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NEW DIMENSION FOR STRAW CONSTRUCTION

NOWY WYMIAR BUDOWNICTWA ZE SŁOMY

A b s t r a c t

The rising interest in the ecological and energy-saving constructions include the whole life cycle of building – starting from materials and ending with remains that a building leaves in the environment. The holistic view of the ecological construction leads to increase in the interest in constructions made from straw. This article focuses on the technology using straw bales in modern buildings. To a great extent the straw bale method fulfils modern, ecological trends because of low production costs, low energy use during production and biodegradation, among others. The article describes physical parameters specific for straw bale and gives examples of current projects of modern buildings made with this technology.

Keywords: straw bale, straw, ecological construction

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

Rosnące zainteresowanie budownictwem ekologicznym i energooszczędnym obejmuje cały cykl życiowy budynku – od produkcji materiałów do śladów w środowisku, jakie budynek po sobie zostawia. Holistyczna wizja budownictwa ekologicznego doprowadziła do wzrostu zainteresowania budownictwem ze słomy. W artykule skoncentrowano się na technologii wykorzystania w nowoczesnym budownictwie sprasowanych kostek słomy – *straw bale. Straw bale* w znacznym stopniu odpowiadają współczesnym, ekologicznym trendom, między innymi, ze względu na niski koszt produkcji, niskie zużycie energii przy produkcji oraz biodegradowalność. W artykule opisano parametry fizyczne cechujące *straw bale* oraz podano przykłady aktualnych realizacji nowoczesnych budynków z wykorzystaniem tej technologii.

Słowa kluczowe: straw bale, słoma, budownictwo ekologiczne

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1. Introduction

Straw is a natural material that has been used in construction for ages. Despite the various possibilities of forming modern wall barriers, straw still remains an attractive material both because of the ecological, economical and usage reasons. Straw constructions are often associated with buildings made in traditional architecture, build in accordance with principles handing down from generation to generation. In this article the authors would like to present products made of straw – straw bale as a building material with specified technical parameters and show that also buildings with modern form that fulfil current technical conditions can be constructed in the straw bale technique.

2. Continuity of the tradition

Nowadays more than 1/3 of Earth population still lives in buildings made from clay and straw [1]. Already from the prehistoric times, when people searched for shelter and dug holes in the ground and covered them with dry grass, materials like clay and straw have belonged to the most common building materials. Straw was already used in the oldest type of constructions like plaited frame from cane, dried grass and straw, filled with clay, which can still be noticed in Africa. In ancient times straw was one of the basic ingredients of dried bricks. Straw, as a commonly available material was also used as a material filling load-bearing constructions. In Europe and particularly among Slavic tribes popular were wooden frame structures filled with mixture of clay, straw and wood. Invention of cutting and pressing machine in 1860s revolutionized usage of straw as a separate load-bearing material. In consequence of achieved weight and volume, the pressed straw was stable enough to bear roof and later also the whole floor. This technique was used in America, where Americans within the act on farmsteads started to settle in the lowland area in Nebraska. In this area wood was almost unavailable and because of that the buildings were made from pressed straw formed in rectangular bales – straw bales.

According to the architecture researcher Roger Welsch the oldest documented building made with straw bale technique was a unicameral school raised in 1886 or 1887 [3]. Because unprotected straw was an attractive source of food for local animals, in 1902 the straw walls

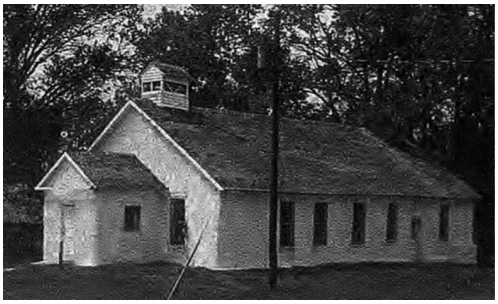

Fig. 1. Piligrim Holiness Church, Nebraska 1928 [2]

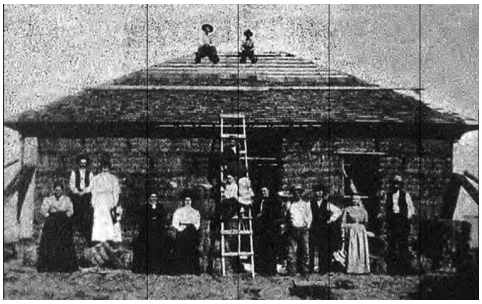

Fig. 2. Simonton House, Nebraska 1908 [2]

began to be covered with cement-lime plaster or clay layer. In Nebraska different type of straw buildings were constructed, starting from utility rooms, through houses and ending with public buildings like churches or offices. This technique was so popular that between 1895 and 1930 70 buildings were built in Nebraska and 13 of them can still be admired today [4]. In Europe the first commercial building made in straw bale technique was constructed in England in 1989. At the height of the ecological movements and an idea of "do it yourself" constructions from straw are getting popular from the beginning of 1990s. Until 1995 about 40 buildings in England were built with this technique, also in France and Norway, whereas in 2001 in Europe more than 400 [5].

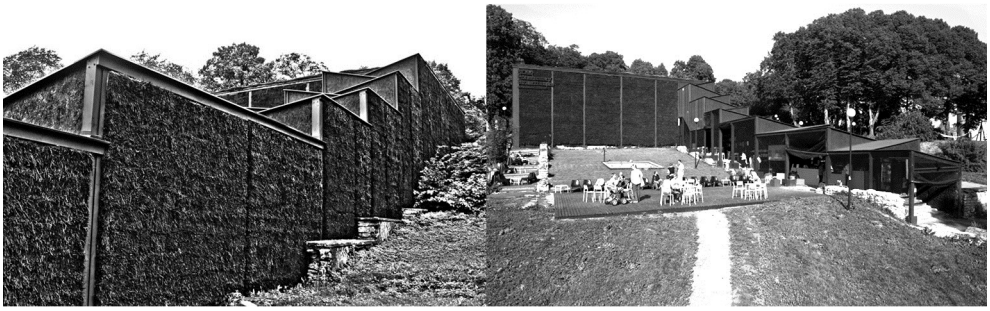

Fig. 3. Temporary Theatre Building – No99 Straw Theatre, Tallinn 2011 [6]

Nowadays both residential and public buildings like schools, warehouses, theatres, offices are made in accordance to the straw bale technique. One of the most innovative solutions was constructed in 2011 in Tallinn and it was a building of theatre with area of 440 m^2 made by the Estonian design office Salto Architects. This is an example of a temporary building that was constructed because of Tallinn being the European Capital of Culture. Modern objects with flat roof and cascade entrance was a wooden form filled with straw blocks. In this building straw blocks were not protected because in authors' opinion this underlined a natural life cycle of the material. In order to emphasize the meaning of this place (the theatre was located in the city centre, along with old fortifications) the walls of the theatre were coloured with sprays to black [6].

Fig. 4. University Building in Nottingham, Great Britain 2012 [7]

In 2012 in Great Britain, a modern academic building at the Agricultural University in Nottingham was put in use and was built with straw bale technique as designed by Make Architects. The construction of this building consists of wooden, prefabricated castes filled with straw bales. In order to produce straw bales, straw from the cultivable field belonging to university was used and that is located about 200 m from the campus. Construction system was cheap and fast in installation which was perfectly fitting to the ecological and economical policy of the university. Four-storey building with an area of 3000 m^2 has a number of functions: labs, workshops and offices are located here. Among others, modern form is stressed with flat roof and oversized glasses [7].

3. Straw as a building material

Straw bale consists of pressed cereals formed in bundles with rectangular and rolled shape. The construction uses bundles in rectangular shape – as a filling material, located between construction elements or used to build load-bearing walls. In Poland straw blocks can be used in buildings as a building product admitted to unit application in a building object according to act from 16th April 2004 on building products (Journal of laws No. 92, unit 881 as amended). To the best materials used in the straw bale technique belongs straw made from wheat, spelt and rye, because it is the most durable product. According to Gernot Minke [4] straw bales can be divided into three groups: small – of about 35 cm height (h), about 50 cm width (w), 50-120 cm length (l), medium – of about 50 cm h, about 80 cm w, about 70–240 cm l and jumbo: about 70 cm h, 120 cm w, 120–300 cm l. Because of the weight of jumbo blocks it is necessary to use some heavy equipment. According to GSBN (Global Straw Building Network) the relative humidity of straw bales during storage and building shall be at the level of below 14%. The bale can fulfil its bear-loading function when its volume density is more than 90 kg/m^3. It is also recommended that straw is without weeds because they are less durable and decompose much faster than plain straw so they can cause destabilisation of the bales. The pressed straw is characterised by very favourable heat conductivity coefficient λ which helps in using this solution in energy-saving houses. The coefficient λ fits into the range of 0.0337-0.086 $W/m \cdot K$ and depends on density of blocks, structure of fibres (parallel or perpendicular to the direction of heat transition), humidity of straw and, to a limited extend, also on the type of straw [3]. According to the code EN 13823 [8] the straw bales can be included to the combustible products with limited liability to spontaneous combustion – group B. A wall made from straw bales that are covered on both sides with 3-cm-thick clay plaster can achieve certified flame resistance of F-30-B [4]. It should be stressed, that thanks to pressing, the straw gets less flammable in comparison with loose straw and the fire insulation is more efficient because of the proper wall plaster. The basic advantage of wall construction in straw bale technique is forming a favourable microclimate with natural materials, together with limitation of building exploitation costs. Nowadays, straw belongs to the basic materials used in ecological construction among others because of the fact that production of straw blocks absorbs relative small amount of energy 14 MJ/m^3, almost 77 times lower than production of mineral wool (1077 MJ/m^3) [3]. The straw bale can be one of the most economical material in construction because of the general availability of straw. Each year Poland produces 29 million tonnes of straw, particularly cereal

and rape straw. Generally it is used in form of feed, bedding or ground fertilizer (because of high silicon content). Nowadays, because of agricultural mechanisation in Poland, surplus of straw is at the level of 12 millions tones each year [9]. All this features are considerate while preparing ecological characteristic e.g. LEED, BREEM that are needed while performing prestigious projects.

4. Example of usage of straw bales in residential building designed in accordance with modern architecture

4.1. General description of building

A house in Raciechowice was designed in wooden construction with straw bales as a material to infill outer walls. As of preparation of this article, this building is in the construction stage. It represents modern architecture trends and propagate houses with minimalistic form, so without eaves, with big glazed surface, where day part is connected with the garden. The problem connected with straw protection from the unfavourable weather conditions is solved here by application of proper finishing materials and thanks to shaping the form with construction overhanging. Popular materials used in modern residential construction with natural materials are connected in this building. The object is designed as a two-storey building, without basement. Dimensions of the building in plan are 24 × 14 m and height in ridge is about 8.5 m. The construction is made from wooden frames, made from truss columns of the exterior walls, roof trusses and floor joists. The distance between frames is 90 cm because of the omission of roof windows and because of the dimensions of straw bales.

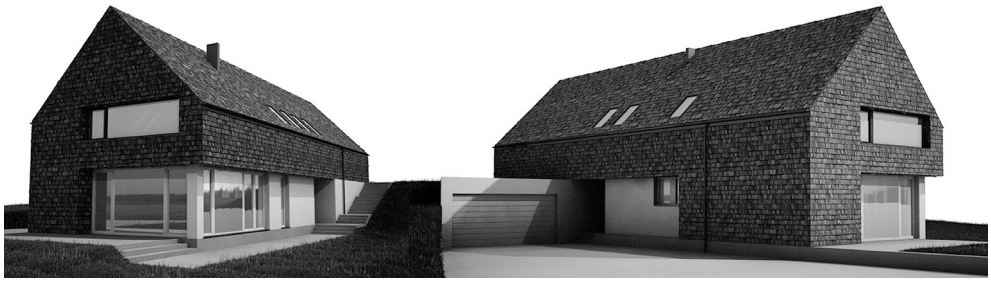

Fig. 5. A detached house, Raciechowice 2015

4.2. Construction of exterior walls

The exterior walls with filling made from straw are characterised by relatively high thickness that normally is greater than 35 cm, which is the result of requirements for the thermal insulation. In case of the house in Raciechowice the exterior walls are 45 cm thick – straw bales with dimensions of 45 cm × 40 cm height × 45 cm length were used. It is worth stressing that dimensions of straw bales shall be specified already during the design stage of the building together with proper position of construction elements in such a way

that the smallest number of bales has to be cut during the construction. In case of such thick walls the thickness of foundation walls is problematic as they shall be above the ground level for a minimum of 30 cm in order to protect the straw from rain water. In this object 30 cm thick reinforced concrete foundation walls were used and overhangs were made of the wooden construction from the exterior side by 15 cm. The details concerning support of wall with wooden construction and filling made from straw bales with reinforced concrete foundation wall are presented at Fig. 6. The overhanging of the ground floor wall allowed to install thermal insulation of the foundation walls, without obligation to be moved out from the face of the ground floor wall. Making the foundation walls with width of the ground floor wall would be connected with excessive usage of materials and unnecessary increase of investment costs, as well as with insulation problems.

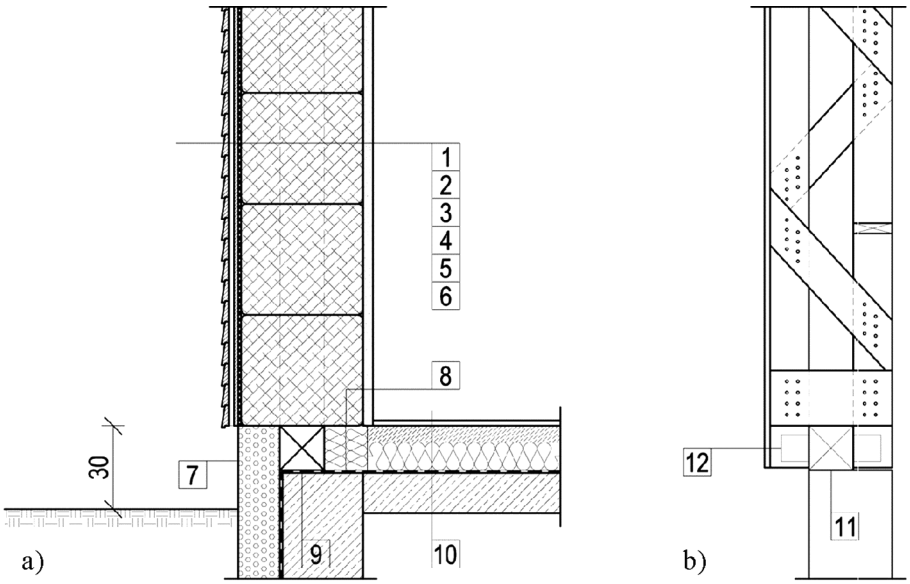

Fig. 6. Details of straw bale wall support on the reinforced concrete foundation: a) finished wall, b) wooden structure made from boards connected with nails; 1 – wooden shingle, 2 – ventilated air gap, 3 – planking, 4 – wind insulation, 5 – straw bales and wooden structure, 6 – clay plaster, 7 – thermal insulation XPS, 8 – thermal insulation EPS, 9 – damp-proof course, 10 – layers of flooring on the ground, 11 – wall plate, 12 – angle bracket

In order to calculate the thermal insulation of the wall the less favourable value of the heat transfer coefficient λ for straw bale that is given in the literature $\lambda = 0.086$ W/m·K was assumed. The thermal resistance (R) of 45 cm thick straw layer by the assumed secured heat transfer coefficient level, was R = 5.23 m^2·K/W. In order to achieve the same thermal resistance by application of thermal insulation made from mineral wool, it shall be used 18–23 cm thick layer, depending on $\lambda = 0.035$–0.045 W/m·K. By assuming that price of straw is about 11.10 PLN/m^2 wall (price of the used bale was 2.00 PLN) and the average price of mat made from mineral wool 20 cm thick is 20 PLN/m^2, the use of thermal insulation with straw is about twice cheaper. The energy consumption by production of 1 m^2 of thermal insulation

in accordance with assumptions described in point 2 of this article is about 30 times lower than in case of straw. Because of the above mentioned reasons and the will to use natural materials, the investors decided to make walls in accordance with the straw bale technique. However, the mineral wool was used to insulate the roof in order to achieve the maximum floor space in the attic by the limited acceptable height of building.

4.3. Shape of roof and finishing of exterior partitions

Traditional roofs are made with eaves with length from 0.5 to 1.0 m. In the modern forms they are designed without eaves because of the aesthetic reasons, so the walls are much more exposed to weather conditions. Critical points are in edge of the roof and walls. The Fig. 7 presents solutions made in house in Raciechowice.

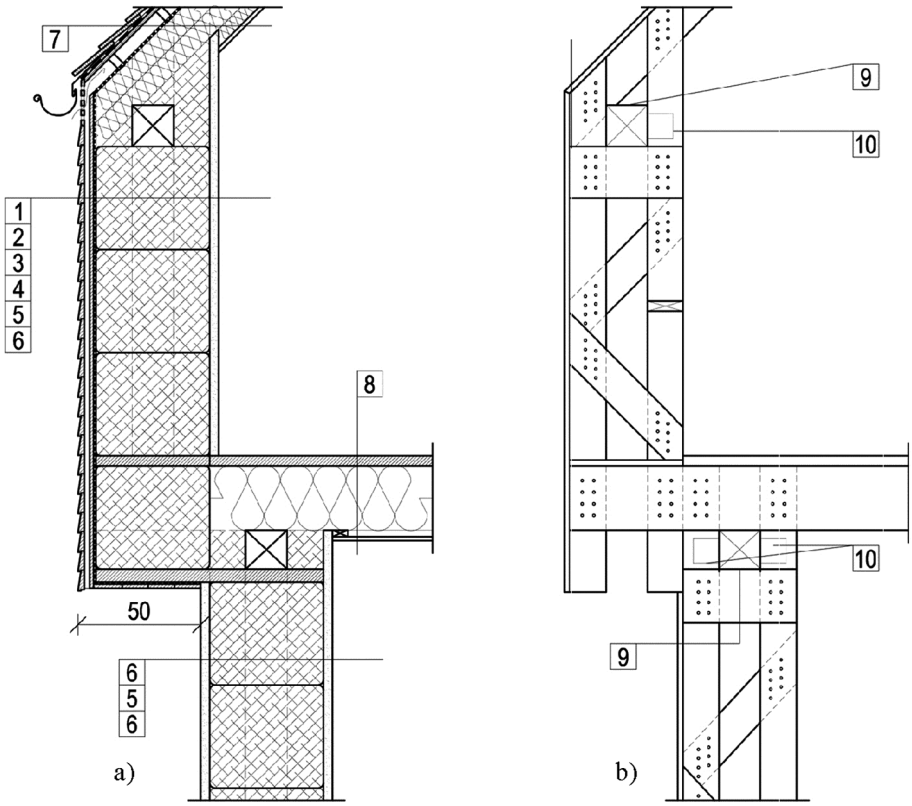

Fig. 7. Detail of first floor wall overhanged towards ground floor wall: a) finished wall, b) wooden structure made from boards connected with nails; 1 – wooden shingle, 2 – ventilated air gap, 3 – planking, 4 – wind insulation, 5 – straw bales and wooden structure, 6 – clay plaster, 7 – roof layers, 8 – ceiling layers, 9 – beam, 10 – angle bracket

In order to protect from the negative influence of rain and melting snow on the walls in the first floor an uniform finishing of walls and roof was designed in the form of a wooden

shingle. The contrast between wood and clay gives opportunity to achieve interesting architectonic effects. Because of that the house in Raciechowice except from application of wooden shingle, consists of some walls in the ground floor that were covered with clay plaster. In order to cover exterior walls in the ground floor with clay plaster an overhang of the first floor construction was made for about 0.5 m. Also the surface of all interior walls was covered with clay plaster. Except from the aesthetic reasons the clay plaster is characterised by a very good moisture vapour permeability. Diffusion resistance factor of the clay plaster can be compared to diffusion resistance factor of lime plaster. The clay plaster that is put inside thank to very good sorption performance helps to regulate proper air humidity in the building [3].

5. Summary

In this article the most important physical features of straw bales and walls made from this material are presented which shall be considered while designing buildings. The authors focused on the use of straw as a material to infill load-bearing structure. By proper construction and way of storage, straw bales have parameters that allow to compete with popular materials used to make thermal insulation of a wall, like mineral wool or polystyrene. The examples of public objects in Europe with modern form and residential object constructed nowadays in Poland listed in the article confirm the thesis that the straw bale technique does not have to be associated with traditional architecture from 19th and 20th century, but can be an interesting alternative for modern constructions.

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