Modern Wooden Construction System Comparison

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Abstract. Wood-based construction is a rapidly growing branch of construction in the world, it is slightly worse on the Polish field. In the era of care for the environment, it is important that newly constructed building objects, including buildings, not only use as little energy as possible, but are also made of materials received as ecological. Wood-based construction combines both of these aspects. There are, however, two other market aspects: price and availability of materials and technological solutions. Wooden buildings are more environmentally and human friendly than other material solutions, and with proper insulation, finishing and well-chosen installation systems, they can also be tempted to become a zero-energy building, i.e. one whose energy balance is zero per year. Among the architectural design offers today you can find a large number of residential or public building designs (low or large volume) with a wood-based structure, both in terms of bar solutions (generally seen through the prism of skeletal objects), as well as massive structures (today mainly seen through the prism plate objects). Each of them has different design assumptions, but in principle the goal is common. The right kind of construction, insulation and finishing materials should be chosen for each. For structural elements, various types of protection should be taken, e.g. in the field of fire safety or against technical wood pests, etc. In the field of insulation, analyses of thermal issues, waterproofing and wind protection are undertaken. The choice of finishing materials should also take into account solutions that are the least burdening the environment and minimize energy losses, among others by avoiding possible thermal bridges. This article attempts to present the topic in a synthetic way, outlining global trends and possibilities of the Polish wood-based construction market. The calculation example illustrates the heat balance and environmental loads of a single-family wooden building with thermal insulation selected so that the building envelope meets the current requirements given in the Technical Conditions.

1. Introduction
The introduction of sustainable development principles is one of the most important priorities in the world. This necessity is dictated by the protection of natural resources that are running out at an alarming rate. Also the quality of the environment in which we live is not the best. European Union countries take specific actions, for example through guidelines contained in the Directives on the energy performance of buildings. In a few months, Europe committed itself to introducing a new "nearly zero energy" (nZEB) building standard. Requirements must be met by all new and thermally modernized buildings. Only historic buildings are exempted from the requirements, but also in this case, it is worth improving energy efficiency if possible [1-2]. Requirements for buildings of this type are very strict but set at national level. In Poland, the requirements relate to the improvement of thermal insulation of partitions and energy improvement, described by the index of non-renewable
primary energy (EP). The effect of introducing a new standard for building and thermo-modernization of buildings can be observed on the building materials market [3-4]. Manufacturers are introducing new technologies, designers are slowly learning what solutions to use to design buildings with such stringent energy requirements [5-8]. Of course, all technological and installation solutions in nZEB buildings should also be cost-effective [7] as well as ecological and environmentally friendly [8]. The multi-faceted user comfort is also significant [9, 10]. A technology that meets these requirements and is becoming increasingly popular in Poland, due to its features is wooden technology. Building new wooden houses is a kind of "back" of building materials, because most of the historic buildings in Poland are made of wood [11, 12].

Wood as a "product" of nature in the construction industry has many disadvantages, but it also has a number of advantages that other building materials cannot boast of. In the era of caring for the environment, it is worth emphasizing two aspects: low energy consumption in LCA life cycle analysis and low amount of waste in this cycle („Cradle to Cradle®” C2C).

Table 1 illustrates the carbon footprint data for various construction products made of wood, including doors and windows, which, in combination with simpler materials, have much higher values due to their complex structure.

| Materials | CO2e g/kg | CO2 uptake* g/kg |
|-----------|-----------|-----------------|
| CLT – Germany | 362 | 1611 |
| Dried Timber (Coniferous) – Germany | 119 | 1637 |
| Dried Timber (Deciduous) – Germany | 167 | 1636 |
| Timber, Fresh – Germany | 49 | 1182 |
| Planed Timber – Germany | 152 | 1638 |
| Internal Door – Sweden | 18450 | 82500 |
| Wooden window – Sweden | 42175 | 27200 |

* The carbon footprint is expressed in terms of CO2e (carbon dioxide equivalent). However, due to the temporary effects of carbon storage in wood products, biogenic carbon storage (expressed as CO2 capture) is also reported. This number is not included in carbon footprints but expressed as a separate number.

In a generalized approach, wood can be said to be a "renewable" product and meets the idea of sustainable construction, which is why in many countries wood-based construction is used as an alternative to concrete and steel. Annual logging is much smaller than the increase and this applies to all parts of Europe. In Eastern Europe, only 16% of the annual increase is used, in Central and Eastern Europe 50%, while in Western Europe this percentage is 65% [14].

However, local development opportunities for wood-based construction are conditioned by many factors that reflect the development of the region, the level of construction culture, investor habits, etc. A specific radar for the development of wood-based construction has been proposed by the authors of the study "The Future of Timber Construction" [15] showing in which direction wooden construction is developing.

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1 C2C – filozofia produkcji używanych przez człowieka dóbr z zachowaniem zasady, że wszelkie dobra i odpady (zużyte produkty i ich składniki) to surowce, które są w całości przetwarzalne i służą produkcji kolejnych wyrobów.
2. Development of wood-based construction

2.1. Development of wood-based construction

The progress of wood-based construction has developed along with the development of wood and glue processing. Initially, coronary walls with high energy losses were shaped from straight hewn logs (Figure 1). The development of heat-insulating materials and more accurate wood processing allowed the formation of mullion-transom technology, followed by beam-beam technology. The next step is the box plates. The development of adhesives, especially the more ecological ones, has contributed to the development of plate technologies and massive construction, today mainly associated with CLT - Cross-Laminated Timber, but the market offers a wider range.

![Figure 1. Directions of development of technologies based on wood products.](image)

Plate technologies include technologies based on bolted connectors or glued ones. Most of the trade names known to us are related to English terms, e.g. concerning "wood": V-veneer, S-strand or N-nail, D-Dowel (Table 2).

Table 2. An example systematics of wood-based materials depending on the fineness of fibers and the method of their re-consolidation [16]

| BASE | PRODUCT / SALES NAME | REPRESENTATIVE CONSTRUCTION STRUCTURE | ORIENTATION OF FIBERS OF NEXT LAYERS |
|------|----------------------|--------------------------------------|-------------------------------------|
| solid wood | glulam (glue laminated timber) | beam | parallel |
| solid wood | glued laminated timber - GL (Glulam) | beam | parallel |
| solid wood | glued laminated timber - BS (Brettschichtholz) | plate | orthogonal |
| solid wood | SWP (Solid Wood Panel) | plate | orthogonal |
| solid wood | CLT (Cross Laminated Timber) | plate | orthogonal |
| plywood | beam | beam and board | orthogonal and parallel |
| plywood | IVL (Laminated Veneer Lumber) | beam | parallel |
| plywood | LSL (Laminated Strand Lumber) | beam | parallel |
| plywood | PARALAM PSL (Parallel Strand Lumber) | beam | parallel |
| plywood | OSL (Oriented Strand Board) | plate | lengthwise |
| composite | MDF (Medium Density Fiberboard) | plate | randomly |
| composite | Wood (oriental bonded with cement or magnesium) | plate | randomly |
| composite | WPC (Wood Polymer Composites) | board | randomly |

In high-rise buildings, the introduction of concrete (e.g. TCC - timber-concrete-composite) allows you to shape objects with high requirements also due to fire safety. Canadians excel in these solutions by building educational and public facilities. The Center for Interactive Research on Sustainability...
(CIRS) located in Vancouver, in the province of Canada - British Columbia can be considered a flagship project in this respect [17].

Among small-scale construction technologies, many of them are based on local solutions, often with small-scale elements. To obtain the parameters required by current regulations quite often require additional thermal insulation solutions.

The development of wooden walls followed the requirements of technical conditions as technology developed [18].

In the case of slab constructions, we insulate the walls as in the case of a traditional brick building technology, while in bar constructions the matter is more complex. The wooden skeleton wall consists mainly of an insulating material, and the wood used as the construction is also characterized by good insulation parameters. It should be borne in mind that the wooden wall in skeletal buildings is a heterogeneous partition and the skeleton element should be treated as a thermal bridge (Figure 2). To eliminate this inconvenience, an additional layer of insulation applied from the outside to the structure is most often used, which at the same time improves the insulation of the partition.

Figure 2. Thermal bridge in a wooden skeleton partition.

2.2. Thermal insulation of spaces between poles
The space between the skeleton elements of the building structure is filled with insulating material, but not all materials will be suitable for this. When choosing insulation material, the following points should be taken into account (Table 3):

- elasticity and flexibility - the material for insulation of skeletal structures should be characterized by high elasticity, which, firstly, will facilitate installation between the poles and, secondly, minimize thermal bridges;
- vapor permeability, sorption - these are important features that allow moisture to escape outside, preventing the insulation itself from getting wet, which increases the thermal conductivity and moisture of the wood, which can damage the frame structure;
- reaction to fire class - these should be materials with high fire resistance, very important in the case of wood-based materials;
- chemical and biological resistance - it should also be high to increase resistance to pests that pose a threat to wooden structures.
In addition, from the point of view of energy-saving and the relatively ecological building they are still important:

- thermal conductivity coefficient - the lower, the better heat transfer properties will have the barrier;
- biodegradability - made from materials of natural origin is important because of the waste, which decomposes quickly after construction (e.g. sheep wool);
- environmental impact and LCA (Life Cycle Analysis).

### Table 3. Selected technical parameters of insulation materials used to fill the frame structure

|                        | glass wool | rock wool | wood wool | ekofiber | hemp wool | ekowata | sheep's wool | styrofoam |
|------------------------|------------|-----------|-----------|----------|-----------|----------|--------------|-----------|
| heat conduction coefficient λ [W/(mK)] | 0,030 ÷ 0,045 | 0,034 ÷ 0,045 | 0,038 ÷ 0,050 | 0,039 ÷ 0,041 | 0,040 ÷ 0,042 | 0,039 ÷ 0,041 | 0,034 ÷ 0,031 + | 0,031 + |
| density ρ [kg/m³]      | 10,0 ÷ 129,0 | 20,0 ÷ 199,0 | 45,0 ÷ 270,0 | 27,0 ÷ 65,0 | 30,0 ÷ 42,0 | 25,0 ÷ 80,0 | 13,0 ÷ 30,0 | 10,0 ÷ 40,0 |
| diffusion resistance coefficient µ | 1,3 ÷ 1,4 | 1,3 ÷ 1,4 | 1/2; 2/5; 3; 5 | 1,4 | 1 bis 2 | no data | 1,0 | 30,0 ÷ 60,0 |
| reaction to fire class  | A1         | A1        | E         | C        | E         | B        | B lub E      | E         |
| biodegradability       | no         | no        | yes       | yes      | yes       | yes      | yes          | no        |

2.3. Additional external insulation

In addition to thermal insulation, additional external insulation is used in the building structure itself, which can be performed in the same way as in masonry buildings, however, in the case of skeletal structure it often has an additional function - it minimizes the share of thermal bridges created as a result of the lack of continuity of the construction material (Figure 2).

2.3.1. Thermal insulation of ceilings. Unless the ceiling separates a heated floor from an unheated floor, the insulation will be more acoustic than thermal. You only need to pay attention to the careful connection between the ceiling and the wall.

2.3.2. Roof insulation. In traditional construction, roofs are usually wooden, so their insulation will be analogous to walls.

2.3.3. Floor insulation. Currently, floors are made in the same way as in traditional buildings, so floor insulation is also implemented by laying thermal insulation material (low compressibility) on a properly prepared substrate.

Bearing in mind the increased energy efficiency of the building, all you need to do is remember to keep tightness between the foundation and the wall (avoiding a linear thermal bridge). The styrofoam used for insulation and bottom edge wall insulation should be chamfered at an angle of 45°. Then, when joining panels, the bridge effect will be smaller. You should also remember about flashing at the junction of the thermal insulation of the foundation and the wall, which will drain condensate outside the insulation layer without causing it to get wet.

2.3.4. Installation of windows and doors. Correct installation of windows and doors in wooden buildings is very important. Problems with moisture and thermal insulation should be taken into account. To prevent thermal bridging and excessive heat loss, the window should be flush with the
thermal insulation layer. This reduces heat loss, facilitates rain sealing and minimizes the risk of moisture damage. Good rain protection is particularly important in places exposed to strong winds and rain.

3. Calculation example
On the example of a single-family house with a usable area of approx. 120 m² (Figure 3) implemented by PalettenWerk near Krakow, it can be seen that good technical and energy parameters can be achieved in a wooden frame building.

Penetration coefficients for external partitions are as follows: for walls 0.12 W/m²K, for roofs 0.13 W/m²K, for floors on the ground 0.10 W/m²K, in addition for doors 1.30 W/m²K, for windows 0.80 W/m²K and for roof windows 1.10 W/m²K.

An air heat pump was used in the building for the needs of central heating and domestic hot water, in combination with floor heating.

Energy performance calculations for the building were carried out in ArCADia software. The primary energy demand was \( EP = 73.54 \text{ kWh/m}^2\text{year} \) (Table 4), while the specific amount of CO\(_2\) emissions is 2.19 t CO\(_2\)/year.

**Table 4.** The results of the energy performance of an example wooden frame building (printout from ArCADia)

| Indicator of the annual demand for usable energy EU | 36.86 kWh/m²rok |
| Indicator of annual final energy demand EK | 24.51 kWh/m²rok |
| Primary energy demand Qp | 8398.42 kWh/rok |
| Indicator of the annual demand for non-renewable primary energy EP | 73.54 kWh/m²rok |
4. Conclusions

Certificates for wood-based construction. Wood-based buildings are equal solutions in the construction market. Therefore, it is worth devoting more attention to the wood-based buildings and it is worth emphasizing that in such construction it is possible and should be introduced by standards of the ecological building based on certification, where many tools and assessment systems are available. We include the most important programs:

- BREEAM (UK)
- Built Green™ (Canada)
- Green Globes (Canada)
- Green Globes – Green Building Initiative (US)
- Leadership in Energy and Environmental Design – “LEED”
- Living Building Challenge (Canada & US)
- The National Association of Home Builders (NAHB) National Green Building Standard. ANSI/ICC 700-2008 (US)
- The R-2000 Program (Canada)
- Zero Carbon Building Standard (Canada)
- PLGBC (Poland)
- MCBE (Poland)

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