An Experimental Study of Mitigating Urban Heat Island Effect by Novel Applications of Bamboo as a Constructional Material

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ABSTRACT

United Nations Development Programme (UNDP) points out, the science is clear and the debate is over: climate change is happening and there is a need to act now. World wide research is being done for developing green and ecofriendly constructional materials. The present paper puts forward the thermal and structural experimental results of using bamboo as a construction material and as a solar energy collector. The thermal behaviour of bamboo was quantified experimentally by observing the temperature inside the cubicals made of ‘half split bamboo’, ‘half split bamboo-concrete composite’ and was compared with the cubical made of bricks with cement concrete roof while its structural behaviour was quantified by making bamboo bows (bamboo parabolic arches), which are the proposed beam elements, and tested for the load bearing capacity and deflections through experimentations. Half split bamboo panels were fabricated to harvest solar energy using air and water as the heat transfer agent. The design philosophy of bamboo structures is developed on the lines of concrete and steel and attempt is made for the possible replacement of steel with bamboo. The experimental results present a strong possibility of using bamboo as a green constructional material which can not only reduce the ‘indoor temperature’ thereby reducing the building energy requirement and combating the urban heat island effect but also will reduce the GHG emissions which can help in fighting global warming and climate change. Its paves the way for its high value application in construction which can make bamboo cultivation an economically viable way of greening the vast wastelands and thereby improving the environment.

Keywords: Urban Heat Island, Green materials, Climate change, Bamboo, Urban Heat Island

Introduction

It is axiomatic that the more advanced the civilization becomes, the more complex the problems related to men’s environment will be. It is no secret that the acceleration of growth and development worldwide has led to various unprecedented changes in the earth’s environment. The rapid industrialization, increasing population and massive urbanization have resulted in various changes in the atmospheric environment. As the human activities significantly affect the chemical composition of the atmosphere, the artificially induced climatic trends are becoming one of the most widely speculated aspects of the climate across the world. Urban areas absorb and reradiate huge quantities of solar radiations due to massive construction material. The decreased sky view factor (Rizwan et al. 2008) in addition to the anthropogenic heat released from vehicles, power plants, air conditioners and other heat sources have resulted in the formation of urban heat islands (Kikegawa et al. 2003) which not only deteriorates the living environment but also increase the energy consumption (Konopacki and Akbari. 2002), elevates the ground-level ozone (Rosenfeld et al. 1998) and even an increase the mortality rates (Changnon et al. 1996). In most countries, energy use in the building sector represents about one third of the total energy consumption. According to the International Energy Administration (IEA 2005), from 1978 to 1997 the electricity use for residential air-conditioning in the US rose from 3.27×10^{17} to 4.43×10^{17} and nearly 75 per cent of all households had air-conditioners (Synnefa et al. 2007). Looking to the pace of urbanization and energy consumption especially for air-conditioning, it has become very important to develop eco-friendly materials for construction which have satisfying performance from both thermal and structural aspects.

Several studies have documented the measured energy savings that result from the 'cool' roofs which reflect a large fraction of the incoming sunlight and keep the roof surface at a lower temperature than that of the regular 'hot' roofs that absorb most of the incoming solar radiation. Synnefa et al. (2006) studied the thermal performance of 14 reflective coatings for the urban environment and demonstrated that the use of reflective coatings can reduce a white concrete tile's surface temperature under hot summer conditions by 4°C and during night time by 2°C. Taha et al. (1999) have reported that proper values of surface-albedo could achieve temperature reductions and peak electric energy savings. Akbari et al. (1997) reported monitored cooling-energy savings of 46% and peak power savings of 20% was achieved by increasing the roof reflectance of two identical portable classrooms in Sacramento. Konopacki and Akbari (2001) documented measured energy savings of 12% in a large retail store in Austin, Texas. Akbari (2003) documented energy savings of 31–39 Wh/m^2/day in two small commercial buildings with very high internal loads, by coating roofs with a white elastomer with a reflectivity of 0.70. Parker et al. (1998) measured an average of 19% energy savings in 11 Florida residences by applying reflective coatings on roofs. Parker et al. (1997) also monitored seven retail stores in a strip mall in Florida before and after applying a high-albedo coating to the roof and measured a 25% drop in seasonal cooling energy use. Hildebrandt et al. (1998) observed daily energy savings of 17, 26 and 39% in an office, a museum, and a hospice, respectively, retrofitted with high-albedo roofs in Sacramento. Akridge (1998) reported energy savings of 28% for a school building in Georgia which had an unpainted galvanized roof that was coated with white acrylic. Boutwell and Salinas (1986) showed an office building in southern Mississippi saved 22% after the application of a high-reflectance coating.

Few other studies show the impact of greenery on temperature and subsequent effect on the building energy requirement. Kikegawa et al. (2006) carried out computer simulation to report that the reduction of anthropogenic heat and planting vegetation on the side walls of buildings could reduce air temperature up to 1.2°C and reduce space cooling energy demand up to 40% while Ashie et al. (1999) used computer modeling and reported air temperature reduction of 0.4 to 1.3°C with building cooling energy savings of as much as 25% through planting vegetation. It was reported in a study conducted by Spronken-Smith et al. (2000) that parks could help control temperatures through an evaporation of more than 300% as compared to its surrounding. Yu and Hien (2006) have used computer simulation to report that parks and green areas could achieve 10% reduction of cooling load. Ca et al. (1998) reported that planting a 0.6 km^2 park could reduce temperatures by 1.5°C and achieve potential savings of 4000 kWh in an hour of a summer day. Another study conducted by Tong et al. (2005) reported that temperature reduction of 1.6°C was possible in the case of replacing urban developments by grass and shrub land.

If the above two themes of study i.e. developing ‘cool’ materials for reducing the heat gain of the building and ‘greening’ of the land for reducing the ambient air temperature are juxtaposed, it indicates the importance and urgency of developing ‘cool’ and ‘green’ constructional materials which should be naturally growing paving the way for economical greening of the land and thereby improving the environmental conditions. In the background of this, attempt has been made to investigate ‘bamboo’ as a ‘cool’ and ‘green’ constructional material. Bamboo is the fastest naturally growing renewable material having the unique property of producing harvestable culms throughout the year for several decades. Through bamboo has been used in various pioneering structural and other applications in the past and bamboo structures have stood the test of time, the lack of detailed scientific investigation has subjugated this material from coming into the main constructional field and still bamboo is seen as a poor man’s material. Developing bamboo as a load bearing structural element would pave way for the for its high value application in construction which can make bamboo cultivation an economically viable way of greening the vast wastelands. Moreover, it should be noted that the production of every ton of cement and steel (the main constructional materials) releases tons of green house gases in the atmosphere, however with every ton of bamboo growing, nearly a ton of CO_2 is sequestered. The present study puts forward the results of the scientific investigation done on bamboo as a green constructional material with focus on its thermal and structural performances to combat urban heat island effect and reduce green house gas emission thereby paving way for mitigating the climate change.

Bamboo: A Modern Constructional Material

In the age of global warming, climate change and exponentially increasing GHG emissions, it very important to investigate naturally growing materials which can be used in construction with confidence. The recent IPCC report clearly mentions that ‘buildings’ offer the highest global potential among all the sectors studied in the report for reducing the projected baseline emissions by 2020. Through energy efficiency, about 30 per cent of the projected GHG emissions in the building sector can be avoided with a net economic gain. Thus, it is the time to have out of the box thinking and a paradigm shift in the building construction technology. From time immemorial bamboo has been used in construction, but still it has not been given a main constructional material status. Bamboo which is known as a ‘miracle plant’ or ‘an ordinary plant’ with ‘extra ordinary qualities’ or ‘a green gold’ or ‘a wonder grass’, is an extremely light weight, functionally graded and high strength natural composite. It fits well into the minimal weight and energy structures that the future demands. Bamboo plant is unique in the entire plant kingdom in two ways: 1) The timber of an individual culm matures in 3-5 years 2) Bamboo culms of mature timber from a single bamboo plant (bush) can be harvested throughout the year for several decades. Among the recognized sectors that offer emission reduction possibilities, forest sector is unique in the sense that it offers opportunities for CO_2 mitigation by removal of accumulated CO_2 in atmosphere, and sequester it in vegetation, soil and wood products. Bamboo is not only the world’s fastest and the strongest growing woody plant but also is an enduring versatile and highly renewable resource. Its adaptability to different climatic conditions makes it one of the most important species for mitigation of the climate change. It has been reported that Phylostachys bambusoides in Kyoto, Japan, has a carbon sequestration potential of around 2 tonnes per hectare. Available studies on sequestration potential of the tree species indicate annual sequestration levels of around 2 tonnes per hacter under a regular planting and harvesting regime for species like Poplar and Eucalyptus with rotation periods varying from 6-8 years (Gera 2008). Agro forestry has been found to be the most cost effective method of addressing the carbon emission and consequent global warming issues (Ravindranathan and Somshekhar, 1995). By going for shorter gestation period, species like bamboo can be used as an effective mitigation option through carbon sequestration. It is in the back ground of this, a detailed scientific study has been done to assess the performance of bamboo as an alternate green constructional material and help in reducing GHG emissions, mitigate urban heat island effect and fight against global warming and climate change.

Quantifying the behaviour of Bamboo as a Structural Load Bearing Element through experimentation:

The structural behaviour of bamboo is quantified by making bamboo bows, which are the proposed beam elements, and tested for the load bearing capacity and deflections through experimentations. The following text discusses the fabrication of the bow arch, the methodology for testing the bamboo arch with simple connector and the experimental results of the structural performance of the bamboo bow arch.

Fabrication of Bow Arch: Bamboo Bow Arch is fabricated using *Dendrocalamus Strictus* species of bamboo. The peculiarity of this bamboo species is that it is a thick skin bamboo, varying from 4 - 5 cm a bottom diameter to 2 – 2.5 cm as top diameter. Owing to the kind of tapering pattern it has, it can be bent into a parabolic form very easily. The single bamboo culm is guided along the parabolic profile generated using iron studs. Further, another bamboo is put above the previous one and connected using a spacer. The bent bamboos are now connected using a bamboo tie, to ensure the parabolic curve profile. Thus, the Bamboo Bow arch so fabricated is connected with another such arch, forming a bridge with bracings and cross bracings; which will ensure the lateral stability of the arch during the experiment.

Methodology for Testing of Bamboo Arch with Simple Connector: Horizontally separated double bamboo bow beam, is connected with similar double bamboo bow beam using bamboo ties as shown in Figure 1. Point load is applied at the crown of bow beam and the deflection of crown was measured with increasing load. To measure the applied load at crown Proving Ring is used which has 100 small divisions and for which 26 division = 1000kg. The deflection of both the arches was measured using displacement dial gauges below the crown point of each arch as shown in the Figure 1(a). Plaster of Paris is put up to restrain the movement in longitudinal direction, thus generating a partially fixed support condition. Figure 1(b) and 1(c) show the use of Plaster of Paris for partially fixed support condition. Two dial gauges were used to measure crown displacements of the arches.

Quantifying the thermal behaviour of Bamboo as a constructional material through experimentation:

The thermal behaviour of bamboo as a building material was quantified experimentally by observing the temperature inside the cubicals made of Bamboo, Bamboo-Concrete composite and was compared with the cubical made of brick masonry with cement concrete roof. The following text discusses the fabrication of the three cubicals i.e. the cubical made of half split bamboo, half split bamboo-concrete composite and that of brick masonry with cement concrete roof as shown in Figure 2(a), Figure 2(c) and Figure 2(e) respectively; the methodology for collecting the temperature data and finally the experimental results of the thermal performance of all the three materials is shown in Figure 2(b), Figure 2(d) and Figure 2(f) respectively.

Fabrication of the three cubicals: The three cubicals i.e. one of bamboo, the other one of bamboo-concrete composite and the last one of brick with cement concrete roof, as shown in Figure 2(a), Figure 2(c) and Figure 2(e) respectively, were made of size 1m × 1m × 1m each. Half split bamboo of the specie *Dendrocalamus Strictus* was used in the fabrication of the bamboo cubical and the bamboo-concrete composite cubical. The thickness of the wall and roof panels of the bamboo cubical was 1 inch. In the bamboo-concrete composite cubical, the exterior surface of the half split bamboo panels (both roof and wall) was covered by plain cement concrete whose mix design is having the following proportion (1:2:4 i.e. 1 part of cement, 2 parts of coarse aggregates and 4 parts of fine aggregates) . The thickness of the wall and roof panels was 2.5 inches. Standard size bricks were used for the construction of the brick cubical having the thickness of 4.5 inches. The plain cement concrete roof was of 2 inches thick. The three cubicals so made were placed at place where they were exposed to an uninterrupted sun shine.

Methodology for testing of bamboo as a cool material: The ambient temperature and the temperature inside the cubicals were measured by the Resistance Temperature Detectors (RTDs). In this study, total 4 RTDs were used. One RTD was installed at the centroid of each cubical. A separate weather station was installed to observe the ambient temperature. The experimental study was done for 10 days during 28th June to 7th July, 2009 and all the four temperature values were recorded at an interval of 30 minutes.

Harvesting solar energy using half split bamboo panels:

Half split bamboo panels were used for harvesting the solar energy. The half split bamboo panels, which are the proposed building blocks of a roof top, consists of four parts namely front glass plate, collector plate, back insulation and the supporting frame and was of dimension 52 cm × 36 cm. This roof panel was made by joining half split bamboo by fevicol and saw dust shown as in Figure 3 (a) and Figure 3 (b). To make it water proof, it was coated from the both sides with glass fibre mat and general purpose resin (GP resin) mixed with proper hardener as shown in Figure 3 (c). A black GI sheet was put over it as absorber and then a glass plate which was transparent for the incident solar radiation. The back insulation is an important factor as it arrests the flow of heat inside the building. For this, PU foam which is an insulator of good standards and is both naturally available and cost effective, was used. Tolylene diisocyanate (TDI) and polyalcohols are the basic ingredients for the production of PU (Poly-Urethane) foam. The mixture of polyol & diisocyanate is in the ratio of 1:1 to form Polyurathane foam (PU foam). Approximately 4 cm coating of PU foam was given below half bamboo panel. For this ($52 \times 36 \times 4 = 7528$ cm^3) 145 g of polyol and diisocyanate each was taken and mixed in a mechanical stirrer until the initiation of foaming, as shown in Figure 3 (d). Then it was spread uniformly on the backside of the half split bamboo panel. A casing made of wood was covered the spread mixed liquid, so that the foaming got a uniform shape and shown in Figure 3 (e).

Thermocouple sensors were connected to inlet, outlet, on the black panel over the half split panel and below the half split bamboo panel to record the diurnal variation of temperature at different points with free natural circulation of air and water. The half split bamboo panel which harvested the solar energy is shown in Figure 3 (f). Thermocouple sensors were connected to inlet, outlet, on black panel and below panel of solar dryer to record the diurnal variation of temperature at different points of solar dryer with free natural circulation of air and water daily. Table 1 shows the temperature (in degree Celsius) at various points in the half split bamboo panel (i.e. temperature above the black panel, the inlet and outlet temperature of the air, and temperature below the panel) with natural air circulation as observed on 5th June, 2008. Figure 3(g) shows the plot of temperature values as mentioned in Table 1. Table 2 shows the temperature (in degree Celsius) at various points in the half split bamboo panel (i.e. black panel temperature, inlet and outlet temperature of the water, temperature below the panel), the temperature of the water container made of rice husk and that made up of PU Foam along with the ambient temperature observed on 17th November, 2008. Figure 3(h) shows the plot of the temperature values as mentioned in Table 2.

Results and Discussion

The results of the above study show a strong potential of bamboo being used as a green constructional material.

Structural performance of bamboo as a constructional material:

The bamboo arch with simple connector when tested under point load at crown, it took 615 kg load and the deflection at the crown was 95 mm. At the maximum load, one of the bamboos of the arch failed from a place where it was affected by borer. The total deflection for the crown was 105 mm for 692 kg load.

Thermal performance of bamboo as a construction material:

The Figure 2(b), Figure 2(d) and Figure 2(f) show the average 30 minutes variation of the temperature at the centroid of the half split bamboo cubical, half split bamboo concrete composite cubical i.e. bamcrete cubical and the brick cubical with cement concrete roof respectively along with the ambient temperature during the study period. Figure 2(g) shows the 30 minutes variation of the ambient temperature along with the temperatures of all the three cubicals together while Figure 2 (h) shows the temperature differences among the three cubicals. In the present setup, there was no ventilation provided. The average ambient temperature observed during the study period was 29.87 ºC. The average temperature observed inside the half split bamboo cubical was 36.49 ºC; inside the half split bamboo concrete composite was 38.89 º C while inside the brick masonry cubical with cement concrete roof was 41.46 ºC. A maximum of 8 ºC and minimum of 1.2 ºC temperature difference was observed between the brick masonry cubical and half split bamboo cubical, while in case of brick masonry cubical and half split bamboo concrete composite cubical a maximum of 5.8 ºC and minimum of 0 ºC temperature difference was observed. When half split bamboo concrete composite cubical was compared to that of half split bamboo cubical, a maximum temperature difference of 6 ºC while a minimum temperature difference of 0.5 ºC was observed. The maximum temperature differences observed above are quite significant. The above study leads to a conclusion that the lowest average temperature was observed in the half split bamboo cubical followed by the half split bamboo concrete cubical. The highest average temperature among the three cubicals was observed in the brick masonry cubical having cement concrete rooftop.

Half split bamboo panel as solar energy collector:

Half split bamboo panels which are the proposed building blocks of the roof top were used for harvesting the solar energy. Air and water were used as the heat transfer agents. The maximum temperature of the air observed at the outlet of the half split bamboo panel was 83 ºC while the maximum temperature of water observed at the outlet of the half split bamboo panel was 37.28 ºC. The solar energy harvesting experiment conducted on 5th June, 2008 was done using air as the heat transfer agent while the experiment done on 17th November, 2008 was done using water as the heat transfer agent. The average ambient temperature on 5th June, 2008 was 28.5 ºC while that on 17th November, 2008 was 24.56 ºC. The temperature below the panel should be low as possible. In the experiment with air as the heat transfer agent, the heat loss was more as evident from the temperature below the panel which rose to 41.6 ºC while correspondingly the ambient temperature was 32 ºC. However, the heat losses were minimized by the change in the heat transfer agent from air to water and by the use of PU foam. In the experiment conducted with water as the heat transfer agent, the temperature below the panel was very close to the ambient temperature.

Conclusions

One of the biggest challenges the new millennium faces is how to balance environmental protection with the demands of the ongoing exponential development. Rising earth temperatures, record losses in biodiversity and species extinction, increasing demands and dwindling supplies of natural resources, etc. all put a gloomy picture of our future. Until and unless there is a change in our lifestyle and advances in technologies backed by government polices and corporate management practices, things will move from bad to worse. No doubt, there are various initiatives taken across the world, but lot more has to be done. The present study reveals a strong potential of bamboo being used a modern constructional material. Though bamboo has been used in hosing since time immemorial but till date it has been used a load distributing element and not as a load bearing element. However, the present study explores that bamboo can be used a load bearing element. Moreover, with the reduction in the heat gain, bamboo has the potential to act as a ‘cool’ material. Through there are various engineering challenges involved in developing ‘Bamboo’ as a ‘Modern Engineering Material’ i.e. creep behaviour of bamboo, non-homogeneity, bio degradability, durability, etc. which requires systematic investigation, however, the results of the present study are encouraging enough to infuse enthusiasm in the scientific community. A systematic and scientific blend of the ‘traditional wisdom’ and ‘modern science’ would result into a cost effective housing technology which would not only be socially acceptable but would also help in a big manner not only to reduce the building energy requirement and combat the urban heat island effect but also to reduce the green house gas emission and fight global warming and climate change.

Future Work

It is proposed to fabricate three cubicals i.e. one of half split bamboo, the other one of half split bamboo with concrete and the third one with bricks; all having their roof top of the proposed half split bamboo panels. Moreover, all the three cubicals would be provided with adequate ventilation to the tune of 20-30 per cent of the wall area to simulate the real time situation. It is in this setup, temperature measurements at the centroid of the cubical would be carried out. In addition to the measurements of the centroidal temperatures, temperatures would be observed at the wall surface and one feet away from the wall to quantify the effect of the material on the environment. The above study would quantify the twin benefit of the usage of the material viz. half split bamboo and half split bamboo concrete composite on the reduction in the indoor temperature thereby reducing the building energy requirement and also the production of the ‘low grade thermal heat’ which could be used for various purposes.

Acknowledgements

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Figure 1 (a) Experimental Setup for bow beam without lateral support


[redacted]

Use of Plaster of Paris for partially fixed support condition

Figure 1 (b)


[redacted]

Figure 1 (c)

Figure 2(a) Bamboo Cubical

Figure 2 (b) Temperature variations in Bamboo Cubical along with Ambient Temperature

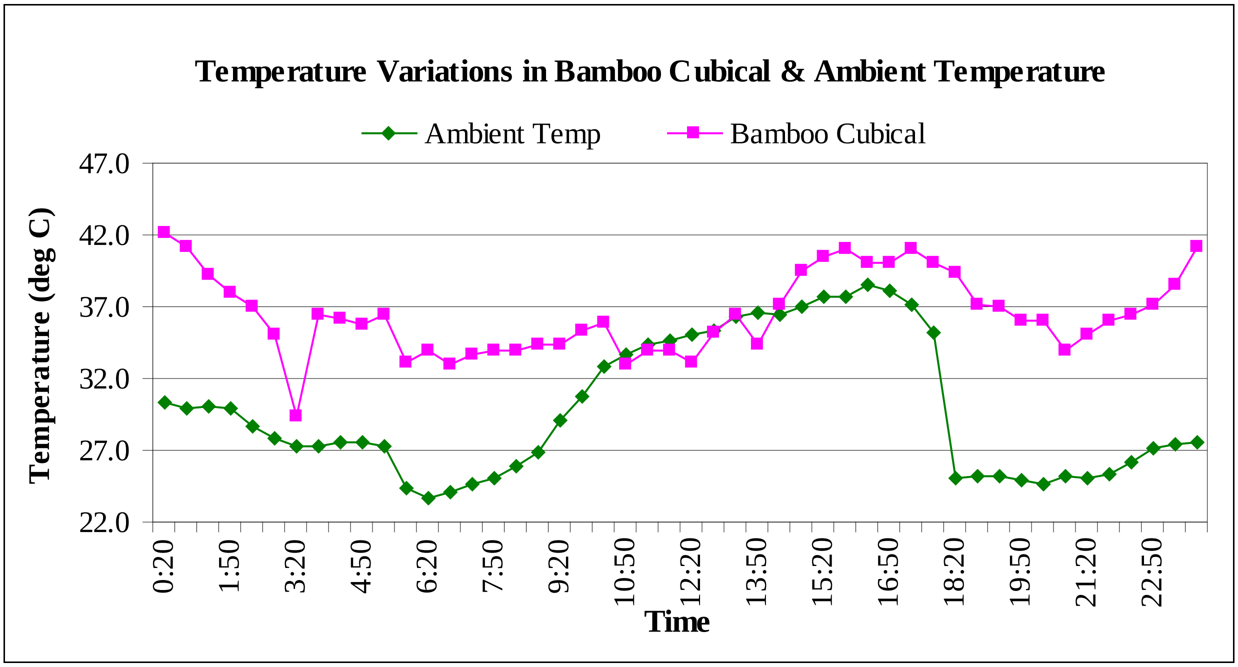

Figure 2(c) Bamcrete Cubical

Figure 2 (d) Temperature variations in Bamcrete Cubical along with the Ambient Temperature

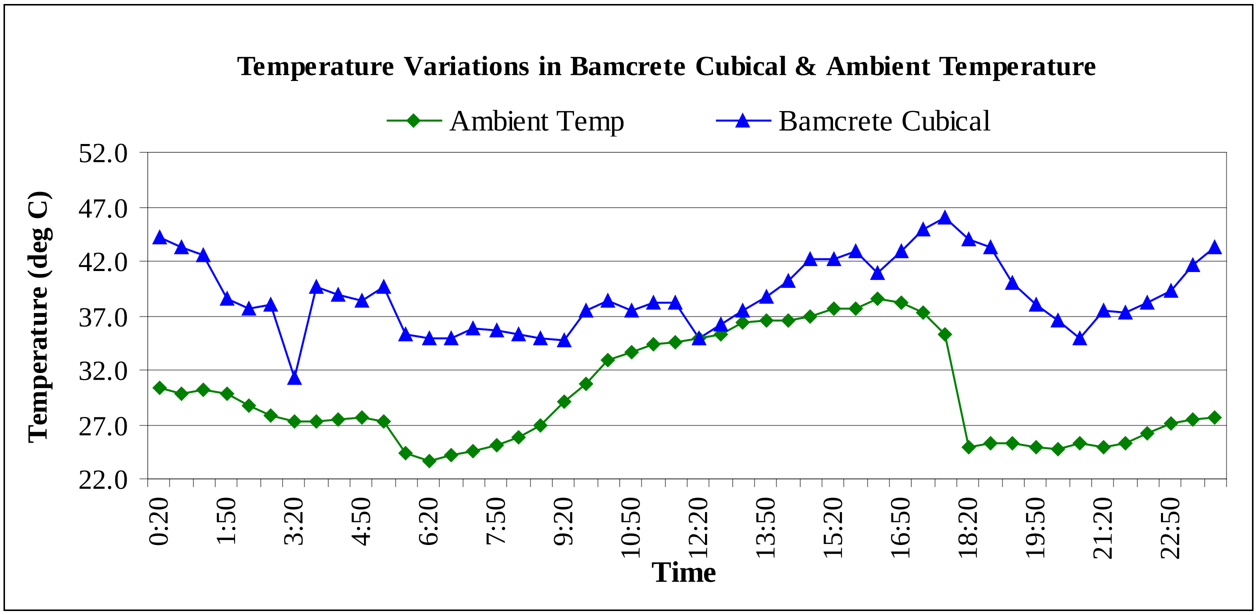

Figure 2 (e) Brick Cubical with Cement Concrete Roof

Figure 2 (f) Temperature variations in Brick Cubical along with the Ambient Temperature

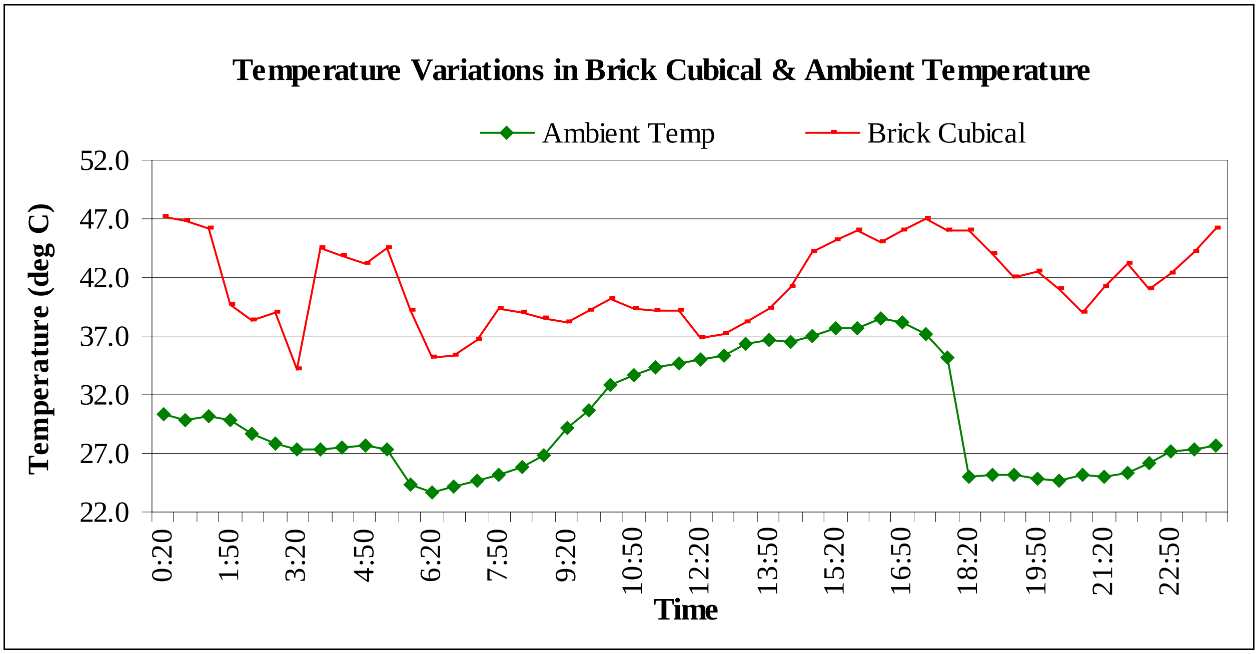

Figure 2 (g) Temperature variations in the Three Cubicals along with the Ambient Temperature

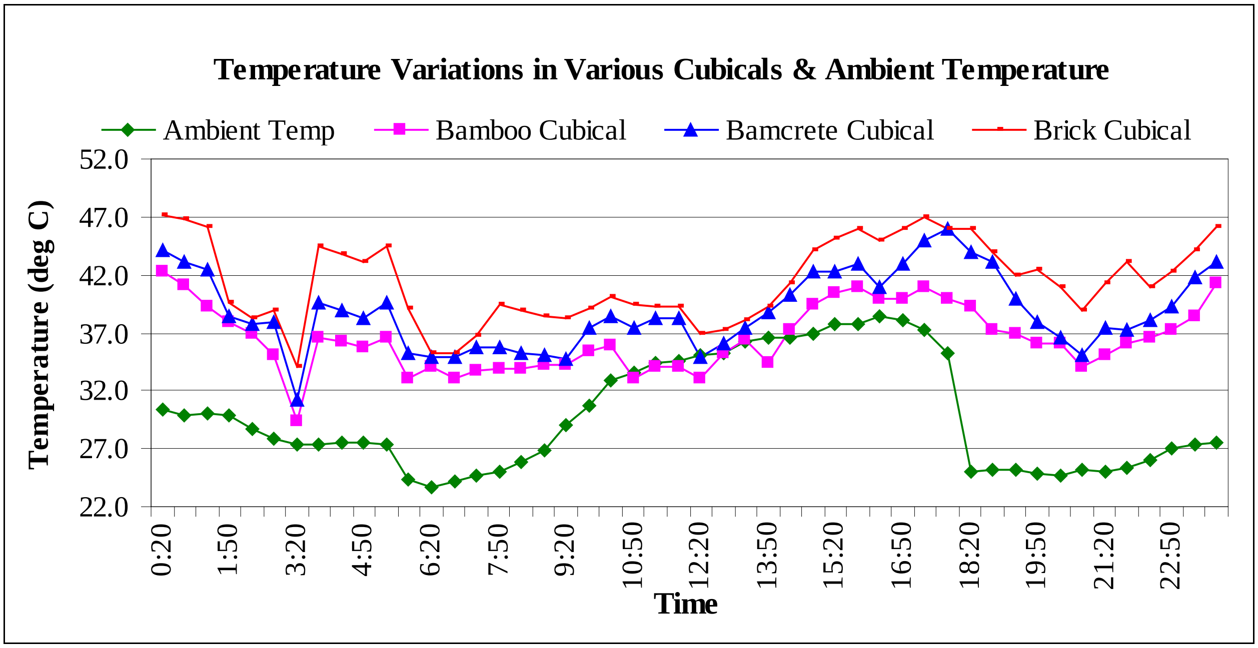

Figure 2 (h) Temperature Differences among the three cubicals

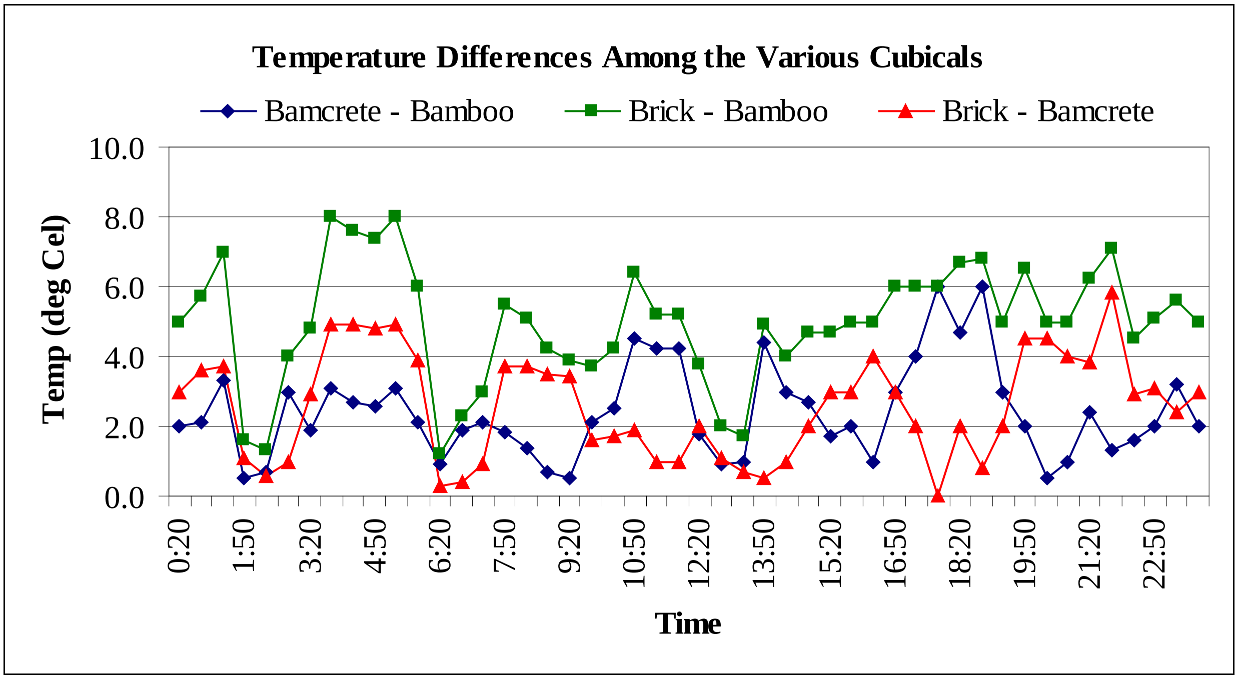

Figure 3 (a) Half split bamboo joined by fevicol

Figure 3 (b) Half split bamboo joined by fevicol and saw dust

Figure 3 (c) Half split bamboo panel coated with glass fiber mat and GP resin

Figure 3 (d) Half split bamboo panel with PU Foam

Figure 3 (e) Half split bamboo panel with a wooden casing

Figure 3 (f) Half split bamboo panel harvesting the solar energy

Table 1 Temperatures (in degree Celsius) at various points in the Half Split Bamboo Panel with Natural Air circulation on 5th June, 2008.

Time	Ambient Temp.	Black Panel Temp.	Inlet Temp.	Outlet Temp.	Below panel Temp.
10AM	25	23.7	31.2	35.9	26.3
11AM	25	29.5	31.9	36.2	27.2
12PM	27	31.6	37.2	50.3	31.2
01PM	27	31.9	40.3	52.5	32.3
02PM	30	41.2	61.5	83.2	41.1
03PM	32	42	62.5	78.8	41.6
04PM	31	36.1	55.6	73.6	39.1
05PM	31	33.2	48.3	65.3	36.2

Figure 3(g) Plot of temperatures (in degree Celsius) at various points in the Half Split Bamboo Panel with Natural Air circulation on 5th June, 2008

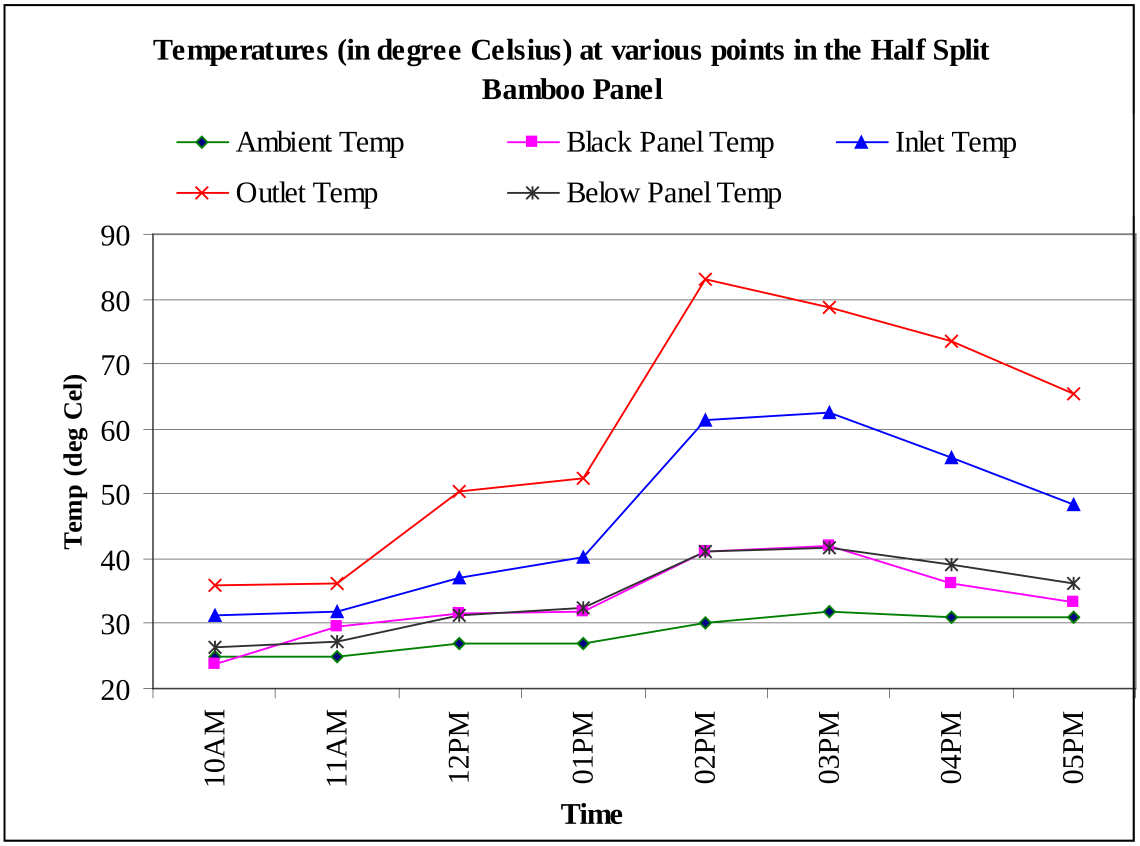

Table 2 Temperatures (in degree Celsius) at various points in the Half Split Bamboo Panel with Natural Water circulation on 17th November, 2008.

Time	Ambient Temp.	Black Panel Temp.	Inlet Temp	Outlet Temp.	Below panel Temp.	Container RH*	Container (PUF)
09AM	22.7	14.6	17.4	18.6	18.7	16.1	19.0
10AM	25.1	20.2	18.7	18.8	21.9	19.3	21.0
11AM	27.0	29.8	25.6	27.3	25.6	27.0	26.0
12PM	26.8	37.4	32.0	33.9	28.2	34.0	32.0
01PM	26.7	38.1	34.6	37.2	27.7	36.3	36.0
02PM	27.5	34.8	32.5	34.7	26.5	35.6	35.0
03PM	25.1	33.2	31.0	32.8	25.6	34.4	34.0
04PM	21.5	34.3	31.9	34.4	24.1	34.7	35.0
05PM	18.6	29.9	27.7	28.0	20.6	34.1	34.0

** RH- Rice Husk*

Figure 3(h) Plot of temperatures (in degree Celsius) at various points in the Half Split Bamboo Panel with Natural Water circulation on 17th November, 2008.