1985

570
HEAT INSULATION

76

1010

Development of alternative heat insulating and waterproofing material for roofs in tropics

P. K. Gangopadhyay, S. P. Jain, Vinod Kumar, K. K. Asthana, R. S. Rawat and R. K. Jain

Various problems associated with the prevailing heat insulating and waterproofing treatments over thick roofs in tropics are well known. In order to find a suitable solution to these problems, an attempt was made to develop a rational, efficient and functional alternative treatment utilising low cost, resin bonded bloated clay aggregates. Laboratory tests on cube samples and field trials on wall and roof panels were carried out to determine the performance of the new treatment. Though the results of the performance study are highly encouraging, further laboratory studies on different compositions of resins and light weight aggregates and rigorous field trials on prototype structures are necessary before actual large scale use in the field.

Apart from the basic requirements of structural safety, certain aspects relating to protection from the direct sun, wind and rains play an important role in the design of roofs for the hot-dry regions. While designing such roofs following considerations are important.

(*i*) The roof which forms a part of the external surface of a conventional building remains more exposed to the sun and external climate than the external walls. The roof receives large proportion of the sun's radiation because of its inclination with respect to solar altitude and it also cools more during night hours. It is very difficult to protect roofs from radiation and, therefore, in the case of unconditioned buildings effects of radiation from the high ceiling are the main source of discomfort. For conditioned buildings, it is mainly the design of roofs that determines the running cost and capacity of airconditioning plant.

(*ii*) The variation in the cost of construction between one or another roof depends on both the material used and the design.

(*iii*) The high surface temperature of the roof increases the rate of deterioration of many roofing materials. It hastens the chemical degradation of unprotected bituminous roofing membrane and causes the formation of blisters and bubbles as a result of the evaporation of water which might have been trapped beneath poorly laid felt during construction. Bituminous roofing membranes can also be damaged by the low night temperatures which make them brittle resulting in cracking under stress and strain. Such failures of the roofing membrane occur more frequently when it is applied over insulation.

(*iv*) Thermal movements resulting from the extreme day and night temperature are experienced in different degree by nearly all materials of the roof. They cause cracks, distortion and sometimes even failure. Severe failures have been observed in the case of concrete slab constructions. Fractures along the line, where the main walls join the roof and the parapet walls, are common failures due to thermal movements in the concrete slabs. The traditional forms of roof construction using materials like lime, concrete or mud-phuska with tiles terracing for heat insulation and waterproofing, though basically very heavy, offer a high degree of resistance to the external climate and to the diurnal variation in temperatures. But these types of roofs are highly expensive, not only due to high material cost but also due to the additional dead load of the structure which increases the cost of reinforcement and concrete in the roof slab, besides increasing the cost of substructure.

(*v*) Due to alternative heating and cooling in summer days the uppermost lime terracing layer is generally chipped of making it ineffective for waterproofing. Any rain water seepage in the mud-phuska roofs can be a serious problem. Therefore, the maintenance cost of such roofs becomes considerable.

Objective

The hot-dry climate is characterised by its wide diurnal variations in temperature and high solar radiation intensity. These variations, which bring about non-steady state conditions of heat flow, make the calculations very complex.

The objective of the preliminary laboratory and field experimental studies under actual weather conditions described in this article, was to develop some suitable alternative thermal insulating and waterproofing light weight polymer concrete, using low cost resins from the indigenous sources. After complete prototype tests and performance studies the new polymer concrete may be advocated as an alternative material for actual use in buildings.

The article is divided in two parts. The first part describes the development of new material, its chemical composition, waterproofing characteristics and other related properties, whereas in the second part the discussions are mainly confined to the heat and thermal insulation aspects.

Material development

Lightweight plastic aggregate concrete using expanded polystyrene beads as aggregate has been developed and used for thermal insulation and large precast components in a number of countries[1, 2]. Work has been carried out at the Central Building Research Institute (CBRI) Roorkee, to develop thermal insulating and waterproofing polymer concrete, using low cost resins from indigenous sources. The resins selected for this work were cashew nut shell liquid (CNSL) aldehyde resin, shellac (a natural resin), celex (sulphonated liquids from paper industry waste) and rubber modified CNSL resins. The resins based on CNSL were developed in the CBRI laboratory[3].

Sand and resins were mixed in different proportions and compaction of the mix in the mould was done by

P. K. Gangopadhyay, Scientist, Physics Laboratory, Central Building Research Institute (CBRI), Roorkee.
S. P. Jain, Scientist, Physics Laboratory, CBRI, Roorkee.
Vinod Kumar, Scientist, Physics Laboratory, CBRI, Roorkee.
K. K. Asthana, Scientist, Building Material Division, CBRI, Roorkee.
R. S. Rawat, Scientist, Building Material Division, CBRI, Roorkee.
R. K. Jain, Scientist, Building Material Division, CBRI, Roorkee.

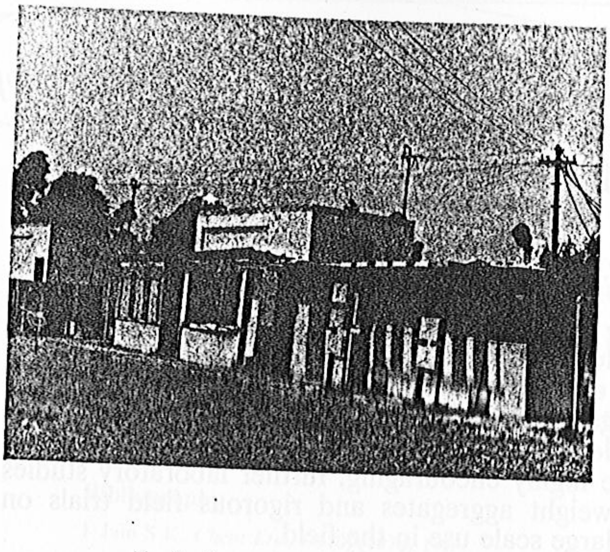

Fig 1 Front view of thermal chambers

rodding. Curing of the specimens was carried out for 7 days at 27°C ± 1°C in a constant temperature room, and in some cases at 100°C for 24 hours in an air-circulating oven. The results of compressive strength and water absorption on 25 mm cubes are reported in *Table* 1.

It is seen from the results that compressive strength obtained are quite low and the maximum strength of 195 kg/cm² is obtained in case of rubber modified CNSL resin sand mortar. The mortars based on these resins have to be evaluated and compared with the mortars based on polyester and epoxy resins. The strengths of the former are much lower compared to the latter. Water resistance of mortar cubes based on these resins was determined by immersing cubes in water for 24 hours. Water absorption of the cubes was determined for resin sand ratio of 1:4. These cubes were cured at 100°C ± 1°C for 24 hours.

It may be concluded from the above work that mortars based on CNSL resins give excellent water resistance. Therefore, these mortars could be used for waterproofing purposes. Since density of these mortars was quite high and they were unsuitable for thermal insulations, attempts were made in the next set of experiments to replace sand by a lightweight aggregate. Initially, three types of aggregates namely bloated clay aggregate, cinder, and expanded polystyrene bead, were used and all were found to be suitable for preparing a lightweight concrete.

In the present work, bloated clay aggregates were chosen for the development of lightweight thermal insulating concrete. CNSL resins can excellently be bonded with bloated clay aggregate (BCA). For this study suitable resin/aggregate ratio was worked out. Density of this composition was found to be of the order of 0.7 to 0.8 gm/cc and water absorption in 24 hours was of the order of 1 to 2 percent. It has been observed that the compressive strength of resin-aggregate concrete increases as the curing proceeds. This is evident from *Table* 2.

TABLE 2: Properties of resin-BCA Concrete

Sr. No.	*Curing conditions*		*Compressive strength kg/cm²*
	Temperature	*Time*	
1	27°C ± 1°C	7 days	2.5
2	27°C ± 1°C	90 days	10.0
3	70°C	18 hours	18.5
4	40°C	18 hours	12.0
5	100°C	18 hours	42.0

Field study

Thermal chambers, *Figs* 1 and 2, which were developed earlier at the CBRI, Roorkee, and were used for the relative evaluation of field thermal performance of isolated wall and roof sections of dimensions 90 cm x 60 cm and 60 cm x 60 cm respectively, were utilized for this study.[4, 5, 6, 7] *Figs* 3 and 4 show the actual installation of various polymer concrete and conventional roof panels on the thermal chambers for testing their field thermal performance. In these chambers, one side of the panel was kept exposed to the outside weather during the entire period of study to have a natural unobstructed wind and solar exposure and the other side i.e. inner side of each panel was placed in the interior of these chambers. These panels and their chambers were properly insulated from each other by using 10.0-cm thick thermocole to avoid any transfer of heat and also to avoid any heat loss from the edges.

Measurements

Temperature measurements were made by 30-SWG calibrated copper-constantin thermocouples, connected to precision self balancing potentiometer through a gang of rotary switches located in a central instrument room. The temperatures were measured up to a fraction of 0.15°C. Several sets of observations were made round the clock to record half hourly temperatures of the outdoor air as well as outside and inside surfaces of the test

TABLE 1: Properties of low cost resin sand mortar

Type of resin	*Curing temperature*	*Water absorption after 24 hours immersion for resin sand ratio of 1:4*	*Compressive strength, kg/cm²*			
			Resin/sand ratio			
			1:4	*1:5*	*1:6*	*1:7*
CNSL	27°C ± 1°C for 7 days	—	5.5	6.5	5.0	5.5
CNSL	100°C	0.1 percent	39.0	55.5	48.8	39.5
CNSL/Celex (50: 50)	27°C ± 1°C for 7 days	—	7.0	6.8	2.3	—
CNSL/Celex (50: 50)	100°C	softened	50.0	46.7	10.9	—
Rubber modified CNSL	27°C ± 1°C for 30 days	—	126.0	—	—	—
Rubber modified CNSL	100°C	0.1 percent	195.0	—	—	—
Shellac	100°C	8.7 percent	43.6	—	33.3	—
Celex	100°C	disintegrates	30.0	—	—	—
Celex	27°C ± 1°C for 7 days	distintegrates	4.5	—	—	—

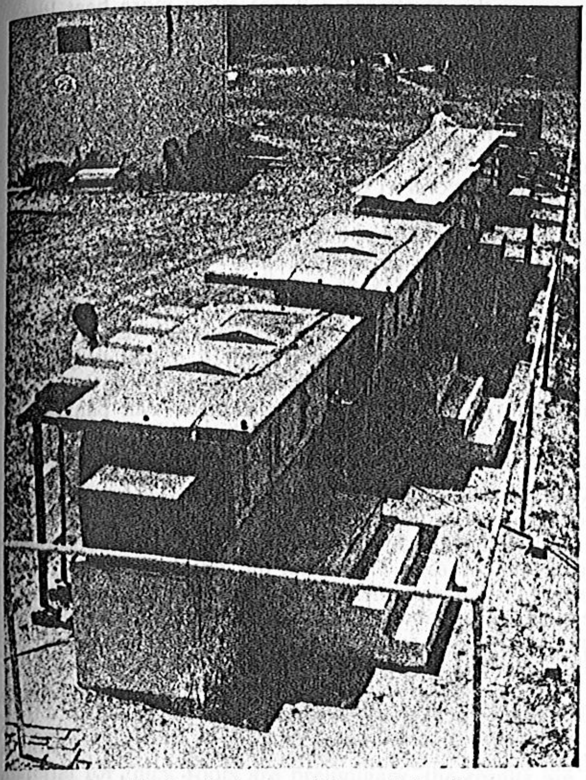

Fig 2 Back view of thermal chambers

panels on hot-dry, clear and calm, sunny days. The data for such a representative day has been considered for interpreting the final results.

In the first instance, studies were carried out for improving the thermal performance of 11.4-cm solid brick wall.[8] The purpose of the study was to economise the cost of construction. This could be achieved by the application of lightweight and reflective 2.0-cm thick lime-surkhi plaster on the exposed surface of 11.4-cm thick solid brick wall so as to bring its thermal performance very near to a conventional i.e. 22.9-cm thick solid brick wall. The following three wall panels were utilised for this study:

(*i*) 22.9-cm thick solid brick panel with 1.3-cm thick cement sand (1:6) plaster both sides.

(*ii*) 11.4-cm thick solid brick panel with 1.3-cm thick cement sand (1:6) plaster both sides.

(*iii*) 11.4-cm thick solid brick panel with 2.5-cm resin bonded BCA treatment at the exposed surface and 1.3-cm thick cement sand (1:6) plaster inside.

The effect of using resin-bonded bloated clay aggregate (BCA) at the exposed surface of walls gave very encouraging results. But considering the difficulties in the application of such resin bonded BCA on vertical walls and very limited advantage of improvement in the indoor thermal conditions due to less exposure of walls to the sun, it was considered to study its effect on the roofs to develop an alternative material for replacing the existing heat insulating and waterproofing treatments such as lime concrete terracing or mud phuska with tiles.

The following five roof panels were utilised for the studies:

(*i*) 11.4-cm reinforced concrete panel.

(*ii*) 11.4-cm reinforced concrete panel + 1.9-cm resin bonded BCA treatment + 1.3-cm cement sand (1:4) plaster.

(*iii*) 11.4-cm reinforced concrete panel + 2.5-cm resin bonded BCA treatment + 1.3-cm cement sand (1:4) plaster.

(*iv*) 11.4-cm reinforced concrete panel + 3.8-cm resin bonded BCA treatment + 1.3-cm cement sand (1: 4) plaster.

(*v*) 11.4-cm reinforced concrete panel + 10.2-cm lime concrete terracing.

To avoid non-uniformity in construction, the materials, specifications, mixes and thicknesses of the panels were strictly the same. Similarly to avoid non-uniformity in workmanship, same mason was employed for all construction work throughout these field studies. However, the difference between the constructional features of various panels was properly maintained.

Results and discussion

Inside surface temperatures: The indoor thermal conditions of any enclosure are basically governed by its inside surface temperatures. For thermal comfort the panel should ensure lower internal surface temperatures to minimise the radiant heat loss by the occupants of any building. Higher inside surface temperatures also contribute indirectly in raising the indoor air temperatures and vice-versa. The radiant heat gain by the human body will assume all the more importance in summer conditions as the body heat balance depends on the radiant heat exchange and sweat evaporation when the ambient air temperature goes up.

Integrated discomfort degree hours: To evaluate the effect of any treatment, it was a common practice to compare the changes that occur in the maxima and minima temperatures of inside surface/indoor air. But this alone does not provide a real basis for the comparison of the overall thermal performance. It is now well known that for proper thermal rating of roof and wall sections the integrated effect of duration and intensity forms a traditional basis and the concept of degree hour rating fulfils this requirement.[9]

Hence, degree hours above a base temperature of 30°C are to be computed and in this calculation the inside surface temperatures above 30°C at each hour are added together leading to the integrated degree hours. Here

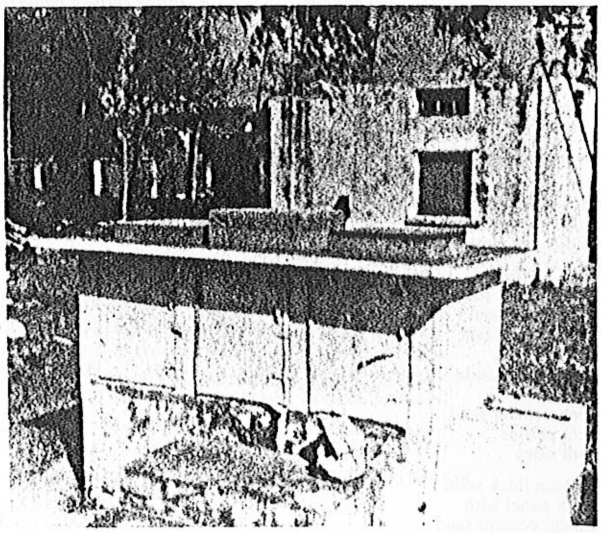

Fig 3 Installation of untreated and treated roof panels

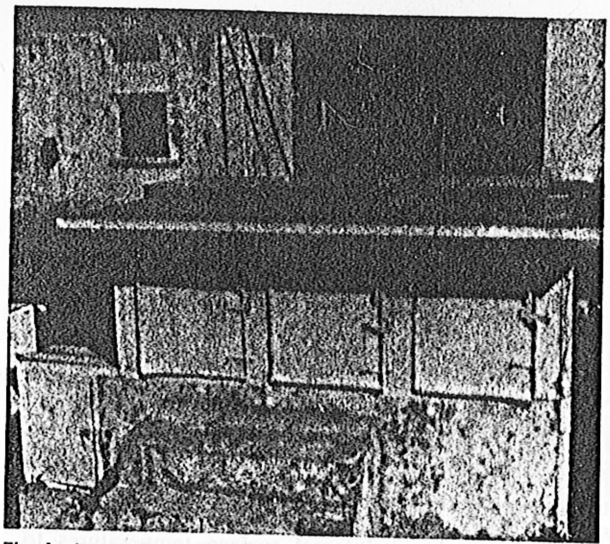

Fig 4 Installation of polymer concrete treated roof panels

the base temperature of 30°C is chosen, as higher temperatures will impair radiant heat losses from the human body. The duration in number of hours when the inside surface temperatures of the panel exceed 30°C are also calculated and based on this criterion, various panels can be compared well for their thermal behaviour.

Wall performance: Fig 5 shows the hourly variation of inside surface temperatures on a representative hot summer day at Roorkee. During the cool morning period between 0000 hours to 0700 hours, 2.5-cm thick resin bonded BCA treated panel recorded higher minima temperature upto 1.5°C than the normal 11.4-cm thick solid brick wall panel. It is clearly due to the higher thermal resistance offered by the resin bonded BCA treatment in the heat flow path from inside to outside surface. On comparing the minima of inside surface temperatures of the resin bonded BCA treatment with that of the conventional 22.9-cm thick solid brick wall, it can be observed that the former is slightly lower by 0.5°C than the latter. Such a performance of resin bonded BCA treatment will also serve a useful purpose in winter season as this treatment will not allow more heat loss during the cool night hours of winter. The resin bonded BCA treatment keeps the indoor minima temperature at a higher level, which is a basic requirement for better thermal performance in winter season.

Table 3 shows the comprehensive thermal performance data of the three wall panels. It includes the integrated discomfort degree hours during day and night and also the total values for 24 hours for the inside surface temperatures above a base temperature of 30°C. It can be observed that although the discomfort conditions (> 30°C) prevails for all the 24 hours in all the three cases, there is a considerable improvement in the overall discomfort degree hours with the use of resin bonded BCA treatment as compared to the untreated 11.4-cm thick solid brick wall panel. With the new treatment the 11.4-cm thick solid brick wall panel has approached very near to the 22.9-cm thick solid brick wall in its thermal performance.

Roof performance: Fig. 6 shows the variation of inside surface temperatures of various roof panels on a representative hot summer day at Roorkee. It can be observed from the curves in *Fig.* 6 that the effect of 3.8-cm resin bonded BCA treatment over 11.4-cm thick reinforced concrete roof panel with 1.3-cm thick cement-sand plaster at the exposed surface is very close to the effect of 10.2-cm lime concrete terracing over 11.4-cm thick reinforced concrete panel. Also there is a very little difference between the inside surface temperatures of the two panels when thickness of BCA treatment is reduced from 3.8-cm to 2.5-cm. Further, by comparing the total integrated discomfort degree hours, *Table* 4, it can be observed that the effect of 3.8-cm resin bonded BCA treatment is very close to the effect of 10.2-cm lime concrete terracing over 11.4-cm thick reinforced concrete panel.

With these observations it may be safely concluded that the density of resin bonded BCA treatment can be redesigned to have the desired thermal performance with the existing heat insulating treatment in its minimum thickness. This will involve evaluation of different compositions of resin and light-weight aggregate so as to optimise resin content, density and the thickness of the polymer concrete from both cost and performance angles.

TABLE 3: Thermal performance of three different wall panels on a hot summer day

Details of test panels facing east direction	*Outdoor temperature*		*Inside surface temperatures and time*				*Integrated discomfort degree hours*		*Total integrated discomfort degree hours (TIDDH) in 24 hours duration*	*Inferiority in TIDDH with respect to 22.9 cm thick brick wall*
	Maximum	*Minimum*	*Maxima*		*Minima*					
			Temperature	*Time*	*Temperature*	*Time*	*1000 to 1900*	*2000 to 0900*		
	°C	°C	C	hours	°C	hours	hours	hours		percent
11.4-cm thick solid brick wall panel with 1.3-cm cement-sand (1 : 6) plaster both sides	44.2	23.6	45.3	1400	32.5	0630	134.4	87.8	222.2	12.4
11.4cm thick solid brick wall panel with 2.5-cm resin bonded BCA treatment outside and 1.3-cm thick cement sand (1:6) plaster both sides			41.4	1730	34.0	0730	101.0	97.7	198.7	0.5
22.9-cm thick solid brick panel with 1.3-cm cement sand (1:6) plaster both sides.			41.8	1730	34.6	0730	96.8	90.9	197.7	–

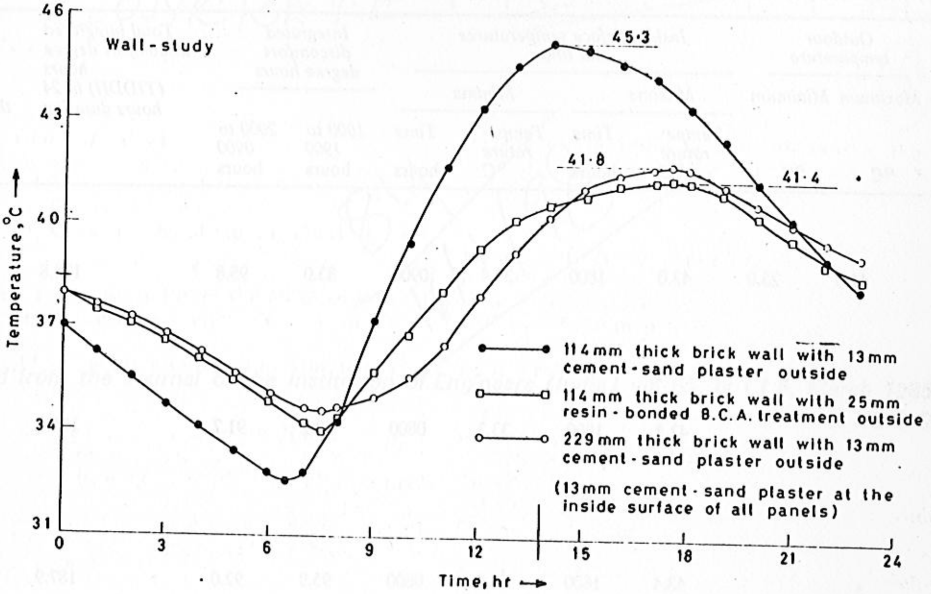

Fig 5 Hourly variation of inside surface temperatures of wall panels

Conclusion

Although the present field studies for the development of a suitable alternative heat insulating and waterproofing material for thick roofs are preliminary, the results are highly promising. Further laboratory studies on different compositions of resins and light-weight aggregates and field trials on prototype structures are necessary so that all important aspects under the tropical climatic conditions are thoroughly examined before any recommendation for actual use of such a material is finally made. A research project on further development in this direction is in progress at the CBRI, Roorkee.

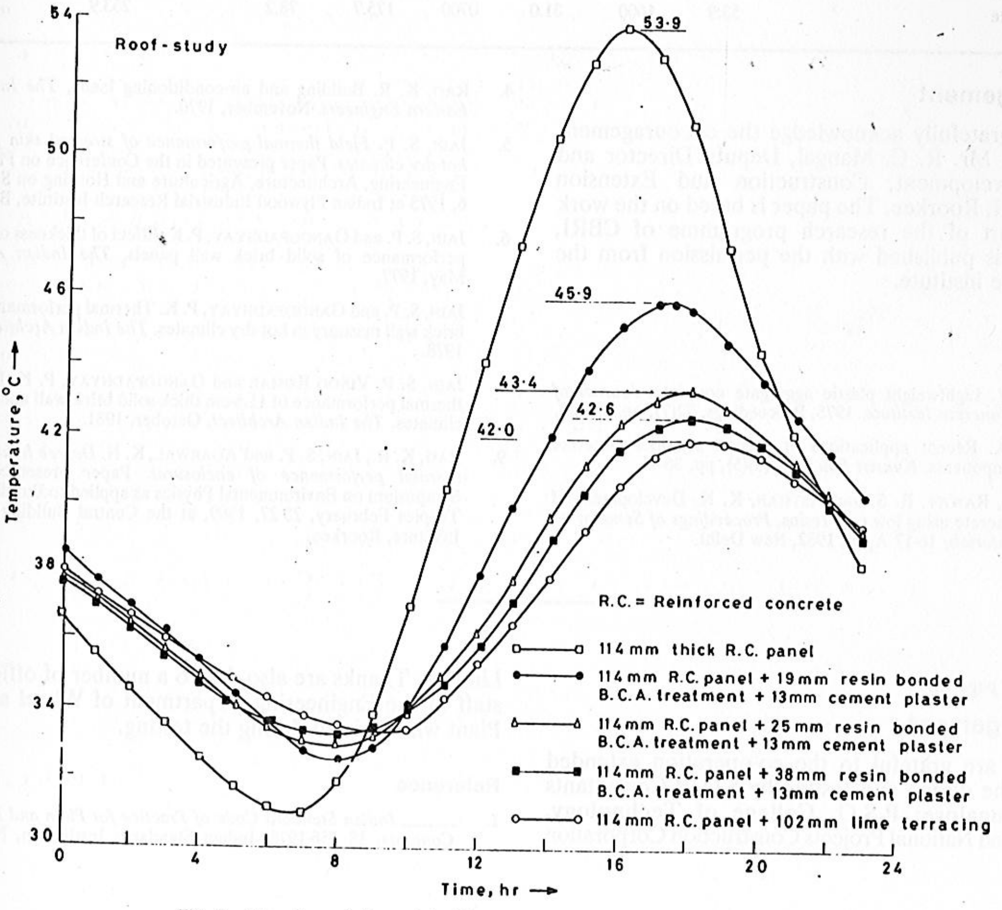

Fig 6 Hourly variation of inside surface temperature of roof panels

TABLE 4: Thermal performance of different roof panels on a hot summer day

Details of test panels	*Outdoor temperature*		*Inside surface temperatures and time*				*Integrated discomfort degree hours*		*Total integrated discomfort degree hours (TIDDH) in 24 hours duration*	*Inferiority in TIDDH with respect to 11.4 cm thick roof panel with terracing*
	Maximum	*Minimum*	*Maxima*		*Minima*					
			Tempe-rature	*Time*	*Tempe-rature*	*Time*	*1000 to 1900*	*2000 to 0900*		
	°C	°C	°C	hours	°C	hours	hours	hours		percent
11.4 cm thick reinforced concrete roof panel with 10.2-cm lime-concrete terracing treatment	41.5	25.0	42.0	1800	33.4	0900	83.0	95.8	178.8	—
11.4-cm thick reinforced concrete roof panel with 3.8-cm resin bonded BCA treatment with 1.3-cm cement sand (1:4) plaser			42.8	1800	33.3	0800	90.2	91.7	181.9	1.7
11.4-cm thick reinforced concrete roof panel with 2.5-cm resin bonded BCA treatment with 1.3-cm cement sand (1:4) plaster			43.4	1800	33.0	0800	95.9	92.0	187.9	5.1
11.4-cm thick reinforced concrete roof panel with 1.9-cm resin bonded BCA treatment with 1.3-cm cement-sand (1:4) plaster			45.9	1700	32.6	0800	115.7	99.5	215.2	20.4
11.4-cm thick reinforced concrete roof panel			53.9	1600	31.0	0700	175.7	78.2	253.9	42.0

Acknowledgement

The authors gratefully acknowledge the encouragement received from Mr. R. C. Mangal, Deputy Director and Head of Development, Construction and Extension Division, CBRI, Roorkee. The paper is based on the work done as a part of the research programme of CBRI, Roorkee and is published with the permission from the Director of the institute.

References

1. SUSSAMA, V. Lightweight plastic aggregate concrete. *Journal of American Concrete Institute*, 1975, Proceedings, 72(7), pp. 321-23.
2. KOHLING, K. Recent applications of precast styropor concrete building components, *Kunstst Bau*, 1974(9)(5), pp. 36-41.
3. JAIN, R. K., RAWAT, R. S. and ASTHAN, K. K. Development of polymer concrete using low cost resins, *Proceedings of Seminar on Building Materials*, 16-17 April, 1982, New Delhi.
4. RAO, K. R. Building and air-conditioning loads, *The Indian and Eastern Engineers*, November, 1970.
5. JAIN, S. P. *Field thermal performance of stressed skin panels in hot-dry climates*. Paper presented in the Conference on Plywood in Engineering, Architecture, Agriculture and Housing on September 6, 1975 at Indian Plywood Industrial Research Institute, Bangalore.
6. JAIN, S. P. and GANGOPADHYAY, P. K. Effect of thickness on thermal performance of solid brick wall panels. *The Indian Architect*, May, 1977.
7. JAIN, S. P. and GANGOPADHYAY, P. K. Thermal performance of half brick wall masonry in hot-dry climates. *The Indian Architect*, April, 1978.
8. JAIN, S. P. VINOD KUMAR and GANGOPADHYAY, P. K. Improving thermal performance of 11.5-cm thick solid brick wall under hot-dry climates. *The Indian Architect*, October, 1981.
9. RAO, K. R., JAIN, S. P. and AGARWAL, K. N. *Degree hour rating of thermal performance of enclosures*. Paper presented at the Symposium on Environmental Physics as applied to Buildings in the Tropics February, 25-27, 1969, at the Central Building Research Institute, Roorkee.

(Continued from page 73)

Acknowledgement

The authors are grateful to the co-operation extended throughout the design and testing by STUP Consultants Limited, Bangalore; P.S.G. College of Technology, Coimbatore and National Projects Construction Corporation Limited. Thanks are also due to a number of officers and staff of the Engineering Department of Wheel and Axle Plant who assisted during the testing.

Reference

1. ——— *Indian Standard Code of Practice for Plain and Reinforced Concrete*. IS 456-1978. Indian Standards Institution, New Delhi.