosynthesis such as wood, straw and reeds or animal products such as wool. Despite the very intensive public education on the advantages of using natural materials for building in recent years, investors either do not trust such constructions or discouraged by higher investment costs.

2 DESCRIPTION OF AN EXISTING FAMILY HOUSE

The evaluated passive wooden house (referred to as version A) was designed and built in 2011. It is situated in northern Slovakia

(altitude 375.2 m a.s.l., outdoor winter design temperature: -15°C, average outdoor daytime temperature in the summer: 18.2°C).

The house is a two-storey building of a simple constructional shape. Natural materials were mainly used for its construction. The building is based on foam glass ($d = 0.5$ m), which is placed on a reinforced-concrete slab ($d = 0.2$ m). The building takes full advantage of solar heat gains. Wooden windows ($U_w = 0.68 - 0.82$ W/(m².K)) with

Fig. 1 Southern view of a wooden family house.

1. Clay Plaster
2. Wooden Panel
3. Vapour Barrier
4. Cellulose Insulation

5. Timber Joist
6. Fibreboard
7. Silicone Plaster

1. Clay Plaster
2. Porous Concrete
3. Adhesive Mortar

4. Expanded Polystyrene
5. Silicone Plaster

Fig. 2 External Walls, $U = 0.107 \text{ W/(m}^2\text{K)}$.

1. Wooden Panel
2. Vapour Barrier
3. Graphite Polystyrene

4. Waterproofing
5. Geotextile
6. Extensive Substrate

1. Clay Plaster
2. Reinforced Concrete
3. Vapour Barrier
4. Graphite Polystyrene

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Fig. 3 Roofs, $U = 0.066 \text{ W/(m}^2\text{K)}$.

triple-glazing are used for fillings. They are protected by an outer shielding, which eliminates overheating of the building in the summer. Part of the southern and western facades is shielded by a terraced roof construction. The compositions of the constructions are shown in Figs. 2-5.

A heat pump, which draws heat from a geothermal source (air to water), provides for the production, distribution and recuperation of heat.

3 COMPARISON OF THE ACTUAL HOUSE CONSTRUCTIONS AND A VARIANT DESIGN

According to the project data, a variant design of the family house was created, which is based on porous elements (referred to as version B). The exterior envelope structures are designed in such a way that it could be possible to achieve the same heat transfer coefficient $U [\text{W/(m}^2\text{K)}]$ (STN 730540, 2012) as in the original structures. The project retained the outer dimensions of the building, the foundation method, the windows, doors, working surface, and the technical solu-

1. Wooden Panel
2. Gravel
3. Hardboard
4. Hardboard

5. Gypsum Board
6. Floor Pad
7. Wooden Parquet

1. Clay Plaster
2. Reinforced Concrete
3. Hardboard
4. Hardboard

5. Gypsum Board
6. Floor Pad
7. Wooden Parquet

Fig. 4 Internal Ceilings.

1. Plasterboard
2. Wooden Panel

1. Clay Plaster
2. Porous Concrete Blocks

1. Clay Plaster
2. Adobe Bricks
3. Timber Frame

1. Clay Plaster
2. Porous Concrete Blocks

Fig. 5 Internal Walls.

tion. The material compositions of the original and variant constructions are shown in Figs. 1 to 4.

4 COMPARISON OF SPACE

The thicknesses d (m) and basis weights m (kg/m²) of the constructions are described in Tab. 1.

The thickness and weight for 1m² of the constructions.

While maintaining the outer dimensions of the building and its disposition, the usable area of Version A is greater by 12 m² than Version B (Tab. 2).

Tab. 2 Total floor areas and weights of houses.

Legend	Symbol	Units	Version A	Version B
Usable Area	A_i	m ²	170.56	158.59
Material Consumption	m	kg/m ²	891.92	1 109.37

Tab. 1 The thickness and weight for 1m² of the constructions.

Legend	Symbol	Units	Version A	Version B
External Wall	d	m	0.482	0.630
	m	kg/m ²	124.680	265.825
Roof	d	m	0.625	0.710
	m	kg/m ²	84.034	163.384
Internal Ceiling	d	m	0.291	0.280
	m	kg/m ²	255.464	162.050
Internal Wall	d	m	0.120	0.120
	m	kg/m ²	60.690	88.900
Internal Wall	d	m	0.180	0.180
	m	kg/m ²	281.327	133.350
Ground Floor	d	m	0.774	-
	m	kg/m ²	716.340	-

5 ENVIRONMENTAL ASSESSMENT

The environmental appraisal for each construction is compared to the indicator $OI3_{KON}$. A structure's $OI3_{KON}$ as an environmental indicator (for 1 m² of a structure) encompasses $OI_{PEI,ne}$ (environmental indicator of non-renewable Primary Energy Input), OI_{GWP} (environmental indicator of Global Warming Potential (GWP)), and OI_{AP} (environmental indicator of Acidification Potential (AP)), in proportions of one-third each.

This is calculated as shown below (IBO, 2011):

$$OI3_{KON} = 1/3 \cdot OI_{PEI,ne} + 1/3 \cdot OI_{GWP} + 1/3 \cdot OI_{AP} \quad [\text{Pts/m}^2] \quad (1)$$

To convert the MJ per 1 m² of structure into $OI_{PEI,ne}$ points, the following linear function is used:

$$f(x) = 1/10 \cdot (x - 500) \quad [\text{Pts}] \quad (2)$$

To convert the kg CO₂ eq. per 1 m² of structure into OI_{GWP} points, the following linear function is used:

$$f(x) = 1/2 \cdot (x + 50) \quad [\text{Pts}] \quad (3)$$

To convert the kg SO₂ eq. per 1 m² of structure into OI_{AP} points, the following linear function is used:

$$f(x) = 100/0.25 \cdot (x - 0.21) \quad [\text{Pts}] \quad (4)$$

Tab. 3 The results of the environmental potentials for 1 m² of a construction.

Legend	Symbol	Units	Version A	Version B
External Wall	$OI3_{KON}$	Pts/m ²	20	68
Roof	$OI3_{KON}$	Pts/m ²	39	55
Internal Ceiling	$OI3_{KON}$	Pts/m ²	16	24
Internal Wall 120	$OI3_{KON}$	Pts/m ²	11	11
Internal Wall 180	$OI3_{KON}$	Pts/m ²	16	13
Ground Floor	$OI3_{KON}$	Pts/m ²	89	-
Windows	$OI3_{KON}$	Pts/m ²	32	-
Door	$OI3_{KON}$	Pts/m ²	29	-

Tab. 4 The results of the environmental potentials for both houses.

Legend	Symbol	Units	Version A	Version B
Environmental Indicator	$OI3_{BGX}$	Pts	31	51
Annual Material Consumption	PEI	MJ/(m ² .a)	82.29	127.97
Annual Bound Production CO _{2,eq.}	GWP	kgCO _{2,eq.} /(m ² .a)	4.39	7.99
Annual Bound Production SO _{2,eq.}	AP	kgSO _{2,eq.} /(m ² .a)	0.0251	0.0283

Tab. 5 The results of the energy balance, PHPP program.

Legend	Symbol	Units	Version A	Version B
Enclosed Volume	V_i	m ³	451.50	414.50
Treated Floor Area	A_i	m ²	166.20	154.20
Specific Heat Demand	E_2	kWh/(m ² .a)	14.86	15.82
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity)	EP_1	kWh/(m ² .a)	71.93	76.86
Total Emissions CO ₂ -Equivalent	m_{co2}	kg/(m ² .a)	18.81	20.10
Heating Load	P_H	W/m ²	15.72	16.65
Frequency of Overheating		%	2.12	2.31
Cooling Load	P_C	W/m ²	5.63	5.87

The environmental quality of conventional structures is shown by the environmental indicator $OI3_{KON}$ on a scale of 0 to 100 points (Tab. 3). For example, an outside wall with an $OI3_{KON}$ of 70 is typical of a standard structure without any environmental optimizations; an $OI3_{KON}$ of 15 or less can only be attained by means of environmental optimization or by a very light structural design (IBO, 2011).

Buildings are made up of a multitude of different structures. One possible way to determine the environmental potential of a whole building is to use the indicator $OI3_{BGX}$. An $OI3_{BGX}$ indicator is the area-weighted mean of the $OI3_{KON}$ values of all the structures contained within an envelope boundary (IBO, 2011).

$$OI3_{BGX} = \frac{\sum_{i=1}^N A_i \cdot OI3_{KON}}{\sum_{i=1}^N A_i} \quad [\text{Pts}] \quad (5)$$

The calculation includes all the materials permanently installed in the house. The lifetime of the building is considered to have a maximum of 50 years. The calculation does not take into account the technical installations, transport and material manipulation on the site.

The results (Tab. 4) indicate that Version A (the wooden house) is the preferable solution with the lowest impacts for all the environmental categories.

6 BUILDING ENERGY BALANCE ASSESSMENT

One of the main criteria in the design of a passive house is the requirement that the building must not use more than 15 kWh/(m².a) in specific heat demands and that the total primary energy (source energy for the electricity, etc.) and consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/(m².a). The specific heat load for the heating source at the design temperature is recommended, but not required, to be less than 10 W/m². In warmer climates and/or during the summer months, excessive temperatures may not occur more than 10 % of the time. The building must not leak more air than 0.6 times the house's volume per hour ($n_{50} \leq 0.6$ 1/h) at 50 Pa or N/m², as tested by a Blower door (Feist, 2007).

Since the value n_{50} can be obtained only from direct measurements in situ, it is considered to have a value of $n_{50} = 0.6$ 1/h in the computations.

The Passive House Planning Package (PHPP) program was used for the computations of the energy balance of the buildings (based on STN EN ISO 13790, 2009). The results are shown in Tab. 5.

The results of the evaluation indicate that the wooden house (Version A) meets the requirements of a passive house, while the results from the porous house (Version B) indicate that it is a low energy house.

7 ECONOMIC ASSESSMENT

The costs for the assessed constructions and their variant solutions were calculated using the CENKROS plus computer programme. The calculations include both material costs and building operating costs.

The resulting values are shown in Tab. 6 and are applied to 1 m² of the given constructions.

Tab. 6 Total cost of materials and building operations relating to 1 m² of both constructions.

Construction	Total cost without VAT [€/m ²]	
	Version A	Version B
External Walls	117.07	103.60
Flat Roof	93.92	102.90
Ceiling	76.13	92.22
Internal Walls 120	48.66	60.89
Internal Walls 180	74.49	65.68

Fig. 6 The resulting comparison of the costs calculated on the total areas of the constructions.

As the versions of the assessed buildings differ only in the structures mentioned above, it is possible to determine the percentage differences without making a detailed budget for the entire buildings (Fig. 6). The porous concrete construction costs (Version B) are lower by 0.8% than the costs of the wooden house (Version A).

8 THE RATE OF THE BUILDING OPERATIONS

The principle behind the rate of the building operations lay in creating an ideal schedule that would constitute a five-day working week and an eight-hour working time.

The building schedule is based on the Critical Path Method (CPM). The critical path represents the shortest possible duration of a project; it means the sections of time that are needed to meet all the project tasks. In this case, the shortest amount of time to complete the building was researched, while only taking the compliance with technological breaks into account and not the season.

When making the concrete and reinforced concrete elements, achieving the required load-bearing capacity was considered after 28 days. In actual conditions, this period can be shortened by using special additives or technologies, while the elements can be loaded after acquiring 60 - 70 % of the required strength. This amount of time is determined by structural engineers.

The beginning of the construction was considered to be 12.3.2010 for both types of buildings. In a case of continual construction, the wooden house (version A) would have been completed on 11.4.2011, with a 396-day realization. The masonry construction (B version) would have been completed on 07.28.2011, and the duration would have been 504 days.

Fig. 7 Time demands for buildings in terms of the number of working days.

Based on the comparison that arises only from the number of working days taken over the timescales (see Fig. 7), the rate of building operations for the wooden construction (version A = 282 working days) is 79 days shorter than in the masonry version made of porous concrete blocks (version B = 361 working days).

Dry assembly technologies are used in wooden buildings; therefore, the period of construction is obviously shorter (a dry constructional process). The requirement for the rate of building operations is also conditioned by the fact that wooden components must not be exposed to weather influences for a long time. For example, the weather can cause an increase in the moisture in wood, resulting in deformations of the timber after its installation or infestation of the wood by biological pests.

Since wooden components are lightweight, they are easy to assemble. In an actual wooden house, the panels for the walls and ceilings are industrially manufactured, and only one crane, with a lifting capacity of up to 14 tons, was needed during its assembling. The great advantage is also unlimited construction, regardless of the time of year.

As far as a masonry building is concerned, there are different techniques used, in which an amount of water is present in the constructions (a wet constructional process). This type of construction is much more time-consuming and requires more technological breaks; the time necessary for the construction is also limited. For example, in terms of production, transport, storage and treatment of concrete, air temperatures that fall below 0 °C or rise above 25 °C at a relative

humidity below 40 % are considered to be extreme. Concreting in such conditions requires the application of appropriate technological measures to eliminate the adverse effects of low or high temperatures on the quality of concrete and concrete structures, but it is a more capital-intensive way of building.

The technology used for masonry buildings is also more demanding, because not only would a mobile crane be necessary for the building operations, but also other machines such as a concrete mixer and a concrete pump would be needed. However, masonry structures are, compared to wooden houses, more resistant to weathering. When the protection of a structure is done properly, the building operations can be interrupted, even for a longer period of time.

9 CONCLUSIONS

Considering that the outer dimensions and dispositions of both assessed family houses remained preserved, wooden houses are the most spacious in terms of useful areas.

Regarding the impact of the buildings on the environment, wooden houses have much better preconditions, mainly in their confrontation with silicate variants. The mining and industrial production of

these materials results in high energy and environmental demands. Stores of silicate resources are estimated to last for about 200 years. Lime-sand blocks, which have a markedly better ecological balance than porous concrete blocks, present a more suitable alternative, such as the use of graphitic extruded polystyrene instead of traditional polystyrene (Marceau, 2008).

From the calculations of the material consumption, it is obvious that wooden houses have a much lower weight and, at the same time, much lower requirements for material transport, which has a positive influence on decreasing air pollution. Their liquidation is quite fast; there is the possibility of recycling or changing the building waste into energy during combustion. Masonry houses need more demolition work, and the costs for moving and storing such building waste are higher (Baďurová, 2013).

The wooden construction seems to be the most expensive alternative in spite of the fact that wooden houses have a higher rate of building works and also have less need for technical equipment at a building site.

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