PERFORMANCE OF STRAW BALE HOUSES IN TROPICAL CLIMATIC CONDITION

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Abstract

Past few decades' construction industry has become the major contributor to the depletion of natural resources and destruction of nature through Global Warming. On top of all the energy crisis and high energy cost forcing on innovations, which can leads low running cost. Due to all, presently there is a high trend to do research on sustainable construction methods. These techniques are varying country to country, since the climatic conditions are changing with their locality. Even though the roof is the main heat gaining element in a building, walls also add considerable amount of heat to the indoor volumes. Straw bale was considered as a low cost sustainable walling material for many decades due to so many inbuilt qualities, such as low cost, durability and low conductivity. The objective of this project was to identify the effectiveness of Straw Bale as a passive element in Tropical Conditions. Straw walls were compared with other common walling materials using computer simulations together with taking actual measurement in real scale buildings, which are located in the same vicinity. The observations clearly show that the thermal performances of straw bales are much better than other common walling materials used in Sri Lanka.

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

1 Introduction

The world has categorized in to different zones according to the climate condition of those areas. One such identified climate condition is the tropical climate condition. The countries, which are closer to equator are mostly falling in to this category. The tropical wet climatic conditions has the characteristics of high daily temperatures ranging between 20 to 30°C, has uniform precipitation all year round, and total rainfall over 2000 millimeters or greater. The humidity levels in these regions vary from 60% to 95%.In some months of the year the temperature is relatively high. Due to this unchanged climatic condition, indoor thermal comfort is the very important and essential for people in tropical countries. Even though the roof is the main heat gaining element in a building, walls also add considerable amount of heat to the indoor volumes and it depends on the colour, texture and thermal capacity of the wall. As a solution for the thermal comfort sustainable construction methods play major roles. Straw bale technology is one of the sustainable wall construction methods and it is becoming increasingly popular in Central American countries, Europe and Australia.

1.1 Present condition of the world

At present the world is facing several critical problems such as urbanization, global warming, energy crisis, etc. Urbanization is the physical growth of urban areas as a result of global change. Urbanization is defined by the United Nations as movement of people from rural to urban areas with population growth equating to urban migration. The United Nations World Urbanization Prospects report on 2009 projected that half of the world's population would live in urban areas at the end of 2008. [1]

Urban areas affect the environment in three major ways: through the conversion of land to urban use, the extraction and reduction of natural resources, and the disposal of urban waste. The impacts of this pollution are experienced both locally and at great distances from the source. For instance, domestic and industrial discharges contaminate air, land and water much beyond the immediate vicinity. The increased levels of consumption characteristics of the population of urban areas lead to generation of many quantities of waste. [2]

As well owing 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. It has been estimated that the humanity’s ecological foot print has already exceeded the global bio capacity to 1.5 planets by 2007, a trend yet continuing [3]. According to the American Energy Information Administration (EIA) and to the International Energy Agency (IEA), the world-wide energy consumption will on average continue to increase by 2% per year.

Since the 1980s, many climatologists have claimed that human activity has caused the near surface air temperature to rise faster and higher than ever before in history. Industrial carbon dioxide emissions, they say, will soon result in a runaway global warming, with disastrous consequences for the biosphere. By 2100, they claim, the atmospheric carbon dioxide concentration will double, causing the average temperature on earth to increase by 1.9°C to 5.2°C, and in the polar region by more than 12°C. [4]

1.2 Sustainable developments

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". [5]

Sustainability in construction is all about following suitable practices in terms of choice of materials, their sources, construction methodologies as well as design philosophy so as to be able to improve performance, decrease the environmental burden of the project, minimize waste and be ecologically friendlier. [6]

Sustainable developments and sustainable technologies have been identified as which can contribute to minimize the harm to the nature at considerable level. [13]

1.3 Thermal comfort in tropical climate

Thermal comfort is defined in British Standard BS EN ISO 7730 as "that condition of mind, which expresses satisfaction with the thermal environment". So the term "thermal comfort" describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold.[13]

A tropical climate is a climate of the tropics. In the Köppen climate classification it is a non-arid climate in which all twelve months has mean temperatures above 18 °C (64 °F) tropical temperature remains relatively constant throughout the year and seasonal variations are dominated by precipitation. [15]

Passive climate control is the concept completely in line with the notion of sustainable building. It is an alternative to a mechanical air-conditioning system and as such is an essential part of sustainable building. Passive climate control implies that the repository is built and arranged in such a way that the thermal and hygroscopic properties of the building and its contents create a good stable indoor climate. [7]

Passive solar designs are very important for tropical countries. Most of the passive solar designs are sustainable methods. Straw bale technology has been identified as a sustainable passive solar building method.

1.4 Straw Bale Technology

The use of plastered straw bales as a residential construction building material has recently been gaining popularity in North American and throughout the world [8]. One of the main reasons for this is an increasing awareness of the negative impacts that logging has on our environment, and a recognition that there is enough straw produced in North America to meet all residential building needs [9]. Furthermore, because straw is an agricultural bi-product, it is considered waste and burning is often chosen as the easiest disposal method. These issues, coupled with the excellent insulation properties of straw bales, makes straw bale construction an environmentally friendly option to typical residential construction. [10]

Straw is an inflammable material but not straw bales. The reason is that 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 such as bricks and cement blocks [12].

Life time of straw depends on its exposure to moisture and insect attacks. It has been proven over century of usage, straw lasts much longer than our imagination, under protective measures. Straw used in the walls should be dry (less than 15% moisture as a percentage of dry weight). Also the straw must be compressed sufficiently to prevent air gaps between leaves (recommended minimum compression 10 tons). Normally, protection of straw walls is done by plastering them. There are documentary records of few buildings with plastered straw walls still over hundred years in America [12].

Far back in late 1800s straw, bundled into rectangular bales, was used to build walls of permanent buildings in North America. Modern straw-building technique is based on the century-long tradition in the USA, started by early settlers in Nebraska, who were faced with a lack of traditional building materials and were forced to experiment with straw. The oldest documented building constructed with straw walls is a single roomed schoolhouse in Nebraska, in North America in 1886. Subsequently; the technology became popular in Mexico, France, Finland and Australia. [11]

Figure 1 - Old straw bale Pilgrim Holiness Church in Arthur, Nebraska constructed in 1928

1.4.1 Benefits of straw as a building material

The thickness and subtle curves of straw walls have a special character and beauty. The thickness and subtle curves of straw walls have a special character and beauty. Building walls from straw is much less labour intensive than using other materials, encourages individual creativity, and leads to final structures that are climatically adapted and energy efficient. Straw bale walls allow smaller heating or cooling systems to be installed because of the increased insulation, leading to ongoing savings in heating costs. As well straw bale construction can provide benefits in regions where straw has become an unwanted waste product.

In contrast to the timber used for wood framing, straw can be grown in less than a year in a completely sustainable production system. The conversion of straw into a sustainable renewable resource to be used as a dominant building material could be especially beneficial in various areas, where the climate is serving and timber is scarce, but straw is plentiful. Another aspect of straw's sustainability is the materials remarkable durability.

Research also has shown that straw bale houses perform well in earthquakes. It appears that straw bale buildings will be of special value in areas where earthquakes are common, as straw bales have a good width to height ratio and can be easily and effectively reinforced. Bale walls may actually absorb much of the shock of an earthquake, with the plaster adds to the strength of these buildings [16].

2 Straw Bale house and Brick Work house with DEROB Modeling

This research based on the comparison of thermal comfort using several walling materials available in Sri Lanka. It is very hard to find similar buildings with different walling materials. Because of this, usage of computer simulation programme is the best way for comparison. Therefore, calibration of software with actual measurements is very important to check the accuracy of the software.

In this research the first straw bale house, which is situated in Kiribathgoda, Gampaha was used to take field measurements. Thermal measurements were measured on a sunny day in the straw bale house and a brick work house, which was situated nearby.

Figure 2 - External view of Straw Bale house

The straw bale house is a single storey house of a basic architectural design. It consists of a hall, a pantry and a bathroom. As this house is a load bearing structure, the entire wall is built using straw bales. However, the bathroom was built using red bricks, as there was the chance of water seeping through.

The straw bale is in rectangular shape with a length of 950 mm, width of 400 mm and height of 450 mm. The box made with 1"GI welded fabric of gauge 14 was placed inside the mould to encase the bale. Two 5.5 mm Mild Steel rectangles were fixed to the wire fabric box to keep the shape of the bale. The quantity of straw that goes into a bale was regulated by weight, 25 kg in each bale, compressed in three layers. Two strings are placed inside the moulds before depositing straw in it, for binding the compressed bales. The bales so compressed and tied should be stacked in a dry ventilated atmosphere until they are used. The straw bale machine is a manually operating machine and 10 ton Hydraulic Jack was used to press the straw inside a rectangular mould. The machine can be operated with two unskilled people who can very soon acquire the art of production with little coaching.

SB walls were built over a concrete foundation, which also act as a physical barrier against moisture and insects. Straw bales are placed along the length of the wall with 40 x 45 cm side touching each other, and 40 cm side to form the width of the wall. Vertical stability of walls is by introducing bamboo sticks or Steel bars (to resist earthquakes) at an interval of 1.0 meter, 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 tied down to the foundation to withstand strong winds.

2.1 Field measurements of Straw Bale House

There were only 2 volumes in that straw bale house. Inside and outside temperature & humidity measurements were taken in the selected volume of straw bale house from 08.00 to 18.00 .Inside and outside temperature of volume 1 of straw bale house are graphically shown below in Figure 4.

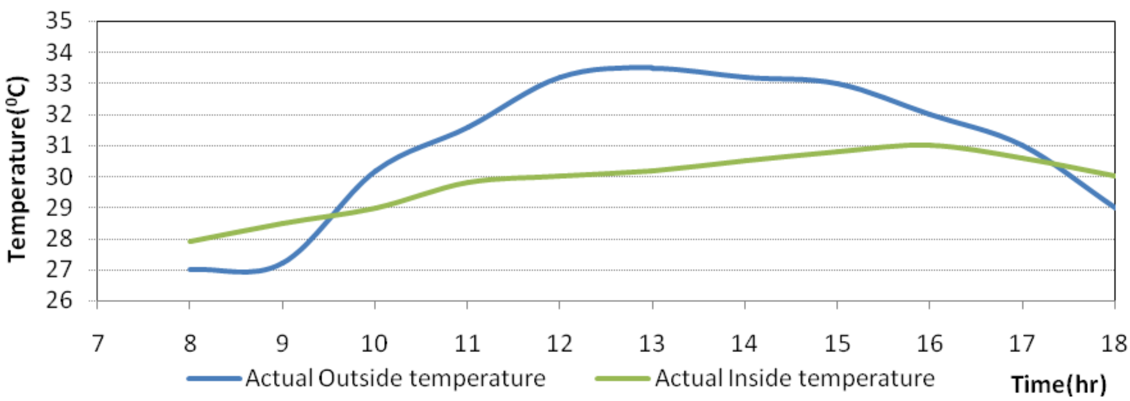

Figure 3 - Actual inside and outside temperatures of Straw Bale house

Figure 3 clearly indicate that the indoor temperature is considerably lower than that of outdoor. Figure 4 shows the day time relative humidity variation in both inside and outside of the straw bale house. This building was then modeled using DEROB-LTH software and properties were calibrated to reach original building model.

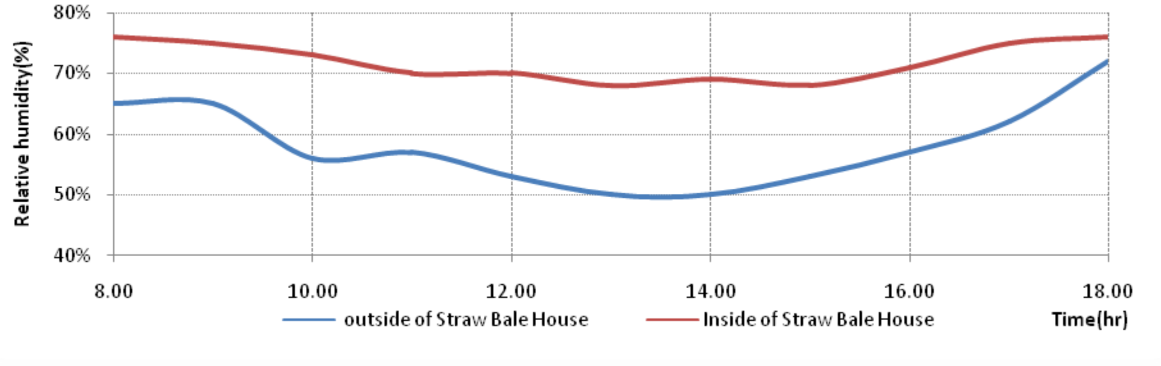

Figure 4 - Inside and outside relative humidity of Straw Bale house

2.1.1 DEROB model of the Straw Bale House

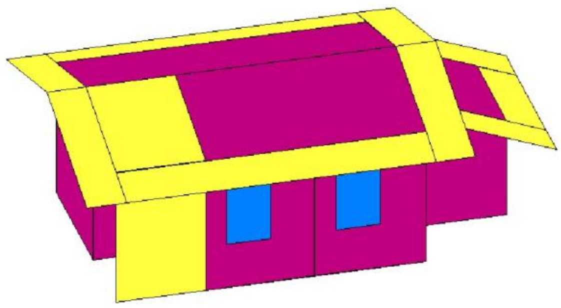

Figure 5 - DEROB model of Straw Bale house

Figure 5 is the DEROB model of the Straw Bale house. This was analyzed for the measured outdoor conditions. Then the indoor temperature values were compared with actual values and properties of the straw bale house had been calibrated until it was same to actual temperature readings. Absorption and Emittance values are obtained according to the colour of walls and roof. It was very difficult to find the accurate value for thermal conductivity and specific heat of straw bales because it is slightly vary according to the moisture content and compressibility. So values of thermal conductivity and specific heat were slightly changed and the model was calibrated for the given case.

After calibrating using the DEROB model, the resulted temperature variation is shown in Figure 6.

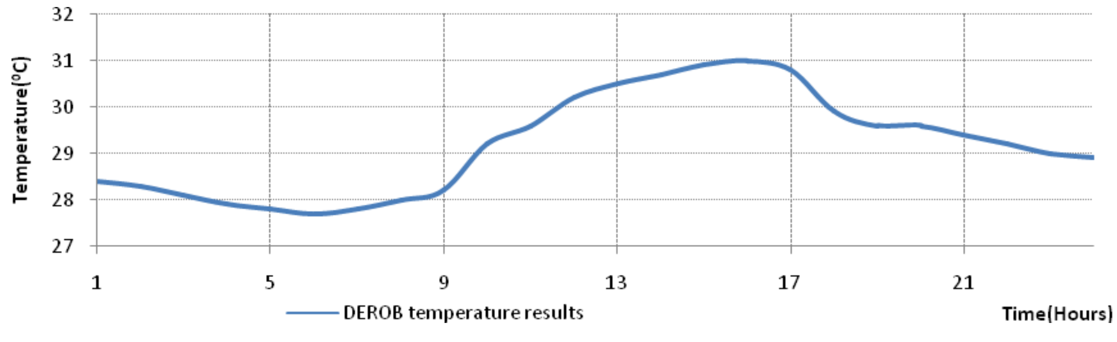

Figure 6 - Temperature results after calibration of properties from DEROB

Actual temperatures were taken only from 8.00 to 18.00. Therefore, using the data from 8.00 to 18.00 temperature comparison was carried out.

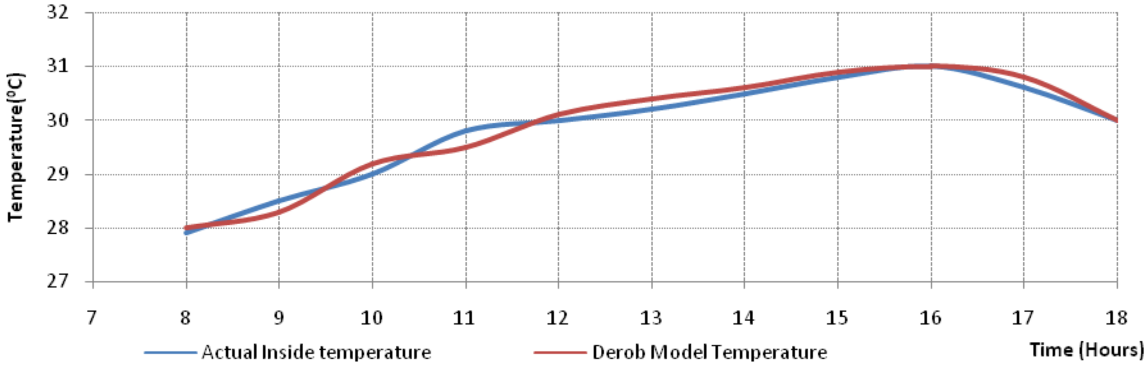

Figure 7 - Actual and DEROB model temperatures with time after properties were calibrated

According to the Figure 7, it can be seen that both curves are matching 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 8 - Selected brick work building (Veterinary Office at Gampaha)

The selected brick work house is Veterinary Office Building at Gampaha. Figure 8 shows the single story building with brick walls.

One volume of above building was selected and temperature and humidity were measured from 08.00 to 18.00. Measures inside and outside temperature are presented in Figure 9.

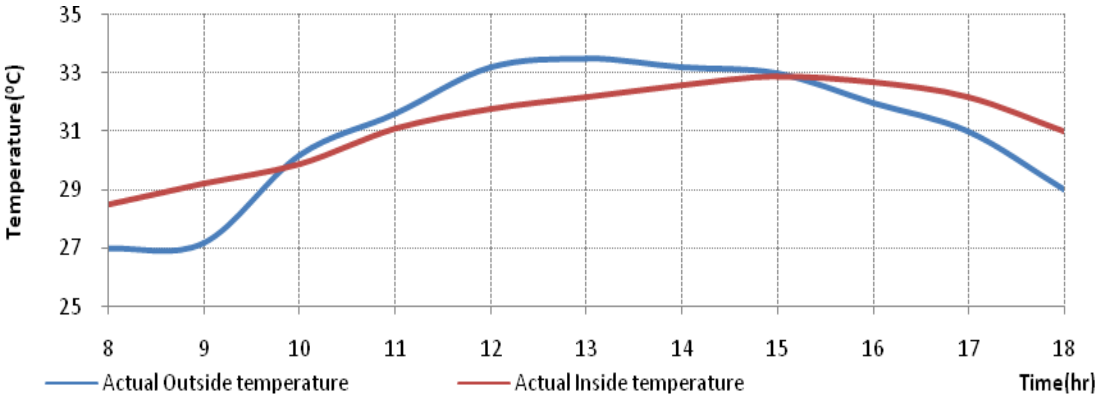

Figure 9- Actual Inside and outside temperatures of brick work house

Figure 10 shows the actual inside and outside relative humidity of brick work building and this building also was modeled using DEROB software and the building was calibrated to reach original building model.

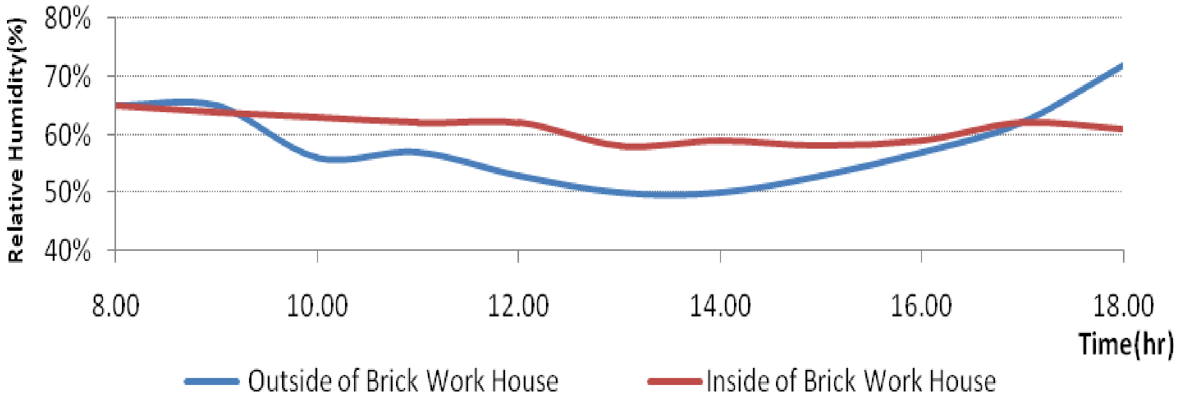

Figure 10 - Inside and outside relative humidity of Brick work house

2.2.1DEROB model of brick work building

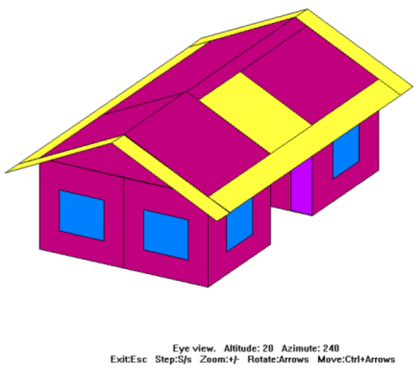

Figure 11 - DEROB model of brick work building

Inside temperature has been taken using DEROB model and the results are present in Figure 13. Figure 7 and 12 clearly shows that DEROB-LTH is capable of handling and modeling buildings, giving fairly accurate results do comparisons, keeping the same external condition. Hence, the properties after calibration can be used for future analysis.

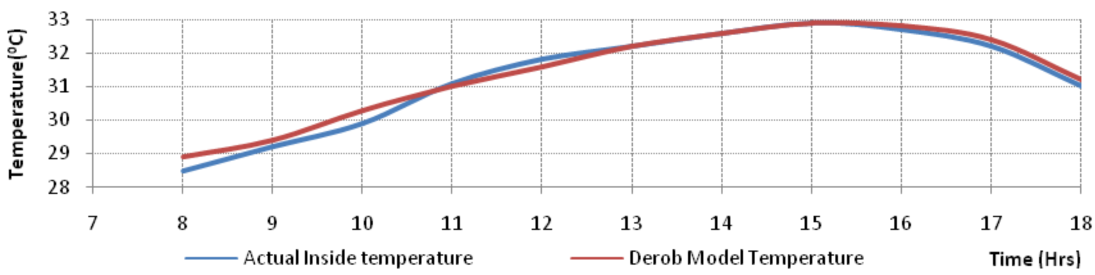

Figure 12 - Actual and DEROB model temperatures

3 Comparison of Thermal Performance

It was clear that DEROB-LTH can be used to simulate buildings in Sri Lankan contest and this can be taken as a good tool to do comparison by changing one parameter, while keeping others constant. Hence, thermal performance of a typical Sri Lankan house was model and the thermal performance of the building was compared by varying the walling material.

3.1 Selection of typical building

When selecting a house for the modeling, it was considered that it should be a typical Sri Lankan house. Northern and North eastern provinces are famous for paddy cultivation. Most of the people in Sri Lanka are economically middle class people and enough quantity of straw is available in above provinces. The target group for promoting the straw bale houses is middle class people. So medium size single storey building with a living room, 2 bed rooms, kitchen, bath room and garage is selected and it is most sufficient for a small family. The layout of the building is given under section 4.2.2

3.1.1Building details – General Details

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 30 mm thick hard wood and windows are made out of plain glass of 3-6 mm thick.

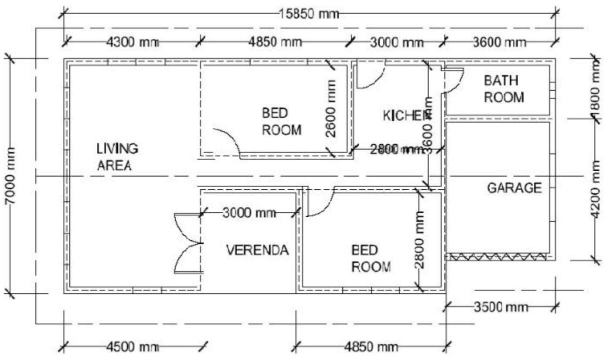

Figure 13- floor plan of typical house

3.2 Modeling of the building

Figure 13 shows the selected floor plan of the simulated building. The selected building is having more 8 volumes. As the software support for maximum of 8 volumes, no of volumes were reduced to 6 by combining similar volumes together. Simulated Building layout is given Figure 14.

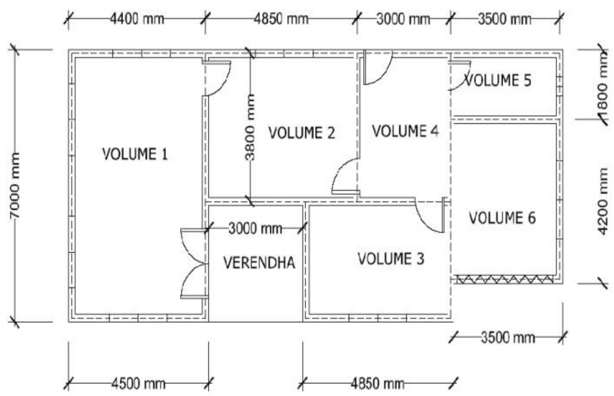

Figure 14 - Simplified floor plan for the DEROB simulation

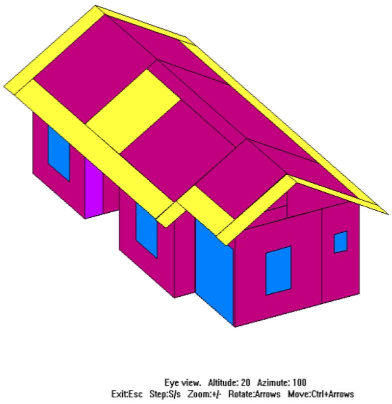

Figure 15 - Final view of DEROB model of typical house

3.3 Analysis of the Model

Here basically 4 walling materials, which are available in Sri Lanka, are used to compare with Straw Bales, namely bricks, cement blocks, compressed stabilized earth block (CSEB), adobe bricks.

Table 1 Layer thicknesses of different walling materials

Type of wall	Material	Layer thickness(mm)
Straw Bale	Plaster	50
	Straw bale	400
	Plaster	50
Brick work	Plaster	15
	Brick work	200
	Plaster	15
Cement Blocks	Plaster	15
	Cement Blocks	125
	Plaster	15
Adobe Bricks	Plaster	15
	Adobe brick	150
	Plaster	15
Compressed Stabilized Earth Block (CSEB)	Plaster	15
	CSEB blocks	112.5
	Plaster	15

Model was run as a passive building with all possible passive techniques by changing the type of walling one by one. All the other conditions remained unchanged. External climatic data of a day in April in Colombo is used for comparison, because April is the hottest month.

3.4 Result from DEROB

Results obtained are shown in Figure 16. It shows the indoor temperature obtained for a selected volume (volume 1) for different conditions selected for the comparison.

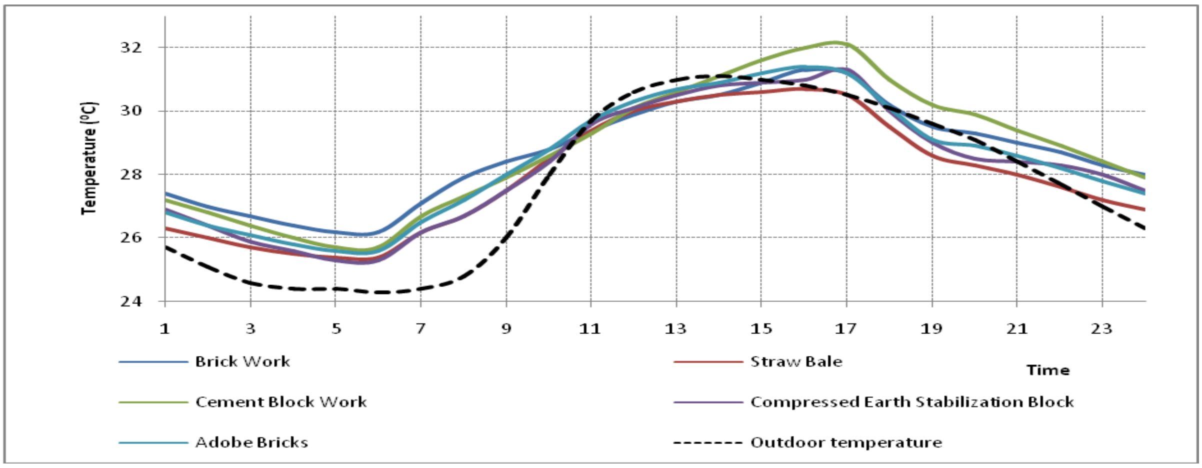

Figure 16 - Temperature Results for different walling materials in Volume 1

According to the figure 16, the peak temperature has drastically dropped in the straw bale case than other walling materials selected. More than that, the indoor temperature was always lesser than the outdoor temperature throughout the day time.

5 Conclusions

The greatest problem, the world is facing today is the depletion of non-renewable resources and global warming. The generating or meeting the energy demand of the world is becoming a major issue. With these, the world is moving towards the development of sustainable production of energy efficient commodities. The world trend is sustainable development. So the passive buildings play a major role there. However, most of the building materials used in Sri Lanka does not support to this, due to high energy cost and embodied energy. And also will not give enough thermal comfortable conditions inside. In this research temperature variations for different walling materials are obtained from DEROB software after calibrating it for two different walling materials. According to the result, it is proved that straw bale building has a good thermal performance than the other walling materials in tropical climatic conditions. It was found that the straw bale construction is a good alternative for common walling materials and also this will be a cost effective construction method in most of Sir Lankan regions, since paddy cultivation is mainly spread all over the country now. So, it is useful to introduce straw bale as a walling material to Sri Lanka.

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