https://doi.org/10.26552/com.C.2013.1.88-95

Pavol Durica – Silvia Badurova – Radoslav Ponechal *

ENERGY AND ENVIRONMENTAL EVALUATION OF THE SELECTED WOODEN FAMILY HOUSES

Existing buildings are responsible for over 40 % of the world´s total primary energy consumption (data from IEA). The EU adopted the Energy Performance of Buildings Directive [1], which obliges Member States to reduced 20 % in greenhouse gas (GHG) emissions by 2020 compared with 1990 levels, a 20 % cut in energy consumption through improved energy efficiency by 2020 and a 20 % increase in the use of renewable energy by year 2020. The Directive also requires Member States to ensure that, after year 2020, all new buildings in the EU will have to consume "nearly zero" energy.

Slovakia has excellent availability of wood and therefore it would be appropriate to build the family houses as wooden houses in combination with light sandwich envelope structures.

However, more extensive use is still hampered by the prejudice about disadvantages of wooden structures, which are from the past.

This paper evaluates the results of calculation and measuring two wooden family houses, located in the Slovak Republic, from the perspective of low energy construction and sustainable development principles. The first one is a wooden house constructed in the year 2000 and built under valid thermo-technical standards. The second one is a newly built passive family house. The results of energy calculations and measurements under real conditions in situ are presented. The calculations of the theoretical evaluation are appraised in accord with the Energy Performance of Buildings Directive 2002/91/EC [2] and EU and Slovak standards or codes.

Environmental evaluations are performed for existing buildings and the results are confronted with the values from various buildings based on different materials (lightweight concrete blocks and lime-sand bricks).

Keywords: *Wooden family houses, energy and environmental performance, building envelopes.*

1. Introduction

In recent years, increased attention has been given to energy certification for buildings. In Slovakia, Directive 2002/91/EC [2], and Act 555/2005 [3] (of the Slovak code) on energy efficiency, is in force. Its purpose is (by calculating heat preservation, heating, ventilation and cooling, heating of water and lighting) to help achieve improved energy efficiency, ensure the conditions required for the building's interior environment, and make the construction and operation of buildings more effective. The legislation was changed and came into force amendments to the cited laws since 1. 12. 2012 [1], [4]. However, this fact does not affect the presented results.

To achieve sustainable construction, it is important to decrease energy demand through energy efficient, low energy and passive houses. However, just because a building is energy-efficient does not mean it is also environmentally suitable. An important criterion is the use of ecological building materials that do not put great stress on the environment throughout their life cycle.

The main task of methods to evaluate buildings environmentally is to appraise comprehensively the building's characteristics by applying an established set of criteria and parameters, and to accomplish higher environmental standards. Comprehensive appraisals increase environmental awareness and set the basic direction for the building industry, with the goal of protecting the environment and achieving sustainability.

2. Description of houses

The first wooden family house (WFH) was designed and built in 2000 (Fig. 1). It was built in the village of Vavrecka in northern Slovakia (elevation 650 a.s.l., external winter design temperature −18 °C, and average external daytime temperature in summer 18.2 °C). The composition of envelope constructions is shown in Fig. 2.

The heating source is a central heating electrical boiler with power capacity of 12 kW. The heating system is in-floor heating on the first floor, and panel radiators with regulating valves on the second floor. Water is heated by a boiler and electrical flow heater.

The second house was designed and built in the year 2011 as a wooden passive family house (WFPH) – Fig. 3. It is situated in

* **Pavol Durica, Silvia Badurova, Radoslav Ponechal**
Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Zilina, Slovakia,
E-mail: pavol.durica@fstav.uniza.sk

Fig. 1 Wooden family house (WFH)

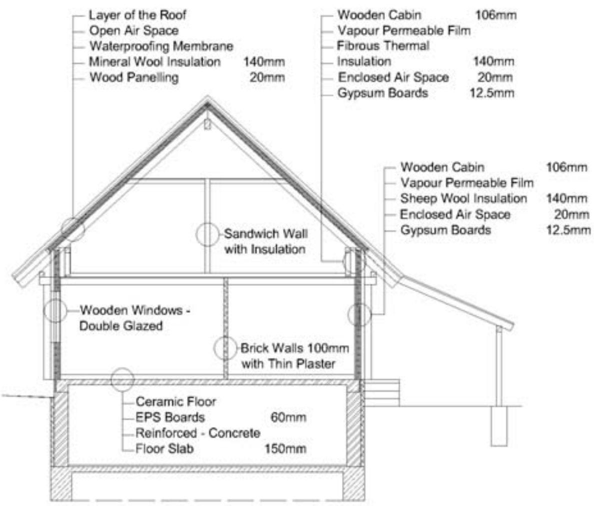

Fig. 2 Section plan of WFH

the village of Brodno in northern Slovakia (altitude 375.2 m a.s.l., outdoor winter design temperature −15 °C, average outdoor daytime temperature in summer 18.2 °C).

It is a two-storey building of a simple constructional shape (Fig. 4). Mainly nature materials were used for its construction.

Fig. 3 Wooden family passive house (WFPH)

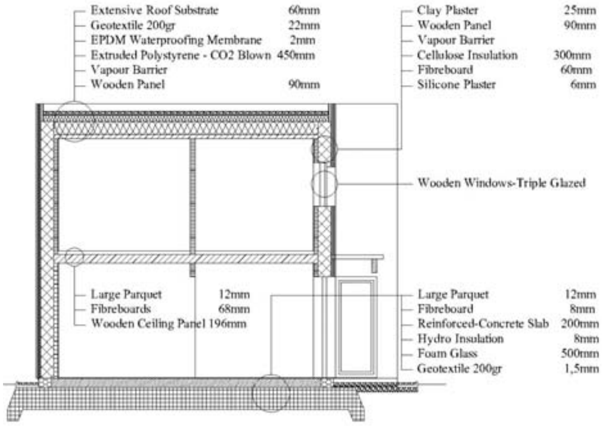

Fig. 4 Section plan of WFPH

Interior walls are made of timber frame constructions which are filled up with clay bricks. The building takes full advantage of solar heat gains. Wooden windows (U_w = 0.68 until 0.82W/(m^2.K)) with triple-glazing are used for fillings. They are protected by outer shielding, which eliminates overheating of a building in summer. The part of southern and western facade is shielded by the roof construction of a terrace.

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

3. Evaluation of thermal performance and protection of buildings

The subjects of the appraisal were the envelope constructions, and the family houses as a whole, as noted in STN 730540:2012 [5].

Thermal performance and protection computations demonstrated that all envelope constructions appraised meet the standard's requirements of stabilized temperature. Evaluation of the building's designed energy consumption indicates that WFH meets the relevant criteria of heat use, and can be classified as an energy efficient building (see Table 1).

This is thanks to the envelope constructions' favourable performance and protection characteristics, and the shape factor. A comparison of the share of individual constructions by transmission heat loss and their flat share of cooling constructions shows the least favourable constructions to be the roof, filling of openings, and basement ceiling.

The evaluation of the project's energy consumption indicates that WFPH meets the relevant criteria of heat rate for heating, and can be classified as an energy efficient house – a passive building (Table 1).

4. Evaluation of energy consumption in operating conditions

Measurement of physical environment parameters was undertaken in the WFH under operating conditions as noted in STN 73 0550 [6]. Measurements were made from 10 February 2010 to 17 March 2010. Temperature and relative humidity of internal air was measured in selected rooms, as was external air temperature and internal surface temperature of selected constructions, in half-hour intervals (Fig. 5). External air temperatures during measurements fluctuated from -14.40 oC to 9.90 oC, with the average outdoor temperature below zero (θae,pr= -1.38 oC).

Thermal energy characteristics under standardizes conditions in STN 730540:2012 [5] — Table 1

Legend	Symbol	Units	Values	
			WFH	WFPH
Total Floor Area	A	[m^2]	190.77	225.66
Enclosed Volume	V	[m^3]	532.93	760.24
Shape Factor	f	[-]	0.75	0.70
Average Heat Transfer Coefficient	UA	[1/m]	0.384	0.14
Heat Use	Qh	[W/(m^2.K)]	13 051	3005.43
Energy Need for Heating	QH,nd	[kWh/a]	68.42	13.32
Specific Energy Need for Heating - standardized	QH,nd	[kWh/(m^2.a)]	83.80	77.66

Regarding average surface temperatures, greater values were recorded for the exterior walls of the ground floor, with average temperatures approaching that of indoor air temperature; this indicates the favourable effect of sunlight (Fig. 6). The lowest temperature was on the wall of the stairway leading to the basement floor ($\theta_{si,pr}$ = 13.98 °C). Indoor surface temperatures observed of the window frame construction, with north-easterly orientation, varied from 14.80 °C to 20.50 °C, with an average value of 17.58 °C. On the glass surface the range was from 12.20 °C to 26.70 °C, with an average of 18.08 °C.

Internal relative humidity was observed in two rooms, each on a different floor. On the first floor, it fluctuated from 20 % to 43 % (averaging 31.43 %); on the second floor it ranged between 30 % and 50 %, averaging 38.78 %. Considering the thermal/humidity microclimate, suitable parameters of heating comfort in the neutral zone were achieved.

Measuring the temperature and monitoring daily consumption of electricity made it possible to assess the WFH for energy consumption for heating under real conditions. The measurement, with a correlation index of IED ≥ 0.7, can be considered an evidentiary measurement in accord with STN 730550 [6], suggesting that the measurement made is highly significant (Table 2).

Energy consumption thus rated corresponds to energy consumption realized by thermal performance and protection attributes of constructions and buildings. It includes the efficiency of the source and distribution of heat in the basement and indicates this wooden house has a very low energy demand (E_2 = 40.10 kWh/(m^2.a)), qualifying it as a low energy building.

Measurements of the WFPH were made from 4th February 2012 to 18th March 2012. The temperature and relative humidity of internal air was monitored in selected rooms, as well as an external air temperature and the internal surface temperature of selected constructions, in half-hour intervals (Fig. 7). External air temperatures during measurements fluctuated from −19.8 °C to 19.5 °C, with the average outdoor temperature below zero ($\theta_{ae,av}$ = −1.3 °C). The temperature of internal air fluctuated from 30.4 °C (the bathroom on the first floor) to 20.1 °C (the children room on the second floor). Average indoor air temperature was $\theta_{ai,av}$ = 22.4 °C.

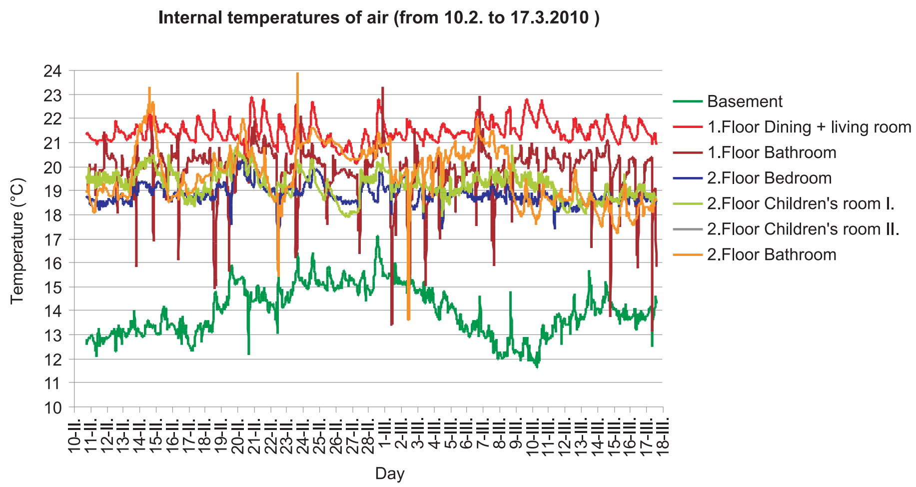

Fig. 5 Indoor air temperatures(WFH)

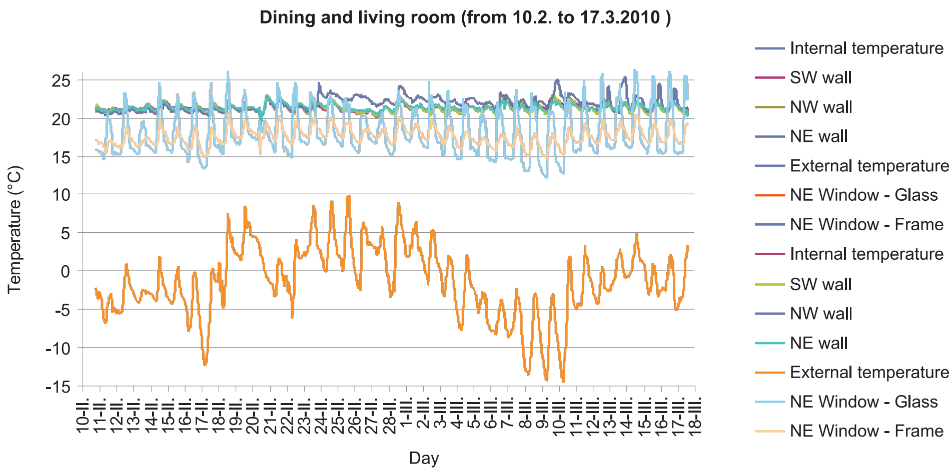

Fig. 6 Temperatures in dining and living room (WFH)

Results of thermal energy evaluation of operating conditions (WFH) — Table 2

Parameter		Unit	Value		
Interval reading	T	day	1	2	3
Regression coefficient – linear	A	–	0.002184	0.002317	0.002239
Regression coefficient – linear	B	–	0.023968	0.042537	0.091369
Energy use for space heating	Ebp	MWh/(V.a)	7.50	7.97	7.75
Energy use	E1	kWh/(m^3.a)	14.07	14.95	14.55
Energy use	E2	kWh/(m^2.a)	40.10	42.62	41.47
Index of correlation	IED	–	0.996	0.998	0.999
Thermal characteristics of building	Q	W/(m^3.K)	41.36	43.97	42.78

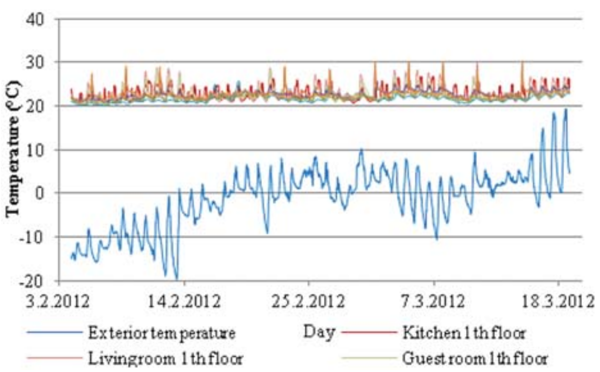

Fig. 7 Real air temperatures(WFPH)

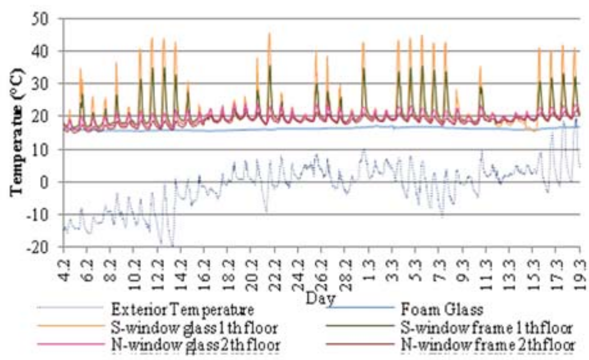

Fig. 8 Temperatures in dining and living room (WFPH)

Family house was ventilated with recuperation. Differences between measured indoor rooms temperatures were minimal (from 0.3 °C to 8.9 °C, the average temperature difference was 2.4 °C). During the whole measured period, indoor air temperatures were not less than 20.1 °C.

In terms of the average values of indoor temperatures were detected fairly consistent progressions between rooms, within a range from about 21 °C to 24 °C. Instant values showed that the influence of direct solar radiation which reaches to the interior, increases indoor air temperature up to 30 °C.

Sensors for scanning internal surface temperature were mounted on the inner window frame as well as in the middle of glazing of the south window situated on the 1st floor (global sunlight) and on the north window situated on the 2nd floor (excluding direct component – diffuse radiation). According to the course of temperatures, it is obvious (Fig. 8) that maximal differences between both glazings are about 10 °C, and at the same time the maximal temperatures were above 40 °C. Temperatures on the inner surface of a frame sill were also higher on the south orientation than on the north one, which means that the south window orientation had positive impact on the energy balance during the monitored time period.

In the basements, there was a temperature sensor installed between a ground slab and foam glass, and together with it the significant, very stable and almost stationary temperature behaviour was observed in changes of outer temperatures. During the measurements, temperatures fluctuated from 15.6 °C to 17.1 °C.

The comparison of two houses shows that the passive house has more stable interior climate. It is resulting from the impact of regulation and recuperation of heat.

5. Environmental assessment of family houses with alternative envelopes

Nowadays there is a rising demand for design solutions that should favour the use of recycled materials for building construction, including the fabrication of building components. Used materials should also allow the recycling of building components at the end of their life cycle or after a building's dismantling.

Quantitative evaluations of building materials are based on a simplified environment model. The system to be analysed is delimited by a precisely defined model. In this assessment model, processes take place independently of inputs and outputs of materials and energy. In the first step, analysis focuses on the material and energy flows which can be clearly assigned to one cause and which are measurable and quantifiable (life cycle inventory). The inputs here are the raw materials and energy requirement and the outputs the emissions into air, water and soil, as well as waste. Environmental effects are ascribed to each input and output, which are then used in the second step for evaluation and weighting purposes [7].

Environmental appraisal for each wall construction is compared to the $OI3_{KON}$. A structure's $OI3_{KON}$ environmental indicator (for 1 m^2 of a structure) encompasses OI_{PECnr} (environmental indicator of non-renewable primary energy content, PEC n.r.), OI_{GWP} (environmental indicator of global warming potential GWP), and OI_{AP} (environmental indicator of acidification potential AP), in proportions of one-third each [7] (Table 3).

The environmental quality of conventional structures is shown by the environmental indicator $OI3_{KON}$ on a scale of 0 to 100 points. 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 [5].

All alternative exterior walls WFH (Fig. 9) are designed to achieve the same heat transfer coefficient as the original walls, U = 0.23 W/(m2.K). Version **a** indicates the real exterior timber frame wall on the first floor and Version **b** on the second floor (Fig. 2).

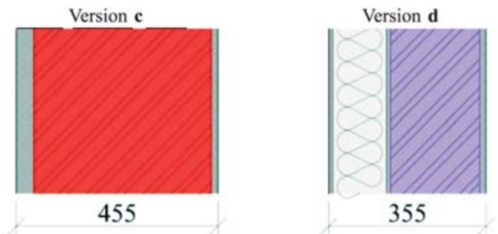

Fig. 9. Considered exterior walls (WFH)
1) Version c – Porous masonry wall (exterior plaster, porous concrete block, interior plaster);
2) Version d – Lime-sand brick wall (exterior plaster, expanded (foam) polystyrene, adhesive mortar, lime-sand block, interior plaster.

The exterior walls results indicate that Version **a** (timber frame with sheep wool insulation) is the preferable solution with the lowest impacts for most categories, whereas the alternatives with higher impacts are Version **c** (porous concrete block masonry).

The results of environmental potentials in comparison with alternatives for 1 m^2 of a structure (WFH) Table 3

Legend	Symbol	Units	Version			
			a	b	c	d
Total weight	m	kg/m^2	77.83	94.21	257.50	416.02
Potential environmental impact	PEI	MJ/m^2	367.07	613.91	807.53	878.09
Global warming potential	GWP	kg/m^2	34.43	28.14	77.96	63.18
Acidification potential	AP	kg/m^2	0.14	0.20	0.19	0.18
Environmental indicator	OI3KON	Pkt/m^2	0.57	15.55	29.11	27.97

The results of environmental potentials in comparison with alternatives for whole house (WFH) Table 4

Legend	Symbol	Units	Real house	Alternative 1	Alternative 2
			Timber frame	Porous blocks	Lime-sand blocks
Effective floor area	A	m^2	221.90	213.17	220.03
Total weight	m	Kg	241 432	272 134	282 370
		kg/m^2	1 088	1 277	1 283
Potential environmental impact	PEI	MJ	662 392	709 081	703 318
		MJ/m^2	2 985	3 326	3 196
Global warming potential (CO2, eqv.)	GWP	Kg	50 250	53 618	49 635
		kg/m^2	226	252	226
Acidification potential (SO2, eqv.)	AP	Kg	203	203	197
		kg/m^2	0.92	0.95	0.90

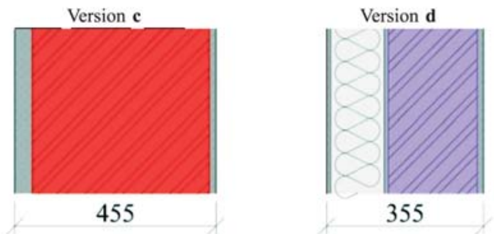

Fig. 10. Considered exterior walls (WFPH)
1) Wall material construction for Version b (Silicone Plaster, Expanded Polystyrene, Adhesive Mortar, Porous Concrete Block, Clay Plaster);
2) Wall material construction for Version c (Silicone Plaster, Graphite Polystyrene, Adhesive Mortar, Lime-sand Block, Clay Plaster)

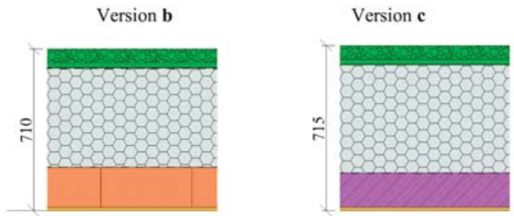

Fig. 11. Considered exterior roofs (WFPH)
1) Roof material construction for Version b (Extensive Roof Substrate, Geotextile, EPDM Waterproofing Membrane, Graphite Polystyrene, Vapour Barrier, Reinforced Concrete Ceiling, Clay Plaster);
2) Roof material construction for Version c (Extensive Roof Substrate, Geotextile, EPDM Waterproofing Membrane, Graphite Polystyrene, Vapour Barrier, Porous Concrete Panels, Clay Plaster)

Evaluation of whole WFH includes all materials permanently installed in the house (Table 4). The calculation does not take into account technical installations, transport and material manipulation in the site.

In the previous case (WFH) only the external walls were changed, but in the second house (WFPH) all the structures were changed (Fig. 10; Fig. 11). All the exterior envelope structures are also designed in such a way that it could be possible to achieve the same heat transfer coefficient as in original structures.). Version **a** indicates the real exterior wooden panel wall and roof (Fig. 4). The results of comparison of all the structures are shown in Tables 5 and 6.

The results of environmental potentials in comparison with alternatives for 1 m^2 of a wall U = 0.107 W/(m^2.K) (WFPH) Table 5

Legend	Symbol	Units	Version		
			a	b	c
Total weight	m	kg/m^2	124.68	265.83	312.58
Potential environmental impact	PEI	MJ/m^2	571.78	1516.33	792.28
Global warming potential	GWP	kg/m^2	24.41	98.64	47.99
Acidification potential	AP	kg/m^2	0.25	0.29	0.17
Environmental indicator	OI3KON	Pkt/m^2	20	68	26

The results of environmental potentials in comparison with alternatives for 1 m^2 of a roof U = 0.066 W/(m^2.K) (WFPH) Table 6

Legend	Symbol	Units	Version		
			a	b	c
Total weight	m	kg/m^2	84.03	163.38	433.83
Potential environmental impact	PEI	MJ/m^2	1064.58	1273.41	1451.54
Global warming potential	GWP	kg/m^2	38.13	64.55	79.30
Acidification potential	AP	kg/m^2	0.25	0.28	0.36
Environmental indicator	$OI3_{KON}$	Pkt/m^2	39	55	73

The results of environmental potentials in comparison with alternatives for 1 m^2 of a whole house (WFPH) Table 7

Legend	Symbol	Units	Version		
			a	b	c
Effective floor area	A	m^2	170.56	169.81	158.59
Total weight	m	kg/m^2	891.92	1491.72	1109.37
Potential environmental impact	PEI	MJ/m^2	3317.90	3883.79	5381.35
Global warming potential	GWP	kg/m^2	178.58	253.14	334.56
Acidification potential	AP	kg/m^2	1.04	0.99	1.21

The results indicate (Tab. 7) that Version **a** (massive wooden panels) is the preferable solution with the lowest impacts for most categories, whereas the alternative with higher impacts is Version **b** (porous concrete block masonry).

6. Conclusions

On the basis of gathered results of theoretical calculations, simulations and measurements in situ related to reference buildings, it is possible to state following conclusions.

The theoretical analysis of current knowledge regarding the issue of envelope constructions and wooden houses as a whole showed their clear advantages from a view of sustainable development.

Realized calculations and experimental measurements of physical parameters applied on the two selected wooden houses show that: the first one was built in the standard level and it is an energy-efficient house, the second house achieves passive standard parameters.

The advantages of a wooden house were vindicated by thermal-energy balance from the energy and also environmental perspective. The comparison showed more assets of a passive building such as a progressive way of building foundation over non-freezing bottom layer thickness using foam glass with saving materials and labour consumption, the considerable decreasing of thermal loss towards the subsoil, getting stable environment in the floor level as well as in the occupable zone, the active use of solar energy, the significant plus share of recuperation in total energy consumption of a family house.

The theoretical and experimental assessment of energy balance and demands of two variants of wooden family houses, made with the aim of comparing them with clasic masonry houses, proved that the most economical family houses are those on the basis of wood, which is possible to work out in the following points:

- Since the outer dimensions and dispositions of both assessed family houses remained preserved, wooden houses are the most spacious as for useful area.
- Regarding the impact of buildings on the environment, wooden houses have much better preconditions, mainly in confrontation with silicate variants. Mining and industrial production of these materials means high energy and environmental demands. Stores of silicate resources are estimated to last for about 200 years. Sand-lime blocks, which have markedly better ecological balance than porous concrete blocks, present more suitable alternative like the use of graphitic (gray) styrofoam instead of traditional styrofoam.
- From the calculation of material consumption, it is obvious that wooden houses have much lower weight and at the same time much lower requirements for material transport, which has a positive influence on decreasing air pollutions. Their liquidation is quite fast, there is a possibility of recycling or changing the building waste into energy at combustion. Mansory houses need more demolition works and the costs for moving and storing such a building waste are higher.

References

[1] Directive 2010/31/EC of the European Parliament and of the Council on the Energy Performance of Buildings (recast), *Official J. of the European Union,* 18. 6. 2010, L 153/13-35.

[2] Directive 2002/91/EC of the European Parliament and the Council on "Energy Performance of Buildings", *Official J. of the European Communities,* U. V. Es L 1, 4. 1. 2003, p. 65-71.

[3] Act No. 555/2005 Coll. on Energy Performance of Buildings and on Amendment and Supplements to Certain Acts, as amended (the "Act").

[4] Act No. 300/2012 Coll. amending and supplementing Act No. 555/2005 Coll. on Energy Performance of Buildings and on Amendments and Supplements to Certain Laws, as amended, and amending and supplementing Act No. 50/1976 Coll. on Land Use Planning and Building Order (Building Act), as amended.

[5] STN 73 0540 part 1-3 Thermal performance of buildings and components. Thermal protection of buildings, Slovak Standards Institute, Bratislava, 2012.

[6] STN 73 0550 Measuring of heating energy consumption. In situ method, Slovak Standards Institute, Bratislava, 1998.

[7] IBO, Guidelines to calculating the OI3 indicators Version 2.2, Osterreichisches Institut fur Bauen und Okologie GmbH, 2011.