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A COMPARATIVE STUDY OF BRICK AND STRAW BALE WALL SYSTEMS FROM ENVIRONMENTAL, ECONOMICAL AND ENERGY PERSPECTIVES

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ABSTRACT

The aim of this study is to compare brick and straw bale wall systems from environmental, economic and energy perspectives. The choice of basic building materials is an important part of each project and is usually based on professional judgment, taking into consideration the importance of various criteria such as economic, environmental, functional, aesthetic and health aspects. Brick is the most commonly used building material worldwide; whereas straw, though widely available and having many advantageous properties, is still poorly exploited. In this study, wall compositions of both materials were examined assuming passive building standards. Three values - Global Warming Potential (GWP), Primary Energy Input (PEI) and Acidification Potential (AP) - of environmental impact were calculated. It was shown that, considering environmental, economic and energy values, the use of straw bales is a good alternative to brick.

Keywords: building, brick wall, straw bale wall, environment, energy, economics.

1. INTRODUCTION

Environmental impact is measured by calculating various factors, such as PEI (Primary Energy Intensity), GWP (Global Warming Potential) and AP (Acidification Potential). These values are already collected for many materials in various databases. By knowing each material and its amount for a specific project, impacts on the environment for the building can be calculated.

These factors are also directly related to the amount of resource use in the building and are, in many cases, part of established green building rating programs such as: DGNB (Deutsche Gütesiegel für nachhaltiges Bauen), LEED (Leadership Energy and Environmental Design), and BREEAM (BRE Environmental Assessment Method). These programs are based on a point collection system and are well publicized [1, 2].

Ecological, environmentally friendly, and healthy buildings demand balance in many different aspects of building design. The selection of the main material often plays an important role in the building process. Natural materials have been shown to have low impact on the environment, their primary benefit being their organic origin, renewability, and low embodied energy, and they usually offer favorable living conditions to its dwellers/users [3]. These materials naturally meet ecological, environmental and health criteria which is becoming an increasingly important issue as the awareness of building impact on the environment increases.

Straw bale construction is a distinctive example of such green building ideals. Alcorn *et al*., [4] affirmed that using biomaterials such as straw, timber, and emission-reducing technologies for house design and construction reduces CO_2 emissions towards net zero. This was shown using a life cycle analysis of different house designs with comparison of the effectiveness of biomaterials with CO_2-minimizing technologies. Additionally, the end-of-life scenarios for materials were discussed. A case study of a straw bale house was presented by Ashur [5]. The experimental work included compression tests, moisture content and thermal stability of bales as well as pH measurements.

Furthermore, Garas *et al*., [6] presented an ecological as well as economical aspect of building with straw bales. Their main focus was comparison between a load bearing wall unit built with locally produced rice straw bales and a traditional load bearing wall unit built with cement bricks. One finding of this paper was that a cost saving in favor of straw bale building of about 40 % of the total construction cost could be achieved, in addition to the indirect cost saving in energy consumption, and thermal insulation.

Sodagar *et al*., [7] discussed a load-bearing straw-bale walls which was examined through the whole-life performance of straw bale construction with alternative conventional external wall systems. Evidence was presented to demonstrate the viability and performance benefits of straw-bale housing for rural communities.

Indirectly connected to this research study are papers of Seyfang [8], Milutiene *et al*., [9], Venkatarama [10], Thormark [11] and Harris [12]. These three papers devote attention to embodied energy in the materials used in building. It is demonstrated with examples that by careful selection of building materials one can have a significant influence on the whole carbon and emission footprint of a building.

This paper presents a case study, which largely meets the criteria of sustainable building particularly in terms of material selection. Two wall systems of the same area are examined from an environmental and economic perspective where values of PEI, AI and GWP are calculated. The first wall is a composite of straw-bale covered with a loam and lime render, presented as the most common practice. The second wall is a composite of honeycomb brick and Expanded Polystyrene (EPS) insolation rendered with lime-cement on both sides which is a common technique used worldwide.

2. MATERIAL CHOICE

Apart from the energy consumed, construction processes, and demolition and disposal of building materials have other significant environmental consequences which are associated with the extraction of raw materials, disposal of wastes, and the effects of building materials on the health of building workers and occupants [12]. Therefore, the choice of basic building materials is an important part of each project and is usually based on professional judgment, taking into consideration the importance of various criteria such as economic, environmental, functional, aesthetic and health aspects. The priority varies depending on the needs, desires and abilities of each user/investor usually in agreement with the designer.

Modern buildings are known to have a major impact on the environment throughout their life cycle [9]. The energy needed for operation can be considerably decreased with well-known sustainable design strategies, such as improved insulation of the building envelope or using high performance HVAC equipment [10]. In a similar manner, the amount of total energy in the life cycle of a building can be decreased significantly with the correct choice of material; this will be demonstrated by a comparison of two wall compositions.

Building with bricks is taken for granted in many parts of the world. It presents a relatively economical and safe choice regarding its tradition, availability and general properties. In the past few years, however, interest in straw (especially straw bales) as a building material has increased, primarily due to the rising attention on environmentally friendly building. The ecological component to planning and building is becoming more significant. Selection of materials and technologies for building construction should satisfy the needs of the user as well as the development needs of the society, without causing any adverse impact on the environment [9]. As a result, low embodied energy materials have become an important and growing field of research.

The materials from which a building is constructed play a significant part in the building's overall impact on the environment. This impact is felt in a number of ways; e.g. locally, through the effects of activities such as quarrying; globally, as a result of carbon dioxide released by using energy to manufacture the materials; and internally, in the effects on the health of the occupants of the building. The embodied energy of a building may constitute 15% of its lifetime energy consumption [11].

The embodied energy of a building material itself is the total energy required to produce it; depending on the material, it could include the energy needed for growing, recycling, extracting, processing and transport. Embodied energy of straw bale is 4kW/m^3 and embodied energy of brick is 1462 kW/m^3 [3].

Therefore, straw bale construction is a logical building material alternative because it is completely organic with low embodied energy. Moreover, many farmers have surplus straw with no obvious need for use. In the past, the excess straw was either burned or buried Today, burning straw is strictly forbidden by law because of excessive pollution and, when buried, decomposition takes a long time. In case of using straw as a building material, its stock is assured annually. It can also represent extra income to the providing farmer.

3. BUILDING SYSTEM

3.1. Straw bale structure system

Straw is a side product created when growing cereal grains such as wheat, oats, barley, rye, rice and others. It is practically unlimited in amount and is assured annually. It has been used as a building material for thousands of years either as a reinforcing additive to clay or mud building techniques or as layer in the form of thatch. The 'straw bale construction technique' uses bales in a brickwork system to form walls which are covered by earthen plaster.

Straw bale building began at the end of the 19th century in Nebraska. It started with the early settlers who were in immediate need of housing. Parallel to the invention of the steam bale engine, straw bales seemed to be the quickest way of creating temporary housing. During the following decades, it was discovered that straw bales make a suitable building material. Straw bale houses rendered with loam and lime have demonstrated excellent results in terms of fire and earthquake resistance, heat and sound insulation values - (almost ten times as much as wood and bricks), energy efficiency, and they require minimum maintenance [13]. The goal in future straw bale building practices is to improve the comfort and health of the built environment while maximizing use of renewable resources (active and passive uses), and minimizing life-cycle costs [6].

Despite already known positive facts and examples of good practice, straw bale building is accepted only by a few. The main concerns are moisture, insect and rodent problems which may occur when attention is not paid to detail. As for every building method, straw bale construction needs special attention to detail. One of the most crucial details is selecting and applying appropriate plaster - a difficult task. The plaster must allow sufficient moisture transport through the wall components and also prevent intrusion of foreign objects such as insects or rodents while ensuring fire safety. If the plaster is applied appropriately, the mentioned problems are avoided.

3.2. Brick structure system

Clay is a raw material for brick production. It is composed of loam, sand, water and a few other ingredients. The history of brick begins circa 7000-6000 BC in the Middle East and Europe when the development of pottery started. The oldest known use of fire-burned brick extends back to 5000-4500 BC. These first bricks were used for drainage dykes in Maddhur. The use of fired bricks became more common when the city of Ur was built in 3100-2900 BC [14].

Up until the industrial revolution in the end of the 18th century, brick represented one of the better choices of building materials, at least in terms of economic, functional and aesthetic values. The industrial revolution has enabled many innovations in the construction sector which have left deep marks on the environment; consequently, there was a need to introduce criteria of material selection, particularly in terms of ecology and health value. The latter is the least discussed and has the largest potential for future investigations.

4. METHODOLOGY

As brick wall construction is the more common building technique worldwide, its characteristics are well known and standardized. On the other hand, the characteristics of straw bale walls have only been a point of interest for researchers since the second half of the 20th century.

In this research, two wall systems are compared: straw bale walls and brick walls. To be as precise as possible, data that were presented by the manufacturers of the discussed materials were used; reference Tables 1, 2. Wall compositions were defined assuming the details of a passive building standard wall. Keeping the ideals of passive construction in mind, we researched the wall systems with a U value lower than 0.15 W/m^2K. In this case, a U value of 0.12 W/m^2K was defined for both walls. Tables 1, 2 shows the structure of the compared walls with equal value of heat transmission coefficient U. The minimum thickness of straw bales is 40.0 cm, which meets U = 0.12 W/m^2K with applied renders. Fixing the U value, the same starting point of both walls is ensured for all further calculations of selected values and comparisons.

Table-1. Straw bale wall structure by layers.

Straw bale wall		**Thickness D** (m)	**Thermal conductivity λ** (W/mK)	**R = D / λ** (m^2K/W)
Heat transfer interior		/	/	0.130
Loam plaster	RÖFIX	0.035	0.80	0.044
Straw bale	Waldland	0.40	0.05	8.0
Loam plaster	RÖFIX	0.020	0.80	0.025
Lime plaster	Baumit Sanova Einlagen Trassputz	0.015	0.40	0.038
Heat transfer exterior		/	/	0.040
Total		0.470	/	8.277
U = 1 / 8.277 = 0.1208=0.12 Wm^2/K				

Table-2. Brick wall structure by layers.

Brick wall		**Thickness** (m)	**Thermal conductivity λ** (W/mK)	**R = D/ λ** (m^2K/W)
Heat transfer interior		/	/	0.130
Lime cement plaster	Baumit MPI 25	0.02	1	0.020
Honeycomb brick	Wienerberger Porotherm N+F (natureplus)	0.25	0.259	0.965
EPS	Austrotherm F	0.28	0.04	7.000
Lime cement plaster	Baumit MPI 25	0.015	1	0.015
Heat transfer exterior		/	/	0.170
total		0.565		8.300
U = 1/8.30 = 0.1199 = 0.12 Wm^2/K				

The wall structure was simplified by omitting some layers. As illustrated in Figure-1, the straw wall (left) was composed of: 1) loam plaster, 2) straw bale, and 3) lime plaster; whereas the brick wall (right) was composed of: 4) lime cement plaster, 5) honeycomb brick, and 6) EPS.

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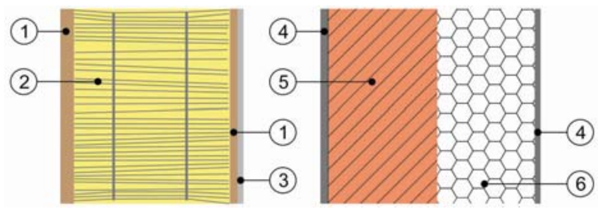

Figure-1. Wall compositions; left straw bale wall (right), right brick wall (left).

Values for density, thermal conductivity and PEI, AI, GWP values per kilogram for each single integrated material for both walls were taken directly from the manufacturer. Based on an equal U value, the thickness of each layer in each wall was determined, (Table-2). All chosen thicknesses correspond to specific manufacturer values. Given layer thickness, mass of each layer - which is basic value for all subsequent calculations - is easily obtained.

The main calculations were divided into two parts:

Environmental considerations

Values of GWP, AI and PEI were calculated on the surface of 1m^2 and compared between two wall compositions.

Economic considerations

Cost was estimated from the current manufacturer's recommended price of each material.

5. TERM DESCRIPTION

The three values: GWP, PEI and AI (IBO, 2008: 321, see Ref. 15) were calculated:

5.1. GWP (Global Warming Potential)

Global Warming Potential is a measurement that establishes the relative climate effects of greenhouse gases. Carbon dioxide (CO_2), the most important greenhouse gas, is used as a reference parameter with a set GWP value of 1. An equivalent amount of carbon dioxide in kilograms is calculated for every greenhouse-effective substance with this value depending on the gas heat absorption properties and the persistence of the gas in the atmosphere. In our study the greenhouse potential was calculated for a timeframe of 100 years.

5.2. PEI (Primary Energy Input)

The amount of energetic resources required to manufacture a product or perform a service is defined as the primary energy content. This value refers to energy involved in all of the performance and production processes involved in making a deliverable product. The gross calorific values of resources serve for classification. The "use of non-renewable energetic resources" is assessed considering non-renewable energy sources only.

5.3. AP (Acidification potential)

Acidification is mainly caused by interaction of nitrogen oxide (NO_x) and sulfur dioxide (SO_2) with air components. A series of reactions, such as the combination with hydroxyl radical, can convert these gases into nitric acid and sulfuric acid which dissolve in water. The acidified drops then fall as acid rain, which appears as a regional phenomenon. The acidification can lead to the movement of heavy metals, can affect water, animals and plants and can cause the corrosion of buildings.

6. RESULTS AND DISSCUSIONS

6.1. Environmental considerations

The calculations were divided into three steps. In the first step, layer thicknesses were calculated as shown in Tables 1, 2 in total and thickness for each layer. With the same heat transfer coefficient, the straw bale wall reached a thickness of 47.0 cm and the brick wall 56.5 cm, Figure-2. In practice that means that there would be approximately 3% more space on the same size floor plan area of 100 m^2, if the walls were constructed with straw bales.

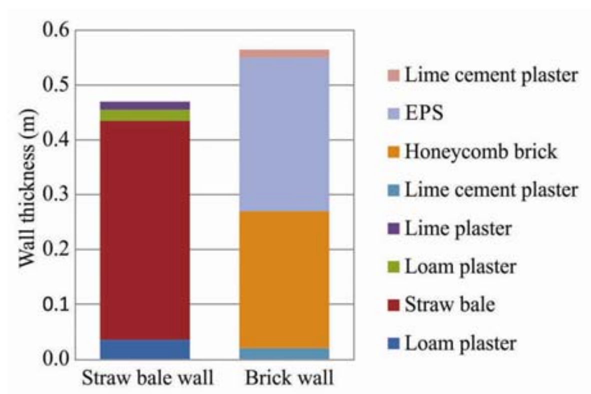

Figure-2. Wall thickness - straw wall vs brick wall.

The environmental impacts of the materials were calculated using the values from the database contained in Baubook [16]. Firstly, the thickness of the layers was defined and multiplied by the density of the material to get the mass of each layer. The values of PEI, AP and GWP are shown in the unit/kg of each material. The result for each layer is obtained by multiplying these values with the material mass used in one m^2 of the discussed wall. Table-3 presents the base data and calculated values for each layer of both walls. In the GWP column, negative values are shown. The reason for this is that a reduction of the amount of carbon dioxide in the atmosphere contributed by straw and clay during their lifetime is incorporated.

Regarding the environmental impacts of the discussed walls, the results show that the brick wall requires 985.65 MJ of primary energy (PEI), which is approximately 9.40 times more than the straw bale wall, where the energy consumption is 104.83 MJ, Figure-3.

Acidification potential (AI) shows that the final value of the straw bale wall layers is 0.052275 $kgSO_2eq$, where the brick wall reaches 0.216688 $kgSO_2eq$, Figure-4. This represents approximately 4.15 times higher efficiency with the straw bale wall construction. Moreover, by comparing the global warming potential GWP, the straw bale wall has a negative value of -50.037 $kgCO_2eq$, and brick wall construction has 61.548 $kgCO_2eq$, Figure-5. Overall, the impact on the environment of the brick wall is higher for 121 $kgCO_2eq$ per m^2. The total mass of the straw bale wall is 147.25 kg, and the brick wall weighs 270.45 kg.

Table-3. Calculations of PEI, AP and GWP for straw bale wall and brick wall.

Straw bale wall		**Thickness** (m)	**Density** (kg/m^3)	**Mass** (kg)	**PEI** (MJ/kg)	**PEI** (MJ)	**AP** ($kgSO_2eq./kg$)	**AP** ($kgSO_2eq.$)	**GWP** ($kgCO_2eq./kg$)	**GWP** ($kgCO_2eq.$)
Loam plaster	**RÖFIX**	**0.035**	**1600**	**56.0**	**0.42**	**23.46**	**0.000110**	**0.006160**	**-0.003**	**-0.189**
Straw bale	Waldland	0.40	105	42.0	0.85	35.53	0.000870	0.036540	-1.250	-52.50
Loam plaster	RÖFIX	0.020	1600	32.0	0.42	13.41	0.000110	0.003520	-0.003	-0.108
Lime plaster	Baumit Sanova Einlagen Trassputz	0.015	1150	17.25	1.88	32.43	0.000351	0.006055	0.160	2.760
total		0.470		147.25		104.83		0.052275		-50.037
Brick wall		**Thickness** (m)	**Density** (kg/m^3)	**Mass** (kg)	**PEI** (MJ/kg)	**PEI** (MJ)	**AP** ($kgSO_2eq./kg$)	**AP** ($kgSO_2eq.$)	**GWP** ($kgCO_2eq./kg$)	**GWP** ($kgCO_2eq.$)
Lime cement plaster	Baumit MPI 25	0.020	1250	25.0	1.04	26.00	0.000198	0.004950	0.150	3.750
Honeycomb brick	Wienerberger Porotherm N+F (natureplus)	0.250	890	222.50	2.30	511.75	0.000514	0.114365	0.182	40.495
EPS	Austrotherm EPS F	0.280	15	4.20	102.0	428.40	0.022300	0.093660	3.450	14.490
Lime cement plaster	Baumit MPI 25	0.015	1250	18.75	1.04	19.50	0.000198	0.003713	0.150	2.813
total		0.565		270.45		985.65		0.216688		61.548

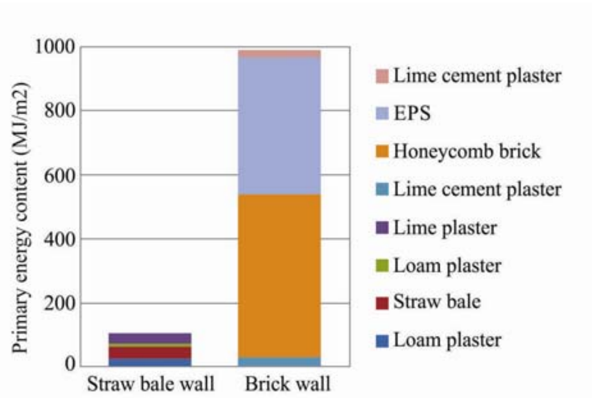

Figure-3. PEI value comparation by layers for researched walls.

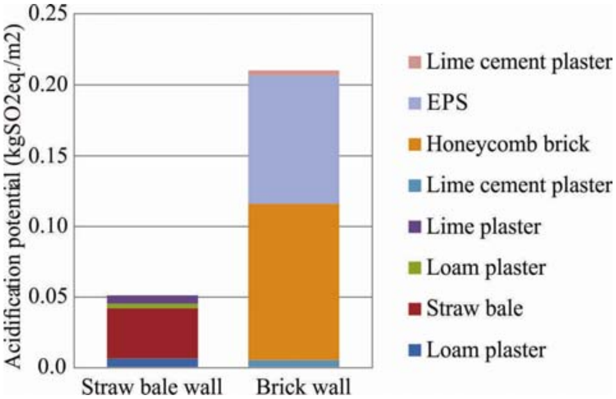

Figure-4. AP value comparation by layers for researched walls.

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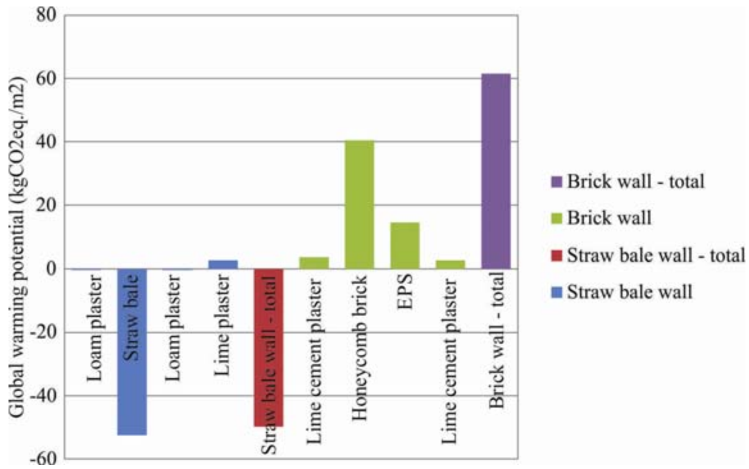

Figure-5. GWP value comparation by layers for researched walls.

6.2. Economic considerations

In the past, the motivation for building was simply shelter and protection from the weather. Today's designs and implementations are often also associated with economic interests, such as profitable facility size, payback period of investment, and the amount of maintenance costs, etc. [17]. From an economical point of view, contractors are interested in the highest possible earnings, while an investor or user usually seeks to make more money with the project, both in the implementation, as well as during operation.

Not many investors build by themselves. Most of them outsource and hire a building company, which adds extra costs. In the majority of cases, investors who *do* decide to build with straw bales, build by themselves, usually with the help of their friends. This is possible partly because the techniques are relatively simple and easy to learn, but mainly because they are forced to self-manage the construction process because the straw bale building technique is not yet fully standardized and contractors with this knowledge are rare.

Economical estimation of both wall systems is presented in Tables 4, 5. It does not take into account costs of material logistics or costs of the material for the structural frame, (i.e., timbers, in case of a straw bale wall if the construction is not load bearing and steel reinforced concrete (or steel beam frame) in case of a brick wall). It should also be noted that the wall system infill presents only a smaller part of the whole investment into the project.

Table-4. Calculation of wall costs per m^2.

Straw bale wall		**Product thickness** (m)	**Price** (€/m^2)
Loam plaster	RÖFIX (geolehm)	0.035	12.07
Straw bale	Waldland	0.40	22.5 €
Loam plaster	RÖFIX	0.020	6.89
Lime plaster	Baumit Sanova Einlagen Trassputz	0.015	6.25 €
Total		0.47	47.71

Table-5. Calculation of wall costs per m^2.

Brick wall		**Product thickness** (m)	**Price** (€/m^2)
Lime cement plaster	Baumit MPI 25	0.020	3.88
Honeycomb brick	Wienerberger Porotherm N+F	0.250	15.51
EPS	Austrotherm F	0.280	31.92
Lime cement plaster	Baumit MPI 25	0.015	2.91
total		0.565	54.22

The results show that the final cost of the brick wall is 14% more expensive than the straw bale wall per m^2. In most cases, local straw bales are used which are not certified, and thus much cheaper, so the saving in comparison to brick wall are even higher.

7. CONCLUSIONS

The choice of the main building material is dependent on many aspects, not only environmental or economic - although they are arguably the most important ones. Materials used in the straw wall system are all natural and completely recyclable, which results in lower energy input in all aspects compared to the brick system.

The idiosyncrasies and perceptions of straw bale construction prevent its universal adoption in the building industry - its use being mainly restricted to suburban and rural applications. Despite the positive qualities outlined in this paper, there has yet to be a breakthrough of straw as a serious building material on a global scale. More research is needed to explore and devise methods to improve upon this method of building. Both straw and brick systems can be used to construct building structures with low energy consumption during operation. The differences found and emphasized in this article were mainly concentrated in terms of their impact on the environment during material production, construction and decommissioning. Our findings show that straw is a good alternative to brick considering economic and environmental factors.

REFERENCES

[1] Azhar S, Carlton WA, Olsen D and Ahmad I. 2011. Building information modeling for sustainable design and LEED rating analysis. Automat Constr. 20: 217-24.

[2] Reed TJ, Clouston PL, Hogue S and Fisette PR. 2010. An analysis of LEED and BREEAM assessment methods for educational institutions. J. Green Build. 5: 1-23.

[3] Atkinson C. 2008. Energy Assessment of a Straw Bale Building. London: University of East London.

[4] Alcorn A and Donn M. 2010. Life Cycle Potential of Straw bale and Timber for Carbon Sequestration in House Construction. 2nd International Conference on Sustainable Construction Materials and Technologies, Ancona, Italy. 885-895.

[5] Ashour T, Georg H and Wu W. 2011. Performance of straw bale wall: A case of study. Energy Buildings. 43: 1960-1967.

[6] Garas G, Allam M and El Dessuky R. 2009. Straw bale construction as an economic environmental building alternative - a case study. J. Eng Appl Sci. 4: 54-55.

[7] Sodagar B, Rai D, Jones B, Wihan J and Fieldson R. 2011. The carbon-reduction potential of straw-bale housing. Build Res Inf. 39: 51-65.

[8] Seyfang G. 2010. Community action for sustainable housing: Building a low-carbon future. Energy Policy. 38:7624-7633.

[9] Milutiene M, Staniskis JK, Krucius A, Auguliene V and Ardickas D. 2012. Increase in buildings sustainability by using renewable materials and energy. Clean Techn Environ Policy. 14: 1075-1084.

[10] Venkatarama Reddy BV and Jagadish KS. 2003. Embodied energy for common and alternative building materials and technologies. Energy Buildings. 35: 129-137.

[11] Thormark C. 2002. A low energy building in a life cycle - its embodied energy, energy need for operation and recycling potential. Build Environ. 37: 429-435.

[12] Harris DJ. 1999. A quantitative approach to the assessment of the environmental impact of building materials. Build Environ. 34: 751-758.

[13] El Gowini M. 2002. Background about rice straw problem in Egypt: (Is rice straw really waste?) Cairo: Copyright Community Times.

[14] Campbell JW and Pryce W. 2003. Brick: a world history. London: Thames and Hudson.

[15] 2008. Osterreichisches Institut fur Baubiologie und -okologie (IBO): Passivhaus - Bauteilkatalog - okologisch bewertete Konstruktionen. Wien: Spinger.

[16] 2012. Baubook, www.baubook.at/oea, August.

[17] Zupancic D. 2003. Vernakularna arhitektura in ekonomika gradnje. AR, Arhitektura Raziskave. 2: 60-63.