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THE ENERGY AND ENVIRONMENTAL EVALUATION OF A WOODEN HOUSE

ENERGETYCZNA I ŚRODOWISKOWA OCENA DOMU DREWNIANEGO

A b s t r a c t

This paper deals with a comprehensive assessment of thermal energy balance of the selected wooden family house. The envelope constructions are made from light sandwich structures. The evaluation includes the theoretical calculations, which are determined in terms of normative requirements of the real implementation of wooden house. The results showed the actual energy consumption measurements of heating and thermal-relaxing parameters in the summer climate period as well as the outputs from dynamic simulations of the behaviour of buildings under various operating modes. Wooden family house is compared with two alternative exterior walls for the same house to identify energy and environmentally preferable solutions.

Keywords: wooden house, building envelopes, energy performance, environmental impacts

S t r e s z c z e n i e

Artykuł zawiera szczegółową ocenę bilansu energii cieplnej w wybranym drewnianym domu rodzinnym. Konstrukcje otulinowe zbudowane są z lekkich struktur przekładanych. Ocena obejmuje obliczenia teoretyczne określone z perspektywy normatywnych wymogów realizacji domu drewnianego. Wyniki ukazały zarówno pomiary rzeczywistego zużycia energii w parametrach ogrzewania i komfortu termalnego w okresie letnim, jak i efekty dynamicznych symulacji zachowania budynków w różnych trybach operacyjnych. Drewniany dom rodzinny zostaje porównany z dwiema alternatywami ścian zewnętrznych dla jednego domu w celu identyfikacji preferowanych rozwiązań w zakresie energii i środowiska.

Słowa kluczowe: dom drewniany, otuliny budowlane, wydajność energetyczna, wpływy środowiskowe

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1. The energy performance of a family house

1.1. Description of a wooden house

Fig. 1. Wooden family house

Rys. 1. Drewniany dom rodzinny

The evaluated family house (Fig. 1) was designed and built in the year 2000. It is located in the village of Vavrečka in northern Slovakia (elevation 650 a.s.l., external winter temperature -18°C, average external daytime temperature in summer 18.2°C).

The house is occupied by a five-person family. The building is rectangular-shaped with 9 x 10 m dimensions. The main building components are described in Fig. 2.

The heating source is a central heating electrical boiler with the 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 an electrical flow heater.

1.2. The evaluation of the thermal performance and protection of the building

The subjects of the appraisal were the envelope constructions and the family house as a whole as noted in STN 730540:2002 [1].

Thermal performance and protection computations demonstrated that all the appraised envelope constructions met the normative requirements of stabilized temperature. The evaluation of the building's designed energy consumption indicates that this family house meets the relevant criteria of heating rate and can be classified as an energy-efficient building (Tab. 1).

Table 1

Thermal energy characteristics under standardized conditions in STN 73 0540:2002 [1]

Calculated parameter	Symbol	Units	Real house
			Timber frame
Total floor area	A	[m²]	190.77
Enclosed volume	V	[m³]	532.93
Shape factor	-	[1/m]	0.75
Average heat transfer coefficient	U_A	[W/(m²·K)]	0.38
Heat use	Q_h	[kWh/a]	13,051
Energy need for heating	E_2	[kWh/(m²·a]	68.42
Specific energy need for heating – standardized	E_{2N}	[kWh/(m2·a]	83.80

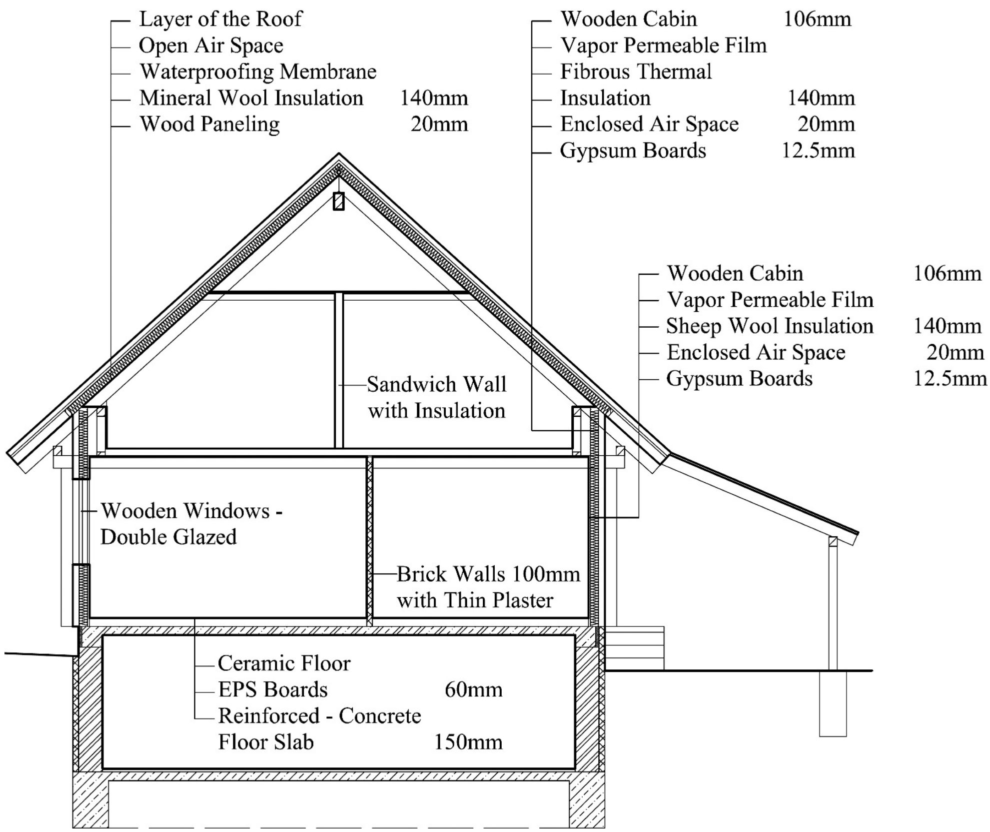

Fig. 2. Simple section plan of wooden house

Rys. 2. Prosty plan przekrojowy domu drewnianego

1.3. The operational evaluation of the thermal performance of the building

The measurement of the physical environment parameters was undertaken in the family house under the operating conditions as noted in STN 73 0550 [2]. The measurements were done from February 10, 2010 to March 17, 2010. The temperature and relative humidity of internal air was measured in selected rooms, similarly to the external air temperature and internal surface temperature of selected constructions, at thirty-minute intervals. During the measurements, the temperatures of external air fluctuated from -14.40ºC to 9.90ºC, with the average outdoor temperature below zero ($\theta_{ae,av}$= -1.38º C). The highest temperature of indoor air ($\theta_{ai,av}$ = 21.44ºC) was measured in the kitchen coupled with the dining room and the living room situated on the first floor. The lowest temperature ($\theta_{ai,av}$ = 18.85ºC) was in the master bedroom where the heating was turned off. The average temperature of indoor air was $\theta_{ai,av}$ = 20.10ºC in heated spaces which indicates the appropriate user mode. The highest temperatures were measured downstairs in comparison with the upstairs.

Measuring the temperature and monitoring daily electricity consumption made it possible to assess the wooden house for energy consumption in heating under real conditions. The measurement, with a correlation index of $I_{ED} \geq 0.7$, can be considered an reliable measurement in accordance with STN 730550 [2], suggesting that the conducted measurement is highly significant (Tab. 2). Thus, rated energy consumption corresponds with energy consumption realized by the thermal performance and protective attributes of constructions and buildings. It includes the efficiency of heat source and distribution in the basement and indicates that this wooden house has very low-energy demand(E_2 = 40.10 kWh/(m^2·a)) qualifying it as a low-energy building.

Table 2

***Heating energy consumption measured in situ under STN 73* 0550:1198 [2]**

Reading interval		1	2	4
T [day]				
$E_{Building}$ – Heating energy consumption	[MWh/(V_B·year)]	7.50	7.97	7.75
E_1 – Heating energy consumption	[kWh/(m^3·year)]	14.07	14.95	14.55
E_2 – Heating energy consumption	[kWh/(m^2·year)]	40.10	42.62	41.47
I_{ED} – Correlation index	[-]	0.996	0.998	0.999

1.4. Energy simulation in the building

Numerical simulation calculations were done by the ESP-r program from the University of Strathclyde [3]. The heating loads, delivered annual energy for heating and maximum dry bulb interior temperatures are evaluated at an eight-zone model. Some external shadings (solar obstacles) are considered in this study (Fig. 3).

For the sake of the simplification of heating load calculation, we have assumed a 24-hour system operation with no day or night time setback at the moment. The sensor of dry bulb air temperature was set at 20.3ºC for each room.

Fully convective heating and cooling have been simulated in this study. The predicted heating loads and delivered energy are strongly dependent on the applied surface convective heat transfer coefficient model. The variation of about 10% to 15% is commonly encountered.

In this study, we use the standard International Weather for Energy Calculation climate file for Ostrava. Some statistics from this hourly climate database is shown below:
Location – OSTRAVA – CZE {N 49°43'} {E 18°10'} {GMT +1.0 Hour}
Elevation – 256 m above sea level
Monthly Statistics for Dry Bulb temperatures °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max.	8.1	6.7	13.5	22.0	26.6	29.1	28.9	32.9	24.6	24.2	17.8	7.9
Min.	-12.7	-14.1	-4.3	-0.8	0.9	7.5	7.6	4.2	3.0	-1.3	-7.5	-12.8
D.avr.	-1.1	-1.2	3.7	8.3	13.5	16.2	18.6	17.7	13.6	9.4	3.4	-0.4

The heating load and annual demand calculations have been done with casual heat gains of 2.3 W/m^2. For each room, we have used the uniform air exchange number n = 0,4 1/h in wintertime.

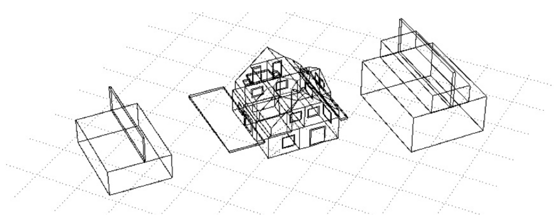

Fig. 3. Simplified simulation model with solar obstacles

Rys. 3. Uproszczony model symulacyjny z przeszkodami słonecznymi

The supply of energy needed for keeping the indoor air temperature in the winter was the basic condition for evaluating the energy performance of the building. Energy needed for heating is 9336.48 kWh in real conditions. This value was compared with other alternatives of different exterior envelopes as described below. In comparison with the wooden house, both alternatives are the highest energy demand: a porous block wall 9659.67 kWh and a lime-sand brick wall 9500.34 kWh, while the second alternative is more favourable.

Light sandwich constructions are characterized by excellent thermal insulation properties but they have a low thermally accumulated effect which causes the overheating of indoor spaces in the summer. The measured results and simulated temperatures were compared with the external temperature from 17.3°C to 30.8°C on a typical summer day. Figure 4 shows traces of measured and simulated dry bulb temperatures in individual rooms. The course of temperatures shows a relatively good match between measurements and simulations. During direct exposure to sunlight, the simulation values are higher than the measurement values.

Despite high external temperatures, the measurements in the rooms were relatively favourable (bellow 26°C – thermal comfort). The temperatures above the borderline 26°C were measured in children's rooms with north-east and north-west orientation.

Figure 5 shows the simulated traces of indoor air temperatures for all alternatives of different exterior envelopes. Approximately the same temperature routing between a light wood sandwich wall (average daily temperature 25.07°C) and a porous block wall (average daily temperature 24.96°C) was observed. The lime-sand brick wall with higher density had lower temperature routing (average daily temperature 24.2°C, i.e. 1-2°C lower).

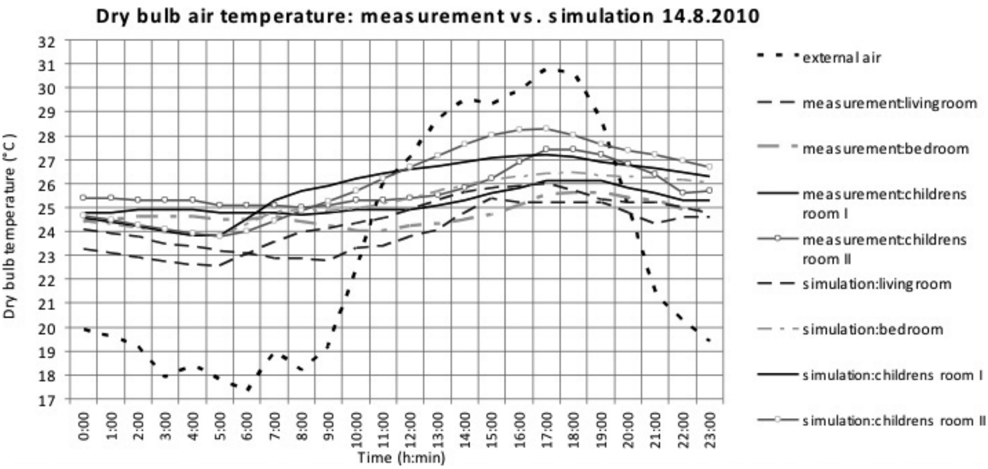

Fig. 4. Indoor one day air temperature curves – measured and simulated

Rys. 4. Jednodniowe krzywe wewnętrznej temperatury powietrza – mierzone i symulowane

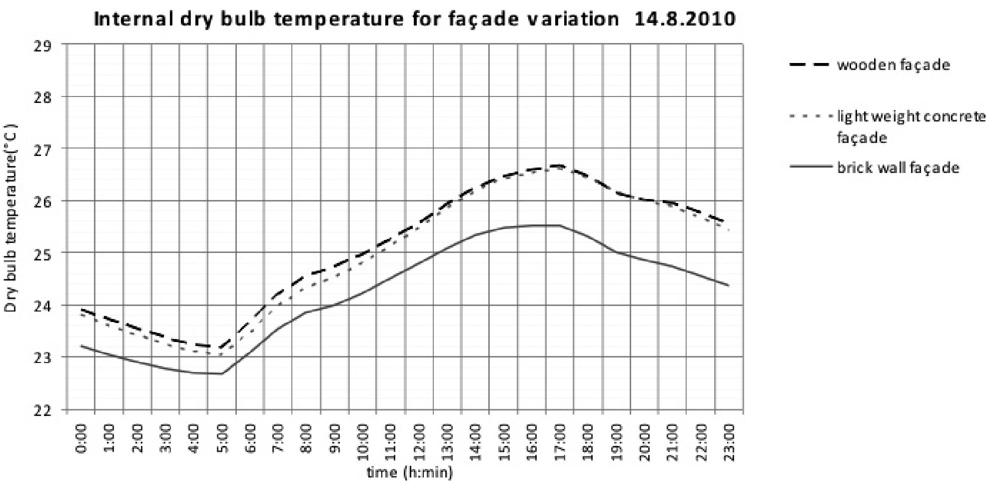

Fig. 5. Indoor one day air temperature curves – simulated façade variations

Rys. 5. Jednodniowe krzywe wewnętrznej temperatury powietrza – symulowane wariacje fasady

2. The environmental assessment of a family house with alternative exterior walls

2.1. An environment model

Nowadays, there is rising demand for design solutions that should favour the use of recycled building materials, including the fabrication of building components. Applied materials should also allow for the recycling of building components at the end of their life cycle or after 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 material and energy inputs and outputs. In the first step, the analysis focuses on material and energy flows which can be clearly assigned to one cause and which are measurable and quantifiable (life cycle inventory). Here, the inputs are raw materials and energy requirements, whereas the outputs are emissions into air, water and soil as well as waste. The environmental effects are ascribed to each input and output which are then used in the second step for evaluation and measurement purposes [4].

2.2. The evaluation of exterior walls

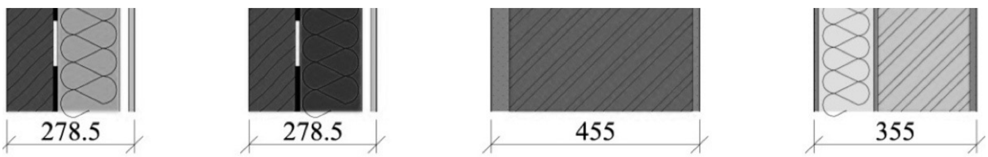

Fig. 6. Considered exterior walls:
a) First floor timber framework wall
(wooden cabin, vapour permeable membrane, sheep wool insulation/wooden frame, service void, gypsum board);
b) Second floor timber framework wall
(wooden cabin, vapour permeable membrane, wood-fibre insulation/vertical stud, service void, gypsum board);
c) Porous masonry wall (exterior plaster, porous concrete block, interior plaster);
d) Lime-sand brick wall
(exterior plaster, expanded (foam)polystyrene, adhesive mortar, lime-sand block, interior plaster)

Rys. 6. Analizowane ściany zewnętrzne

All alternative exterior walls are designed to achieve the same heat transfer coefficient as the original walls: $U = 0.23$ W/(m2·K).

Environmental appraisal for each wall construction is compared to the $OI3_{KON}$. A structure's $OI3_{KON}$ environmental indicator (for 1m² 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 one-third proportions each [4].

Table 3

The results of environmental potentials in comparison with alternatives for 1 m² of a structure

Legend	Symbol	Units	Version			
			a	b	c	d
Total weight	m	[kg/m²]	77.83	94.21	257.50	416.02
Potential environmental impact	PEI	[MJ/m²]	367.07	613.91	807.53	878.09
Global warming potential	GWP	[kg/m²]	34.43	28.14	77.96	63.18
Acidification potential	AP	[kg/m²]	0.14	0.20	0.19	0.18
Environmental indicator	$OI3_{KON}$	[Pkt/m²]	0.57	15.55	29.11	27.97

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).

2.3. The evaluation of the whole house

The calculation includes all the materials permanently installed in the house. The calculation does not take account of technical installations, transport or material manipulation on site.

Table 4

The results of environmental potentials in comparison with alternatives for the whole house

Legend	Symbol	Units	Real house	Alternative 1	Alternative 2
			Timber frame	Porous blocks	Lime-sand blocks
Effective floor area	A	[m²]	221.90	213.17	220.03
Total weight	m	[kg]	241,432	272,134	282,370
		[kg/m²]	1,088	1,277	1,283
Potential environmental impact	PEI	[MJ]	662,392	709,081	703,318
		[MJ/m²]	2,985	3,326	3,196
Global warming potential (CO2, eqv.)	GWP	[kg]	50,250	53,618	49,635
		[kg/m²]	226	252	226
Acidification potential (SO2, eqv.)	AP	[kg]	203	203	197
		[kg/m²]	0.92	0.95	0.90

The presented theoretical ratings demonstrate that using ecological materials and optimizing architectural constructions can guarantee better quality of a house and provide a healthier indoor environment. This leads to reducing the amount of applied materials. The objective of environmental evaluation systems is to design, construct and maintain buildings with minimal environmental risks for the users and minimal negative impacts on the environment.

3. Conclusions

The results of energy and environmental assessment, done by using measurements, stationary and non-stationary calculations and light sandwich wooden house confirmed an appropriate use of low-energy buildings under the climatic conditions in Central Europe.

It is possible to claim that a wooden house is more suitable in comparison with alternative ones. The biggest disadvantage of a wooden house is its lower thermally accumulated effect but the temperatures in the monitored rooms were similar to the porous block variant in the summertime.

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Denotations

PEI – potential environmental impact
GWP – global warming potential
AP – acidification potential
$OI3_{KON}$ – environmental indicator
m – total weight
E_1 – heating energy consumption

References

[1] STN 730540 Thermal performance of buildings and components. Thermal protection of buildings, Slovak Standards Institute, Bratislava 2002.
[2] STN 730550 Measuring of heating energy consumption. In situ method, Slovak Standards Institute, Bratislava 1998.
[3] University of Strathclyde, Energy Systems Research Unit (http://www.esru.strath.ac.uk).
[4] IBO, *Guidelines to calculating the OI3 indicators Version 2.2*, Österreichisches Institut für Bauen und Ökologie GmbH, 2011.