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COMPARISON OF THE THERMAL RESPONSES OF BRICK AND CONCRETE HOUSES TO OUTSIDE AIR TEMPERATURE AND SOLAR RADIATION IN KANO: A CASE STUDY OF A NBRRI MODEL HOUSE

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ABSTRACT

Models of the thermal response of a NBRRI model brick house and a similar house built of concrete have been constructed using a periodic theory. Using Fourier series the hourly temperatures of the inner wall surfaces were obtained as a direct response to the variations of the outside air temperature and the solar radiation incident at the location. The maximum temperatures for the inner walls surfaces of the concrete house for the four wall directions were all higher than those of the brick house. Temperature swings for October were between 8.5 and 11.1°C for the brick house while it was between 15.6 and 17.0°C for the concrete house. In January it was between 7.7 and 9.7°C and between 14.0 and 15.2°C for the brick and concrete houses respectively. These results show that the brick house would likely keep a more temperate climate within than the concrete building.

1. INTRODUCTION

Laterite or mud is found in abundance all over the world and in fact constitutes about 74% of the earth's surface (Awad, 1988). For centuries laterite has been used in building houses in many parts of the world until the advent of the concrete and sandcrete which virtually replaced mud as a building material. Apart from the stated abundance another advantage of mud as building material from experience is that for thermal comfort, mud has the property of keeping the inside surface temperatures of buildings temperate throughout the year even in hot and dry places. However, the drawback of this material as a building component are the effect of rain and wind on it. This however can be solved through research into proper materials engineering.

The cost of building materials especially cement have shot up astronomically in the recent past in Nigeria. The situation is such that the provision of housing for the ever expanding population is becoming a nightmare. This situation has led to the search for alternative and cheap materials to use in building dwelling houses. The Nigerian Building and Road Research Institute (NBRRI), has been in the forefront of this research and has come out with its own type of bricks which it produces with its own brick making machines. These NBRRI bricks are basically made of mud (laterite) stabilised with 4% cement.

In this work we use the NBRRI model house built in Kano as a test case and consider the response of a similar concrete house to bring out the appropriateness of these brick houses. Fig. 1 shows the floor plan of the house which consists of three bedrooms, a sitting room and adjoining dining room, a lounge, a kitchen and a garage. An open courtyard is situated in the centre with all the bedrooms having an access to it.

2. THEORETICAL ANALYSIS

In the present work we do not consider the functional design of the building and as such the interior partitions are presumed not to have any effect. The brick walls are 140 mm thick and with 10 mm plastering in the inner surface. The concrete house considered is assumed to be 150mm thick with 16mm of plaster inside and outside of the walls. Transient heat transfer analysis is carried out in the thermal analysis of the two types of buildings. Table 1 shows the total areas of walls with windows and doors.

Table 1: Walls, windows and doors dimensions for the different directions.

Direction	Total Wall Area (m^2)	Total Window Area (m^2)	Total Outer Doors Area (m^2)
NW	47.374	0.387	-
SW	32.038	2.880	5.970
SE	54.712	5.760	1.890
NE	29.008	3.960	-

The total roof area is 245.904 m^2. In the present work we consider only a flat roof option for the two types of houses. The roof for the brick house is made of 300 mm brick mixture, with a 16 mm plaster underneath and also a 16 mm thick asphalt as a rain proof cover at the top. For the concrete house the roof is made of 300 mm of concrete and a 16m of plaster underneath and asphalt of 16mm is used as water proof cover on the outside surface. Windows are 6 mm thick clear glass, the main entrance door is 44mm thick flush door, and the garage door is a 30 mm thick batten door.

The thermal analysis here presented is based on a model that combines the effect of outside air temperature and solar radiation into a single quantity which is known as the sol-air temperature T_{SA} which is calculated as:

$$T_{SA} = \frac{\alpha S}{h_{so}} + T_A + \frac{h_r}{h_{so}}(T_{SKY} - T_A) \quad (1)$$

T_{SKY} is calculated using Swinback's (1963) relation:

$$(T_{SKY} + 273) = 0.0552(T_A + 273)^{1.5} \quad (2)$$

The solar radiation for clear sky was obtained using the Gueymard's (1989) CPCR2 computer model. The outside air temperature was obtained from actual data recorded with a Delta-T weather system for the period under consideration. Data used for the analysis were for 15th of October 1996, and 3rd January, 1997. These represent a hot and a cold period respectively. α used for the brick walls is 0.6 while a value of 0.9 was used for the asphalt to cover the roof.

In the analysis presented here, a constant inside thermal environment (i.e. the space temperature is taken as 27° C) with periodic variations of outdoor air temperature and solar radiation intensity is assumed to be prevailing. The diurnal variation of the sol-air temperature T_{SA} is analysed along the lines used by Alfigri et al (1992) as:

$$T_{SA} = T_o + \sum_{n=1}^{\infty} M_n \cos\omega_n\theta + N_n \sin\omega_n\theta \quad (3)$$

where

$$T_o = (1/24) \int_0^{2} 4T_{SA}\, d\theta$$

$$M_n = (1/12) \int_0^{2} 4T_{SA} \cos\omega_n\, d\theta$$

$$N_n \approx (1/12) \int_0^{2} 4T_{SA} \sin\omega_n\, d\theta$$

$$\omega = 2\pi n/\theta$$

In terms of phase angle this can be written as:

$$T_{SA} = T_o + \sum_{n=1}^{\infty} C_n \cos(\omega_n\theta - \phi_n) \quad (4)$$

$$C_n = \sqrt{M_n^2 + N_n^2}$$

$$\tan\phi_n = N_n / M_n$$

The resulting temperature of the inside wall surface is determined as:

$$T = T_{in} + (1/h_{si})\left[U(T_O - T_{in}) + \sum_{n=1}^{r} V_n C_n \cos(\varpi_n\theta - \phi_n - \Phi_n)\right] \quad (5)$$

where

$$V_n = \frac{h_{si} h_{so}}{\sigma_n k \sqrt{Y_n^2 + Z_n^2}}$$

$$\sigma_n = \sqrt{\omega_n / 2\delta}$$

$$Y_n = A_1 \cos \sigma_n L \sinh \sigma_n L + A_2 \sin \sigma_n L \cosh \sigma_n L$$
$$= + A_3 \cos \sigma_n L \cosh \sigma_n L$$

$$Z_n = A_1 \sin \sigma_n L \cosh \sigma_n L - A_2 \cos \sigma_n L \sinh \sigma_n L$$
$$= + A_3 \sin \sigma_n L \sinh \sigma_n L$$

$$\tan \Phi_n = Z_n / Y_n$$

$$A_1 = \frac{h_{si} h_{so}}{2\sigma^2 k^2} + 1$$

$$A_2 = \frac{h_{si} h_{so}}{2\sigma_n^2 k^2} - 1$$

$$A_3 = \frac{h_{si} + h_{so}}{\sigma_n k}$$

The values of the thermal conductivities, u-values h_{so} and h_{si} used in this work are those given by Sodha et al (1986) and Markus and Morris (1980). The solar radiation incident on the walls and roof for the four directions have been estimated from the CPCR2 results using the Liu and Jordan method as given by Duffie and Beckman (1991). The Fourier coefficients were determined and only six coefficients were used since this number is generally sufficient to describe the periodic variation.

3. RESULTS AND DISCUSSIONS

The results for the 15th of October 1996 and 3rd January, 1997 have been obtained for the purpose of this study. The first six harmonics for the Fourier series of the sol-air temperatures for the two chosen days are shown in Tables 2a and 2b for the different surfaces.

Table 2a Fourier coefficients for the daily variation of sol-air temperature on horizontal and various surfaces for 15th October, 1996. (AMP and ϕ are amplitude and phase of Fourier coefficient respectively)

	n	0	1	2	3	4	5	6
Horiz'l	AMP (°C)	36.70	35.776	15.043	5.459	0.479	1.013	0.208
	ϕ (rad)	-	0.000	0.661	0.941	0.822	1.292	0.946
NE Wall	AMP (°C)	29.43	28.899	10.422	3.965	0.764	0.646	0.206
	ϕ (rad)		0.000	0.887	1.399	0.181	1.329	1.214
SE Wall	AMP (°C)	28.07	27.499	8.266	2.147	1.541	0.803	0.277
	ϕ (rad)	-	0.000	0.737	0.481	0.935	1.043	0.288
NW Wall	AMP (°C)	27.12	26.671	8.423	2.417	0.751	0.862	0.183
	ϕ (rad)	-	0.000	0.930	1.396	1.143	1.362	0.454
	AMP (°C)	26.70	26.166	7.638	1.704	0.852	0.310	0.546
SW Wall	ϕ (rad)		0.000	0.884	1.028	1.178	1.180	0.586

Table 2b: Fourier coefficients for the daily variation of sol-air temperature on horizontal and various surfaces for 3rd January, 1996. (AMP and ϕ are amplitude and phase of Fourier coefficient respectively)

	n	0	1	2	3	4	5	6
Horizontal	Amp (°C)	31.84	31.175	12.509	4.970	0.694	0.952	0.227
	ϕ (rad)	-	0.000	0.822	1.227	0.953	0.747	0.144
NE Wall	AMP (°C)	26.64	26.262	9.406	4.160	1.042	0.499	0.434
	ϕ (rad)	-	0.000	1.033	1.550	1.000	1.155	0.259
SE Wall	AMP (°C)	24.78	24.418	6.963	1.931	1.241	0.872	0.088
	ϕ (rad)	-	0.000	0.941	0.904	0.104	0.360	0.466
NW Wall	AMP (°C)	23.27	23.009	6.672	2.106	0.167	0.663	0.347
	ϕ (rad)	-	0.000	1.163	1.444	0.347	0.643	0.408
	AMP (°C)	23.20	22.854	6.442	1.767	0.525	0.522	0.244
SW Wall	ϕ (rad)	-	0.000	1.171	1.487	0.143	0.030	1.081

The results for the brick house is shown in Fig. 2 while that for the concrete house is seen in Fig. 3. October is generally hot in Kano and on the date in question the highest temperature was 37.82°C at 15:00 hours while the minimum was 18.50°C at 7:00 hours. The highest inner surface temperature for the walls was in the north-east walls which was 31.91° at 13:00 hours. The time lag between the occurrence of the maximum outside air temperature and those for the walls was 3 hours in general. The lowest was 20.85°C in the north-west direction at 4:00 hours. The time lag between the lowest temperatures of the walls and the outside air temperature was 3 hours also. For the concrete building the highest temperature was also in the north-east direction and was 34.44°C while the lowest was 16.99° C in the north-west direction. Time lags were generally ~ 2 hours between the highest outside temperature and those of the walls and 3 hours generally for the lag between the lowest outside temperature and the lowest temperatures for the walls. Temperature swings are between 8.5° and 11.1°C for the brick walls while those of the concrete walls are between 15.6°C and 17°C. These when compared to the 19.3°C of the outside air temperature shows that the brick structure helps in keeping the inner surface of the walls more stable than the concrete edifice.

The results for the 3rd of January 1997 are shown in Figs. 4 and 5. Again we find the temperatures for the brick house remaining moderately lower than those of the concrete edifice. The brick structure keeps the inner surfaces warm during the cold morning hours of the harmattan month of January, while in the case of the concrete structure some walls are colder than the outside air temperature in the morning hours. Between 7:00 and 12:00 hours both structures have higher temperatures than the outside air temperatures. Between 13:00 and about 21:00 hours the temperatures are generally lower than the hot outside air. The brick edifice maintains a lower temperature than the concrete one even at this period. The temperature swings are between 7.7 and 9.7°C for the brick walls and between 14.0 and 15.2°C for the concrete house. The lower temperature swings for the bricks walls indicate that for the cold harmattan months the brick house will keep warm better than the concrete walls.

The inner roof temperatures for the brick house are generally higher than those of the concrete building both in October and in January as seen in Figs. 2-5. Temperature swings for the inner roofs are low. For the brick buildings the temperature swing for October was 5.8°C and 5.0°C for January. For the concrete building the temperature swing for October was 7.7°C and 6.7°C for January. Again this indicates that the brick material maintains a lower temperature bracket than the concrete walls.

Table 3 shows a summary of the thermal analysis for the two types of houses in Kano with a flat roof. It indicates the maximum and minimum temperatures for the inner surfaces for the different directions and the lag times for the achievement of these temperatures and finally the temperature swings for the different seasons considered.

4. CONCLUSION

In the work presented the thermal response of a brick house and a concrete house have been studied using the city of Kano as the location of interest. A Fourier series technique was employed using the sol-air temperature as the main input. The results show that the inner surface temperatures of the brick house would remain temperate for most parts of the year. The inner surfaces of the walls of the concrete house on the other hand show temperatures higher than those of brick building in general. With these results it can be recommended that the NBRRI brick be used in building low cost houses within the Nigerian environment. Further work needs to be done using passive options to improve the thermal response of brick houses to the tropical climate of Nigeria. These options are already been studied and will form the focus of future work.

Table 2: Summary of thermal analysis of the brick and concrete houses at Kano

Day		Surface	Max. Temp. °C	Min Temp. °C	Time Achieved (Hours)		Lag time, (Hours)		Temp. Swing $T_{max}-T_{min}$
					Max. Temp	Min. Temp	Max. Temp	Min Temp	
Oct 15th 1996	Brick	T_A	37.8	18.5	15.00	7:00	-	-	19.3
		T_{SW}	31.3	21.9	12:00	4:00	3.0	3.0	9.4
		T_{NW}	31.1	20.9	12:00	4:00	3.0	3.0	10.3
		T_{NE}	32.0	20.9	13:00	4:00	2.0	3.0	11.1
		T_{SE}	30.3	21.8	12:00	3:00	3.0	4.0	8.5
		T_R	23.09	17.30	10:0	23.0	5.0	-16.0	5.8
	Concr.	T_A	37.82	18.50	15.0	7.0	-	-	19.3
		T_{SW}	33.96	18.39	13.0	4.0	2.0	3.0	15.6
		T_{NW}	33.66	16.99	13.0	4.0	2.0	3.0	16.7
		T_{NE}	34.44	17.49	13.0	4.0	2.0	3.0	17.0
		T_{SE}	33.57	17.58	12.0	3.0	3.0	4.0	16.0
		T_R	17.50	9.80	9.0	22.0	6.0	-15.0	7.7
Jan. 3rd 1997	Brick	T_A	34.7	17.10	16.5	8.0	-	-	17.6
		T_{SW}	32.0	23.5	13.0	4.0	3.5	4.0	8.4
		T_{NW}	31.8	22.4	12.0	4.0	4.5	4.0	9.4
		T_{NE}	32.4	22.7	13.0	4.0	3.5	4.0	9.7
		T_{SE}	30.8	23.1	12.0	3.0	4.5	5.0	7.7
		T_R	26.01	21.00	10.0	23.0	6.5	-15.0	5.0
	Concr.	T_A	34.70	17.10	16.5	8.0	-	-	17.6
		T_{SW}	34.72	20.74	13.0	4.0	3.5	4.0	14.0
		T_{NW}	34.41	19.20	13.0	4.0	3.5	4.0	15.2
		T_{NE}	34.90	20.11	13.0	4.0	3.5	4.0	14.8
		T_{SE}	34.11	19.53	12.0	3.0	4.5	5.0	14.6
		T_R	23.16	16.47	9.0	22.0	7.5	-14.0	6.7

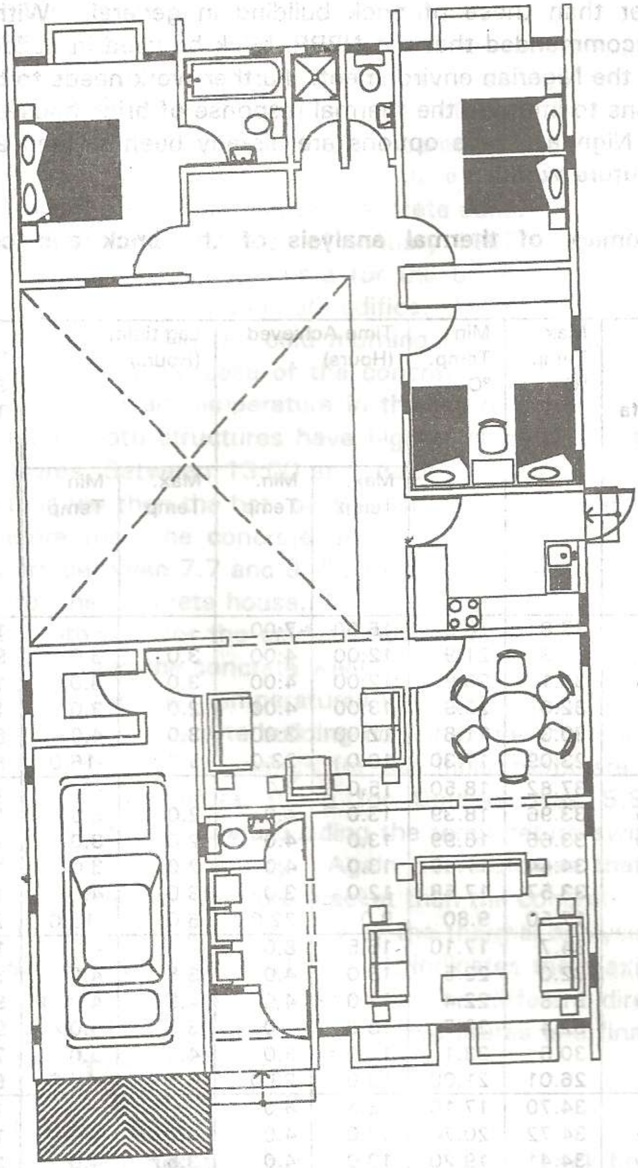

Fig 1 : Floor Plan of NBRRI House in Kano

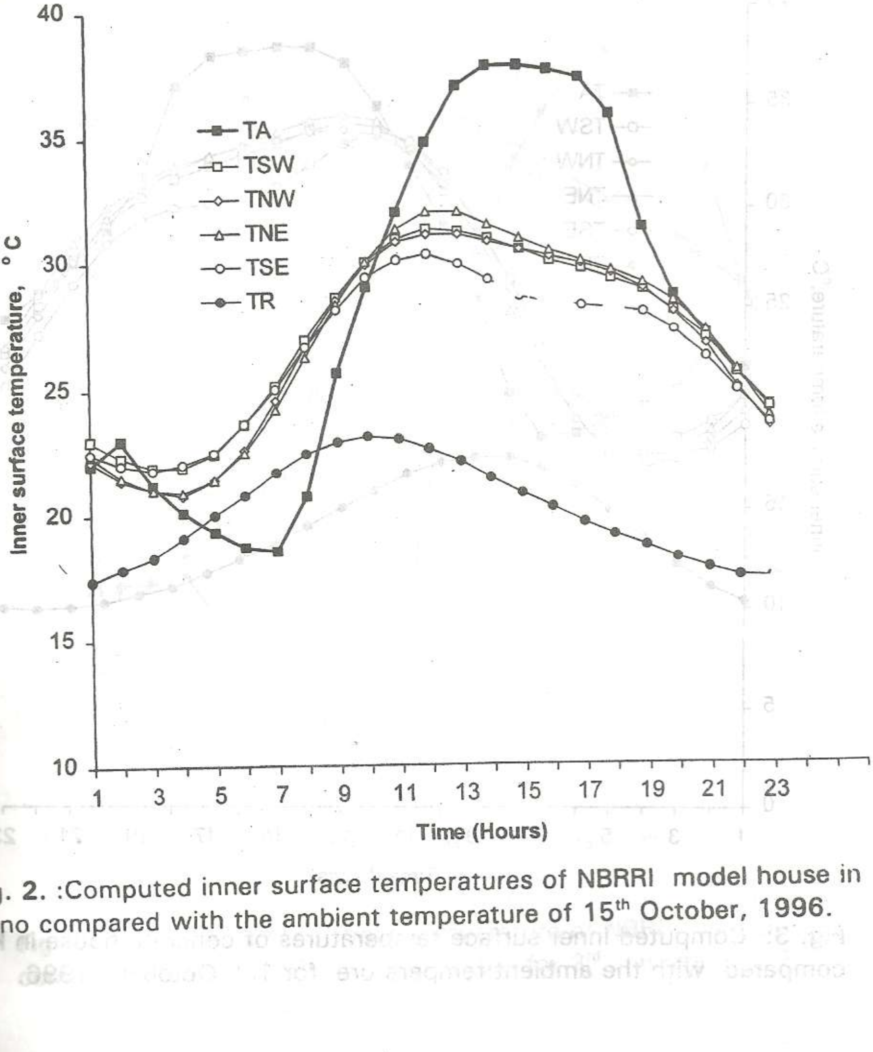

Fig. 2. :Computed inner surface temperatures of NBRRI model house in Kano compared with the ambient temperature of 15th October, 1996.

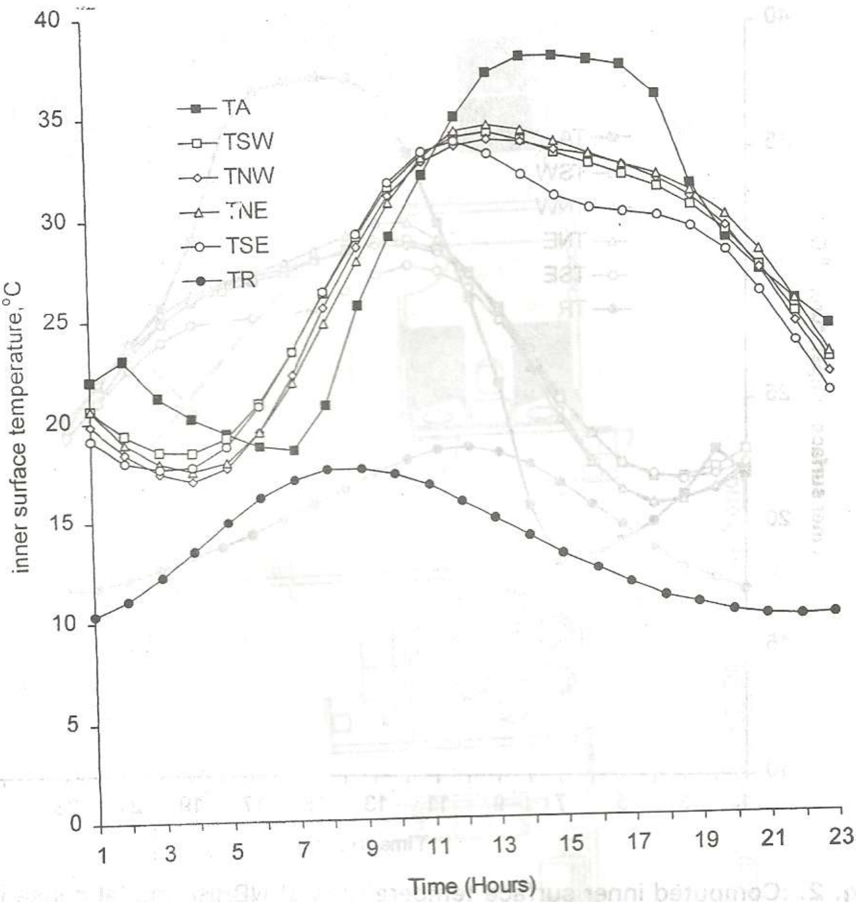

Fig. 3: Computed inner surface temperatures of concrete house in Kano compared with the ambient temperature for 15th October, 1996.

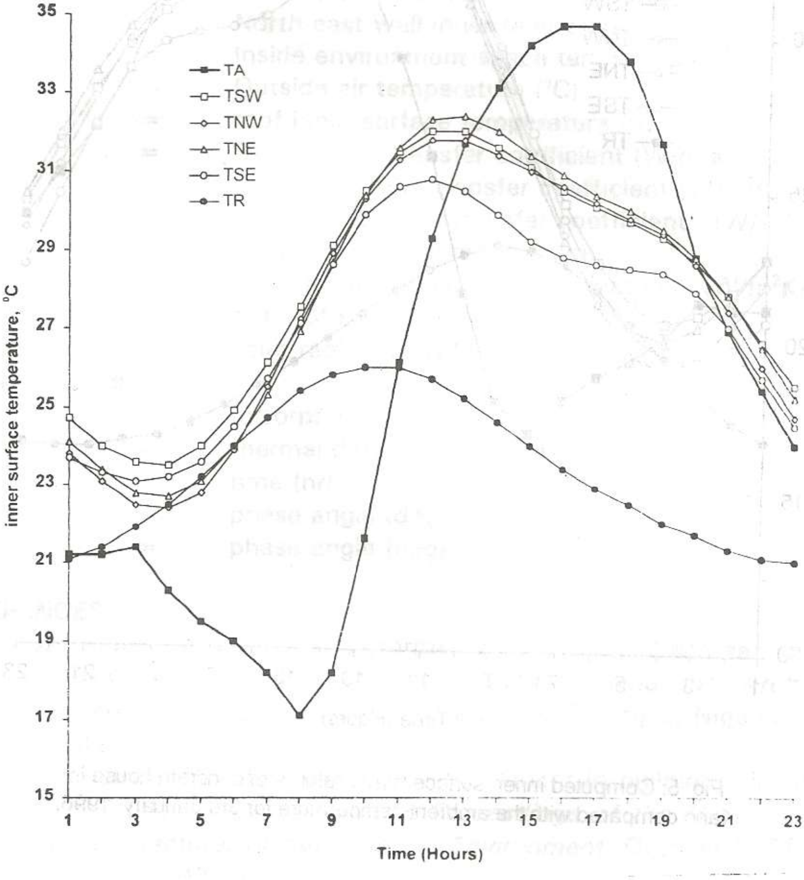

Fig. 4: Computed inner surface temperature of NBRRI model house in Kano compared with the ambient temperature for 3rd January, 1997.

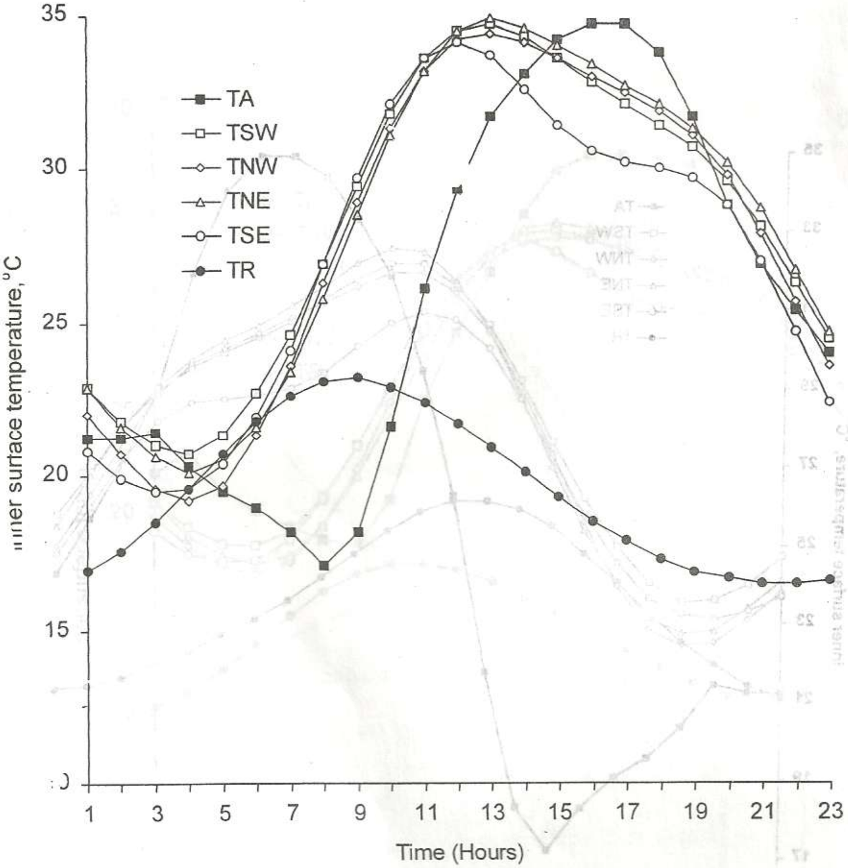

Fig. 5: Computed inner surface temperatures of concrete house in Kano compared with the ambient temperature for 3rd January, 1996.

NOMENCLATURE

T_{SA}	=	sol-air temperature (°C)
T_{SW}	=	South-west wall inner temperature (°C)
T_{SE}	=	South-east wall inner temperature (°C)
T_{NW}	=	North-west wall inner temperature (°C)
T_{NE}	=	North-east wall inner temperature (°C)
T_{in}	=	Inside environment space temperature (°C)
T_A	=	Outside air temperature (°C)
T_R	=	roof inner surface temperature (°C)
U	=	Overall heat transfer coefficient (W/m^{2}K)
h_{si}	=	inside wall heat transfer coefficient (W/m^{2}K)
h_{so}	=	outside wall heat transfer coefficient (W/m^{2}K)
L	=	thickness of wall material (m)
k	=	thermal conductivity of wall material (W/m^{2}K)
n	=	order of harmonics in Fourier series
s	=	solar radiation (W/m^{2}K)
Greek symbols		
α	=	absorptivity of the surface
δ	=	thermal diffusivity (m^2/hr)
θ	=	time (hr)
ϕ_n	=	phase angle (deg)
Φ_n	=	phase angle (deg)

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