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INNOVATIVE TIMBER CONSTRUCTION SYSTEMS IN TERMS OF DESIGN AND STRUCTURE PHYSICS SOLUTIONS

INNOWACYJNE SYSTEMY BUDOWNICTWA DREWNIANEGO W ASPEKCIE ROZWIĄZAŃ KONSTRUKCYJNYCH I FIZYKI BUDOWLI

Abstract

This paper presents examples of modern timber building systems. The beginnings of the wooden structure systems of frame and massive structure as well as new solutions with reference to traditional ones are presented in the paper. Modern timber systems presented in the paper are selected in such a way as to show the diversity of their structure. Examples of systems based on logs, beams and plate (solid and boxes) elements are shown in the paper. Description of each system contains information about the basic elements of the structure, connection methods and materials used in their production. Degree of prefabrication and assembly methods are also discussed. Special attention is paid to the issues of the building physics of wooden partitions, thermal parameters and the thermal bridges in these structures.

Keywords: timber building system, connections, materials, assembling methods, thermal parameters

Streszczenie

W artykule omówiono przykłady nowoczesnych rozwiązań drewnianego budownictwa systemowego. Przedstawiono także początki drewnianego budownictwa systemowego, czyli budownictwo szkieletowe i masywne oraz zaprezentowano współczesne rozwiązania w porównaniu do tradycyjnych. Prezentowane w artykule systemy wybrano w taki sposób, aby pokazać różnorodność ich kształtowania – zaprezentowano przykłady systemów opartych na elementach balowych, belkowych oraz płytowych (masywnych oraz skrzynkowych). W opisie każdego z systemów przedstawiono informacje o konstrukcji elementów podstawowych, sposobach ich połączeń i materiałach użytych do ich produkcji wraz z omówieniem stopnia prefabrykacji elementów oraz sposobu ich montażu. Omówiono także zastosowania danych systemów do wznoszenia różnego rodzaju konstrukcji. W artykule zwrócono szczególną uwagę na zagadnienia fizyki budowli przegród drewnianych – parametry cieplne oraz występowanie mostków cieplnych w takich konstrukcjach.

Słowa kluczowe: drewniane budownictwo systemowe, połączenia, prefabrykacja, montaż, parametry cieplne

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1. Types of timber building systems

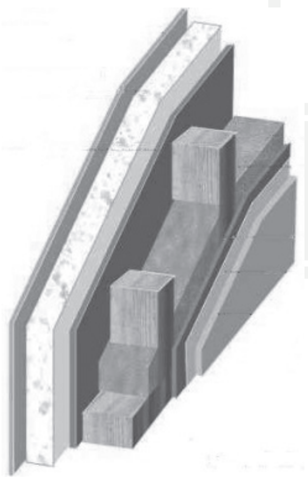
A complex group of interdependent elements with specific designing, realization and technological methods allowing efficient implementation of building structure is called the technological system of building construction. Each technological system has specific materials, methods of transport, processing and embedding materials and prefabrication, selection of machinery and equipment, and work organization [1].

The basic and specific elements (logs, beams or plates) and set of connectors can be found in each system. In some of them elements are connected on the site, in others, the whole walls, ceilings, roof trusses are made in the factory and brought to the building site. Whole modules of buildings, including installations, finishing and equipment can also be produced.

Generally, systems can be divided into frame and solid structures.

2. Timber framing structures

Post and beam walls as well as frame structures (platform and balloon) are the traditional types of structures in this group of walls. The characteristic feature of these walls is that the structural layer and insulation fills the same space. Thermal insulation of frame walls depends largely on the use of an additional layer of insulation, which limits the thermal bridges near the frame construction elements. This additional insulation is made by the ETICS method (External Thermal Insulation Composite Systems) or by the use of hard wood frames. In this way, any required value of heat transfer coefficient can be obtained.



Ill. 1. Cross section of the frame wall [6]

2.1. Post and beam structure

This structure consists of vertical columns, horizontal beams, foundation and head beams, struts, ceiling beams and a roof structure. Traditional buildings are overlapped by the timber roof construction (rafter, span or major purlin system). Dimensions of each element are usually large (140 mm × 140 mm, 120 mm × 160 mm, 140 mm × 180 mm) due to the greater distance between the columns and beams (about 120cm) and the use of carpentry connections (notches, pins, plates). In these structures solid wood is used. A cross-section through the typical wall in the frame structure is shown in Ill. 1. The walls are filled mainly by mineral wool. From the inside vapor barrier foil should be placed and from the outside: permeable foil. Nowadays an extra layer of insulation is needed to fulfil the requirements of the Technical Conditions [4]. Roof layers are similar to the wall layers, the only difference being the cover layer (laths and battens or full boarding nailed to the rafters).

This structure is presently used for residential, farming and stockroom buildings. A modification of this structure is a half-timbered wall called a Prussian wall: a wooden frame structure filled by bricks. This structure is popular in traditional and regional buildings in the northern part of Poland.

2.2. Light frame structure

It is a modification of the previous type of structure, but there are no transoms or struts. Strengthening in this structure is provided by various plating (boards, wood-based plates, OSB plates or oriented strand board, plywood). Horizontal beams are inserted for installing the woodwork only above the windows and doors. There are two types of these structures: the platform structure (Ill. 2) and the balloon structure (Ill. 3).

Ill. 2. Platform structure [7]

Ill. 3. Balloon structure [7]

The main advantage of the platform structure is the independent assembly of walls and ceilings, which allows them to be made completely in the factory. An upper and lower transom connects columns and merges walls together. It is also the base for ceiling mounting. Building the balloon structure is much more labour consuming and difficult for prefabrication because the columns have a height of more than one storey. The ceiling is supported by beams.

The only difference between this structure and the post and beam structure is the spacing of structure elements. In the Polish and German module (spacing of 62.5 cm, cross-section of elements 60 mm) while in the American module (spacing of 40 cm, cross-section of elements 38 mm) is used. Elements are made from solid wood logs, laths and boards with mechanical connectors (spiked plates, nails and screws) [5].

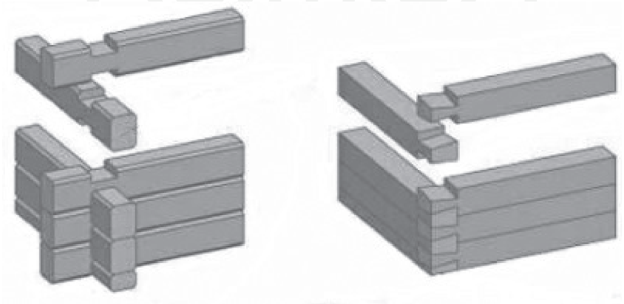
Nowadays these structures are used to construct one-family or multifamily buildings. Several storey buildings can be built in this technology.

3. Massive timber structures

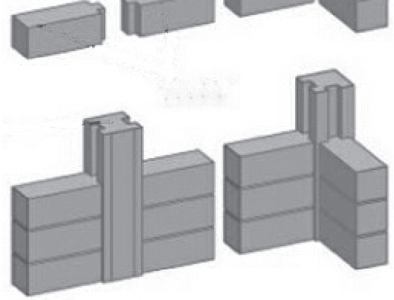
This group contains timber log cabin and board-patch structures. They are characterized by the separation of structure and insulation layer. In fact, to fulfil the requirements of the Technical Conditions [4] it is necessary to insulate the wall. Usually mineral wool insulation is used on the inside part of the wall to expose the wooden structure.

3.1. Timber log cabin structure

This structure consists of logs arranged horizontally one on top of the other (Ill. 4). The first beam laid on the plinth, which is insulated against moisture, is called the base beam. Further beams are joined together by pins (traditional solution) or tongue and groove (modern solution). Loads are transferred directly from the ceiling and roof to the foundation by the wall beams. Logs can have different shapes (oval, rectangular or square) and size (thickness 100–300 mm). In the corners, so-called "ostatki" are used, which protect against the creation of large thermal bridges connected with the isotropic properties of wood. Because these structures are used primary for single-family houses, regional and vacational buildings, the ceilings and roofs are also made in traditional solutions [3].



Ill. 4. Log cabin structure [8]



Ill. 5. Board – patch structure [8]

3.2. Board-patch structure

Board-patch construction consists of vertical columns (patches), spaced at approximately 2 m with additional patches by the door and window openings, and horizontal logs (boards), which are placed at the patches by the with profiled locks (Ill. 5). The wall can also be made of two layers of boards with a layer of insulation between them [3].

4. Modern timber framing structures

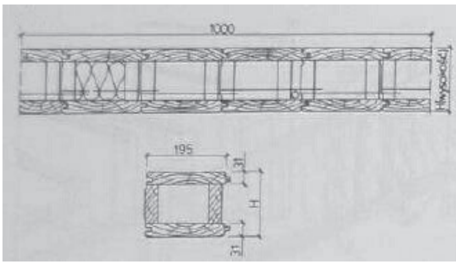
Systems of timber framing structures were spread in Poland in the 90s of the 20th century. These systems can be divided into several groups.

The first group is the Canadian structure. The building is made of linear elements on the site. Dimensions of the elements are the same as in the traditional frame structures. Columns, transoms, ceiling beams, foundations and head beams are made from solid wood boards, laths and logs and joined by traditional engineering connectors. Due to the low weights of items, manual assembly is used.

The second group is the Scandinavian structure shown in Ill. 6. In this case the building is made of prefabricated plates, which vary depending on their use (wall, roof, ceiling plates). Construction of wall and roof panels is usually similar; there are only different cross sections of the construction frame and thickness of the filling. The frame is built by 50 × 10 mm columns spaced at 60 cm and connected at the top and bottom by transoms with nails or screws. The frame is filled by mineral wool of the same thickness as the structure (100, 125, 140, 150, 175 mm). The frame is secured from the inside by a vapor barrier foil and coated on both sides by hardboard, OSB plate, plywood or chipboard. The height of the wall panel is usually equal to the height of the storey. Ceiling construction depends on the specific system, but generally there are two solutions. The first one consists of laying down the roof plates on timber beams, which are the main structure. The second solution uses plates with bigger element sections. Roof structure can also be made in two solutions. Prefabricated roof trusses are popular in non usable lofts while rafters with roof plates are used in usable lofts.

Ill. 6. Scandinavian structure [9]

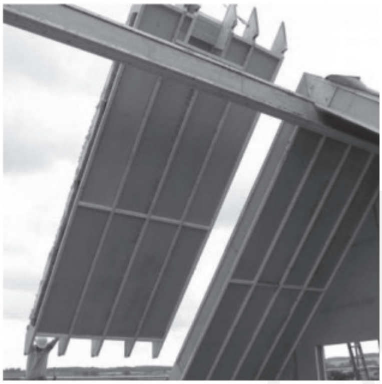
After the assembly of prefabricated elements, an extra insulation layer can be used. It adequately limits the thermal bridges x. When appropriately thick insulation is used, thermal bridges are negligibly small. This layer can be made on a wooden shelf filled with wool or by the ETICS method. Assembly of the elements can be done manually or mechanically depending on the system. Wall panels weigh 130–330 lb. A crane is necessary if prefabricated trusses are used. Nowadays, there are a greater variety of buildings constructed using this technology in Poland.



Ill. 7. Box element [1]

The next group includes box section plates (Ill. 7). Elements have various dimensions depending on the use of the system. Due to the favourable weight to load ratio, these panels are often used in warehouses and industrial halls.

These panels are made of planks, plywood or hardboard and glued or bonded with screws. The plates are produced with a height from about 120 mm to 320 mm and a span of 16 m. Typically, the width of plates is adapted to the system module and is about 0.5–1 m. The external components (walls and roof) are filled by insulating material with vapor barrier foil on the inside. Roof structure is usually formed by laminated timber trusses. Plates are laid on them without the purlin system. This technology does not usually apply additional insulation from the outside. After the assembly of the elements, the structure is covered by plastics or brass facing.



Ill. 8. Assembly of plate elements [10]

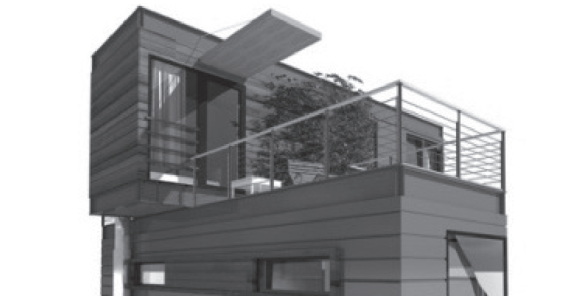
Installation of such construction is carried out by using a crane (the components' weight is approximately 1800 lb).

The next group is created by buildings made of various types of beams. The most common are rectangular or I-joist beams (solid or openwork). For example, belts in I-joist beams can be made of laminated timber and webs of fibreboard or OSB plates. Beams are selected depending on the span and spacing. In the halls, the height of the beams reaches up to 500 mm while in residential buildings it is 200 mm. Column spacing ranges from 2 to 8 m.

For the assembly of hall system buildings, a crane is used. The elements are combined using standard engineering connections; however, beam systems are also used in single-family houses (systems in Alpine regions). In these systems, special connectors developed by specific producers are used. The beam systems are covered by plate panels (Ill. 8) and filled by an insulationx layer of foils. The advantage of such solutions is the easy placement on any type of installation cables.

Because of the relatively large height of beams and columns, this system does not need an additional layer of insulation. These buiding systems fulfil the insulation requirements.

The last group is module technology shown in Ill. 9. The degree of prefabrication here is the highest and the spatial modules are only installed on the site with vertical and horizontal timber frames fully or partially closed. Depending on the system, elements have walls, ceilings,



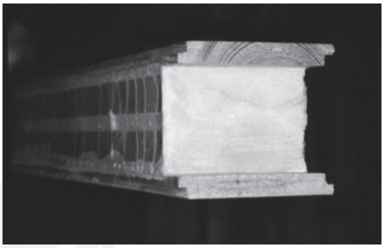
Ill. 9. Module house [11]

floors and even installations, finished partitioning and equipment (each module is a separate room or set of rooms).

Assembly on the site is limited to making foundations and fixing modules. The advantage of this system is possibility to move the building easily and the high speed of execution.

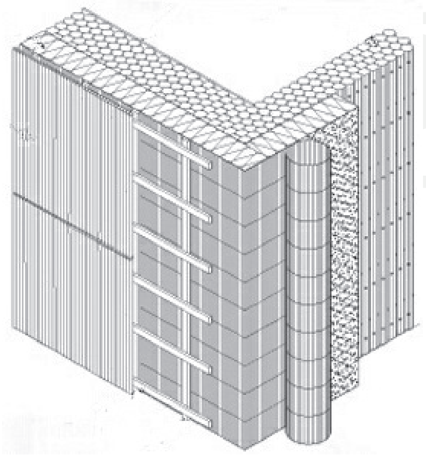
5. Modern massive structures

Massive systems, similar to frame structures, are very various. On the market there are systems based on old timber log cabin structures and structures composed mostly of laminated timber plates. A log structure element is shown in Ill. 10.



Ill. 10. Log structure element [7]

Modern timber log cabin structures are made of properly profiled logs and insulated from the inside. An interesting solution is connecting the frame and massive structures by making logs which are made of boards connected with polyurethane foam in the expansion process. The boards act as a structural (transfer bending forces) and clad material (large capacity allows for assembly of heavy façade, hanging shelves etc.). Polyurethane foam transfers shear forces. Such elements are placed vertically, joined by locks and turned by the screws. In this system corners, windows, doors and ceiling elements are produced.



Ill. 11. Palisadio system [12]

Another interesting log system is a structure based on solid wood stakes which are connected by wooden beech pins (Ill. 11). This gives great freedom in forming the shape of the building. Elements are also joined at an angle, which allows an easy connection between the wall and the roof. Non insulated walls composed of 5 stakes have a heat transfer coefficient at the level of 0.27 W/(m^{2}K). In addition, this wall can be insulated from the inside or the outside. Assembly of these structures is carried out mostly by hand because of the low weight of the elements.

The second group of massive structure is a system made of plate elements. These are systems dedicated to housing and public buildings. Depending on the purpose, plates made of three, five or seven board layers with a thickness of 18–32 mm glued by epoxy resin are produced (Ill. 12). The load capacity of such a ceiling is similar to ceilings made of concrete.

Structures made from these elements should be further insulated. It is made similarly to masonry structures using the ETICS method or a heavy wood frame filled with mineral wool.

Ill. 12. Timber glued elements [13]

Plates, which are brought to the site, have the size of the whole or part of the wall. Ceiling and roof plates have a width of 120 cm so assembly is done with the use of a crane.

The next system is based on small-sized wood elements shown in Ill. 13. A building in this technology is made in the same way as a building in masonry structure. Items are usually larger than in masonry systems because of smaller wood volume weight. They are joined with pins, screws, bolts and tongue and groove. Ceilings can be made of laminated timber. Any roof structure can be used: traditional or prefabricated. The walls are made manually, however, for the assembly of the ceiling or roof, a crane is usually needed.

Ill. 13. Small – sized wood elements [14]

Buildings in this technology should be thermally insulated. These systems are designed primarily for single-family housing.

6. Conclusions

Timber structure systems are a good alternative to traditional masonry and reinforced concrete systems which are very popular in Poland. The advantages of system solutions are first of all the speed and accuracy of the assembly and the ability to achieve high thermal insulation. There is a variety of timber technology, so the most suitable system for the building can always be chosen.

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