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An Assessment of Temperature Variation In Building Types in Nigeria: Akure as A Case Study

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Five existing buildings constructed with different combinations of building materials were identified around FUTA area in Akure, Ondo State. These buildings are mud houses with corrugated iron roof sheeting, cement block houses with corrugated iron roof sheeting, fired clay houses with corrugated iron roof sheeting, cement block houses with asbestos roof and cement block houses with concrete roofs. The temperature of one room, having the same orientation in each of the buildings was measured with the aid of a mercury-in-glass thermometer at two-hour intervals between 8am and 6pm every day for 10 days. The variation of the inside temperature with time for the different types of roofing and building materials was analysed graphically. The measured outdoor temperature of each building was also regressed against the inside/indoor temperature in order to determine the best combination of the building materials under assessment. The result of the analysis showed that the best combinations of materials are fired clay wall with concrete roof.

Keywords: Building, roof sheetings, temperature, comfort.

1. Introduction

A building can best be described as an enclosure that protects its occupants from harsh weather conditions, intruders and within which human activities, such as cooking, sleeping, working, etc. take place (**Stulz** and **Murkeji, 1988**). Its purpose is to provide a safe, comfortable internal environment despite variation in external conditions.

However, in air-conditioning, the essence of a building is to provide thermal comfort to its occupants. Towards this end, the most important factors to be considered in the choice of materials for the various components of a building are climate, the thermal properties of materials and the building orientation.

There are two basic climates in the world, namely, the cold climate and hot climate (**Stoll** and **Estratov, 1987**). The cold climate is characterised by low temperature, long cold months and short summer months. This climate is a feature of the temperature regions of the earth. However, the hot climate is characterised by high temperature. This type of climate is obtained around areas of the world close to the equator, in the tropics and arid regions of the Earth.

A good building design can be described as the one that goes a long way to establish a suitable level of thermal comfort to its human occupants

ASHRAE comfort standard defines comfort as a state of mind, which expresses satisfaction with the thermal environment (**Jones, 1989**). For a body to be comfortable thermally, the rate of heat generated within the body should be equal to the rate of heat loss from the body (**Stocker** and **Jones, 1988**).

The normal human body temperature is 37ºC and for the body to be comfortable, the surrounding temperature should not be too low as to cause shiverring or too high.

There are four properties of the environment that influence comfort. These are Dry-bulb temperature, Relative humidity, Air velocity and Mean radiant temperature, radiation (**Jones, 1989**). The dry-bulb temperature is the temperature of the air around

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us and it is the most important factor. It is this temperature that has to be within comfort conditions while designing structures for habitation. Humidity refers to the amount of moisture in the air. Humidity of the atmosphere has little effect on thermal comfort unless it is extremely low or extremely high. Air velocity also accelerates evaporation, providing a physiological cooling. Its effect is significant at humidity lower than 30%. Radiation has the greatest reflect on thermal comfort next to air temperature. When radiation falls on intervening surface such clothes, the radiant heat is converted to long-wave electromagnetic radiation causing sensible heat that is conducted through the material to the skin. Mean-radiant temperature (MRT) is the mean of thermal radiation reading from all materials around us. These materials include walls, floors, other human bodies, etc.

Basically, materials used for building construction are based on the available natural resources and these differ from one locality to another as the nature has made it.

These natural materials include clay, stone, mud, timber, bamboo, thatches, spare grasses, raffia palm, large leaves, bark of trees, etc. The application of these materials is based on availability, technological constraint, financial constraint, transportation system and climatic effect. The application of these materials based on climatic effect is the basis of this study.

Generally and for the purpose of this work, building materials are classified into six types. They are stone, soil and laterite, cement, timber, bamboo and glass, metal-roof sheetings.

A building structure consists of walls, floors, windows and doors, and roofs and ceilings. **Fathy (1986)** reported that in choosing these materials, consideration must be given to their physical properties such as thermal conductivity, resistivity, etc. while **Kicklighter** and **Kicklighter (1986)** implied that the choice of the appropriate materials for these various elements for buildings depends on location, climate, cast, taste and lifestyle. The focus of this study is to assess the ability of some or all of these materials to prevent external heat from entering the building during the day and to allow moderate flow of heat outwards at night so as to provide comfort in the buildings.

2. Methodology

A survey was carried out on five existing residential buildings with different combinations of building materials at different locations around FUTA in Akure, southwest of Nigeria. The buildings were selected such that their layout and orientation are averagely the same. This is necessary to provide a basis for comparing the building materials that the study is interested in, by keeping the layout and orientation constant. The layout of the buildings is such that each has five bedrooms, one sitting room, one dining room, one kitchenette, two toilets and bathrooms. Also, the buildings were selected at their different locations to face the north where the sun is expected to have a distributed effect as it is rising and falling. The indoor temperatures of each of the rooms in these buildings and the relative average outdoor temperature were measured at regular intervals from 08.00 hours to 18.00 hours for a period of 10 days in the month of April, 2002. Results were recorded, analysed and interpreted to see the effect of these building materials on the indoor temperature of these buildings.

3. Data Documentation and Analysis

The data for this study was collected and documented in **Tables 1 - 10**. Hence, a graph of the variation in the average inside temperature was drawn with a view to compare the different material under the same condition as shown in **Figure 1** and **Figure 2**. In order to establish a relationship between the outdoor temperature and the indoor temperature, a regression analysis was carried out with the outdoor temperature being the criterion variable (Y) and the indoor temperature as the Predictor Variable (X) for each of the buildings under study. That is, we represented the Average Inside Temperature (°C) by Y and the Average Outside Temperature (°C) by X and applied regression analysis to the data in **Tables 6, 7, 8, 9** and **10**. This resulted in the trend given in Equations (1), (2), (3), (4) and (5) in **Table 11**.

4. Results and Discussion

Heat transfers from the outside to the inside of a building or vice versa occur via steady state heat transfer. In steady state heat transfer problems, more than one heat transfer mode is involved. The various

TABLE 1: *Temperature Variation of Mud House with Corrugated Iron Sheet Roof for 10 Days*

	Inside Dry-Bulb Temperature (°C)										
Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AT °C
08.00	23.60	25.00	26.00	26.20	25.00	25.80	27.00	26.20	25.80	27.20	25.78
10.00	25.20	26.80	29.20	28.20	28.00	29.60	30.00	29.70	24.00	30.20	28.04
12.00	26.80	27.00	29.80	28.80	28.80	30.80	31.00	29.80	24.00	31.00	29.48
14.00	27.00	29.40	31.20	30.00	30.60	31.60	32.00	30.20	25.20	32.40	30.16
16.00	30.80	30.20	32.00	31.00	31.20	31.20	33.00	31.00	26.00	33.20	31.02
18.00	31.00	31.80	33.20	29.80	31.80	31.80	33.40	31.20	27.40	33.80	31.70
							Total Daily Average Temperature				29.79

TABLE 2: *Temperature Variation of Cement-Block House with Corrugated Iron Sheet Roof for 10 Days*

	Inside Dry-Bulb Temperature (°C)										
Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AT °C
08.00	24.20	26.40	27.80	28.20	26.80	27.20	28.00	27.00	27.40	27.10	27.10
10.00	27.00	27.80	29.20	29.00	28.20	28.60	29.80	29.60	21.80	29.40	28.04
12.00	29.60	28.00	29.80	30.00	29.60	29.80	32.00	31.80	21.80	32.40	29.48
14.00	30.80	29.20	31.60	30.20	31.20	31.60	32.20	32.60	25.60	32.80	30.76
16.00	31.20	30.40	32.40	31.00	31.60	31.80	33.80	33.60	26.80	33.20	31.58
18.00	31.80	31.00	32.80	32.00	30.80	32.80	32.20	33.80	27.60	33.40	31.80
							Total Daily Average Temperature				29.79

TABLE 3: *Temperature Variation of Fired Clay House with Corrugated Iron Sheet Roof for 10 Days*

	Inside Dry-Bulb Temperature (°C)										
Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AT °C
08.00	24.20	24.80	25.60	26.80	26.00	28.20	29.20	27.20	24.80	28.00	26.48
10.00	25.00	26.40	28.40	27.40	27.00	29.40	30.60	29.00	23.00	29.20	27.54
12.00	27.00	26.80	29.00	28.00	28.60	30.20	31.80	30.20	23.20	30.00	28.50
14.00	28.20	28.80	30.80	29.60	30.00	31.40	33.00	31.80	24.00	31.40	29.90
16.00	29.00	29.20	31.60	30.00	30.80	32.00	34.20	32.40	25.80	32.60	30.76
18.00	30.20	30.40	32.00	29.60	31.40	32.80	34.80	33.20	27.00	33.00	31.44
							Total Daily Average Temperature				29.10

TABLE 4: *Temperature Variation of Cement-Block House with Asbestos Roof for 10 Days*

	Inside Dry-Bulb Temperature (°C)										
Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AT °C
08.00	22.80	23.00	24.60	25.60	25.00	27.00	28.00	26.40	23.60	27.00	25.30
10.00	23.40	24.40	27.60	26.40	26.20	28.40	29.60	28.00	22.00	28.60	26.46
12.00	26.00	25.20	28.00	27.00	27.40	29.20	30.80	29.20	22.40	29.00	27.42
14.00	28.00	26.80	29.80	28.40	29.20	29.80	32.00	30.80	23.20	30.80	28.88
16.00	29.20	28.20	30.60	29.00	29.80	30.60	33.40	31.60	24.00	31.20	29.78
18.00	30.00	29.60	31.00	29.80	30.20	31.20	34.00	32.40	26.20	32.00	30.64
							Total Daily Average Temperature				28.08

TABLE 5: *Temperature Variation of Cement-Block House with Concrete Roof for 10 Days*

	Inside Dry-Bulb Temperature (°C)										
Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AT °C
08.00	22.60	23.00	24.00	25.20	24.80	26.60	27.00	25.40	22.60	26.00	24.76
10.00	23.00	24.20	27.40	25.80	25.60	27.20	28.20	27.60	21.80	27.50	28.55
12.00	25.60	24.80	27.80	26.60	26.80	28.00	29.80	28.40	22.00	28.40	26.82
14.00	27.00	25.00	29.00	27.80	28.00	28.80	31.00	29.60	23.00	29.20	27.84
16.00	27.80	25.80	30.00	28.60	28.80	29.80	32.20	31.00	23.80	30.60	28.84
18.00	29.40	27.80	30.80	29.00	29.60	30.60	32.80	31.80	25.20	31.00	29.80
							Total Daily Average Temperature				27.77

TABLE 6: *Variation of Inside Temperature against Outdoor Temperature for Mud House with Corrugated Iron Sheet Roof*

Time	0800	1000	1200	1400	1600	1800
Average Inside Temperature (°C)	25.78	28.04	29.48	30.16	31.02	31.70
Average Outdoor Temperature (°C)	24.95	27.35	29.70	31.35	32.00	29.25

TABLE 7: *Variation of Inside Temperature against Outdoor Temperature for Cement-block House with Corrugated Iron Sheet Roof*

Time	0800	1000	1200	1400	1600	1800
Average Inside Temperature (°C)	27.10	28.04	29.48	30.76	31.58	31.80
Average Outdoor Temperature (°C)	24.95	27.35	29.70	31.35	32.00	29.25

TABLE 8: *Variation of Inside Temperature against Outdoor Temperature for Fired Clay House with Corrugated Iron Sheet Roof*

Time	0800	1000	1200	1400	1600	1800
Average Inside Temperature (°C)	26.48	27.54	28.50	29.90	30.76	31.44
Average Outdoor Temperature (°C)	24.95	27.35	29.70	31.35	32.00	29.25

TABLE 9: *Variation of Inside Temperature against Outdoor Temperature for Cement-block House with Asbestos Roof*

Time	0800	1000	1200	1400	1600	1800
Average Inside Temperature (°C)	25.30	26.46	27.42	28.88	29.78	30.64
Average Outdoor Temperature (°C)	24.95	27.35	29.70	31.35	32.00	29.25

TABLE 10: *Variation of Inside Temperature against Outdoor Temperature for Cement-block House with Concrete Roof*

Time	0800	1000	1200	1400	1600	1800
Average Inside Temperature (°C)	24.76	28.55	26.82	27.84	28.84	29.80
Average Outdoor Temperature (°C)	24.95	27.35	29.70	31.35	32.00	29.25

TABLE 11: *Summary of Result of Regression Analysis*

Building Type	Regression Equation Trend	
Mud house with corrugated iron sheet roofing	$Y = 0.7089X + 8.733$	........(1)
Cement block house with corrugated iron sheet roofing	$Y = 0.6361X + 11.283$	........(2)
Fired clay with corrugated iron sheet roofing	$Y = 0.5919X + 11.879$	........(3)
Cement block house with asbestos roofing	$Y = 0.6178X + 10.024$	........(4)
Cement block house with concrete roofing	$Y = 0.4137X + 15.731$	........(5)

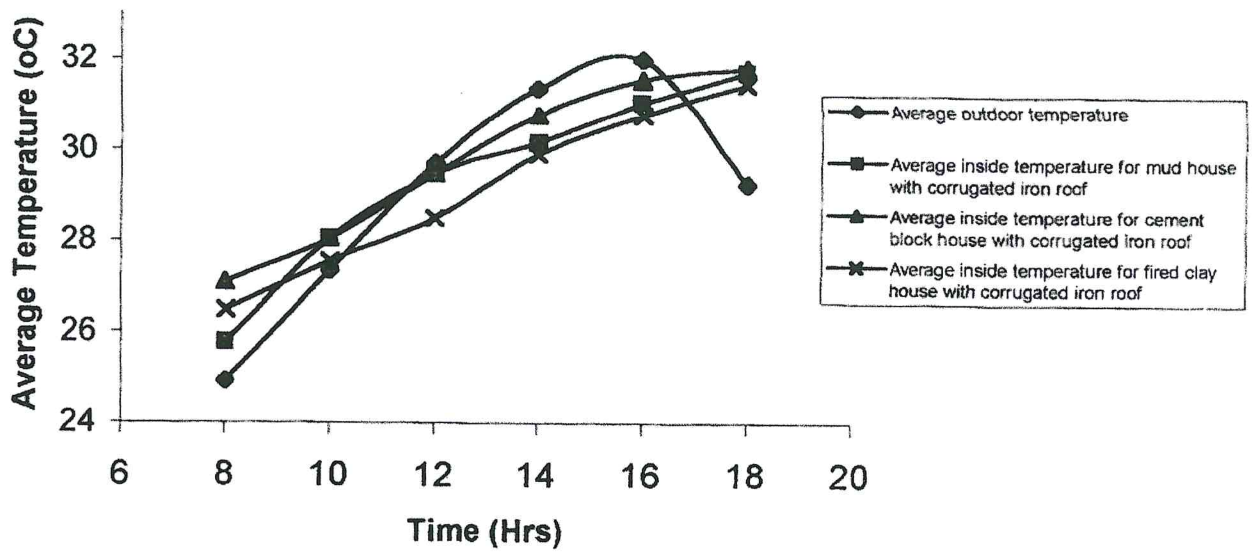

FIGURE 1: *Variation of Average Temperature (Outdoor and Indoor) against Time for Different Wall Materials with Corrugated Iron Roof*

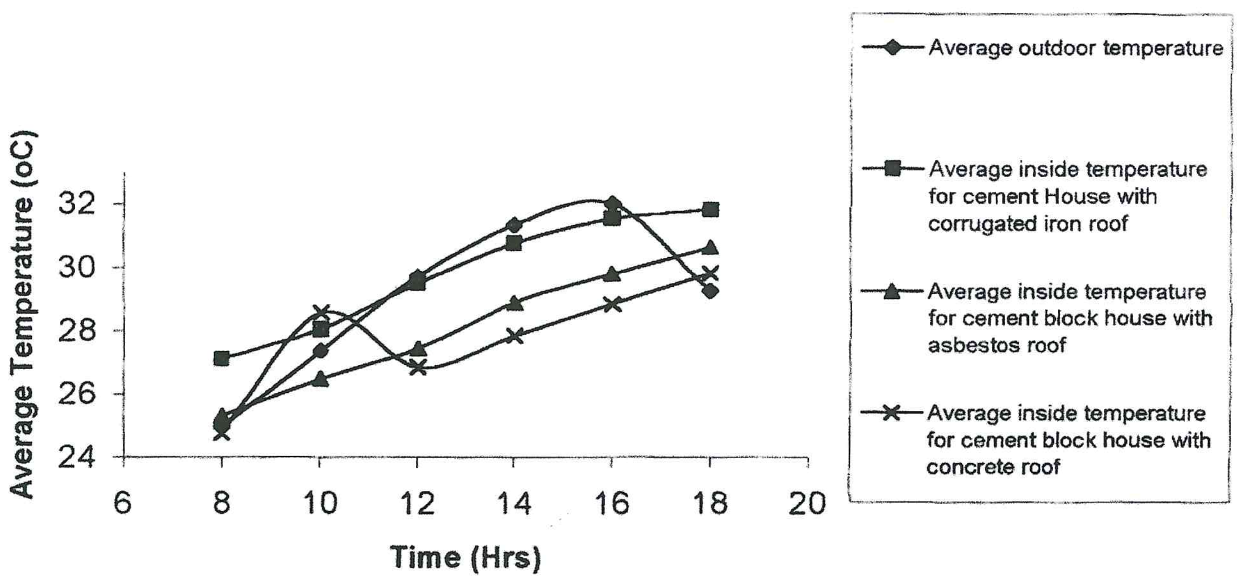

FIGURE 2: *Variation of Average Temperature (Outdoor and Indoor) against Time for Cement Block House with Different Roofing Materials*

heat transfer coefficients may be combined into an overall coefficient so that the total heat transfer can be calculated from the terminal temperatures. If we consider typical heat transfer processes in a building as represented with two simple models shown in **Figure 5** and **Figure 6**.

Figure 7 can be extracted from **Figure 5** to give the heat transfer through a particular section of the wall or roof of a building during the daytime. For the model described in **Figure 7, ASHRAE (2001)** considered the heat transfer using a three-step steady state process: from a warmer fluid to a solid wall, through the wall, then to a colder fluid and defined the overall heat transfer coefficient U based on the difference between the bulk temperature T_o - T_i as follows:

$$q = UA(T_o - T_i) \quad \text{......................................(1)}$$

Where q is the heat flux in the positive x direction through the wall surface area A. T_o and T_i are the warm outside and cold inside temperature during the daytime. In terms of steady state thermal conduction, **Ozisik (1985)** gives the thermal conductivity equation as

$$Q = kA\frac{dT}{dx} \quad \text{..(2)}$$

$$q = Q / A = -k\frac{dT}{dx} \quad \text{.................................(3)}$$

Where Q is the rate of heat flow through the area A. The proportionality constant k is called the thermal conductivity of the section. The analysis in this study takes into consideration the fact that the rate of heat flow depends on the surface area of the transmission medium as obvious from equations (1), (2) and (3), hence all the buildings used were selected to keep this parameter constant so as to give room for a favourable comparison of the thermal conductivity of the various types of wall and roof materials considered in the study.

Figures 1 and **2** show that the inside temperature is higher than that of the outdoor at night and since heat flows from the higher temperature region to lower temperature region, heat will flow from the inside to the outside until the inside temperature equals that of the outside. During the day, due to the sun's radiant heat, the outside temperature becomes hotter than the inside and therefore the direction of heat flow is reversed. These are in agreement with the models in **Figures 5** and **6** and show the authenticity of the data collected for this study. However, a graph of the variation in the average inside temperature against time was drawn with a view to compare the different wall materials and roofing materials under the same condition as shown in **Figure 3** and **Figure 4** respectively.

Figure 3 shows that the inside temperature of a fired clay house tends to the human comfort temperature at all times as compared with those of the mud house and concrete block house. Also, **Figure 4** implies that buildings with concrete roofs have their inside temperatures closer to comfort temperatures for most of the period considered as compared with buildings having corrugated iron sheet or asbestos sheet as their roofs.

There is a peculiar trend for each of the buildings studied as shown by the result of the regression analysis in **Table 11**. This trend explains the relationship between the outdoor temperature and the indoor/inside temperatures of these buildings and is obviously in agreement with **Figures 3** and **4**.

For instance, in the case of mud houses with corrugated iron sheet roofs, Equation (1) implies that for 1°C rise or fall in the outdoor temperature (X), the inside temperature (Y) rises or falls by 0.70896°C.

Similarly, an outdoor temperature change of 1°C causes a corresponding change of 0.6361°C in the inside temperature of cement-block houses with corrugated iron sheet roof according to Equation (2). Also, Equation (3) can be interpreted to mean that a unit change in the outdoor temperature brings about a change of 0.5919°C in the inside temperature of fired clay houses with corrugated iron sheet roofs.

Also, Equations (2), (4) and (5) of **Table 11** can be interpreted by an outdoor temperature change of 1°C will result in an indoor/inside temperature change of 0.6361°C, 0.6178°C and 0.4137°C for buildings made of similar walls having corrugated iron roofing sheets, asbestos roofing sheets and concrete roofs respectively.

From the results above, it can be inferred that of all the buildings under study, the one made of fired clay wall is able to prevent influx and outflow of heat

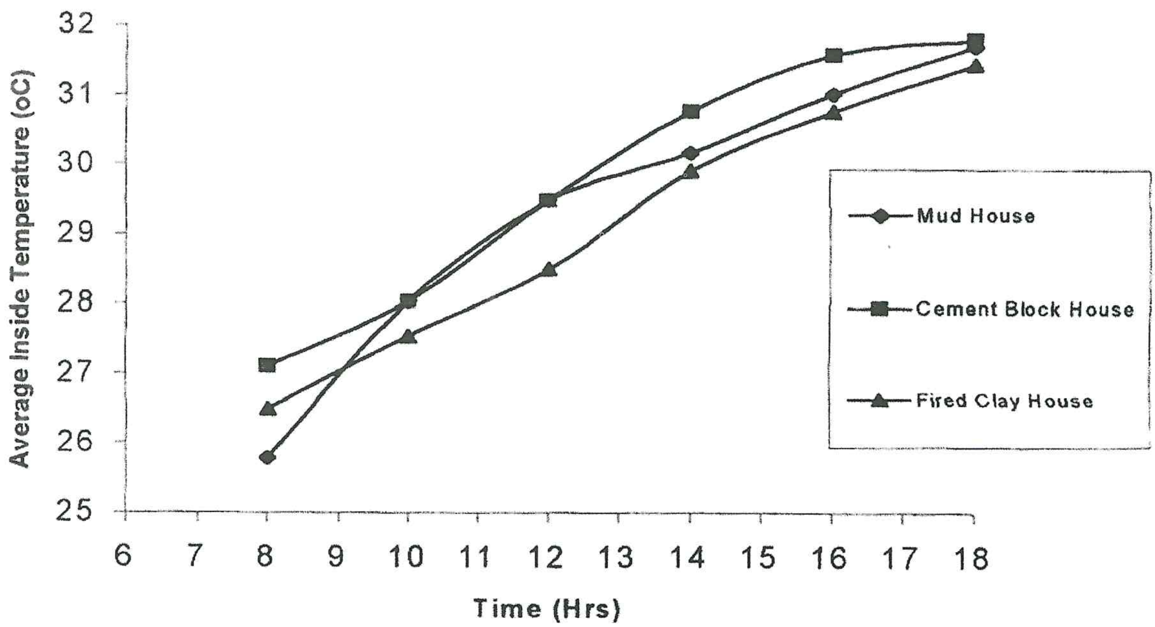

FIGURE 3: *Variation of Average Inside Temperature with Time for Different Types of Wall Materials with Corrugated Iron Sheet Roofing*

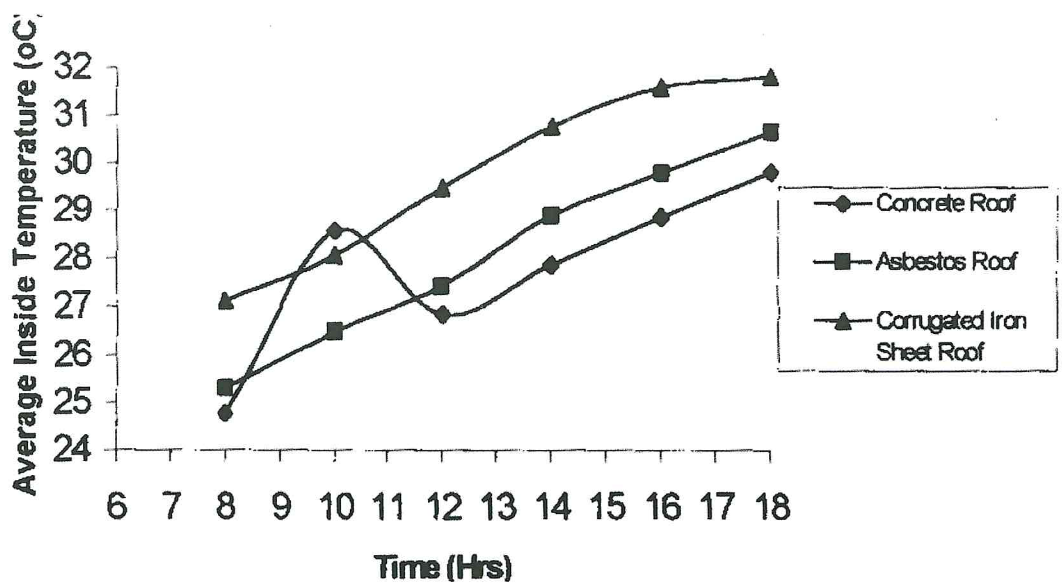

FIGURE 4: *Variation of Average Inside Temperature with Time for Different Types of Roofing Materials with Cement Block Houses*

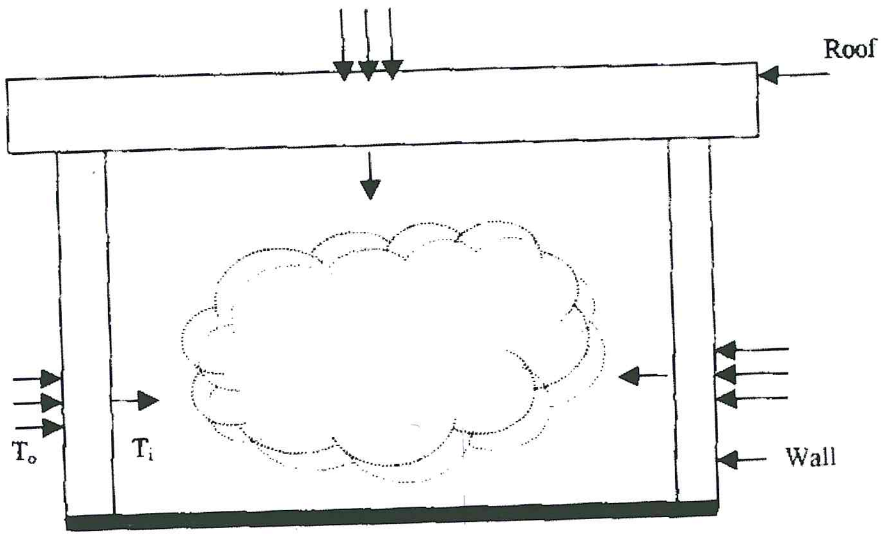

FIGURE 5: *Typical Model of Heat Transfer in A Building during Daytime*

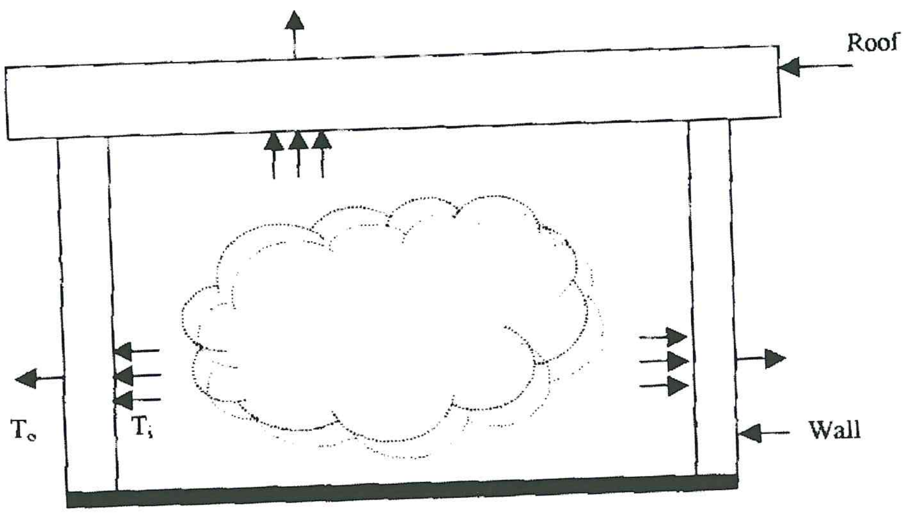

FIGURE 6 *Typical Model of Heat Transfer in A Building at Night*

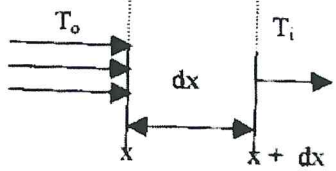

FIGURE 7: *Heat Transfer through A Section of Wall or Roof at Daytime*

into and out of the building during the day and at night respectively. Also, the situation is the same for buildings made of concrete roofs.

4. Conclusion and Recommendation

A functional building in the tropics is the one that prevents influx and outflow of heat into/out of the building envelope. Hence, the most appropriate materials are those with low thermal conductivity. Based on the results of this study, it can be concluded that for walls, fired clay blocks are the most appropriate material, followed closely by mud blocks which still have low thermal conductance compared to cement blocks.

In the case of the roof, concrete roofs are the most appropriate followed by asbestos roofing sheets compared to corrugated iron sheets that have a high thermal conductivity.

Since Nigeria is located in the Tropical region of the world, the major challenge to building is to ensure protection against heat and to provide adequate cooling. This can effectively be overcome by choosing appropriate building materials. Therefore, from the result of this study, fired clay blocks and concrete roofs are recommended for walls and roofs of buildings respectively.

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