INFLUENCE OF STRAW BALE CONSTRUCTION IN AIR CONDITIONING IN TROPICAL CLIMATIC CONDITION

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Abstract

Due to heavy industrialization that took place after the Industrial Revolution, per capita energy consumption in the world has risen exponentially, depleting the planet's limited energy deposits. As a result of most the modern technologies, unfavourable conditions on the environment are created. So, there is an urgent requirement to move towards the methods, which minimize the energy demand. Electricity demand in Sri Lanka is higher than its production and the usage of Air Conditioning is increasing day by day. Therefore, straw bale was identified as a feasible substitute to be used in addressing the increasing demand for A/C due to many reasons such as low initial cost, low conductivity and durability. Hence, studying on the long term performance of straw bale construction will be highly essential. On this regard, actual measurements were taken and were used to validate the computer simulations for straw bales and other walling materials to get the A/C demands for different cases. These findings were expanded to its life cycle by adopting them to an A/C building. Comparisons were made with other common walling materials available in Sri Lanka. It was noted that the straw walls can reduce the A/C demand of a building and hence it can lead to a low life cycle cost of the structure.

Key words: tropical climates, straw bale construction, A/C demand, life cycle costing, computer simulations

1 Introduction

Countries located close to the equator experience tropical climatic conditions. The main features of tropical climates are the high humidity throughout the year coupled with low diurnal temperature variations. Most of the countries with tropical climatic conditions in Asia are developing countries and experience rapid development with respect to mass scale building construction [1]. This has led to higher energy demand for transportation and thermal comfort in recent years. [2] The use of air conditioning has again played a vital role in many buildings in this region to achieve the thermal comfort. Moreover this is gradually becoming a fashion due to affordability resulting from improved economic standards and reduced capital cost of air conditioners [3]. There are various researches conducted on improving the performance of air conditioning and more than the performance, in achieving thermal comfort in buildings it was found that the behavior of the external building elements is very important. [4]

Further, it contributes to global warming through excessive usage of resources, energy intensive materials, and technology [1]. The existing conventional building technology has already contributed to disrupt the natural balance of the eco system through several activities such as over extraction of sand and lime stone, over usage of energy, over exploitation of forest resources for timber requirement and pollution. Capital investment on such technologies would deepen the economic imbalances between the rich and poor. Moreover, lack of different building techniques other than the conventional techniques, which include fired bricks and cement blocks have resulted in encouraging an inflow of new building technologies to the country.

Rice straw has been studied for various applications. Further, it is considered as a sustainable material, due to its' inbuilt properties of law thermal comfort and this was tested against building construction [5]. Therefore, this research is aimed at promoting straw bale technology with their benefits such as sustainable construction method, ability to reduce indoor air temperature and reduction of energy cost.

1.2 Thermal Comfort in Tropical Climate

Tropical moist climates extend northward and southward from the equator to about 15° to 25° of latitude. In these climates all the months have an average temperature greater than 18° Celsius. Annual precipitation is greater than 1500 mm [6].

Thermal comfort is defined in British Standard, BS EN ISO 7730 [7] as the state of mind in humans that expresses satisfaction with the surrounding environment.

The most commonly used indicator of thermal comfort is air temperature – it is easy to use and most people can relate to it. But although it is an important indicator to be taken into account, air temperature alone is neither a valid nor an accurate indicator of thermal comfort or thermal stress. Air temperature should always be considered in relation to other environmental and personal factors [8].

The six factors affecting thermal comfort are both environmental and personal. These factors may be independent of each other, but together they contribute to the thermal comfort [8].

- Air temperature
- Radiant temperature

- Air velocity
- Humidity
- Clothing Insulation
- Metabolic heat

1.3 Comfort Zone

The comfort zones are usually expressed graphically as an overlay on the psychometric chart or some other diagram which shows the relationship between temperature and humidity. Only a few comfort charts attempt to express the additional major comfort variables of mean radiant temperature (MRT) and air motion. Other major variables affecting comfort can have overriding effects on human comfort. It is now relatively well known among building analysts. For instance, the mean radiant temperature of a building environment is of great importance to comfort.

Additionally, ventilation, which increases air motion across the skin, can greatly increase the tolerance for higher temperature and humidity levels. The comfort can be maintained at 27^{0}C and 100 percent relative humidity as long as air velocities of 300 feet per minute across the skin are maintained. Most of the good ceiling fans produce this degree of air motion. At lower relative humidity (50 percent and below) much higher temperatures (up to 90°F) are comfortable at this air velocity [9].

The figure 1 shows the comfort zone. If the air temperature, air velocity and relative humidity is maintained in the given values which falls in the comfort zone a person will feel comfortable in that environment.

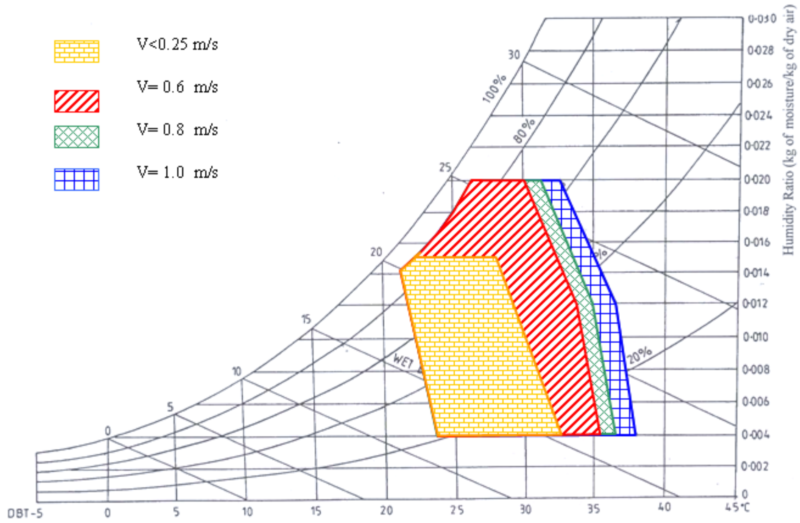

Figure 1: Modified Comfort Zone with different Wind Speeds [9]

1.4 Straw Bale Technology & Benefits

Rice straw, with its low embodied energy, excellent thermal insulation properties, high tensile properties, relative resistance to insect attacks and durability in the absence of moisture has been successfully used as a sustainable building material in several countries [5].

Figure2: Hay-bale house built in Nebraska in 1925 [11]

The first straw bale structures in the Sand Hills of Nebraska were built by European settlers entering the area from the 1800s onwards. Having few other means to shelter themselves, they were driven by necessity to improvise; there was little stone or cement, the sod was often too sandy to cut or too valuable as cropland, and most of the available lumber was what little had come on their wagons. Using the newly invented horse-powered balling machines, they bundled the grasses that surround them, stacked to form walls, an applied mud plasters inside and out. Many of those homes still exist in good shape, as do a few more in other parts of the world where balling machines had appeared over the subsequent decades. This was the birth of a promising and completely new building technology, yet with roots in various historic forms of earth and straw-base construction that were widespread in Europe. Nonetheless, as the industrial revaluation spread in the form of railroads and modeled building materials, interest in the straw bale construction faded [10].

1.5 *Benefits of Straw Bale Construction*

Straw bales are produced from a product that can be sustainably grown in a short period of time which are biodegradable, and can help alleviate multiple environmental problems with their use. They are easy to modify, flexible enough to be used in a variety of way, solid and substantial, durable overtime, and easy to maintain. In addition they require only inexpensive uncomplicated tools and unspecialized labour, and are easily acquired and affordable in most of the locations around the world.

Straw bales are used in two ways in building walls. In small buildings particularly, straw bales are stacked as load bearing walls, to directly support the roof over it by the straw wall itself. In larger and storied buildings, straw bales are used as an infill cladding in between a concrete/ timber/ steel structure.

In the former type of buildings, the straw walls must be strong enough to bear the loads of the structure itself together with any loads imposed by winds, cyclonic or earth tremor situations. Also, they should not be easily punched or sheared off for security reasons. The latter type walls do not demand the load bearing strength but the other strength requirements [11].

There is no sufficient Oxygen in between the leaves of straw in the compressed bale to create fire. External plaster provides additional protection against fire. According to published research data, tests done by the National Research Council of Canada and testing authorities in New Mexico have proven that the straw bales are more resistant to fire than many conventional building materials [11].

2 Selection of Buildings and DEROB Modeling

In this research it is very important to compare thermal properties for straw bale and brick work. Therefore, computer simulation programme is better for the purpose because it is hard to find similar buildings with different walling materials. First, computer simulations for straw bales and other brick work should be validated using actual measurements. Here DEROB-LTH software is used for the analysis. The same procedure has been used by various researches and found DEROB-LTH can be taken as a tool for thermal comparisons [1, 9].

Straw bale technology is a new sustainable construction method. Fortunately there is a straw bale house in Gampaha area, which experience tropical climatic conditions. It's apparently a single storey house, with a load bearing structure; in which all the walls are built using straw bales. To get the calibration correct, it was important to find a building with the traditional building materials in the same climatic conditions. Hence, a brick wall house, which is situated in the same locality of the straw bale house was also selected for the research purpose.

2.1 Straw Bale Building

Figure 3: Exterior View of the first SB House in Sri Lanka

The selected straw bale building was the first straw bale house in Sri Lanka with basic architectural design. The house consists of a hall, pantry and a bathroom. The building is a rectangular enclosure of 7.0 x 5.1 meters in size with an attached toilet of 2.54 x 2.2 meters. The main building is constructed with Straw Bale (SB) walls and the toilet with red bricks. The enclosure consists of a small veranda space pantry and sitting area with semi enclosure area for a bed. This house would be sufficient for a caretaker's quarters.

The straw bale producing machine and the method of bale production make the Sri Lankan straw bale technology unique. In other countries straw bales are produced by engine driven compacting machines which require fuels. But in Sri Lanka a manually operated machine with 10 ton Hydraulic Jack is used to press the straw inside a rectangular mould. The machine can be operated with two unskilled people.

The quantity of straw that goes into a bale is regulated by weight, 25 kg in each bale, compressed in three layers and it is in rectangular shape with a length of 950mm, width of 400mm and height of 450mm. Two strings are placed inside the moulds before depositing straw in it, for binding the compressed bales. The bales compressed and tied, should be stacked in a dry ventilated atmosphere until they are used.

Walls were built over a concrete foundation which also acts as a physical barrier against moisture and insects. Straw bales were placed along the length of the wall with 40x 45cm side touching each other, and 40cm side to form the width of the wall. Vertical stability of walls can be increased by introducing bamboo sticks or Steel bars (to resist earthquakes) at an interval of 1metre, running from the foundation up to the wall plate along both sides of the walls, and connected to the wall plate with the help of brackets. This arrangement helps the roof and walls to get tied down to the foundation in order to withstand strong winds.

The openings for windows and doors were formed by plywood frames positioned while the bales being laid. It is important to keep the walls protected by temporary shelter like tarpaulin to prevent from rain or mist.

The walls were finally plastered with lime/sand/cement plaster in two layers to protect the walls from moisture.

2.1 .1 Measurements Recording

Inside and outside temperature and humidity measurements were taken in a selected volume of the straw bale house from 08.00 to 18.00.

Variation of temperature and relative humidity are shown below graphically.

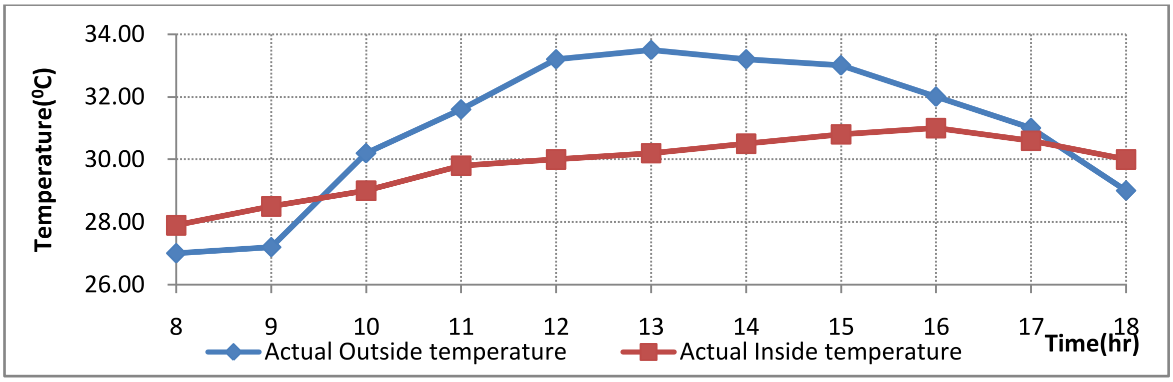

Figure 4: Actual inside & Outside Temperatures of SB house

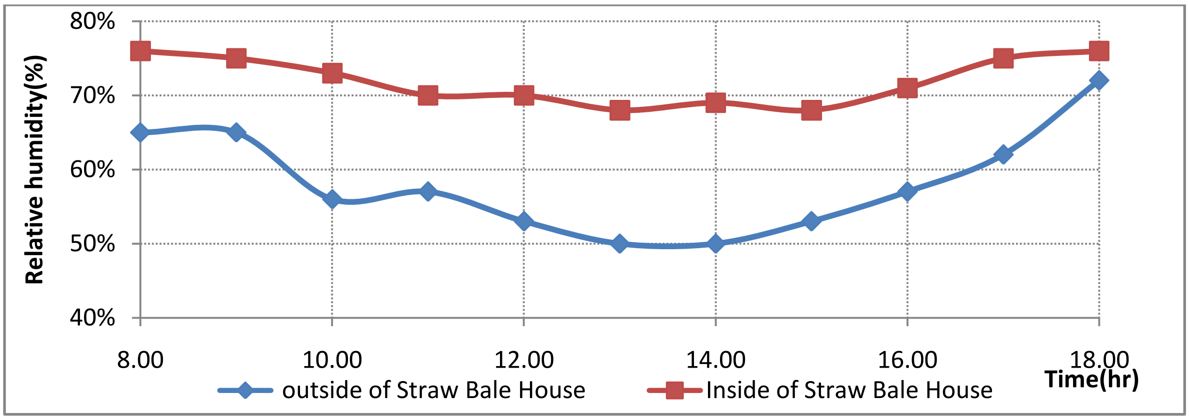

Figure 5*: Inside* and outside relative humidity of SB house

This building was modeled using DEROB software and properties were calibrated to reach original building model.

2.1.2 DEROB model of the straw bale house

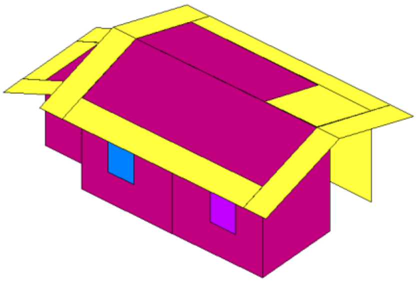

Figure 6: DEROB Model of building with SB

Figure 6 is the DEROB model of SB house. Inside temperature values of volume 1 are obtained by running the DEROB software. DEROB inside temperature values and actual inside temperature values are compared and properties of SB house are calibrated until above two temperature values are same. For that, absorption of outer walls, emittance of outer walls, absorption of inner walls and emittance of inner walls were changed according to the colour of the walls. Thermal properties of straw bale were slightly changed because those properties depend on the moisture content and compressibility of straws and finally actual thermal properties of straw bale can be obtained by calibration.

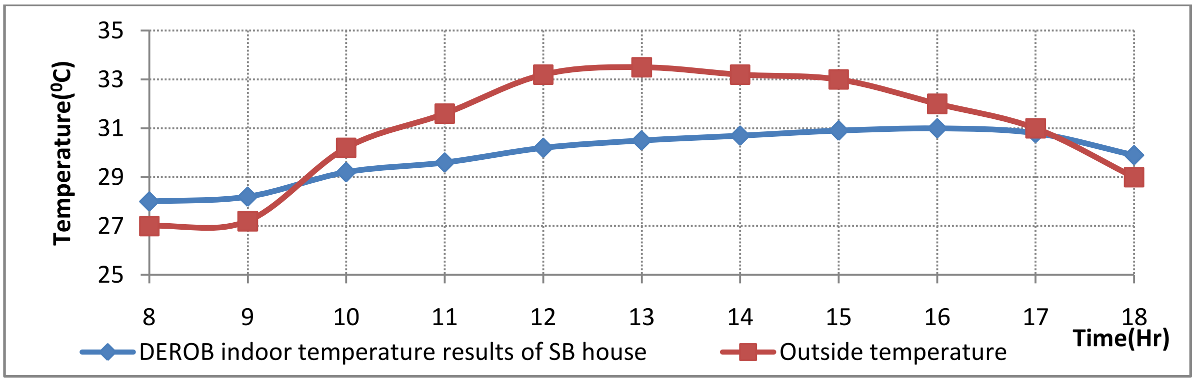

Figure 7: DEROB Indoor temperature values of volume 1 & outside temperature of SB house

Actual temperature values were taken only from 8.00 to 18.00. Following Graph shows the comparison of Actual inside temperature and calibrated DEROB indoor temperature values.

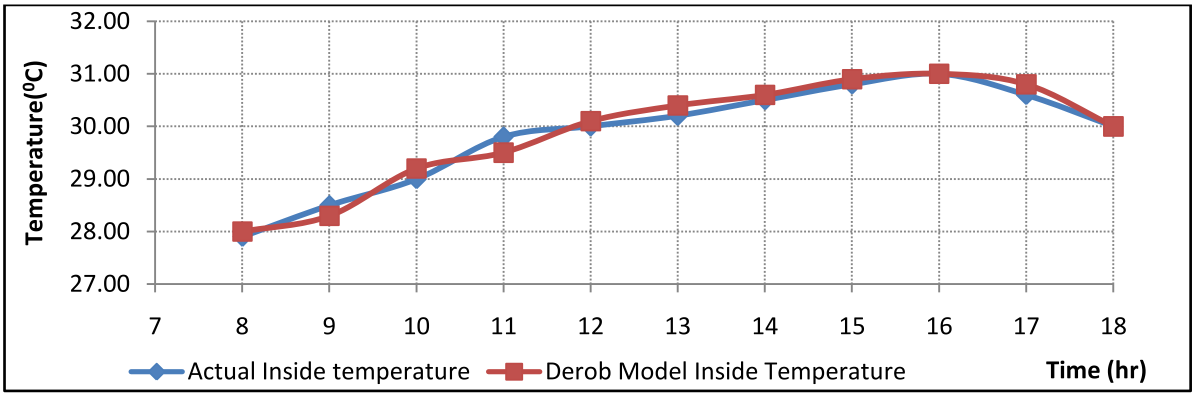

Figure 8: Actual inside temperature and calibrated DEROB inside temperature values of SB house

According to the Figure 8, it can be seen that both curves match and hence computer model can be used for further comparisons.

According to the calibration, thermal properties of straw bale can be mentioned as follows:

Thermal conductivity - 0.09(W/m.K) Specific Heat -0.40(Wh/kg.K)

The properties after calibration can be used for future analysis.

2.2 Brick Work Building

Figure 9: Selected brick work building

A brick work building which was situated about 100m away from the straw bale house was selected to take temperature measurements. That brick work building is the Veterinary Office Building at Gampaha.

2.2.1 Measurement recording

Indoor temperature and humidity measurements of volume 1 of brick work house and that of outside were recorded from 8.00 to 18.00.

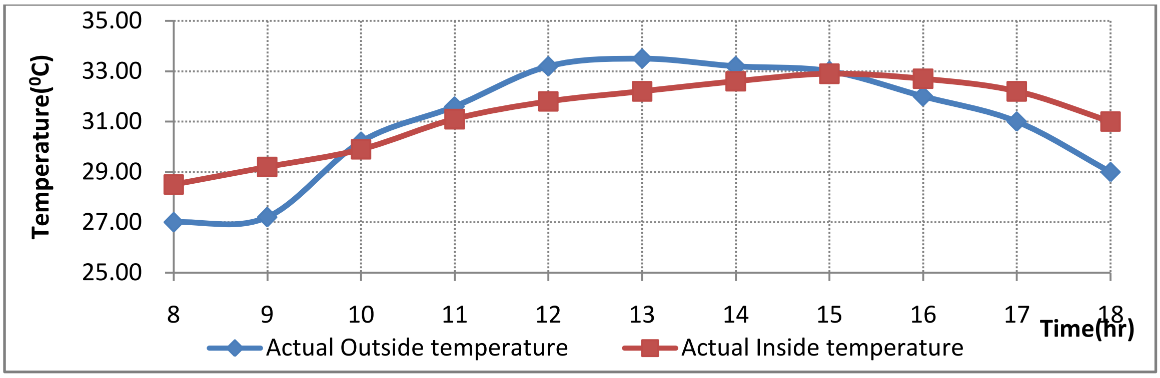

Figure10: Actual inside & outside Temperatures of brick work house

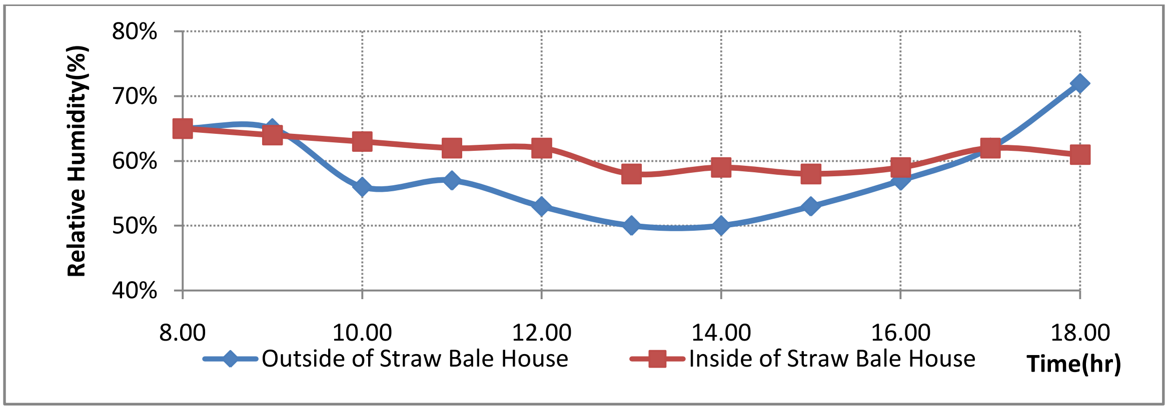

Figure 11: Inside and outside relative humidity

Variation of actual inside and outside temperature is given in Figure 10. Then a model house was created for this brick work house using DEROB software and properties were calibrated to obtain original building properties.

2.2.2 DEROB model of the brick work house

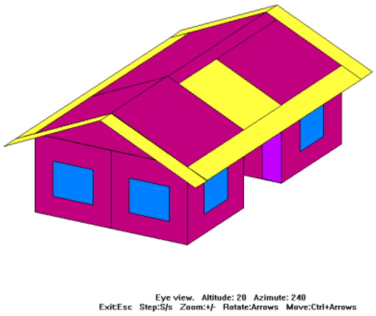

Figure12: DEROB Mode house for brick work house

Inside temperature has been taken using DEROB model and the results are presented in Figure 13. Figure 8 and 13 clearly shows that DEROB-LTH is capable of handling and modeling buildings, giving fairly accurate results to carry out comparisons, keeping the same external condition. Hence, the properties after calibration can be used for future analysis.

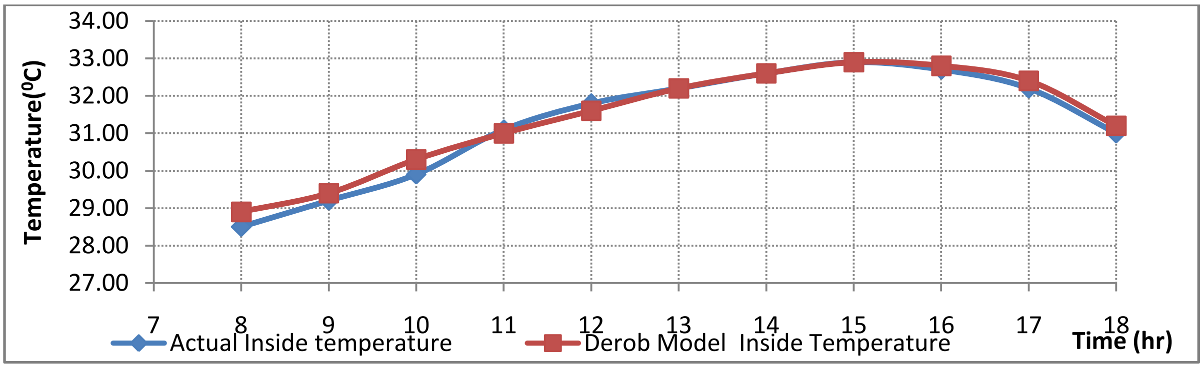

Figure13: Calibrated DEROB with inside temperature values of the Brick house

4 Life Cycle Cost Analysis for Straw Bales and Brick Works

Cost plays the major role in building construction. Life cycle cost analysis has shown the economical way of building construction. In this chapter AC demand of a typical building is calculated using DEROB-LTH software by changing the walling material as straw bale and brick work. All the other properties except walls are remained unchanged. Construction cost for both the walling materials is calculated.

Usage of Air Conditioning in public and commercial buildings is higher than that of private houses in Sri Lanka yet. Because of this a three storey building with three conference halls was selected as the typical building. A typical building was selected for the analysis and the layout of the building and the 3D view of the model are given below:

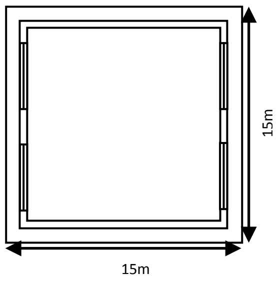

Figure 14: Layout of a typical floor of the building

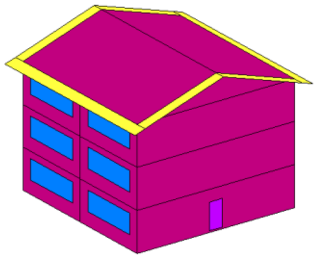

Figure 15: Final view of the Model

Some of the general details are under mentioned.

- Roof is covered with corrugated asbestos sheets and there is a flat ceiling made of asbestos ceiling sheets painted with light green.
- Floor is finished with concrete and covered with light brown tiles.
- All the doors are made out of 30mm thick hard wood and windows are made out of plain glass of 3-6mm thickness

4.1 Procedure

First, the cost for construction of brick walls in typical volume is calculated using BSR 2011. Then, the cost for the construction of straw bale walls of the building is calculated.

Next the cost of air conditioning is calculated for all three volumes with SB walls and brick work walls separately using DEROB software.

Table 1: Wall thickness for straw bale and brick work

	Material	*Wall thickness(mm)*
Straw Bale	*Plaster*	*50*
	Straw bale	*400*
	Plaster	*50*
Brick work	*Plaster*	*15*
	Brick work	*200*
	Plaster	*15*

Finally Net Present Value for AC and Total Net Present Value are calculated for interest rates 8%, 10%, 12% for design lives of 10 years and 20 years and the NPV values are compared.

Air Conditioning load is calculated for the building for straw bale walls and brick work walls. Here, climatic file of a typical year is used for DEROB software to calculate the cooling load for a year. As this is a comparison of cost of building for different walling materials, it is assumed that there are no internal loads. Two air conditioning schedules were selected for the comparison as follows:

Option 1 -Air conditioner is operating at 26^0C temperature level from 8.00 to 17.00

Option 2 -Air conditioner is operating at 26^0C temperature level for whole day

The total A/C load for a typical year was obtained by running the DEROB software. Then it was analyzed together with other initial cost to compare the life cycle cost for different options. The unit Rate of Electricity was calculated based on the current electricity tariffs and the average amount was found as Rs. 24.38/kwh. Table 2 and table 3 shows the AC cost for a typical year.

Table 2: Cost for A/C for a year (A/C operating period is from 8.00 to 17.00)

	Straw Bale building			Brick Work builing		
	Volume 1	Volume 2	Volume 3	Volume 1	Volume 2	Volume 3
A/C LOAD wh	7,319,538.10	7,734,945.10	11,214,897.50	10,743,714.10	10,845,692.70	12,875,083.90
AC LOAD Kwh	7320	7735	11215	10744	10846	12875
COST FOR AC Rs.	178,425.00	188,540.63	273,365.63	261,885.00	264,371.25	313,828.13
TOTAL COST FOR AC Rs.	640,331.25			840,084.38		

Table 3: Cost for A/C for a year (A/C operating period for 24 hours)

	Straw Bale building			brick work builing		
	Volume 1	Volume 2	Volume 3	Volume 1	Volume 2	Volume 3
A/C LOAD wh	8,669,313.70	9,641,202.30	14,309,383.30	16,714,274.90	17,817,262.40	19,994,484.70
AC LOAD Kwh	8669	9641	14309	16714	17817	19994
COST FOR AC Rs.	211,306.88	234,999.38	348,781.88	407,403.75	434,289.38	487,353.75
TOTAL COST FOR AC Rs.	795,088.13			1,329,046.88		

Table 4:Summery of NPV

AC Operating period			From 08.00 to 17.00		From 00.00 to 24.00	
Building type			Straw Bale building	Brick work builing	Straw Bale building	Brick work builing
Cost for construction of walls			1,217,082.36	1,394,229.34	1,217,082.36	1,394,229.34
Total cost for AC			640,331.25	840,084.38	795,088.13	1,329,046.88
	N=10	i=10	3,934,558.34	5,161,954.82	4,885,472.34	8,166,417.71
		i=12	3,618,014.37	4,746,664.08	4,492,425.23	7,509,411.26
		i=8	4,296,674.81	5,637,034.54	5,335,106.04	8,918,012.71
	N=20	i=10	5,451,500.90	7,152,111.86	6,769,033.42	11,314,925.26
		i=12	4,782,918.17	6,274,962.88	5,938,865.93	9,927,240.71
		i=8	6,286,866.60	8,248,072.23	7,806,292.41	13,048,778.13
Total NPV	N=10	i=10	5,151,640.70	6,556,184.16	6,102,554.70	9,560,647.05
		i=12	4,835,096.73	6,140,893.42	5,709,507.59	8,903,640.60
		i=8	5,513,757.17	7,031,263.88	6,552,188.40	10,312,242.05
	N=20	i=10	6,668,583.26	8,546,341.20	7,986,115.78	12,709,154.60
		i=12	6,000,000.53	7,669,192.22	7,155,948.29	11,321,470.05
		i=8	7,503,948.96	9,642,301.57	9,023,374.77	14,443,007.47
Total NPV/m^2	N=10	i=10	7,632.06	9,712.87	9,040.82	14,163.92
		i=12	7,163.11	9,097.62	8,458.53	13,190.58
		i=8	8,168.53	10,416.69	9,706.95	15,277.40
	N=20	i=10	9,879.38	12,661.25	11,831.28	18,828.38
		i=12	8,888.89	11,361.77	10,601.40	16,772.55
		i=8	11,116.96	14,284.89	13,367.96	21,397.05

4.1.5 Graphical Representation of Result of NPV

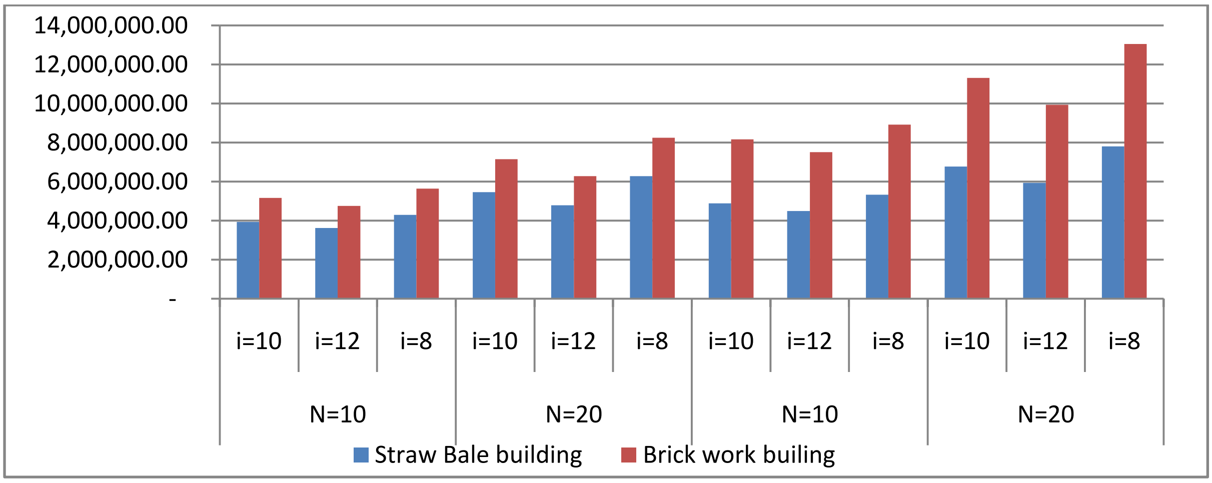

Figure 16: NPV variations for AC cost for Straw Bale building and Brick work building

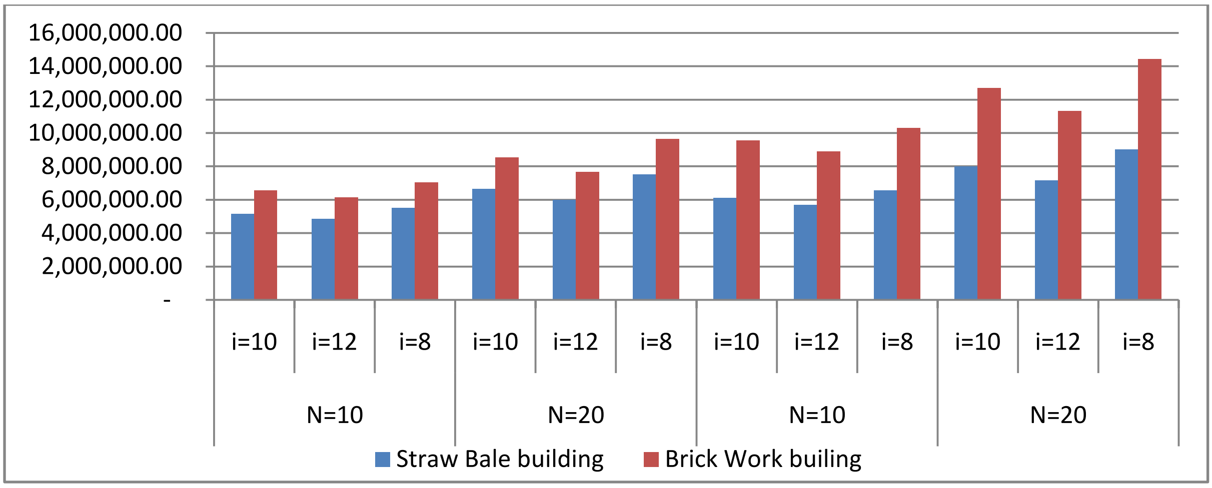

Figure 17: NPV variations for total cost for Straw Bale building and Brick work building

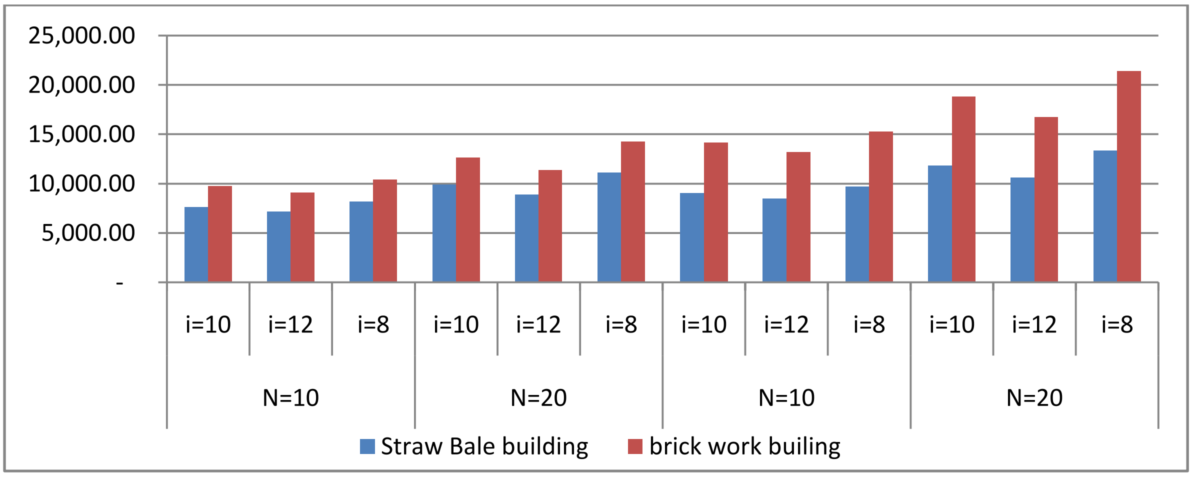

Figure 18: NPV variations for cost per 1m² for Straw Bale building and Brick Work building

5 Conclusion

Depletion of non-renewable energy is one of the critical problems that the world has faced. It has led to the increase of energy price day by day and the world will be unable to address the huge demand for energy in near future. Because of this, world is moving towards the sustainable developments today.

The level of comfort in different regions in the world varies due to several factors such as the wind velocity, air temperature, radiant temperature, humidity, clothing insulation and metabolic heat. The living space must be comfortable and should be sustainable. To achieve all these, an old technology but which is modified accordingly comes out as the Straw Bale technology.

In this research variation of AC load for straw bale walls and brick walls are calculated using DEROB software. Further, a cost analysis is done for both straw bale walls and brick walls. According to the above two tasks, it is proved that the life cycle cost for straw bale walls is lesser than the brick walls in tropical climatic condition. Therefore, it is concluded that straw bale construction is a sustainable construction method with superior energy efficiency quality.

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