

Design of envelopes for timber buildings in terms of sustainable development in the low-energy construction

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Abstract. The paper focuses on theoretical analysis of physical determinants affecting construction of envelopes for wood-based structures in the intentions of sustainable development under the current and expected legislation in Slovakia after 2020. It deals with the optimization of model building envelopes in terms of heat loss according to the requirements of the Europe 2020 Strategy and consequently calculates the values of the fire resistance considering Eurocode 5. It assesses the application and fire safety of analysed envelopes in construction of buildings with a combustible construction system, i.e. wood-based buildings intended for housing and accommodation, in accordance with the Slovak legislation. The paper also concentrates on the optimisation of built-in thermo-insulating and facing materials of wooden load-bearing members in the model building envelopes in terms of the environmental burden throughout their life cycle and the impact on the resulting fire resistance. It assesses the possibilities of using building components made from recycled materials in the construction of timber buildings as a full-valued replacement of standard building materials from non-renewable sources.

1. Introduction

At the beginning of this millennium, the world's communities began to deal with the issue of sustainable energy consumption due to the pollution of macroclimate by production-based emissions. Possibilities for the global use of renewable energy sources are being sought. Builders now prefer low-emission manufacturing processes and products to maintain the sustainable development and the balance in all areas of human life including global responsibility of each individual for the current and future human coexistence with the ecosystem. The energy consumption and production-based emissions should be significantly reduced in the construction of buildings. The environmental burden associated with building's construction comprises the three stages - preparation and construction, operation, and disposal at the end of its lifetime. The choice of materials and compositions strongly affects the production of emissions in all the stages.

2. Slovak legislation in sustainable construction

Since 1992, when the UN Conference on Environment & Development was held in Rio de Janeiro, the main objective of the international community has been to achieve sustainable development. The document from this summit outlines the principles for sustainable land development in terms of social, environmental, and economic growth. Twenty seven principles of sustainable development result from Agenda 21, the declaration on environment and development adopted by more than 178 Governments



at this conference. Chapter 7 contains the basic concept for sustainable construction. It specifies main problems, determines the resulting tasks for the individual participants of the construction process, and defines the criteria of sustainable construction considering their significance during all phases of the building's life cycle. It deals with the following issues: dilution, product quality, building's environmental impact, resource consumption - energy, water, soil, materials, impact of building construction on sustainable urban development, ecological burdens, social, cultural, and economic issues. This document is a follow-up to the Europe 2020 Strategy which is one of the main economic reforms of the EU.

One of the main objectives is to construct all new buildings as nearly-zero-energy ones as of 31 December 2020. As for the buildings in state ownership, this requirement has been in effect since 2018. The obligation of all EU members is to reduce greenhouse gas emissions by min. 20% by 2020 and to increase the energy efficiency of buildings including the use of energy from renewable sources by 20%. [1] Specification of the requirements for eco-friendly products is defined in the Regulation of the European Parliament and European Council No. 305/2011 [2] replacing the European Council Directive No. 89/106 /EEC on construction products. The basic requirements for the buildings defined therein are supplemented by the new seventh requirement - the sustainable use of natural resources. This requirement is supported by a set of European Standards incorporated into Slovak legislation. [2] The standards for designing sustainable buildings are as follows: STN EN 15643-Part 1-4, STN EN 15942 (73 0911) Sustainable construction, Environmental product declarations, Communication Formats in the Business Environment (1 April 2012); STN EN 15804 (73 0912) Sustainable construction, Environmental product declarations, Basic rules for Building Products (1 August 2012); TNI CEN/TR 15941 (73 0910) Sustainable Construction, Environmental product declarations, Methodology for the selection and use of generic data (1 August 2010).

3. Analysis of determinants affecting the construction of lightweight wood-based envelopes in the intentions of Europe 2020 Strategy

3.1. Thermal protection

The first determinant affecting the construction of a lightweight wood-based envelope is the **thermo-insulating efficiency** and the subsequent energy performance of a building under the given climatic conditions in both winter and summer. Currently, the legislative requirements for thermal insulation of building envelopes are specified in STN 735040-2:2012, Z1-2016 so that the building would meet the condition of the global indicator - primary energy in kWh/(m².a) within class A1 of Energy Efficiency Index (EEI) Classification. The limited values depend on the building's category, i.e. its functional use. From 2020 onwards, all the designed buildings, including those for housing, will have to meet national requirements for energy consumption in the category of nearly-zero-energy buildings within the global indicator - primary energy in kWh/(m².a) within class A0 of EEI. The increasing demands for reduction of heat loss through the building envelopes means the increasing demands for thermo-insulating efficiency of the thermal insulation related to its thickness and thermal conductivity coefficient. Apart from the thermo-insulating effectivity, the flammability class, lifetime, and recyclability are also important. [2]

3.2. Fire safety

The second determinant fundamentally affecting the construction of a lightweight wood-based envelope, both in terms of the composition and use, is the **fire safety**.

Wood-based construction systems are in terms of fire safety classified as combustible structural units. The fire height of the buildings with the timber supporting system according to legislation valid in Slovakia is limited to maximal 12 m, except the buildings intended for housing and accommodation (typically 4-storeyed). This goes provided that the fire load calculated in the most critical fire section of such buildings is up to 20 kg/m². If the fire load is higher than 60 kg/m², the maximal allowable fire height is 9 m. The requirement for maximal fire resistance of the load-bearing members is REI 90.

According to the currently valid standards, residential buildings and houses may contain wood-based load-bearing systems up to the 3rd storey (see Table 1). The fire resistance requirement for the first level of fire safety is REI 30.

Considering the above limitations, the non-combustible construction system, e.g. the concrete skeleton, is combined with the envelope made of timber sandwich panels. The use of this system is limited by the requirement for non-combustible fire sections to be situated between the fire areas in both vertical and horizontal direction. This system may be used in buildings with the fire height of 12 m where the fire sections are not required. It does not go for the residential buildings where the fire sections are always required.

The resulting fire resistance of wooden load-bearing structures depends on the covering and filling materials and is a criterion for the possibility of their application in a building.

Table 1. Fire safety degrees for residential buildings and buildings from B group and the required fire resistance of the load-bearing building envelope with the combustible construction unit.

Construction unit	Maximal number of above ground storeys	Required fire safety	Minimal fire safety degree of fire sections	
			above ground storey + 1st below ground storey	2nd and further below ground storey
Combustible	1	REI 30	I	
	2	REI 45	II	inadmissible
	3	REI 60	III	

3.3. Environmental burden

The third determinant important for choosing materials and construction of a lightweight wood-based envelope is the **environmental burden** at the time of its construction as well as disposal. The environmental burden is defined by the built-in energy consumption and the emissions produced throughout its life cycle.

It is determined by the embodied energy consumption and emissions produced throughout the life cycle. The aspect of embodied energy consumption is monitored - the energy consumed throughout the life cycle of a product given in MJ/m² PEI and the amount of emissions produced in the production, use, and disposal of a product: CO₂ekv - GWP (global warming potential), SO₂ekv - AP (acidification potential), PO₄ekv - EP (eutrophication potential), R-11ekv - ODP (ozone depletion potential), C₂H₄ - POCP (ground-level ozone formation potential).

In terms of emission reduction, it is optimal to use slab covering and recycled thermo-insulating materials for the load-bearing structures in the construction of lightweight wood-based envelopes.

4. Composition optimization of wooden sandwich structures in terms of thermal and fire protection in the context of sustainable efficiency in the model solution

4.1. Composition optimization of wooden sandwich structures in terms of thermal protection for the construction after 2020

Nowadays, wood-framed construction systems are the most commonly used in the construction of wood-based structures. In the low-storey structures, the frame construction acts as both a supporting system and a load-bearing structure of the envelope. The load-bearing structure of the envelope is made of vertical wooden posts with an air gap filled with thermal insulation.

The choice of thermal insulation for sandwich timber structures is conditioned by its thermo-insulating efficiency, combustibility class, durability, and recyclability. The building envelope and timber load-bearing framework must be designed so that the water condensation would not occur on joints of timber elements. As for hygienic demands, the layers of thermal insulation and its physical parameters must be designed to keep the minimal surface temperature of the interior wall above the critical surface temperature for mould growing, depending on the boundary environmental conditions

and the type of heating. The type and thickness of thermal insulation is essential for the fire resistance of a timber panel. Its melting temperature should be above 1000 °C and a minimal mass weight should be above 30 kg/ m³. Thermal insulation based on mineral-wool or glass-fibre meets these physical parameters. [3]

Each of the compositions analysed is designed considering the approximately required standard heat transfer coefficient $U \leq 0.15$ W/m²K which will be in force for buildings in Slovakia after 2020. All the model structures have the same supporting timber construction differing in the thermal insulation as well as in the interior and exterior surface finishing. Detailed compositions of model solutions are given in Table 2.

Table 2. Construction solutions of envelope model compositions with physical parameters of layers.

	Type of a layer (from inside to outside)	Thickness [mm]	ρ [kg/m ³]	λ W/mK	R m ² K/W	$\Delta OI3$ Pkt/m ²
Wall 1 Glass wool	Gypsum plasterboard	15	900	0.25	0.06	4
	90% Glass wool MW	60	18	0.038	1.57	6
	10% Timber – frame a' = 625 mm	(60/40)	475	-	-	0
	Polyethylene (PE) vapour brake	1	-	0.5	0	5
	OSB boards	18	650	0.13	0.14	4
	80% Glass wool MW	140	18	0.038	3.68	8.4
	20% Timber – frame a' = 625 mm	(140/60)	475	-	-	-1
	OSB boards	18	650	0.13	0.14	4
	Mineral adhesive	5	-	1.0	0.01	3
	Mineral thermo-insulating panel	80	112	0.044	1.8	9.5
	Silicate plaster with synthetic resin additive, reinforced	5	-	0.8	0.01	9
Wall 2 Wood fibre	Gypsum plasterboard	15	900	0.25	0.06	4
	Wood fibre WF-W Fibreboard soft	60	50	0.042	1.43	2.4
	10% Timber – frame a' = 625 mm	(60/40)	475	-	-	0
	Polyethylene (PE) vapour brake	1	-	0.5	0	5
	OSB boards	18	650	0.13	0.14	4
	Wood fibre WF-W Fibreboard soft	140	50	0.042	3.33	5.6
	20% Timber – frame a' = 625 mm	(140/60)	475	-	-	-1
	OSB boards	18	650	0.13	0.14	4
	Wood fibre WF-W (130 kg/m ³)	80	130	0.046	1.74	7
	Silicate plaster (without synthetic resin additive)	10	-	0.8	0.01	3
Wall 3 Cellulose	Gypsum plasterboard	15	900	0.25	0.06	4
	90% Glass wool MW	60	18	0.038	1.57	6
	10% Timber – frame a' = 625 mm	(60/40)	475	-	-	0
	Polyethylene (PE) vapour brake	1	-	0.5	0	5
	OSB boards	18	650	0.13	0.14	4
	89% Cellulose vertical cavity wall insulation	140	54	0.041	3.41	6
	(11%) Timber	(140/60)	-	-	-	-1
	OSB boards	18	650	0.13	0.14	4
	Mineral thermo-insulating panel	80	112	0.044	1.8	9.5
	Silicate plaster (without synthetic resin additive)	10	-	0.8	0.01	3
	Clay plaster	15	900	0.81	0.02	1

Wall 4 Sheep wool	Wood wool panel WW, magnesite-bonded	60	550	0.14	0.43	6
	Polyethylene (PE) vapour brake	1	-	0.5	0	5
	OSB boards	18	650	0.13	0.14	4
	90% Isolena Schafwolle, Optimal,	140	18	0.043	3.25	1
	20% Timber – frame a' = 625 mm	(140/60)	475	-	-	-1
	OSB boards	18	650	0.13	0.14	4
	Wood fibre WF-W (130 kg/m ³)	120	130	0.046	2.6	13.9
	Silicate plaster (without synthetic resin additive)	6	-	0.8	0.01	3
Wall 5 Hemp fibre	Gypsum plasterboard	15	900	0.25	0.06	4
	90% Isolena Schafwolle, Optimal,	60	18	0.043	1.4	1
	10% Timber – frame a' = 625 mm	(60/40)	475	-	-	0
	Polyethylene (PE) vapour brake	1	-	0.5	0	5
	OSB boards	18	650	0.13	0.14	4
	80% Hemp fibre insulation	140	41	0.045	3.11	8.4
	20% Timber – frame a' = 625 mm	(140/60)	475	-	-	-1
	OSB boards	18	650	0.13	0.14	4
	Wood fibre WF-W (130 kg/m ³)	80	130	0.046	1.74	9.3
	Silicate plaster (without synthetic resin additive)	10	-	0.8	0.01	3

4.2. Composition optimization of wooden sandwich structures in terms of fire protection

The fire resistance of the designed perimeter walls is directly dependent on the materials used. All the compositions consider the fire resistance of the interior covering up to timber supporting structure.

The required time for the fire resistance and the criteria for limit states of timber load-bearing elements of external walls are directly related to the static load. In the case of frameworks, the timber vertical elements are part of the supporting walls and are linked up by the horizontal ceiling or roof supporting elements. These structures, including all bracing and anchor elements, must meet the REI criterion.

The composite supporting elements of the fire-separating structures, as well as all the elements related to the supporting ones in terms of load, are required to meet the criteria for the fire resistance time. The interaction of all the elements provides the fire resistance of the whole structure. In the case of timber supporting elements, the value of fire resistance can be determined by calculation methods depending on the static load using STN EN 1995-1-1 (Eurocode 5). The fire resistance of timber or wood-based load-bearing and construction elements depends on the burning and charring speed.

As the analysed compositions are model solutions and the static stress of the supporting wall elements is unknown, the assessed fire resistance comprises layers up to the timber supporting wall structure. The chart in Figure 1 compares the individual construction solutions in terms of fire resistance and the extent of their use in multi-storey structures according to the requirements given in Table 1.

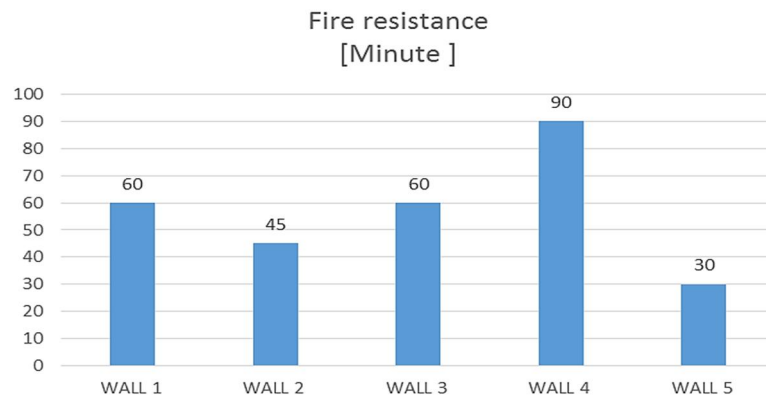


Figure 1. Comparison of construction solutions in terms of fire resistance.

5. Composition optimization of wooden sandwich structures in terms of environmental burden

The environmental burden is determined by the built-in energy consumption and emission production throughout the life cycle. The generally accepted equivalent for environmental impact assessment of building materials is the environmental index OI_{3KON} ; it is given in Table 2 for individual envelope layers. It refers to $1m^2$ of a structure and takes into account the third-weights of eco-indexes drawn on $1m^2$ of a structure. www.baubook.at

The chart in Figure 2 compares the individual construction solutions in terms of the environmental burden of a member and it is expressed by the environmental index OI_{3KON} . Mainly recyclable materials with a high recycling rate were used in the proposed solutions.

Generally accepted equivalent for assessing the impact of building materials and structures on the environment is the value of CO_2ekv emission production along with the assessment of primary energy tied, and, from the regional point of view, the value of SO_2ekv emission production. OI_3 calculates these three important categories of environmental protection for each squared meter of a building element on a scale 0 to 100.

Buildings are rated better if their ecological impact measured by OI_3 is lower. Parametric data of the environmental burden for the individual layers were taken from the website www.baubook.at. Compositions are classified as A+ and A in terms of construction sustainability. [1]

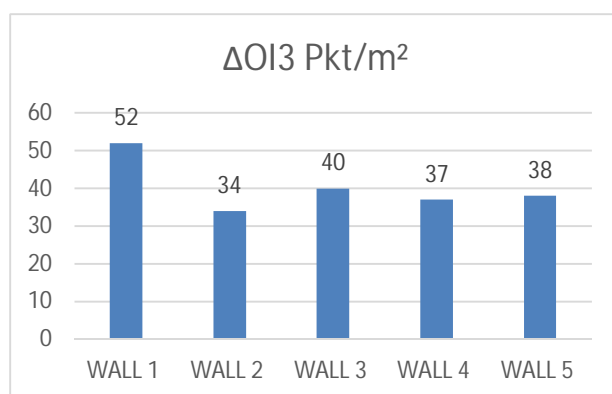


Figure 2. Comparison of individual construction outer solutions in terms of construction sustainability

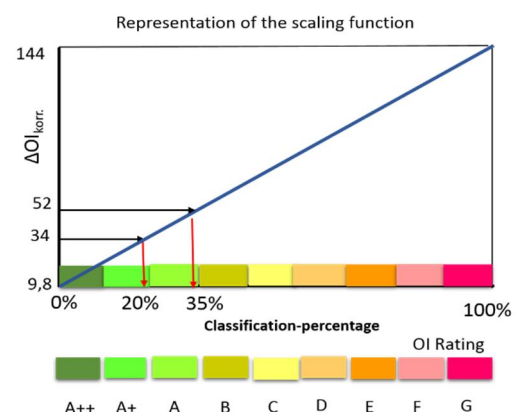


Figure 3. Representation of the - example. [1]

6. Possibilities of using building elements from recycled materials in the construction of wood-based houses

Environmental impact of buildings in the contemporary building standard is considerable. Optimization of building materials and products is important because the environmental burden in the building sector should be the lowest. The model composition solutions are based on using thermal insulation and covering from renewable resources such as wood, cellulose, hemp, sheep wool etc.

They are excellent thermal insulators and accumulators with low eco-index values. It is possible to use boards made from recycled municipal waste, e.g. TetraPack carton packages, as interior coverings. The production technology consists in grinding and pressing it under the high pressure and temperature into the shape of boards. The important fact is that no binding agents or chemical fillers are added to the base mixture, i.e. there is no environmental burden, and waste does not pollute the environment. The Slovak market currently offers TETRA K boards of size 2.700 x 1.200 mm and thickness up to 20 mm. The boards are made from a crushed polyethylene (PE) and have a paper cover layer. Their utility and physical parameters are comparable to the commonly used material such as plasterboards or cement-wood boards. They are re-recyclable after the lifetime period.

7. Conclusion

The increasing thickness of a thermal insulation, in terms of energy performance optimization, causes increasing fire resistance of the building envelopes where the non-combustible thermal insulation with the melting temperature of 1000 °C is used. The low-storey panel buildings, as well as kit homes with framework systems, are provided with the adequate fire-resistant load-bearing members of a building envelope, if thermal insulation is chosen optimally.

As for sustainability, it is important to reduce amount of waste from a building construction to an environmentally acceptable level, which means to use renewable and recycled materials.

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