VOL. 4, NO. 9, NOVEMBER 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

STRAW BALE CONSTRUCTION AS AN ECONOMIC ENVIRONMENTAL BUILDING ALTERNATIVE- A CASE STUDY

Garas G., Allam M. and El Dessuky R.
Department of Civil and Environmental Engineering, National Research Centre, Cairo, Egypt
E-Mail: gihangaras@yahoo.com

ABSTRACT

Approximately 4 million tons of rice straw- an agricultural residue is produced in Egypt annually. A great percentage of this amount is disposed of by burning causing high degrees of environmental pollution known as the Black Cloud that causes seriously chronic chest diseases to the great population of Egypt. This paper explores the different architectural styles of straw bale construction worldwide, with an aim to reach an economic environmentally adapted system for wide application of straw bale construction in Egypt. The paper presents an economical 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. A direct cost saving that reaches about 40% of the total construction cost is achieved, in addition to the indirect cost saving in energy consumption, and thermal insulation.

Keywords: rice straw bales, building types, load bearing walls, pollution, black cloud, economic building, Egypt.

1. INTRODUCTION

Straw is a natural fiber that can last many thousands of years under certain conditions. Intact straw has been found in dry Egyptian tombs and buried in layers of frozen glacial ice. However, under typical conditions straw will slowly degrade as do all natural fibers materials like wood, paper, cotton fabric, etc.

The rate at which this happens is highly dependent on the conditions under which the straw is stored, primarily moisture content and temperature. With proper attention to moisture control, a straw bale structure should be able to last as long as any conventional wood framed home [1].

1.1 Advantages of using rice straw for building

Straw-bale building is a practical and perhaps under utilized construction method. Initiated in the United States at the turn of the century, straw-bale building is showing new merit in today's marketplace. Straw bale load bearing walls were first built in the USA in the late 1800s directly with the bales as if they were building blocks [3].

Enough straw is currently produced every year in North America to meet most residential building needs. The same is true worldwide, since grain farming is common across most cultures and regions. This fact alone is enough to move towards using this abundant renewable resource for construction purposes, even if it held no particular advantage over other building materials. A well built wall creates an unbroken wall of high insulation. Also materials used to create bale walls are less expensive than other common wall systems [8]. Straw bale construction is owner-builder friendly because the wall raising is easily done, thus cutting down on labor costs. Straw bale houses have demonstrated overwhelming results; fire and earthquake resistance, extremely high heat and sound insulation values, almost ten times as much as wood and bricks, energy efficient, and require minimum maintenance [4]. All these advantages in favor of straw bale construction cumulate significant cost advantage compared to conventional building techniques with bricks or wood.

1.2 Energy saving in straw bale buildings

Combining straw bales and solar orientation can create very comfortable and extremely efficient buildings. Figure-1 presents an example from Fresno, California with a very hot summer and cool winter. In Mongolia straw bale buildings reduced energy use by 80% of traditional buildings energy consumption. There are 3,410 BTU in a kilowatt hour [7]. Another example of a study on energy consumption comparison was conducted by the British Columbia (BC) bale builder Habib Gonzalez. The study was funded by the Canada Mortgage and Housing Corporation who presented a report that was based on using energy consumption data from BC bale homes, compared to equivalent frame-walled homes via computer modeling. The study concluded that straw bale houses used over 20% less space heating energy when compared to the modeled conventional houses [9].

2. RICE STRAW PRODUCTION IN EGYPT

Straw is currently produced surplus to requirements in most northern Egyptian governorates. According to the Egyptian Ministry of Agriculture the amounts of rice straw produced annually exceed 4 million tones (Figure-2). It is regarded as an agricultural waste product, where a bale costs an average cost of 10EGP in order to compress it and tie it with a two-string polypropylene twine. This cost includes transportation from the field to the end user. The high cost for processing the straw into bales as well as the lack of adequate compressors leads to quick and costless solutions adopted by the farmers such as burning. The illegal and uncontrolled burning of rice straw causes seriously chronic chest diseases to the great population of Egypt. Also, the pollutants which remain in the air, close to the earth surface without dissociation, block the sunlight and form the annual black cloud that has been appearing over the skies of Great Cairo for the past 10 years [2].

3. THE REASON WHY IT IS NOT BEING WIDELY USED

Passive resistance to bale construction comes from two sources: homeowners and the building industry [8]. Although rice straw can be used in many industries and can save a lot of money, the reason why it is not being widely used is mainly due to lack of peoples awareness. Surprisingly, countries such as India and China who are the worlds' largest cultivators of rice, who should be suffering tremendously from the problems of rice straw, are not. They are constantly developing new technologies for the utilization of rice straw and have succeeded in using the straw in many aspects especially paper industry [4].

4. TYPES OF STRAW BALE CONSTRUCTION

Different styles and opinions have grown up around the world as bale building has spread. What was suitable in one climate has not proved to be best practice in others, and availability and cost of materials varies from country to country [5].

There are two primary forms of straw bale construction, load bearing and non-load bearing (post and beam). In load bearing structures (commonly known as the Nebraskan style), the weight of the roof and lateral shear pressures are actually carried by the bales and the plaster which encases them. This is an easy load for straw bales each of which can withstand up to 15,000 pounds of vertical pressure when laid flat. In non-load bearing (commonly known as post and beam method) straw bale construction, a frame is first built out of wood, and the bales serve as an in-fill insulation. The advantage of this type of structure is that inspection officials recognize and understand this process, and it provides a roof structure under which to build up straw bale walls [6].

5. STRAW BALE LOAD BEARING WALLS VERSUS CEMENT BRICKS WALLS- A CASE STUDY

5.1 Objective of the study

Recently, great awareness is raised through implementing the legislations of the environmental law (2004), to avoid the use of mud in making red bricks especially with the lack of muddy lands. Alternatively cement and silty bricks are used in constructing load bearing walls with a cost ranging between 300-500 EGP/thousand bricks.

The main objective of this paper is to encourage the idea of adopting the local type of Hassan Fathy's architecture in constructing economic and comfortable residential buildings using rice straw bales instead of the mud or cement bricks. The bales will act as a cheap and sustainable material which is more environmental friendly than the bricks in order to produce low cost housing with local architectural taste.

5.2 Scope of the study

The paper addresses the economics of building a unit with rice straw bales versus a traditional unit built by using cement bricks. The study is based on using local materials from the Egyptian market and the prices are in Egyptian pounds (1 US$ = 5.6 EGP).

A standard compartment unit of 3.0 m x 3.0 m area with a height of 3.0 m has been chosen for this study .The walls of the building are load bearing walls of one story. Plain concrete foundations are used for the straw bale unit, while plain and reinforced concrete foundations are used for the bricks unit.

5.3 Specifications of the load bearing unit

5.3.1 Cement brick unit

- The walls are of cement bricks with standard dimensions of 6 x 12 x 25 cm.
- The roofing consists of a slab 12 cm thickness of reinforced concrete resting on four side reinforced concrete beams of 25 cm breadth and 50 cm depth.
- The foundation consists of reinforced concrete beams of 25 x 50 cm width and breadth, respectively.Table-1 illustrates the cost analysis of the cement brick unit.

5.3.2 Straw bale unit

- The walls are built of a standard compressed straw bale unit with dimensions 1.0 x 0.5 x 0.45 m (width x depth x breadth).
- The roofing is made of a wooden ceiling with main longitudinal wooden beams of (6.5 x 10 cm) as well as transversal beams with the same cross sectional area.
- Plywood boards of 8 mm thickness were used on top of the wooden beams.
- Plain concrete foundation beams with a 0.6 m width and 0.6 m depth were used underneath the straw bale units. Table-2 illustrates the cost analysis of the straw bale unit.

5.4 Cost analysis

5.4.1 Bricks

1000 cement bricks = 320 EGP
5 Sacks of cement = 5 x 24 = 120 EGP (1 ton = 480 EGP)
1.0 m^3 of sand = 30 EGP
Labor and handling = 100 EGP
Total = 570 EGP/ 1000 Bricks
1000 bricks equivalent to 8 m^2 of a 25 cm wall thickness.
<u>Brick wall price = 70 EGP/ m^2.</u>

5.4.2 Reinforced concrete

100 kg of steel reinforcement = 767 EGP (1 ton of steel reinforcement = 7670 EGP)
(Assuming that 1 m^3 of concrete contains approximately 100 kg of steel)

- 7 Sacks of cement = 7 x 24 = 168 EGP
- 0.4 m^3 of sand = 15 EGP
- 0.8 m^3 of coarse aggregate = 55 EGP
- Labor = 140 EGP

Price of reinforced concrete = 1145 EGP/ m^3

5.4.3 Plain concrete

- 5 Sacks of cement = 5 x 24 = 120 EGP
- 0.4 m^3 of sand = 15 EGP
- 0.8 m^3 of coarse aggregate = 55 EGP
- Labor = 100 EGP

Price of plain concrete = 290 EGP/ m^3

5.4.4 Straw bale unit

Compression and transportation = 8 EGP/ bale

5.4.5 Steel mesh

Steel mesh = 4 EGP/ m2
Labor = 2 EGP
Price of steel mesh = 8 EGP/m2

5.4.6 Timber roofing

- Wooden Main beams = 0.065 m x 0.1 m
- Every 0.5 m = 350 EGP
- Wooden cross beams = 0.065 m x 0.1 m
- Every 1.0 m = 250 EGP
- Plywood with 8 mm thickness (4 boards)
  1 board is (1.2 m x 2.44 m)
  4 x 90 = 360 EGP
- Labor = 300 EGP

5.5 Discussion of the direct and indirect cost savings of using rice straw in building

5.5.1 The direct cost saving

The economical study indicates that for a standard compartment unit of 3 x 3 x 3 m dimensions:

a) By using load bearing walls of cement bricks and reinforced concrete slab as roofing
The total direct cost = 7933 EGP 881 EGP/m^2

b) By using load bearing walls of straw bale units and wooden ceiling as roofing
The total direct cost = 4813 EGP 535 EGP/m^2

A saving of approximately 10 % in the direct cost of the walls is achieved when building with straw bales. The tremendous increase in the cost of steel and cement indicates the great variance between the foundations used under the masonry brick unit which reaches 2413 EGP, while the straw bale unit foundation costs 1253 EGP with an approximate saving of 50%. Saving in the roofing system of the straw bale unit exceeds 50% of the total direct cost. This is over and above the indirect cost saving in energy consumption achieved from reducing the amounts of producing reinforcing steel and cement as raw materials which are used in the traditional ways of building.

5.5.2 Indirect cost saving

The goal in forthcoming straw bale building 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. To get a maximum benefit the architect focus on the basics of climatically adapted phenomenon such as: Orientation, Insulation, Daylight, Thermal mass, Natural Heating and Cooling, Natural Ventilation, Weatherization, Shading, Acoustics Control, Recycling, Water Conservation and Harvesting, Environment Friendly, Built to last, and Easy to Monitor and Maintain.

The comparative study of the energy efficiency between typical brick construction and rice straw bale construction using “Alware” [10] energy software package- which is based on the principles and concepts developed by the International Commission of Energy- includes a set of Energy Saving tables and charts (Energy Saving Calculator ESC) used to measure and monitor the efficiency of using smart environmental systems and energy saving tools.

Alware Energy Saving Calculator proved the increase of energy efficiency using natural lighting building due to the reduction of glare, shine, and brightness levels rate by (89%) in straw bale construction. This is due to the increase in walls thickness to the double, but the amount of internal lighting is not enough in some directions. This can be solved by inserting opposing large slots which improves the quantity and quality of internal lighting rate by 76 %.

According to Alware ESC, large windows depth in straw bale construction operates as solar louvers that increase the levels of thermal comfort and reduce the acquisition rates of warming by up to 94% compared to the typical brick construction.

As for natural ventilation, wall thickness and large opposing windows help to dislocate and recycle indoor air. This is due to the relatively proportional relation between natural ventilation and thermal efficiency. The Alware ESC indicated that the low rate of acquisition increases the ventilation rates by approximately 72%.

In addition, rice straw bales construction has low levels of acoustic and transport noise by up to 81% and the possibilities of recycling and maintenance by 97%. It is also recommended to use architectural treatments and local environmental compatible with the nature of climate, such as wind towers, interior courts, roof levels, site openings and ratios, which increase in the overall total amounts of energy efficiency by up to 94.45%.

The direct relation between total direct costs and energy calculations by using Alware energy software approved that the proportion of costs provided rice straw bale buildings will save up to (250 EGP / kw-month). Worth mentioning that the efficiency of energy saving with rice straw bale building could be improve by design

VOL. 4, NO. 9, NOVEMBER 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

photovoltaic cells, solar heaters, wind towers, backyard, smart architectural and environmental uses.

6. CONCLUSIONS

Rice straw is currently produced surplus to requirements in most Nile and delta Egyptian governorates with a total amount of 4.0 million tones in 2007. The illegal and uncontrolled burning of rice straw causes seriously chronic chest diseases to the great population of Egypt. This is considered one of the main environmental pollutants as it results in the annual phenomena known as "The Black Cloud".

Straw bale construction is considered relatively new to most of the people who are financially exhausted from the traditional systems of building, but could find no other alternatives. This paper addresses the financial saving of using straw bale units in building load bearing walls systems of one storey. The paper presents an analysis of the economics of building a unit with rice straw bales versus a traditional unit built by using cement bricks. The analysis presents clearly a direct cost saving of about 40% when using straw bale units to build a unit of area 3 x 3 m^2 with wooden roofing and plain concrete foundation.

This direct saving in costs is added to the environmental profit of reducing the energy consumption rates resulting from cement and reinforcing steel production. Besides, rice straw bales are known for there high insulation properties which add to the indirect saving of using heaters and air conditions inside the houses.

Finally, the energy calculations by using Alware energy software proved that the proportion of costs savings provided by using rice straw bales in building reaches up to (250 EGP / KW-month)

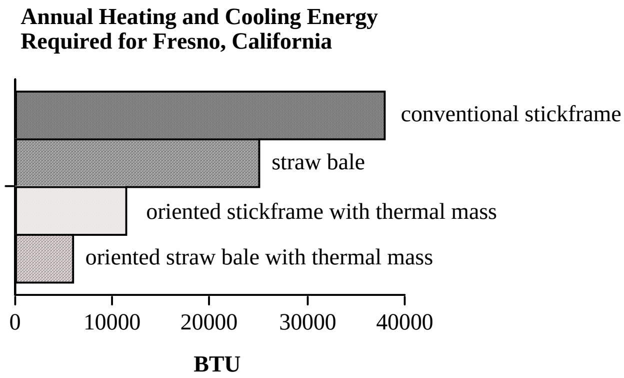

Figure-1. Energy saving example from Fresno, California [7].

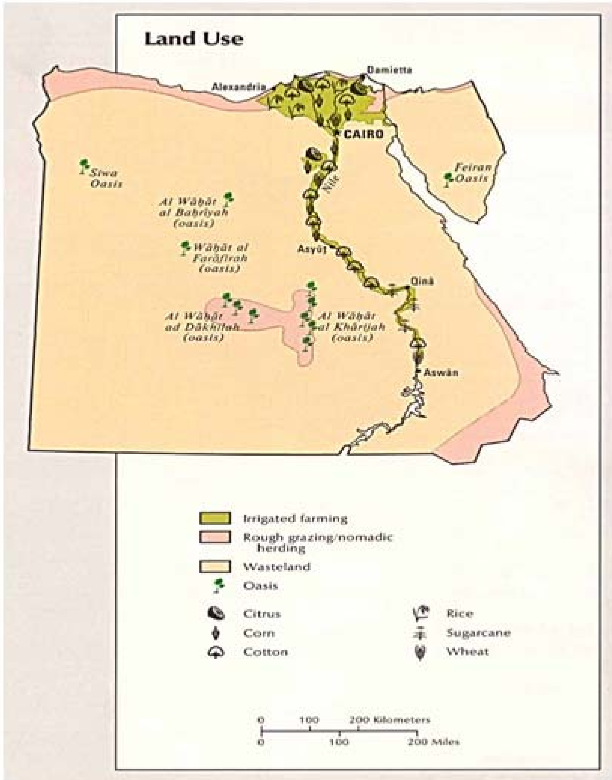

Figure-2. Rice cultivated area in Egypt [4].

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1 Cost analysis of the masonry brick unit.

#	Type of work and supplies		Dimensions: Length (m)	Width (m)	High (m)	Volume (m^3)	Units of measu-rement (S.A)	Cost calculations: Units: No.	Detail	Cost details EGP	Total cost EGP
1	**Building surface**		3 x 3 x 4			-	36	1000	Bricks	320	**(36/8) x 570 = 2565**
								5 Sack	Cement	120	
								1 m^3	Sand	30	
									Labor	100	
									Total = 570		
2	**Reinforced concrete** (R.C)	**(R.C) Slab**	3	3	0.12	1.08		100 kg	Steel	767	**1145**
		(R.C.) Beam	12	0.25	0.50	1.50		7 Sack	Cement	168	
		(R.C) Foundation	12	0.25	0.50	1.50		0.8 m^3	Gravel	55	
			Total (R.C)			4.08		0.5 m^3	Sand	15	
									Labor	140	
								Total (R.C) 4.08 x 1145			**4672**
3	**Plain Concrete Foundation**		12	0.50	0.40	2.4	m^3	5 Sack	Cement	120	**290**
			Total concrete (C)					0.8 m^3	Gravel	55	
								0.5 m^3	Sand	15	
									Labor	100	
								Total concrete 2.4 x 290			**696**
Total Cost (3 m x 3 m) of using bricks (Bearing Walls)								**Total Cost**			**7933**

VOL. 4, NO. 9, NOVEMBER 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2 Cost analysis of the straw bale unit.

#	Type of work and supplies	No. of units	Dimensions				Units	Cost calculations (EGP)			
			Length (m)	Width (m)	High (m)			Units		Cost EGP	Total cost EGP
1	**Rice straw bale**	72	1	0.450	0.50	72	Bale	Bale	36 m^2 / 0.50 = 72 Bale		
2	**Building walls**	1	3	3	4 sides	36	m^2	Cost details(EGP)			
								Bale	Compressed Bale + Transport	8	**2300**
		Total building surface						72 Bale	Bales for erection	72 x 8 = 576	
								m^2	Wire mesh	6 x 36 x 2 = 432	
								kg/m	Expanding steel (R = 16mm)	108 x 1.56 x 7.67 = 1292	
3	**Timber roof**	1	3	3	0.12	-	-	m	Wooden beams	600	**1260**
		Roof support : load bearing							4 Plywood boards	360	
									Labor	300	
4	**Plain concrete foundation**	1	12 m	0.60	0.60	4.32	m^3	m^3	Plain concrete	290 x 4.32	**1253**
Total Cost (3m x 3m) of using rice straw bales									**Total Cost**		**4813**

REFERENCES

[1] Summers M.D., Blunk S.L. and Jenkins B.M. 2003. How straw decomposes. EBNet Straw Bale Test Program. http://www.ecobuildnetwork.org.

[2] Garas G.L., Wahaba A.S., Hadid M.A., N.M. Farag and Dessuky R. 2008. Adaptation of straw bale building techniques to the Egyptian environmental conditions. Proceeding of the 3rd International Conference of Engineering Research Division onT Engineering Sciences and Technologies, NRC-Cairo-Egypt. March.

[3] Roberts C. 2002. A House of Straw: A Natural Building Odyssey. Chelsea Green Publishing Company.

[4] EL Gowini M. 2002. Background about rice straw problem in Egypt: (Is rice straw really waste?) By Copyright Community Times, Cairo, Egypt. October.

[5] Straw Bale Futures. 2001. Information Guide to Straw Bale Building, for self builders and the Construction. Industry Amazon Nails, Hollinroyd Farm, Todmorden. http://www.strawbalefutures.org.uk

[6] Renewable energy and sustainable living fact sheets. 1999. Straw Bale Construction. Midwest Renewable Energy Association. http://www.the-mrea.org

[7] D. A. Bainbridge. Straw Bale Building Resources Brainbridge. Sustainable Management Alliant International University, San Diego, CA.

[8] Magwood C. *et al*. 2005. More Straw Bale Building: A complete Guide to designing and Building with Straw. New Society Publisher, Canada.

[9] Technical Series 02-115. 2002. Energy Use in Straw Bale Houses. Canada Mortgage and Housing Corporation. http://buildingsgroup.nrcan.gc.ca

[10] ALWARE4-2: Building Energy Use and Cost Analysis Tool. http://www.alware.de