Comparative Analysis of Thermal Performance of Roof Component using Alternative Materials Taking case of Hot and Dry Climatic Condition of Bhuj-Kutch

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Abstract:- Looking at the humongous quantum of construction undertaken annually, the construction industry consumes an enormous amount of energy every year. A good portion of this is attributed to the materials used for construction, considering right from their extraction to the building application. Also in terms of building's operational energy, an appropriate building envelope design can greatly result in reducing the energy consumption. Amongst these envelops amongst these envelops use are the major component which are in maximum contact with the sun and hence, become the highest source of heat gain to a larger extent. So analysing the larger perspective, in order to achieve thermal comfort indoors maximum energy consumed is after occupation, thus varying the occupational energy. An appropriate choice of material can help improve the structure's thermal performance particularly in hot and dry climate why quantifying heat gain. Also, there is a need to bridge the gap between the techniques from traditional vernacular systems to present context with conventional techniques, innovation takes a major role. Few vernacular and conventional materials were identified, innovated and have been evaluated based on their material properties for relative thermal performance and surface temperatures with an idea to understand its impact socially, ecologically and economically sustainable. The exercise was conducted on site where at one time eight modules were executed keeping the roofing components variable and the wall, module size, size of the opening and materials were maintained constant to produce the results that are compared. to conventional practice. Further, all the eight modules where analysed for relative thermal performance.

Keywords:- *Thermal Performance; Building Component - Roof; Building Material Innovation; Monitoring.*

I. INTRODUCTION

For any building thermal performance becomes one of the key factors in determining the overall level of comfort. In specific case of hot and dry climate, the region receives solar radiation throughout the year, and to achieve thermal comfort indoors mechanisms are needed for cutting down the heat gain by surfaces of the building. Roofs are that component of a building which come in maximum contact with Sun and hence, becomes the biggest source of heat gain during the day and heat loss during the night which affects the ambient temperature to a greater extent. Modern buildings consume energy in five phases - Embodied energy (extraction and manufacturing), Grey energy(transportation), Induced energy (construction), Operational energy and Demolition energy.

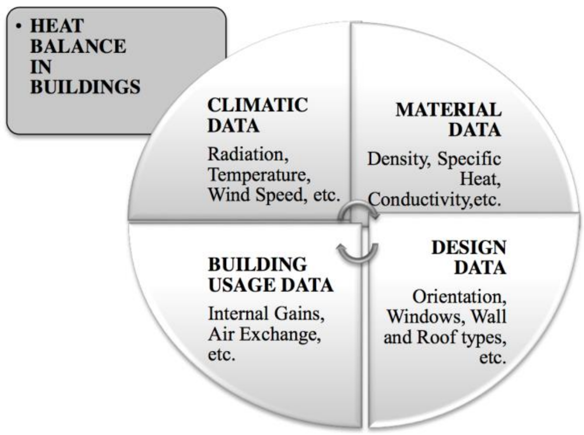

Fig 1:- Diagram showing Heat balance in buildings

A judicious decision about the entire construction process can reduce the energy consumption at each of these five phases. Architects and designers play a key role in this decision, by appropriate selection of material which further can reduce embodied energy, grey energy and even occupational energy.

In countries like India, housing deficit is one of the largest problems faced by the society and would continue to increase as the population increases. According to the World Bank report 2010, 37.2% of the total population of India falls below poverty line which means almost 1/3 of our population has no access to advanced cost intensive construction process. The most serious obstacle to low-cost housing in developing countries is the lack of low-cost roofing material that will provide satisfactory performance for a reasonable time under many adverse conditions. Roof is an essential component of a dwelling, critical for shelter thermal comfort and privacy. In many developing countries roofing alone represents more than 50% of the total cost of low-cost house[1]. In addition to thermal performance, a number of factors involved in assisting the decision of a choice of material, to be used for any components such as physical properties, mechanical properties, availability, aesthetic's and cost are the major contributors. In that sense a decision making metrics would be of use where all these are weighed against one another. This would remove the existing ambiguity and notions about several components that adversely affect the building.

A. *Aim and Objective*

The aim is to innovate and analyse thermal performance of roof component in hot and dry climate taking the case of Bhuj-Kutch. Hence, the objective was to develop roofing component using varied locally available materials and identifying and exploring the potential of the material for thermal performance in an economical level. The thermal performance of selected configurations will be monitored on site and hence, comparative analysis would be conducted for roofing components.

B. *Methodology*

Identification of materials to be used in selected region followed by understanding properties of different materials selected for the study. Finalising materials for the testing based on the conclusions drawn from the comparative chart and exploring methods to make roof component for economically weaker sections.

To evaluate the properties of selected material as a roof component with its limitations, strengths and weaknesses.As per the above conclusion, the testing unit will be designed.

Onsite execution of the designed module for further study for thermal evaluation and continuous monitoring of individual modules in regular intervals. Deducing Thermal performance analysis and conclusions based on readings.

C. *Scope and Limitations*

The scope of the study is limited to flat roof exposed to the sun in hot and dry conditions. Across the comparative analysis, it is the thermal performance which is considered and not thermal comfort across the scope. The thermal performance measured by on-site monitoring only. Another limitation across the exercise was that it was conducted in summer months only.

II. THEORY

A. *Thermal Performance*

There are basically three aspects required for considering any discussion of thermal design of a structure. Firstly, an evaluation must be made of the indoor environmental conditions most conducive to comfort, health, safety and general well-being of the occupants. Secondly, it is necessary to describe representative or typical weather conditions that must be taken into account while developing the best design to suit specific requirements. Lastly and most importantly, it must be shown how design procedures and physical properties of different structural materials can be effectively utilised to ensure the best possible control of living and working and working environments[2].

At the same time micro climatic variations even within the same general climatic zone must be taken into account as these can have significant effects on the building design. The main factors determining the thermal response of a building are the heat gains and losses through the various structural at elements which are walls, windows, roof and floor, internal heat loads and the rate of ventilation. Structural heat gain or losses are dependent on certain properties of the elements concerned; for instance heat gains through roof depends on the surface area of the roof the heat storing capacity of the roof and their thermal resistance or installation properties.

B. *Bhuj - Kutch, Gujarat, India*

City of the Bhuj, Kutch District is located in the state of Gujarat in western India. Which falls under the western edit zone of India and hence is an extremely dry region. The climate of Bhuj is extreme with maximum and minimum temperature ranging from 40-45°C in summer and 5-10°C in winter. Rainfall is Case, with the annual rainfall ranging between 300 to 400mm. In summer its accompanied by harsh sunlight and dust storms. The winds majorly flow from south and south-western direction for major part of the year.

III. EXPERIMENT FOR THE ROOFING COMPONENT - MATERIAL INNOVATION

Traditional construction systems have always given us learning. They have worked excellent in terms of comfort and environmental aspects. But these construction systems are not applicable in the present context; and to make the systems and materials work out in present scenario alterations and innovations needs to be done. The purpose of this experiment is to compare thermal performances of various alternative Materials of roof component with the conventional tin and reinforced concrete. Three roofing materials have been developed for comparative study. The developed materials were finalised after trials and tests for

[1] Roofing in developing countries, National Academy of Science, Washington DC 1974

[2] Thermal Performance of Buildings by J.F. Van Straaten

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the various proportions of constituent materials. Local availability was one of the main criteria for material selection. Along with this cost effectiveness of the material was also taken into consideration.

A. Development of Mud rolls with Lime, Surkhi and Fly-ash

Mud rolls have high weight due to high density, hence the structural members which carry these materials to be thickened. So the mean aim was to reduce the density of mud roll and hence that aspect became the main criteria for material innovation. Combinations of mud roll with rice straw, lime, fly-ash and *Surkhi* where tried, and for final experiment mud roll with rice straw and mud roll with lime where selected as these two had relatively low densities.

Fig 2:- Mud Roll Samples

Mud Roll Proportion (in Litre)					
Sample	Lime Slurry	Surkhi	Fly-ash	Clay Soil	Water
1	2.5				1
2	2	1			2
3	1	2			2
4	1		2		2
5	0.5	1		4	7

Table 1:- Mud Roll Proportions

Sr. No.	Proportion by Volume				Dry Wt.	Density
	Clay Soil	Lime Slurry	Surkhi	Fly Ash	Kg	gm/ cm3
1	0	2.5	0	0	1.966	0.413
2	0	2	1	0	2.340	0.544
3	0	1	2	0	2.938	0.599
4	0	1	0	2	2.904	0.541
5	4	0.5	1	0	2.298	0.592
6	Clay Soil	0	0	0	4.424	0.720

Table 2:- Density of different Samples

B. Development of Straw-Clay Panels

The idea for this material was inspired by cobalt technique and traditional roof slab technique. Since traditional hatch is organic material and has tendency to deteriorate the straws we are treated to increase durability as well as to gain fire as it resistance. In order to apply the idea of slab in present conditions modular panels where introduced. As per the standards for roofing tiles, the tiles or panel should take 50kg load at the centre.Panels be prepared with combinations of proportions of clay, lime, *Surkhi* and fly ash. All the combinations were made to undergo 50kg test for which only play/panel and lime/panel could pass.

Sample	Clay Slurry		Lime Slurry		Block Proportion (in Litre)							
	Clay Soil	Water	Lime	Water	Clay Slurry	Lime Slurry	Saw Dust	Surkhi	Fly-ash	Wheat straw	Rice Straw	Water
1	5	7.5			4.5					5.75	5.75	
2			1	1		4.5				5.75	5.75	
3			1	1		2.5	5					
4			1	1		3		3		5.75	5.75	2.5
5			1	1		1.5		3		5.75	5.75	4
6			1	1		1.5			1.5	5.75	5.75	2.5
7			1	1		1.5			3	5.75	5.75	4

Table 3:- Straw Clay Panel Proportions

Fig 3:- Straw Clay panels

C. Development of Paper tube panels

Tubes were quite easily available material in Bhuj vicinity. Paper tubes with fixed dimensions where is selected and tests were performed to check their strengths. The loading test was performed by stacking stones on the paper tube and observing deflection of the paper tubes against the weight they carried. The outcome was sample too could be more weight just by increasing the thickness of the tube by 0.2 cm and gauge by 0.1 cm the load carrying capacity was doubled with decrease in the displacement.

Sr. No.	Length (cm)	Inner Dia. (cm)	Outer Dia (cm)	Guage (in cm)	Centre to Centre	Disp. Readings	CSEB Block (9.6 each)	Weight
1	91.5	7.75	8.5	0.375	76.5	12.9	0	0
						12.6	4	38.4
						11.9	8	76.8
						11	12	115.2
						10.9	16	153.6
						9.9	20	192
	Displacement = 3cm							
2	91.5	7.75	8.7	0.475	76.5	28.1	0	0
						28	4	38.4
						27.8	8	76.8
						27.7	12	115.2
						27.7	16	153.6
						27.5	20	192
						26	42	403.2
	Displacement = 2.1cm							

Table 4:- Load Testing of Paper-tubes

Fig 4:- Load testing of Paper tubes

IV. MODULE DESIGN

Eight basic modules were considered for testing and were constructed such that all its parameters like wall thickness volume floor finish and materials remain constant except for the roofing materials. The dimensions of the module is 4' X 4' X 7' and is constructed of local stone - Pardhi (18.5" X 10.2") with clay mortar. An opening of 18.5" X 10.2" is provided on north east wall of the module in order to be able to take internal temperature readings. The modules have been placed and oriented on the site in such a way that the wall of the module has less solar heat gain. The distance and orientation of the modules is such that mutual shading does not happen.

Fig 5:- Modules Constructed on site

The module experiment is primarily done to compare the thermal performance of the developed materials with the conventional materials. The aid module is basically consisted of roofing materials as:

- Mud rolls with Ferrocrete
- Paper tube with Ferrocrete
- Lime rolls with Country-tiles
- Mud rolls with Country-tiles
- paper tube with Country-tiles
- Concrete
- Tin
- Straw-Clay panel

The context is like a typical hot and dry region, flat with sandy conditions, and sparse vegetation comprising cacti, thorny trees and bushes. The underground water level is also very low. Due to intense solar radiation (values as high as 800-950 W/m^2), the ground and the surroundings of this region are heated up very quickly during day time. It may be noted that the diurnal variation in temperature is quite high, that is, more than 10°C . The climate is described as dry because the relative humidity is generally very low, ranging from 25 to 40 % due to low vegetation and surface water bodies.

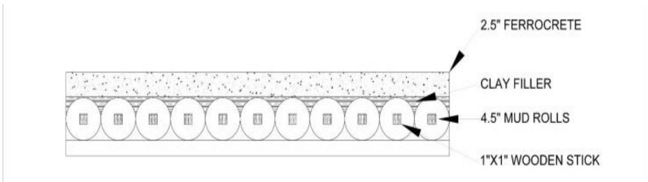

Fig 6:- Section of Mud Roll with Ferrocrete

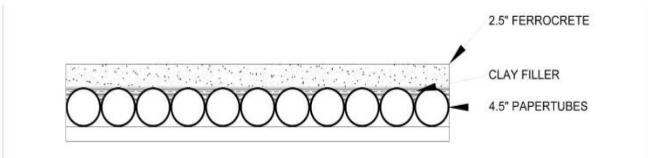

Fig 7:- Section of Paper-tube with Ferrocrete

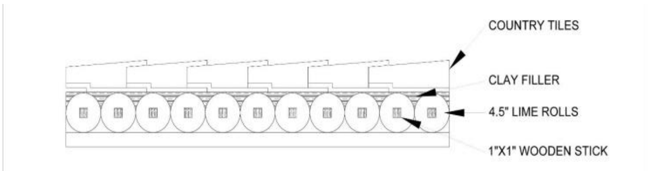

Fig 8:- Section of Lime Roll with Country Tiles

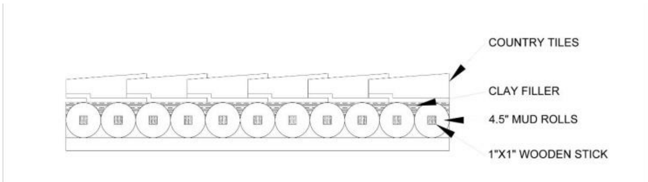

Fig 9:- Section of Mud Roll with Country Tiles

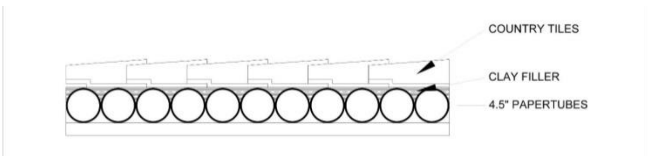

Fig 10:- Section of Paper-tube with Country Tiles

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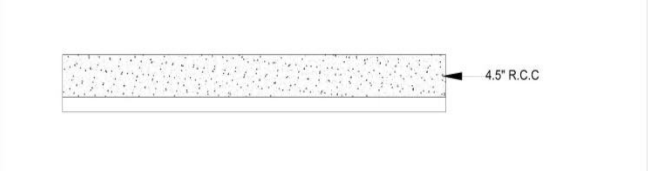

Fig 11:- Section of Concrete

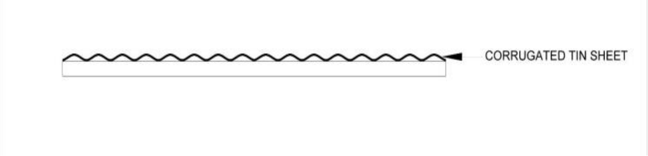

Fig 12:- Section of Tin Sheet

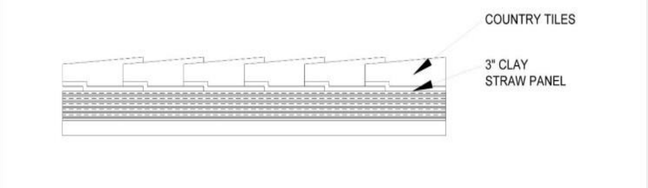

Fig 13:- Section Straw-Clay Panel with Country-Tiles

A. On-site Monitoring

In order to compel temperature performances of all materials nine readings of all the modules have been taken for 30 days. Monitoring was done on to early basis starting from 6 AM to 10 PM. The temperature had been measured at the outer as well as in a surface of the roof. The readings will taken by the instrument 'Raytek Mini Temperature'.

V. FINDINGS AND CONCLUSION

A. Mud Rolls with Ferrocrete

The time lag achieved is four hours and the temperature reduction of external to internal roof surface is 18.4°C. The night heat is 26.8°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.8	22.4	26.6	17.7
08:00 AM	25.9	29.5	26.3	23.6
10:00 AM	26.4	32.5	27.4	32.7
12:00 PM	30.6	35.4	30.5	47.6
02:00 PM	31.7	38.0	35.6	54.0
04:00 PM	34.6	37.8	37.8	46.5
06:00 PM	35.5	33.4	38.7	36.4
08:00 PM	36.1	29.7	37.5	29.3
10:00 PM	33.9	26.8	34.5	24.7

Table 5:- Temperature readings of the module

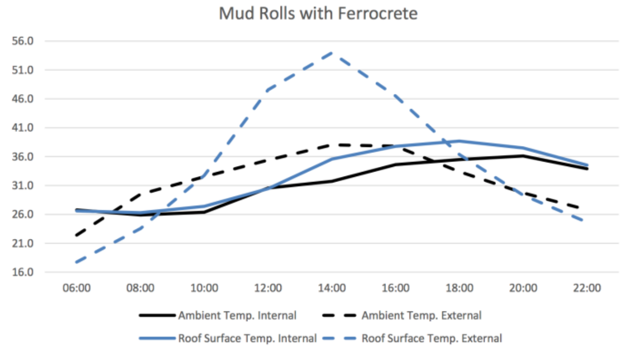

Fig 14:- Graphical representation of the readings

B. Paper-tube with Ferrocrete

The time lag achieved is two hours and the temperature reduction of external to internal roof surface is 16.1°C. The night heat is 26.6°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.6	22.4	25.2	17.6
08:00 AM	25.7	29.5	25.5	25.3
10:00 AM	26.9	32.5	28.9	39.9
12:00 PM	29.6	35.4	32.4	51.8
02:00 PM	32.0	38.0	36.9	53.2
04:00 PM	34.6	37.8	37.1	44.9
06:00 PM	35.6	33.4	35.1	32.2
08:00 PM	35.0	29.7	33.0	28.2
10:00 PM	33.0	26.8	30.2	28.4

Table 6:- Temperature readings of the module

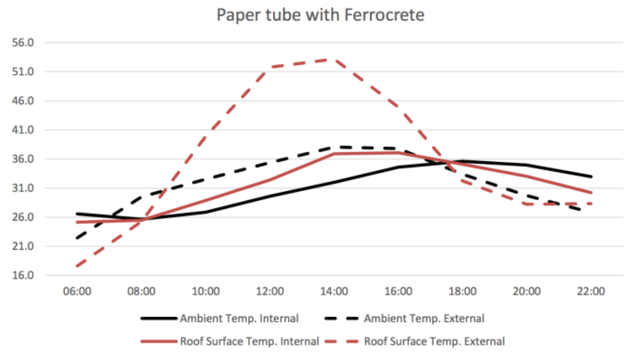

Fig 15:- Graphical representation of the readings

C. Lime Rolls with Country Tiles

The time like achieved is six hours and the temperature in reduction of external to internal roof surface is 12.8°C. The night heat is 26.7°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.7	22.4	26.7	17.6
08:00 AM	25.7	29.5	26.6	25.2
10:00 AM	26.5	32.5	27.0	37.2
12:00 PM	29.6	35.4	29.4	49.8
02:00 PM	31.5	38.0	33.3	48.2
04:00 PM	34.3	37.8	35.4	41.3
06:00 PM	35.8	33.4	37.0	31.1
08:00 PM	35.0	29.7	36.1	29.1
10:00 PM	33.5	26.8	33.7	22.4

Table 7:- Temperature readings of the module

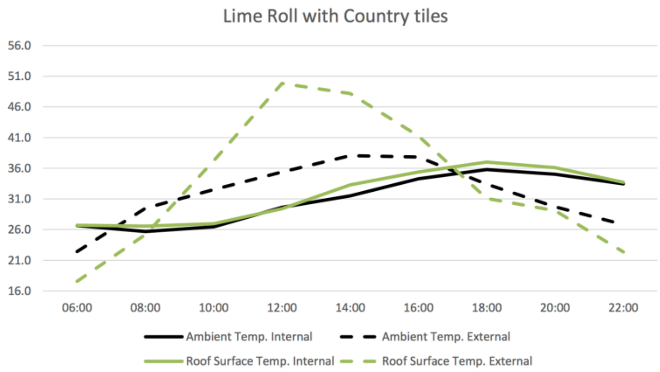

Fig 16:- Graphical representation of the readings

D. Mud-Rolls with Country Tiles

The time lag achieved is six hours and the temperature in reduction of external to internal roof surface is 13°C. The night heat is 26.7°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.7	22.4	26.5	17.7
08:00 AM	25.7	29.5	26.3	24.8
10:00 AM	26.6	32.5	26.6	35.9
12:00 PM	29.0	35.4	29.4	49.7
02:00 PM	32.0	38.0	33.4	48.3
04:00 PM	34.6	37.8	35.7	40.3
06:00 PM	35.7	33.4	36.7	31.0
08:00 PM	35.2	29.7	36.2	26.1
10:00 PM	33.2	26.8	33.6	22.5

Table 8:- Temperature readings of the module

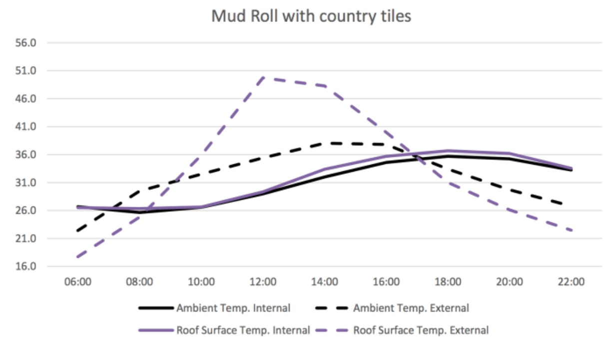

Fig 17:- Graphical representation of the readings

E. Paper-tube with Country Tiles

The time lag achieved is four hours and the temperature reduction of external to internal roof surface is 13.9°C. The night heat is 26.1°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.1	22.4	25.2	18.1
08:00 AM	25.4	29.5	25.2	26.1
10:00 AM	26.5	32.5	26.7	37.1
12:00 PM	29.2	35.4	29.9	49.6
02:00 PM	31.7	38.0	33.7	46.0
04:00 PM	34.5	37.8	35.7	40.1
06:00 PM	35.7	33.4	34.8	30.5
08:00 PM	34.4	29.7	33.8	25.5
10:00 PM	32.7	26.8	30.6	22.6

Table 9:- Temperature readings of the module

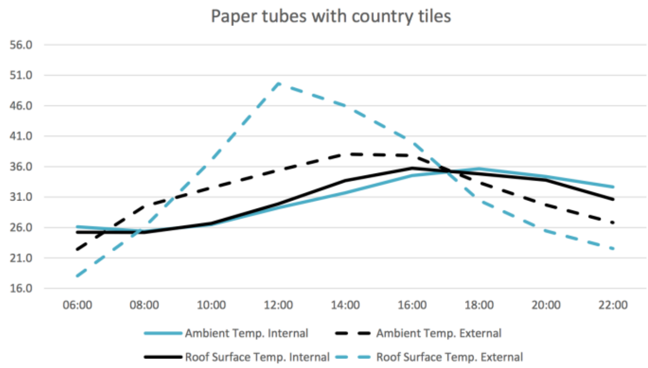

Fig 18:- Graphical representation of the readings

F. Concrete

The time lag achieved is two hours and the temperature in reduction of external to internal roof surface is 3.4°C. The night heat is 25.8°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	25.8	22.4	23.2	19.4
08:00 AM	25.0	29.5	23.2	24.1
10:00 AM	26.8	32.5	29.2	34.6
12:00 PM	30.1	35.4	38.4	46.6
02:00 PM	33.2	38.0	45.9	49.8
04:00 PM	36.1	37.8	46.4	45.3
06:00 PM	37.2	33.4	39.7	34.4
08:00 PM	35.6	29.7	33.3	28.7
10:00 PM	32.9	26.8	31.8	25.0

Table 10:- Temperature readings of the module

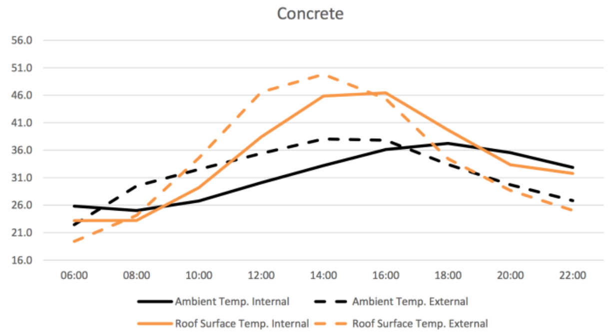

Fig 19:- Graphical representation of the readings

G. Tin Sheet

The time lag achieved is zero hours and the temperature reduction of external to internal roof surface is -0.8°C. the night heat is 25.3°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	25.3	22.4	21.3	19.4
08:00 AM	25.3	29.5	30.2	29.5
10:00 AM	27.2	32.5	40.6	40.1
12:00 PM	30.6	35.4	50.0	49.2
02:00 PM	33.2	38.0	47.4	48.7
04:00 PM	35.4	37.8	40.7	39.4
06:00 PM	35.1	33.4	32.7	27.6
08:00 PM	33.9	29.7	29.4	26.8
10:00 PM	31.7	26.8	26.6	23.8

Table 11:- Temperature readings of the module

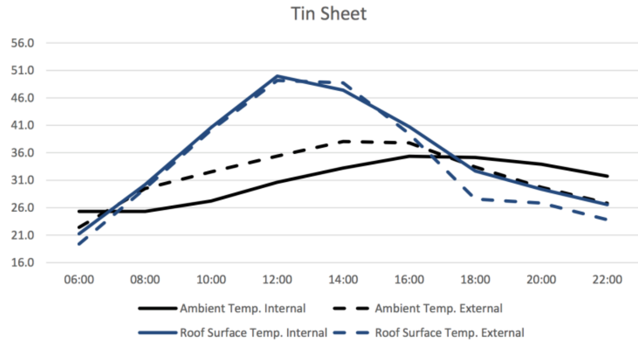

Fig 20:- Graphical representation of the readings

H. Clay panel with Country-tiles

The time lag achieved is six hours and the temperature in reduction of external to internal loop surface is 7.6°C. the night heat is 26.3°C.

Time	Ambient Temperature (in °C)		Roof Surface Temperature (in °C)	
	Internal	External	Internal	External
06:00 AM	26.3	22.4	26.0	18.4
08:00 AM	25.6	29.5	26.6	26.1
10:00 AM	26.6	32.5	26.1	30.7
12:00 PM	29.4	35.4	29.6	47.7
02:00 PM	32.1	38.0	34.7	42.3
04:00 PM	34.3	37.8	35.7	39.3
06:00 PM	35.6	33.4	39.4	29.8
08:00 PM	34.7	29.7	35.1	27.6
10:00 PM	33.6	26.8	31.9	22.6

Table 12:- Temperature readings of the module

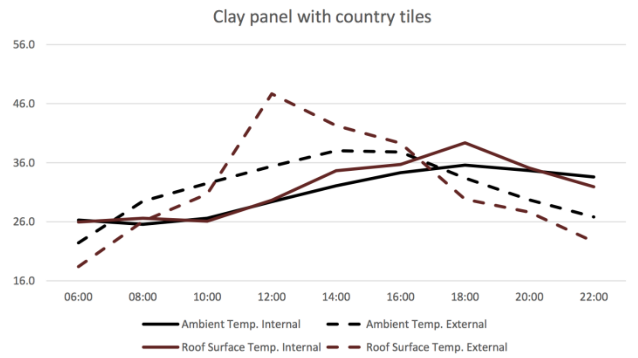

Fig 21:- Graphical representation of the readings

VI. RESULT AND DISCUSSION

The idea of the study was to develop roofing component which would use the application of alternative materials that would result in providing better thermal performance, which is cost-effective in case of hot and dry climate as well as vernacular in the context of Bhuj. The experiments were carried out in innovative materials like Mud-rolls, Clay panels and Paper-tubes for roofing component. Only concerns were generated with the clay panels having fly-ash with *Surkhi* and fly-ash with lime, as they failed in the strength because of insufficient binding. The other innovative combinations tried with the materials

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responded well with the strength experiments as well as pertaining to the context of thermal comforts.

Innovation was also carried out in the processes of material development and various compositions. It was considered important to reduce the density of Mud-Roll, and the same was achieved by 50% density reduction as compared to the standard Mud-roll sample. The comparative analysis of thermal performance carried out across modules reflected that the module developed with new combination of mud-roll reflected similar thermal performance as that of standard mud-roll. Materials in combination with waste materials like paper tube with clay tiles and ferro-crete also have a promising scape for future development to have application as a material for roofing component.

The modules which were developed with alternative innovative materials under this research reflected better thermal performance as compared to regular materials i.e. tin sheet and RCC. In the case of ferrocrete-mud rolls and ferrocrete paper-tubes as roofing component for the modules, though the external layer is the same for both there is difference in their thermal performances. When compared, the external surface temperature of roof component with ferrocrete papertubes rise faster but also it falls quicker then ferrocretemud rolls. The modules having Paper tube - country tiles, lime roll - country tiles, mud roll - country tiles, lime roll - country tiles and clay panel - country tiles as the roof components are the four modules which show minimum internal surface temperature levels as compared to the other modules at the time when external ambient temperature is maximum. In comparison with the above four modules,paper tube - country tiles has its internal surface temperature lower during the morning and evening time when the external ambient temperature starts falling. This also showsthat paper tube - country tiles performs relatively better as compared to the other options under evaluation. Also cost is considered the same configuration is found to be more economically viable than the other options.

Modules	Max. Internal Roof Surface Temp. (in °C)	Time-lag (in Hours)	Temp. Reduction of surfaces (in °C)	Night Heat (in °C)
Mud Roll with Ferrocrete	38.7	4	15.3	26.8
Paper tube with Ferrocrete	37.1	2	16.1	26.6
Lime roll with Country tiles	37	6	12.8	26.7
Mud roll with country tiles	36.7	6	13	26.7
Paper tube with country tiles	35.7	4	13.9	26.1
Concrete	46.4	2	3.4	25.8
Tin Sheet	50	0	-0.8	25.3
Clay panel with Country tiles	39.4	6	7.6	26.3

Table 13:- Comparative chart of Time-lag, Temperature drop and Night heat

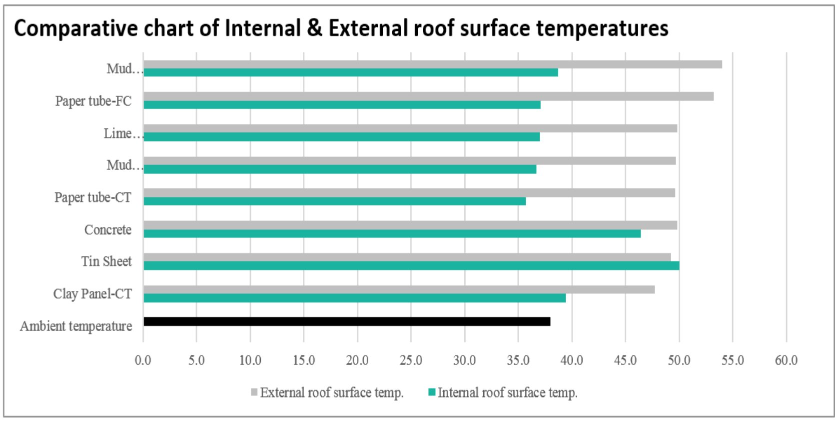

Fig 22:- Comparative chart of Internal and External roof surface temperatures

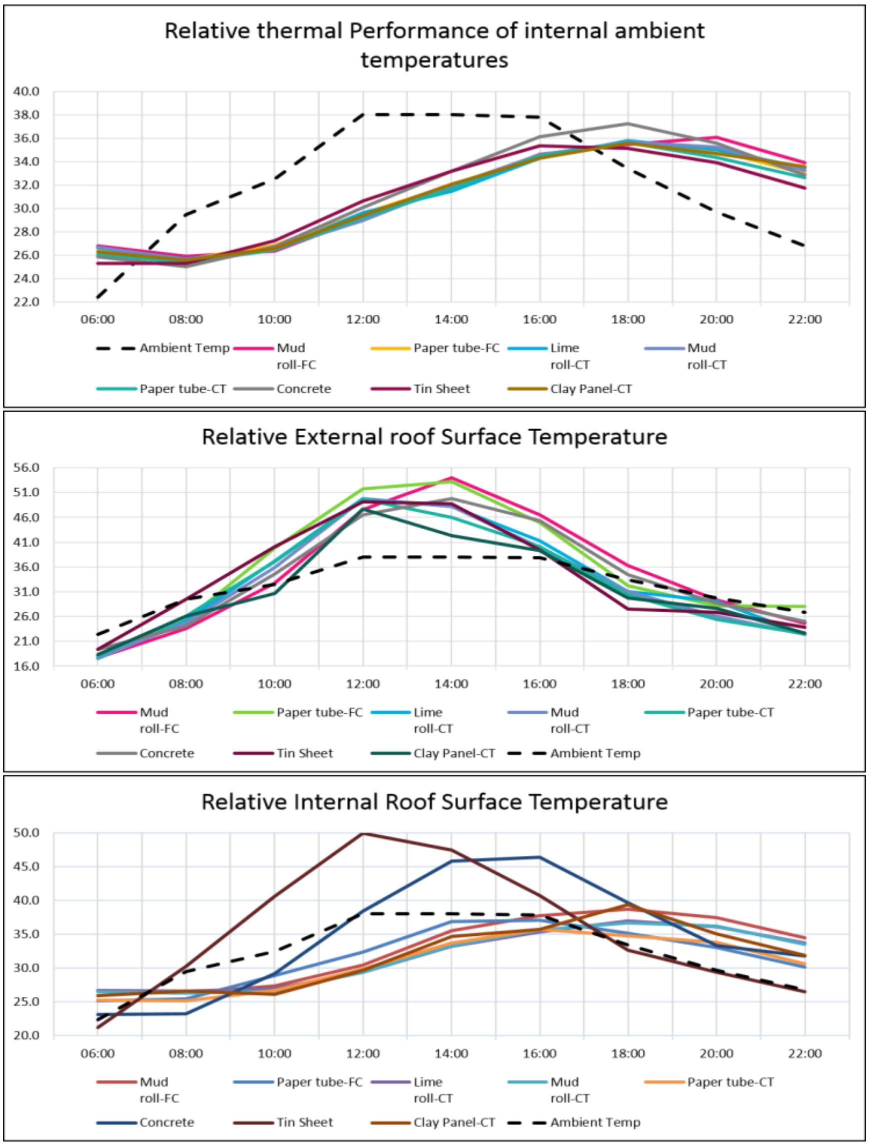

Fig 23:- Comparative analysis of Thermal performance of internal ambient temperatures, External and Internal roof surface temperatures

VII. FUTURE SCOPE OF RESEARCH

The modules having alternative materials as roofing materials which were showing positive results in the thermal performance process can be taken forward for further refinement in terms of improving material composition and improved thermal performance.

For study purpose, only standard samples of alternative materials were used for the analysis of thermal performance. Individual variants of the Mud Rolls, Clay Straw Panels and Paper tube panels can be similarly analysed and developed further.

Paper-tubes has got the potential as a structural member and also for thermal performance, it can be taken forward to a greater extent as it is one of major wastage found from packaging to everything and easily available. It as a construction material could be exploited much more and used more prominently for construction industry.

Paper-tubes also could be tested for thermal performance by having double layer with varying diameters and varying gauge thickness.

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