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NATURAL MATERIAL IN SUSTAINABLE CONSTRUCTION WITH REGARDS TO "STRAW BALE" TECHNOLOGY – SELECTED ISSUES

MATERIAŁ NATURALNY W BUDOWNICTWIE ZRÓWNOWAŻONYM NA PRZYKŁADZIE TECHNOLOGII *STRAW BALE* – WYBRANE ZAGADNIENIA

A b s t r a c t

The article raises issues of natural architecture, presenting the advantages of ecological construction and demands of sustainable development. It presents an example of the use of natural material (straw) to erect buildings in the *straw bale* technology. On the basis of the presentation of the building it is shown that future bio-construction may be based on simple, natural and environment-friendly materials [2]. It underlines the benefits and the need to develop natural construction for the good of a mankind and the environment, with regards to the aspect of energy efficiency – both in the process of building and operation. It emphasizes that nowadays the natural architecture gives more and more possibilities of building passive objects or even zero-energy ones. The idea of the publication is also to sensitize the audience to the fact of the use of straw to create objects representing contemporary polemic against the traditional solutions of form and architectural building blocks.

Keywords: *natural architecture, construction of straw, straw bale, natural construction materials, traditional construction materials, straw, ecological houses, energy efficiency, sustainable construction, bio-construction*

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

W artykule poruszono problematykę z zakresu architektury naturalnej, prezentującej walory budownictwa ekologicznego i postulaty zrównoważonego rozwoju. Przedstawiono przykład wykorzystania materiału naturalnego (słomy) do wznoszenia budynków w technologii *straw bale*. Na podstawie zaprezentowanego budynku wykazano, że biobudownictwo jutra może być oparte na prostych, pozyskiwanych wprost z natury i przyjaznych środowisku materiałach [2]. Podkreślono korzyści i potrzebę rozwoju budownictwa naturalnego dla dobra człowieka i jego otoczenia, poprzez wzgląd na aspekty energooszczędności – zarówno w procesie budowania, jak i eksploatacji. Zaakcentowano, iż architektura naturalna daje dzisiaj coraz częściej możliwość powstania obiektu pasywnego czy wręcz zeroenergetycznego. Ideą publikacji jest także uwrażliwienie odbiorcy na fakt zastosowania słomy do wznoszenia obiektów stanowiących współczesną polemikę wobec tradycyjnych rozwiązań formy i bryły architektonicznej budynku.

Słowa kluczowe: *architektura naturalna, budownictwo ze słomy, straw bale, naturalne materiały budowlane, tradycyjne materiały budowlane, słoma, domy ekologiczne, energooszczędność, budownictwo zrównoważone, biobudownictwo*

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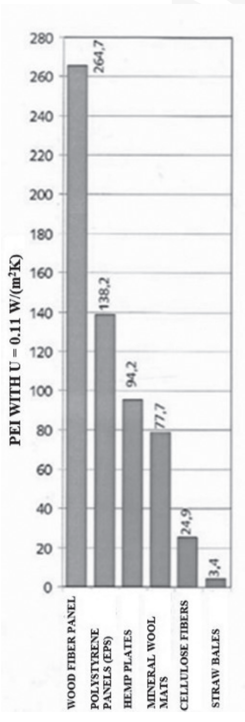
1. Introduction

Natural materials are becoming increasingly important in modern times, especially in the context of environmental protection, which means that the choice of construction material, to a great extent, shapes the eco-footprint of the building. One way to protect it is to act in accordance with the principles of sustainable development, which sustainable construction is a part of. Attention was paid to analyze the legitimacy of the selection of construction materials problem in the context of energy efficiency (with regards to *straw bale* technology). The validity of the use of natural materials in contemporary construction was also demonstrated, especially as it is one of the criteria taken into account in the LEED or BREEAM global organic certification.

2. Organic material in the context of energy efficiency



Energy is needed to produce any construction material. In comparison to industrially processed products, the more natural material is the less embedded PEI energy[1] it comprises. Although this assumption is not always so obvious – as it can be seen in the graph on insulating materials (Fig. 1), a wood fiber panel has almost twice the PEI value in comparison to polystyrene panels (EPS) for the heat transfer coefficient $U = 0.11$ W/(m^{2}K), which is normally sufficient for the implementation of passive building. Slabs of wood fiber definitely have the highest content of embedded energy (produced by means of wet method). Although hemps, like straw, are agricultural products – hemp plates are less preferred as insulation material because of the value of PEI, than mineral wool mats. Low PEI value for straw bales is due to the fact that straw is a waste product; therefore the energy required for the cultivation of straw is not taken into consideration, as in the case of hemps, which are grown for the production of thermal insulation materials. However, if the processes of cultivation of grain for the production of straw would be taken into account, than its embedded energy value would be at the level of the value presented for cellulose fibers.

Fig. 1. Embedded energy content with heat transfer coefficient $U = 0.11$ W/(m^{2}K) [6]

1 An adopted Polish term *embedded energy* is a translation of the German PEI – Primärenergieinhalt. According to [6]: “Energy required to produce a given material is defined as energy embedded in it. The content of PEI embedded energy applies to »all initial and production processes up to the finished product ready for sale. This criterion takes into account only the energy from non-renewable sources. The energy content of wood, water, sun etc. is not included here«. [Kohler/Klingele (ed.) 1995]. Therefore, PEI describes the amount of non-renewable energy, which is needed to produce a product (for example a construction product)”.

The walls can be insulated with various materials. The graph (Fig. 2) shows the content of the embedded energy in conventional partitions (includes fragments of walls with no details) in juxtaposition with partitions with straw bales. As a point of reference of submitted comparison there were selected: a wall of calcium silicate bricks, thermally insulated with polystyrene foam (EPS), on the inside covered with resinous plaster, and on the inside with cement and lime plaster (position 1). Energy intensity of a thermal insulation is increased by replacing the EPS with wood fiber panels (position 2). On the next combination of layers of partition wall, with included replacement of wood fiber panels on straw bales, it can be seen a dramatic reduction in the PEI value. Replacement of the supporting layer made of silicates with panels made of glued laminated timber resulted in further reduction of PEI. Analyzing the chart below, it can be finally stated that the use of straw bales significantly reduces the content of PEI embedded energy, where the last option (position 9) turns out to be the most favorable, where the content of PEI is equal to about 10% of the original option.

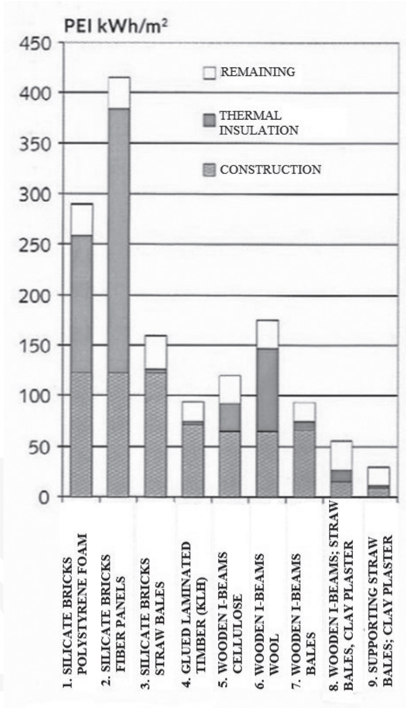
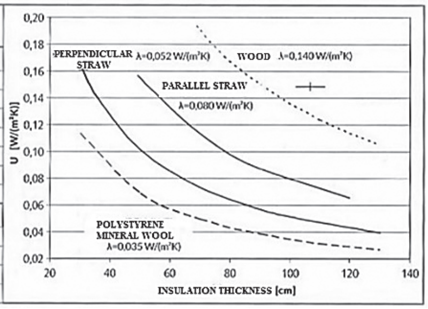


Fig. 2. Embedded energy content for walls of different structure with heat transfer coefficient U = 0.11 W/(m^{2}K) [6]

A significant aspect of the formation of construction materials is a method of their production and processing. It is important to take into account the fact that there is a fundamental difference in the level of PEI energy value of construction material for the production and processing when using the traditional method, and using the industrial method.

THICKNESS OF THE LAYER OF STRAW WALL d [M]	COEFFICIENT U FOR THE WALL [W/(m²•K)]
PERPENDICULAR HEAT TRANSFER	
0,31	0,16
0,36	0,14
0,50	0,10
0,70	0,07
0,90	0,06
1,00	0,05
1,30	0,04
PARALLEL HEAT TRANSFER	
0,41	0,19
0,49	0,16
0,80	0,10
1,20	0,07



Material thickness for which U = 0.11 W/(m^{2}K) are:
46 cm (perpendicular straw λ = 0,052 W/(m^{2}K))
72 cm (parallel straw λ = 0,080 W/(m^{2}K))

Fig. 3. The value of heat transfer coefficient U for walls made of straw bales depending on the thickness of the straw layer and on the arrangement of stalks [6]

3. Straw as a natural material in *straw bale* technology

A *straw bale* technology [11] is one of the bio-construction technologies. The straw is formed into cubes of specific dimensions by means of a press. Strong compression of straw fibers placed in the press hampers the access of air to the interior parts of structure, which in turn ensures its high fire resistance class. Such modules, made of straw, are deposited in a wooden frame construction of the building or are prepared to be used as wood and straw prefabricated elements. In the construction process de facto it is necessary to build a foundation and to impregnate wall face with clay and protect it with plaster, which would provide straw modules protection against: moisture, rotting processes and against rodents and insects.

Straw is one of primary waste products in agricultural production. It is a renewable resource and in the context of the construction it is a material, which is: very cheap, widely available in most climate zones and not causing any recycling problems. Due to the natural provenance it is characterized by a low value of primary energy (PEI) – approx. 3 kWh/m^2 [3], as compared to the products obtained industrially. It can be a very good thermal and acoustic insulation and the wall built in this technology, which has suitably a thick layer of plaster, is characterized by excellent energy parameters (thermal insulation, heat storage) and it has a high resistance to fire. The very construction the process is classified as ecologically pure, low-energy and optimized in terms of cost. In objects built with straw and clay there is a proper microclimate, resulting from a high absorption and commissioning of steam capacity and also the steam-permeability. An additional advantage generates the possibility of replacing heavy foundation with the foundation points.

With many indisputable advantages of this type of construction the opponents can detect few flaws. The use of clay creates a possibility of crack occurrence during drying the plaster. In addition, a special attention must be paid to the need for highly accurate protection of the straw against moisture acting here as one of the biggest threats. The thickness of buildings' walls from 50 to 60 cm (approx. 20 to 23 inches) can be considered as a minus point because it may translate into an increase in floor space with the same usable floor space. There are also aspects of a social nature situating described construction in the experimental field, which does not raise such a high confidence among users as traditional technologies.

4. Passive buildings as an example of *straw bale* technology

The technology under discussion has, over the past decade, gained great popularity in Western Europe. The objects already built provide not only an innovative approach of abroad cities to alternative construction but also they show great sense of aesthetics and workmanship.

"Larix Haus" (*House of larch*) [9] (Fig. 3), is the first in the Iberian Peninsula passive house, whose design is based on the use of straw and wood. The building is located in the

Fig. 4. Wooden building envelope [9]

Fig. 5. The construction of a "Haus Larix" house (2013) [9]

town called Collsuspina, approx. 70 km (43.5 miles) north of Barcelona. It is a two-story building with a usable floor space of 94 m^2 (approx. 112 square yards). The construction took only five months for the sake of the use of prefabricated elements (Fig. 5), which saved time, minimized costs and eliminated waste on site. Construction of the building was based on a wooden frame filled with straw bales. Materials used in the construction are mostly natural and fully renewable (certified wood, straw and cork from a local source) – which minimized energy consumption and CO_2 emission associated with the construction of the house. Unnecessary heat losses have effectively been reduced by executing a tight housing of the building, insulation made of straw and insulating cork and the use of three-glass windows covered with low-emissivity coating and filled with argon. The building was certified as a passive house (to which also contributed: ventilation system with heat recovery, thoughtful placement and orientation of windows equipped with additional shading systems, electric heaters, fireplace using biomass, compact air heat pump, installation of a photovoltaic system, system of recovery of rainwater).

A special system of prefabricated modules with a height of the entire floor was developed for passive residential-training building in Austrian city of Stollhof (Fig. 6). Moreover, a typical vapor barrier has been replaced by a new clay-woven technology. In addition, the building was covered with green roof with extensive vegetation. Good insulation and high class joinery in cooperation with the installation of heat recovery and controlled ventilation minimize thermal losses. Glazing on the southern facade allows for passive solar gain and for the protection against overheating of the rooms they are equipped with external blinds.

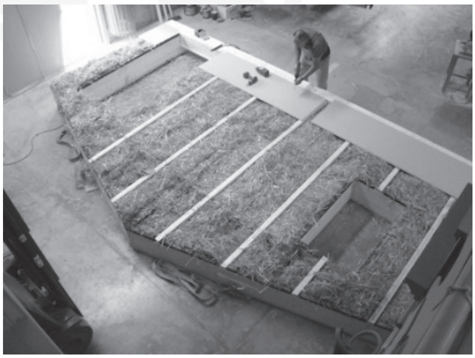


Fig. 6. Prefabricated elements based on wood and straw [9]

5. Straw bales in Polish natural architecture

What is optimistic is the fact that many of the successful implementations of the straw bales are also present in Poland. The facilities created, over the past years, are attractive both from technical and visual point of view and are in no way inferior to Western examples. Recently great popularity was gained by a trend of prefabrication of wall and ceiling elements insulated with straw, which has an impact on the reduction of dependence on weather conditions during installation.

One of the most interesting is the building situated in the town called Gajowiec, located near the town called Mirsk (Fig. 7 and 8), that by decision of SARP (Polish Architects Association) in Jelenia Góra received the first place in the Regional Architectural Review called KASA in 2013 [11].

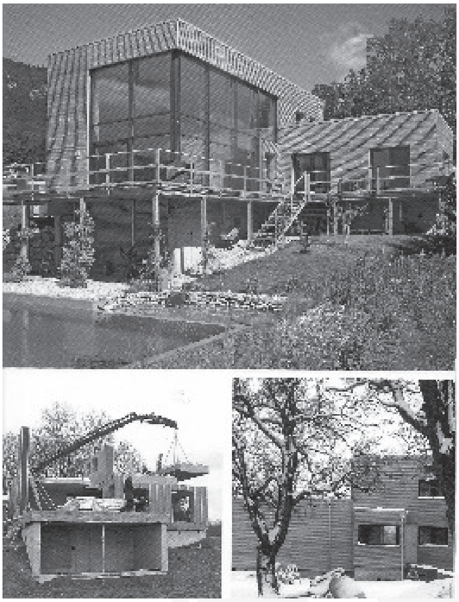


Fig. 7. Residential-training building in Stollhof, Austria [6]

Fig. 8. Holiday cabin situated in Gajowiec near Mirsk (author's archive)

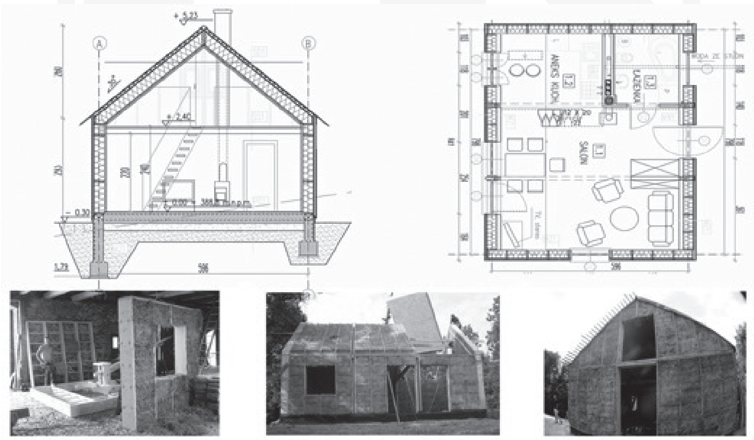


Fig. 9. Summer building situated in Gajowiec near Mirsk – plan, section, the assembly process [11]

Bearing walls of this building are 2.5 m × 2.5 m (8.2 × 8.2 feet) wooden modules filled with straw bales (same dimensions were used in the roof) with cladding, DWD plates and elevational decking on counterbattens. Clay plasters with chaff and with lime plaster were made inside. The thickness of the partition is of 36 cm (approx. 14 inches). Straw bales with a thickness of 30 cm (approx. 12 inches) were used as thermal insulation of external walls and the roof [11].

6. Conclusions

Bio-construction unquestionably benefits from low-processed materials of organic origin in respect to the environment. However, as shown above – not always natural materials (on which such a strong emphasis is put because of a natural origin in the certification system) have a lower PEI indicator than materials produced from fossil or mineral resources. Perhaps this observation should be considered when formulating and specification of the criteria of certification of BREEAM or LEED type?

Building with straw bales abounds with numerous benefits. First to mention here would be: wide availability of the material, its universality, the possibility of recovery, lack of toxicity, waste minimization, and environmental friendliness because of its plant origin and binding of carbon dioxide during the time of the use [7]. Moreover, the presented technology has good thermal insulation parameters, and therefore is predestined for buildings in passive standard and proves that it is possible to build houses that are: healthy, energy economical and affordable.

Using this relatively inexpensive and existing since ages construction material does not need to have a negative impact on the form of designed buildings and bring them into the form of: ancient huts, primitive mud huts or 'fantastic' houses from Tolkien's books, thus being a technically regression. A XXIth century building form in *straw bale* technology does need not be a quote from the past but a refreshing and contemporary release of natural architecture that exists for centuries. These structures not only have positive impact on human's body and safety of the environment but also it can be beautiful, functional and modern, more and more as objects with passive standard. In the context of discussion the following statement seems to be justified: "(...) Natural construction is more necessary for actual architecture rather than multiple neo-, post-, or ultra-modernism" [6].

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