Available online at
http://journals.usamvcluj.ro/index.php/promediu

ProEnvironment

ProEnvironment 8 (2015) 17 - 23

Original Article

Using Wheat Straw in Construction

CANTOR (ANDREŞ) Dana Maria*, Daniela Lucia MANEA

Technical University of Cluj-Napoca, 28 Memorandumului Street, 400114, Cluj-Napoca, Romania

Received 1 March 2015; received and revised form 5 March 2015; accepted 8 March 2015
Available online 29 March 2015

Abstract

Agricultural production leaves behind it a considerable amount of agricultural waste. Some of these are reused in agriculture as fertilizer, but most are burned. Uncontrolled burning is a solution with a negative impact on the environment and energy waste. Straw is a healthy alternative to modern construction materials, being a natural material. While prices of construction materials have increased in recent years, agricultural waste recycling presents a continuous challenge for the fields of engineering, attention being directed to the materials made from agricultural waste showing characteristics similar to the traditional production, at a considerably lower price. Straw bales have demonstrated standard insulation capacity two times better than that required by regulations, with power consumption reduced by 50%. At the same time, the straw bales significantly reduce the energy consumed to build a wall with up to 90%. Globally, the construction of straw bale is rising. In many countries governments encourage the use of straw in the construction industry; local authorities are among the biggest beneficiaries. In Romania natural and green houses are becoming increasingly popular and more and more specialists are interested in this type of construction.

Keywords: sustainable building materials, agricultural waste, wheat straw.

1. Introduction

Waste management refers to materials resulting from human activities and to the reduction of their effect on the people's health and the environment. Waste management may also contribute to saving natural resources through the reuse of recoverable parts [2, 11].

At the same time the request for a living environment free from toxins and allergenic substances, providing the basis for stress-free living and working conditions is increasingly demanded by clients for newly built homes [17]. In the last century, researchers' attention was directed towards non-conventional building materials with properties similar to those traditionally used in civil engineering.

These materials could help reduce the housing deficit and could provide a low-cost housing which would allow more people to have their own home [10]. The recycling of agricultural waste in the building materials industry is an efficient solution, with beneficial effects both for the construction industry and for environmental protection and improvement, allowing at the same time the protection of natural resources [1].

This paper seeks to address vegetable fibres, which are good materials for reinforcement, are renewable and are found in large amounts in nature. Given the physic-mechanical properties and high fibre variety, it was concluded that they can develop new sustainable materials with suitable properties [14]. While cereal grains are the main objective of agricultural activity, there is great interest in developing uses for residues that are currently burned or returned to the earth.

* Corresponding author.
Tel: +40-264-401 548
Fax: +40-264-401 548
e-mail: andres.dana.maria@gmail.com

The most common agricultural waste is wheat straw, which is often burned in the field, contributing to carbon dioxide emissions, annually recurring phenomenon that has become a concern to the appropriate authorities. To return to the earth as fertilizer, straw needs to be chopped and spread, which involves a mechanical process, energy consumption and carbon dioxide emissions. This has led to the recommendation of using straw in construction [10].

Researches were made on the use of rice straw and husk fibers [5], jute fibres [12] and wheat straw fibres as reinforcements in composites [13] etc. Natural straw fibres can be used also as aggregates for the design of lightweight aggregate concretes [6]. Sustainable construction materials that have low embodied energy include earthen construction and straw bale construction [15].

Straw bale buildings are a new building solution using bales of straw (wheat, rice, barley, etc.) as well as structural elements, a filler or insulation. This solution is very common in natural building projects, green buildings with low energy consumption. Research has shown that this is a sustainable method which uses materials that actively contribute to the energy needed to heat the building [4].

While prices of construction materials have increased in recent years, recycling agricultural waste presents a continuous challenge for the fields of engineering, with a focus on materials made from agricultural waste, showing features similar to the traditional production at a considerably lower price.

The oldest straw bale construction in the United States dates from 1900 and certified in 1901. That building was a school which was not plastered so in winter was eaten by cattle. Around the 1900s, white settlers who lived in Nebraska, USA, grew cereal in areas without forests. Thus having the necessary materials for home building, wooden wagons barely reaching next spring, they began to build temporary housing with bales, which for them was a waste. The inhabitants of these houses have noticed that these houses offered them special comfort, retain heat in cold winter days and restrained them from the summer heat, was a very good sound insulator, protecting them from the wind sounds outside. This positive experience of building and living in such houses determined them to build permanent straw bales houses, many of them are there nowadays.

Because of the war and the widespread use of concrete, they showed a downward trend until 1970 when two American scientists have brought to people's attention this type of housing. For the environmental protection enthusiasts and nature lovers among permaculture groups and among the committed nature, these types of building became slightly the prototype of their own home.

In Europe, the first such constructions appeared in Britain in 1994 and in Ireland in 1996. Nowadays thousands of these buildings are made annually across the globe.

Worldwide research interest turned to carbon, which is one of the biggest problems facing humanity. Most of the buildings have a positive carbon footprint. Taking into account all the construction materials done and it examines how much carbon dioxide being released into the atmosphere in their production process or emissions of carbon dioxide produced during the transportation of raw materials, it is observed that the amount emissions is much greater than the amount of carbon that can retain material over their life. All governments encourage housing construction with a carbon footprint that tend to zero, but it can easily get a negative carbon footprint by building walls with new materials such as wheat straw [8]. Buildings made of natural materials such as straw, wood, hemp, are totally different, because these raw materials are growing in the ground and do not require a manufacturing process, and like any plant retain carbon dioxide and release oxygen, thus having a negative imprint carbon dioxide emissions.

In figure 1, can be seen 25 materials by the specific emission of carbon dioxide. It can be seen that the biggest polluter is metal because its extraction from the earth consumes a tremendous amount of energy. Cement is the middle graph, but given the large amount that is used to achieve a building we can speak of a positive carbon footprint. After water and sand, cement is the most widely used material worldwide, becoming the biggest polluter in the world.

Researcher Jakub Wihan, in his thesis "Humidity in Straw Bale Walls and Its Effect on the Decomposition of Straw" showed that a bale of straw weighing 16 kg holds 32 kg of carbon dioxide. To build a typical 3 bedroom house requires about 350 bales, which would be 11.2 tons of carbon dioxide retained [18]. In Romania, people's interest in the construction of new materials, clean, natural constructions or green is becoming greater. A study shows that in early 2012, in Romania existed only one straw bale house with wooden structure, made by a German prototype. At the beginning of 2014 in Romania were 11 straw bale constructions completed, and more in the planning phase. Slowly, the construction of new materials from natural, environmentally friendly materials becomes more extensive, showing interest among all classes and in all age levels.

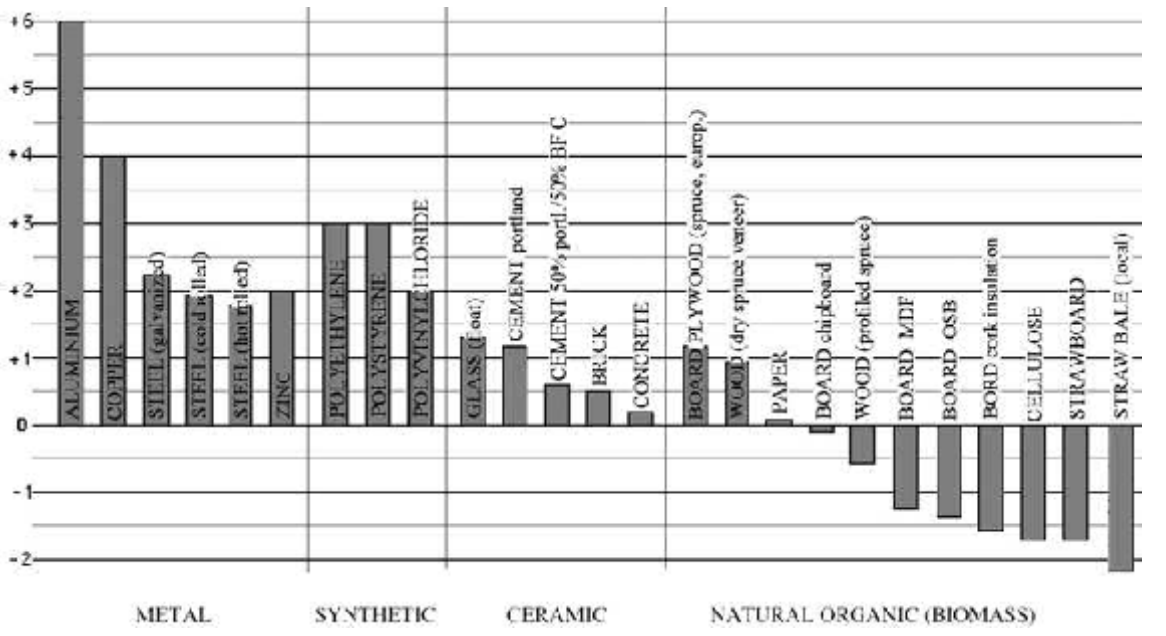

Figure 1. CO_2 net emission to produce a kg of material [18]

2. Material and Method

Straw bale constructions are classified into three categories according to the type of structure resistance: construction with load bearing straw bale structure, straw bale construction with timber frame structure, straw bale construction with prefabricated walls [3].

Construction with load bearing straw bale structure, called Nebraska-style building, is the original way of building with bales of wheat straw. Most builders prefer this style for its simplicity, flexibility and easy design to achieve, but mostly for thermal efficiencies and minimal price.

In this method, straw bales which are building blocks are ready to take the weight of the roof so there is no need for an adjacent structure. In Fig.2 can be seen that bales are positioned as masonry blocks, caught base pin (wooden stakes fix size) and each pin drop as wood. In buildings with a height of ground floor and first floor, between the two levels is positioned all around the walls a wooden base so that it can be fixed and intermediate floor.

Windows and doors can be arranged in different ways. Simple method is to place a wooden frame in the building's wall structure. This method is particularly useful in the construction of small or experimental buildings. Use more wood but keep the simple look of construction and is very accessible [9].

The solution of using load-bearing straw bale walls is a simple, uncomplicated, easy to use method even for people without training, just following the basic principles of this method. This construction technique is most often used in the USA, UK and Ireland.

The straw bale construction with timber frame structure is also a traditional solution. It was first used in the United States in the late 1970s. In this way the weight of the roof is taken by a wooden frame (Fig. 3). Straw bales are basically just filler with no charge. This technology requires an adequate design of the building, correlated with the size of the bale which is to be used. Even if plans are made by classic construction, the bales can easily be resized to suit the size of the building. The most difficult part is preparing bales for plastering that require high attention. Long wires protruding straw bale are cut to give a touch of uniformity to the wall.

In case of straw bale construction with timber frame structure it is important that the bundle to be well compressed in various methods, to avoid heat losses while achievement. It is preferable to use as well pressed bales but is recommended the additional compression of the walls before applying the plastering on the wall.

Figure 2. Construction with load bearing straw bale structure [21]

Figure 3. Straw bale construction with timber frame structure [20]

A *straw bales prefabricated wall* (Fig. 4) is a solution that brings benefits of straw bale construction:

- prefabricated walls are perfectly straight, they do not require special attention;
- vertical space are filled perfectly with straw, unlike the methods described above, in this case there is no chance to appear gaps after pressing the bale;
- no need to resize bales for wall ends;
- handling of the wall is easily accomplished.

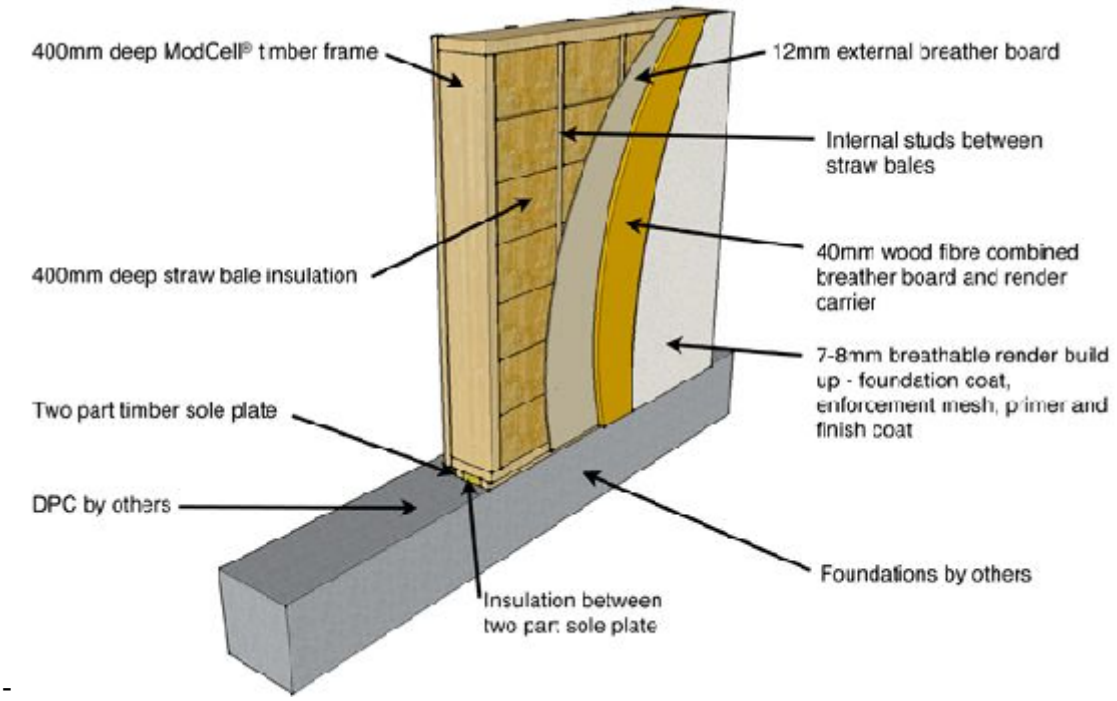

Figure 4. Straw bales prefabricated walls [22]

The wall is assembled and subjected to compression in a horizontal plane, being much easier to achieve.

3. Results and Discussions

More than 50% of total emissions worldwide come from the construction industry and transport associated with them. Research shows that if surplus of straw in the UK would be used in the construction industry, at least 420,000 homes could be made annually. That would mean almost half a million houses built of materials that absorb carbon dioxide throughout their lifetime [8].

Building energy-efficient homes became XXI century challenge. Straw bale buildings are sealed construction offering a high degree of comfort.

Straw is a healthy alternative to modern construction materials, being a natural material. Straw bale walls, unlike those of conventional materials, improve indoor air quality through their property to breathe, formaldehyde and other dioxins are no longer present.

The rooms that were finished with the natural materials, such as clay or natural colouring pigment, have been found to be the most healthy and comfortable living space. Another benefit is the atmosphere inside a straw bale house, being calm and soothing. Most existing buildings have a positive carbon emission due to the materials they are made. Governments around the world encourage the construction industry to reduce to zero carbon dioxide emissions. Straw bale buildings provide a negative emission of carbon dioxide.

On straw bale walls, insulation is the bale itself, unlike classical constructions where insulation is a separate material, representing at the same time finish to the surface.

Insulating quality of a material is given by the heat transfer coefficient U, which is inversely proportional to the thickness of the material. Straw bales have a heat transfer coefficient between 0.13 and 0.20 W/m^2K, depending on the type of bales used, especially depending on their density [16]. Straw bale walls, plastered on both sides, have a fire resistance of up to F90. After the Austrian and German rules, the coefficient of thermal conductivity is 0.0456 W/mK [7].

National Research Council of Canada has conducted safety tests on straw bales walls on fire and the result was that the walls have withstood temperatures up to 1010° C for two hours.

Fire test ASTM E-119 made by AGRA SHB New Mexico, USA, 1993 states that "straw bales

panel was subjected to two hours at temperatures that have reached 1061°C. On the part that was not exposed to fire, temperature changed by more than 1°C. It has been shown that straw bale walls do not burn due primarily to render and secondly because the bales are compressed.

The result of a fire resistance test done on a bale walls without plaster showed that it has withstood the heat and open flame furnace for thirty minutes before flames break through the wall in the area where the bales are combined.

Research shows that they are 3 times more fire resistant than conventional buildings because inside the pressed bale is not combustion air [19].

Figure 5 (a). Straw bale wall after fire test [19]

Figure 5 (b). Unexposed part of wall [19]

Fire Test ASTM E 119-05a made by Intertek Testing Services NA, demonstrate that straw bale wall plastered with clay has stood the test fire without flame or gases to pass to the other side of the wall, no water from the tube test. It was not identified any openings that allow water to pass to the other side of the wall.

The dimensions of the wall under test are 3.66 x 4.27 m, can be seen in figure 5 a and 5 b, made from rectangular straw bales, dimensions of 91.4 cm long, 35.6 cm high, 45.7 cm wide, with a weight of 19.2 kg. Each bale of wheat straw has two polypropylene ropes to keep straw pressed. The wall was plastered with clay plaster applied in two layers each 1.25 cm. The mixture was made of 3 parts of clay, 2 parts of chopped straw, 6 parts of sand and water to the desired consistency. The second coating was applied to 18 days after the first layer, thereby providing the time needed for drying of the first layer. After application of the second layer, the wall plastering was allowed to dry for a period of 28 days. The day of the test was measured humidity both inside and on the sides plastered bale. Average humidity recorded was 11.1%.

Transmitted through the wall, the temperature during the test did not exceed the recommended average temperature and the individual temperature measured on the unexposed wall did not exceed 162 degrees Celsius.

In 1998 at "The Centre for Research in Construction, University of New South Wales, Australia", it was performed the ASTM E72 test on load bearing walls cross the bales (Nebraska style). The tests revealed that both walls withstood the test maximum static air pressure that has been applied, representing a strong wind over 134mph (60m/s).

Another ASTM E72 compression tests on straw bale walls, by the University of Colorado at Boulder in 1999, concluded that for round walls resistance the final average was 6156 pounds per linear foot which means 930kg/m and is more than enough in terms of the requirements of ASTM E72 [19].

Tests conducted in compression and earthquake showed that plastered straw bale walls have an almost ideal behaviour. The ASEM acoustic tests showed that straw bale walls are a perfect barrier against noise.

4. Conclusion

Globally, the construction of straw bale is on the rise. In many countries governments encourage the use of straw in construction; local governments are among the biggest beneficiaries. In Romania, natural, green homes started to become increasingly popular and more and more specialists are interested in this type of construction.

It is shown that, straw bales as a building material:

- save energy due to low embodied energy to bale;

- save operational energy with heating and cooling;
- decrease the level of carbon dioxide emissions.

Standard straw bale insulation capacity showed two times better than that required by regulations, with a power consumption reduced by 50%. At the same time straw bales significantly reduce the energy consumed in the construction of a wall by 90%.

It is shown that during growth, 10 kg of wheat straw absorb 14 kg of carbon dioxide, which they retain during the term of life.

Acknowledgement. This paper is supported by the Sectorial Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government.

References

[1] Aciu C., 2014, Use of Sawdust in the Composition of Plaster Mortars, ProEnvironment, 7 (17), 30–34.

[2] Aciu C., D.A. Ilutiu – Varvara, N. Cobirzan, A. Balog, 2014, Recycling of Paper Waste in the Composition of Plastering Mortars, Procedia Technology, 12, 295–300.

[3] Adedeji A.A., J.A. Bello, 2011, Construction Procedure of a Straw Bale Walled Building – a review, Annals of Faculty Engineering Hunedoara – International Journal Of Engineering, IX (3), 255–262.

[4] Atkinson C., 2008, Energy Assessment of a Straw Bale Building, London, http://www.homegrownhome.co.uk/pdfs/Energyassessmentofastrawbalebuilding.pdf.

[5] Bassyouni M., S. Waheed Ul Hasan, 2015, The Use of Rice Straw and Husk Fibers as Reinforcements in Composites, Biofiber Reinforcement in Composite Materials, Woodhead Publishing, pp. 385–422.

[6] Bouasker M., N. Belayachi, D. Hoxha, M. Al-Mukhtar, 2014, Physical Characterization of Natural Straw Fibers as Aggregates for Construction Materials Applications, Materials (Basel), 7, 3034–3048.

[7] Bynum R.T., 2000, Insulation Handbook, McGraw-Hill, DOI: 10.1036/0071414614.

[8] Gouthier-Gignac F., J.M. Vittrup, 2007, Environmental Impacts of Passive Houses, http:// www. strawworks.co.uk/wp-content/uploads/2014/11/passivhouse impact.pdf.

[9] Hodge B., 2006, Building Your Straw Bale Home: from Foundation to the Roof, CSIRO Publishing, Australia.

[10] Hollis M., 2005, Practical Straw Bale Buildings, Landlinks Press, ISBN: 978064306977.

[11] Iluţiu – Varvara, D.A., 2009, Experimental Researches Concerning the Volatileorganic Compounds (Vocs) Emissions to the Steelmaking. MetalurgiaInternational, 14 (7), 38–43.

[12] Khan J.A., M.A. Khan, 2015, The Use of Jute Fibers as Reinforcements in Composites, Biofiber Reinforcement in Composite Materials, Woodhead Publishing, 3–34.

[13] Panthapulakkal S., M. Sain, 2015, The Use of Wheat Straw Fibres as Reinforcements in Composites, Biofiber Reinforcement in Composite Materials, Woodhead Publishing, 423–453.

[14] Rusu A., 2009, Valorificarea Surplusurilor de Paie, Pontos Publishing, Chişinău, Moldova, ISBN: 9789975510271.

[15] Swan A.J., A. Rteil, G. Lovegrove, 2011, Sustainable Earthen and Straw Bale Construction in North American Buildings: Codes and Practice, Journal of Materials in Civil Engineering, 23 (6), 866–872.

[16] Thomson A., P. Walker, 2014, Durability Characteristics of Straw Bales in Building Envelopes, Construction and Building Materials, 68, 135–141.

[17] White C.M., T.J. Howard, T.A. Lenau, 2012, Opportunities And Barriers To Straw Construction. Proceedings of the Asme International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 7, 475–484.

[18] Wihan J., 2007, Humidity in straw bale walls and its efect on the decomposition of straw, University of East London, School of Computing and Technology, http://www.enertech.fr/pdf/45/humidite_murs_paille.pdf.

[19] ***, 2007, ASTM E 119-05a Fire Tests of Building Construction and Materials, 1-hr Resistance test of a non-loadbearing straw bale wall, Project No. 3098054 B.

[20] ***, http://earthzine.org/2009/10/07/the-millennium-development-goalsenvironmental-sustainability-and-energy-savings-with-straw-bale-homes/.

[21] ***, http://greenpassivesolar.com/2011/05/passive-solar-straw-bale-house/.

[22] ***, http://www.treehugger.com/green-architecture/prefab-straw-bale-houses-hit-market-bristol.html.