The Introduction of A Sandcrete-Strawbale Interface Mould (SSIM) for Urban Housing Development in Tropical Regions of Nigeria

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***Abstract*:-This research focuses on the use of a mixed sandcrete-straw interface mould for urban housing development in tropical regions of Nigeria with Lokoja, Kogi state as a case study.A mixed sandcrete-stawbale interface mould is that which contains a strawbale on one side and sandcrete on the other side. This research addresses the thermal performance of a sandcrete-strawbale Interface Mould (SSIM) walls plastered with cement mix. The thermal performance is determined by comparing the temperature gradients of wall made of SSIM and conventional sandcrete wal. Strawbale-Sandcrete Interface Mould, SSIM possesses higher temperature gradient values. This indicates good heat retention and cooler interior. The straw bale wall test is undertaken by collecting actual measurements on site. Thermal sensors are installed on both external and internal sides of the wall to record the heat transmission through the plastered walls. The thermal conductivity of the SSIM sample is calculated from measured parameters. The interface temperature values of the strawbale- sandcrete Interface Mould, SSIM, are then calculated from Fouriers law of heat transfer. The quantity of heat retention were then calculated from level of temperature gradient.This study also examine and test the sustainability of a sancrete-strawbale interface mould, SSIM, in Urban housing designs and development.The prototype enclosed walls are constructed and tested. Questionnaires were administered for this study to validate the experimentation of the research process on thermal comfort valuation. The pearson's Chi Square statistic is used to determine the level of significance in the best responses given on the thermal insulation property. Other factors to be considered for questionnaire for this study are thermal insulating property, availability, cost of construction, aesthetic, economical value, sound insulation,fire resistance and moisture resistance. Statistical tools including tables and graphs are used for further analyses.The SSIM design that will give the optimal thermal conductivity of the composite mould was determined for the environment and used for the research. Findings reveal the merits of the introduction of Sandcrete-Strawbale wall construction in Lokoja, Kogi state and other temperate regions in Nigeria.**

***Keywords:* Sandcrete-Strawbale Interface Mould (SSIM), straw bale, Thermal Conductivity, Temperature, Lokoja.**

I. INTRODUCTION

The need to create comfort for users and sustainability in Urban housing is constantly on the increase.The primary aim of modern housing development from conception and design to construction is the delivery of comfortable, energy efficient, durable and affordable structure.As a result of this, there is an evolving need for sustainable building materials.

Previous research works have been executed in the use of straw as a more effective walling material in terms of many factors as compared to sandcrete blocks.Nevertheless, the challenges in the moulding, acceptability and marketability of straw have made it difficult to be used in housing development.Straw is one of the finest renewable building materials available and is found around the world in abundance. It is the strong stalk of tall grain plants such as guinea corn, maize, wheat, hemp, rye or rice that remain in the field after the seed grains have been harvested. Its chemical composition is primarily cellulose, just like trees. When bundled together into a bale it becomes solid block that is highly resistant to decomposition. When assembled together and covered with a plaster skin, straw bales make a beautiful, strong, energy – efficient and ecologically sound house. Rice straw is locally abundant in Kogi state, thanks to the commissioning of the new commercial rice production mill in Kogi west.

Lokoja, Kogi state is located in the Sudan savannah region of Nigeria. It is a region characterized by high temperature most time of the year. The conventional sandcrete mould have failed to adress this problem and therefore, there is urgent need to introduce a durable walling design component of sandcrete-strawbale interface mould that will ameliorate the impact of heat on housing structures.

The introduction of a Sandcrete-Strawbale Interface Mould (SSIM) will not only make for a condusive habitation in housing design, it will also enhance housing economics and increase the marketability value of straw. The Government of Kogi State can stop the pollution of the environment and depletion of ozone layer resulting from burning of straw bales and harness straw bales from Kogi rice plantation project into a viable economic commodity. This will in turn increase the well- being of the population of the state,Nigeria and indeed the World- and also increase the Internally Generated Revenue of the state Government for the development of the state.

1.1 Study Area

The study area, Lokoja, which is a town expanding in both size and population is located between latitudes $7^0 46^1$N – $7^0 52^1$ and longitudes $6^0 38^1$E - $6^0 46^1$.Lokoja derives its name from two (2) Hausa words, a tree and a colour. 'Loko' which means 'Iroko and 'ja', which means red. So, the name Lokoja means Red Iroko (tree). Lokoja is the Headquaters of Lokoja . local Government capital of Kogi state and the major confluence town in Nigeria. Kogi is also a Hausa word which means river. The area enjoys both wet and dry seasons with the mean annual temperature of about 27.7^0C.The graphical representation of the temperature reading in Lokoja is depicted below showing the maximum, minimum and the average temperature

Fig 1 : Sample of straw bale

II. METHODOLOGY

2.1 Production of Strawbale Block Specimens

A. Selection of Materials And Dimension: This experimental program covered the model of strawbale-sandcrete mould units (sizes: 450mm x225mmx300mm).Since the SSIM wall is a load bearing, materials needed for the construction has to be selected such as Ordinary portland cement(OPC), sand aggregates, a steel mould of 450x300x225mm was fabricated for moulding the strawbale- sandcrete block units. Rice straw was also used as the strawbale material.

B. Batching, Mixing, Moulding, and Curing of Blocks: In moulding the block, after cement and aggregates have been acquired, then following the mix ratio of 1:7 (cement to fine aggregates) for moulding a half of the block with thickness 150mm, thorough mixing was done for the cement and sand. This was poured into the mould say to one half of the mould, then a chemically treated rice straw (this is to remove the carbohydrate content of the straw and also to aid cohesion) as our bale was arranged into the other hald of the mould which is then compacted. After the molding, it was allowed to cure for twenty eight days of which the first three days of curing was very important until sufficient strength is gained for 28 days. After curing has been done, setting and plastering were then done with cement and fine sand mix.

C. Plastering of the Constructed Sandcrete-Strawbale: The materials used for plastering include Cement and fine sand. After plastering has been done, it was allowed to set and dry for 28 days before setting and testing.

Fig 2 : The SSIM Mould wall under construction.

2.2 experimental procedures

A walling system consisting of sandcrete-strawbale (SSIM) is plastered and enclosed. It is roofed so as to prevent external factors on the experimental results. Temperature sensor, such as the thermometer was used to take a daily temperature for thirty days and the results documented. The straw bales are arranged in parallel orientation in the mould. The mass to volume ratio of mould sample is taken to calculate the mould density, which is then used on a graph to get the estimated thermal conductivity of the mould sample. The total thermal resistance for the strawbale-sandcrete mould interface, SSIM, is then calculated in series and the resultant value generated.

The quantity of heat generated in the interior wall is then calculated for the mould. The energy generated is the used to iterate the thermal conductivities at different mean temperatures. The result is then interpreted graphically and analysed. The results are then compared to that of a walling made with a mixture of sand and cement only.

2.3 Heat Flow Analysis

The heat flow rate is defined as the amount of heat transferred per unit time in the material. Heat flow rate in a sandcrete-strawbale walling material depends on the cross-sectional area of the mould, the temperature difference between both the ends and the length of the mould.

According to the second law of thermodynamics, heat will flow from the hot environment to the cold one in an attempt to equalize the temperature difference. This is quantified in terms of a heat flux Q, which gives the rate, per unit area, at which heat flows in a given direction (in this case the x-direction). In many materials, Q is observed to be directly proportional to the temperature difference and inversely proportional to the separation:

$$Q=-k(A/l)(\Delta T) \qquad (6)$$

The constant of proportionality k, is the thermal conductivity; it is a physical property of the material. In the present scenario, since heat flows in the minus x-direction and is negative, which in turn means that K>0. In general, K is always defined to be positive. The same definition of K can also be extended to gases and liquids, provided other modes of energy transport, such as convection and radiation, are eliminated.

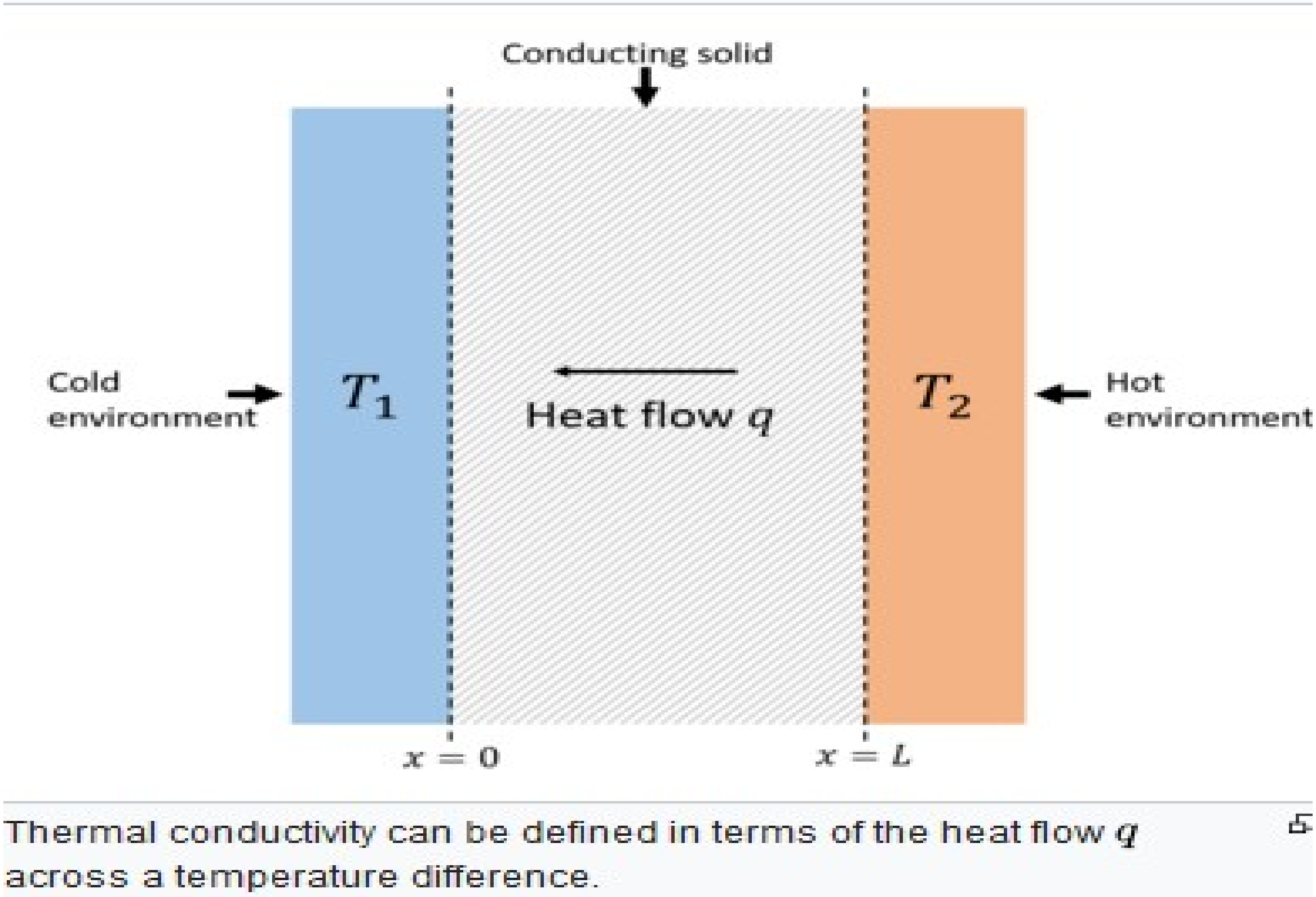

Fig 3 : A diagram showing the direction of heat flow through a SSIM mould

$Q_{sandcrete} = -k_{sandcrete}(A/l)(\Delta T)$ (7)

$Q_{strawbale} = K_{strawbale}\ (A/l)(\Delta T)$ (8)

Total heat transfer is $Q_{total} = Q_{sandcrete} + Q_{strawbale}$

Where,

- Q is the heat transfer per unit time
- k is the thermal conductivity
- A is the cross-sectional area
- l is the length of the material
- ΔT is the temperature difference

2.4 Heat Flux formula

Heat flux is the amount of heat transferred per unit area per unit time to or from a surface. Basically, it is a derived quantity since it involves the principle of two quantities viz. the amount of heat transfer per unit time and the area to or from which the heat transfer occurs.

The derived SI unit of heat rate is joule per second or watt. Heat flux density describes the heat rate per unit area. In SI unit of heat flux density is measured in W/m^2. Heat flux is a vector quantity.

Fourier's law is an important application of these concepts. For a pure solid substance, the conductive heat flux JH_c in one dimension is expressed by

Fourier's law.

$JH_C = \lambda dTdZ$ (9)

Where,

- JH_c = conductive heat flux
- T = temperature
- λ = thermal conductivity constant

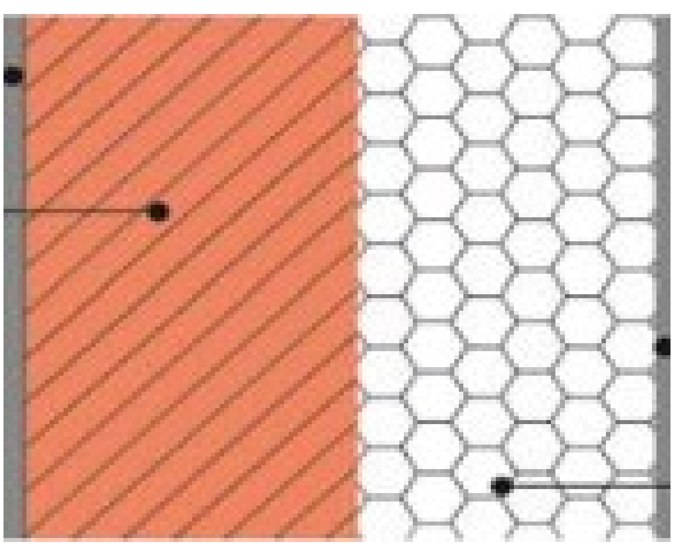

Fig 4 : Mould Composition showing the straw Bale on the left and the sandcrete mix on the right

2.5 calculation of the interface temperature of the sandcrete-strawbale interface mould

The heat comes through the mould through the exterior sandcrete section and passes through the bale-sancrete interface before being dissipated in the interior wall. Since the sandcrete layer is gaining the heat in a positive direction and the strawbale later is gaining the heat flux in the negative direction, the heat flux of the sandcrete layer is given as

$Q_s = K_S A_S (T_s - T_1)/L$ (10)

While the heat flux of the strawbale section is given as,

$-Q_b = K_b A_b (T_b - T_1)/L$ (11)

Since the heat loss by the sandcrete section is gained by the strawbale section, it can be written as

$Q_S = Q_B$ (12)

Which implies that $K_S A_S (T_s - T_1)/L = K_b A_b (T_1 - T_b)/L)$

So, $K_S A_S (T_s - T_1)/L = K_b A_b (T_1 - T_b)/L$, where $A_S = A_b$

$K_S (T_s - T_1) = -K_b (T_1 - T_b)$ (13)

2.6 Thermal conductivity of straw

To ascertain the thermal conductivity of the straw bale used, it will be important to calculate the density as thermal conductivity varies with density. When the density is calculated, the thermal conductivity will be extrapolated from the previous research works on strawbale (see the table of straw bale above)

Density = Mass/Volume = 1.11 Kg/ $0.01515 m^3$ = $73.3 Kg/m^3$

Thermal conductivity of straw bale the corresponds to this value on the graph is 0.062 W/m.K

Table I : A Table of Thermal Conductivities at Various Densities

DENSITY (Kg/m^3)	THERMAL CONDUCTIVITY ($Kg/K.m^3$)
63	0.0594
76	0.0621
85	0.0619
102	0.0632
108	0.0632
110	0.0635

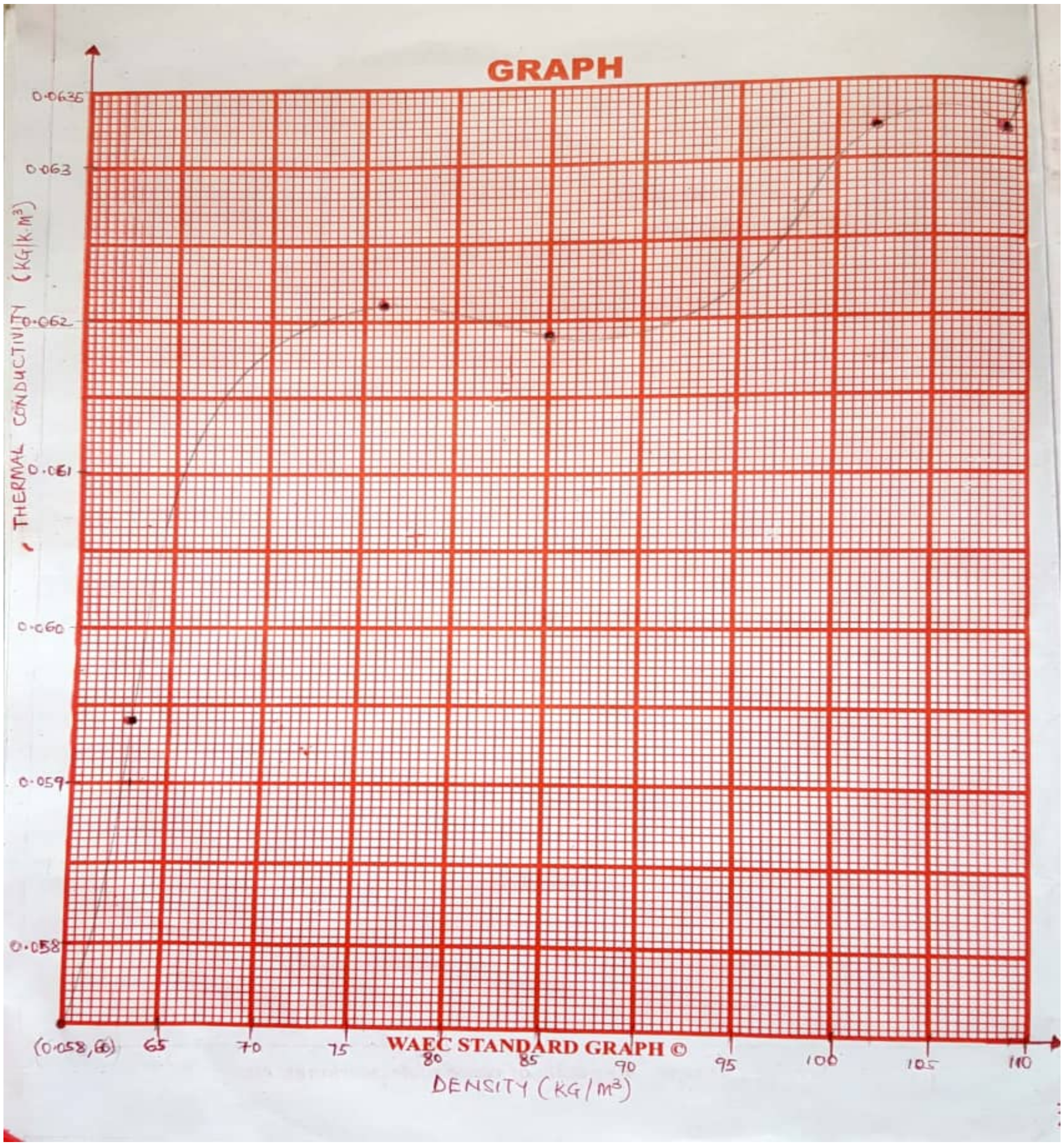

Fig 5 : A graph showing thermal conductivity of straw bale at different densities

2.7 Calculations for Sandcrete Block Mould:

Area= 0.045m x 0.225m = 0.101m^2

Length = ½ of Total mould length = ½ x 0.300 m = 0.150m

Volume of Sand-crete Mould = Area x Length = 0.101m^2 x 0.150m = 0.01515m$^{3.}$

Thermal Conductivity of sandcrete block mould at 1:7 mix ratio = 0.115 W/m.K (http://datad.aau.org:8080/jspui/handle/123456789/739)

2.8 Calculation for Straw Bale Mould

Area = 0.045m x 0.225m = 0.101m^{2}Length = ½ of Total mould length = ½ x 0.300m = 0.150m.Volume of straw bale mould = Area x Length = 0.101m^2 x 0.150m = 0.01515m^3

Density of Straw-Bale Mould = Mass/Volume = 1.11Kg /0.01515m^3 = 73.3 Kg/m^3

Thermal Conductivity of Straw bale mould(from graph 1) = 0.062 W/m.K.

Temperature readings for 20 days were taken and the results tabulated as shown in the next chapter.

The internal Temperature measurement was made for 20 days by using a room thermometer

Table II : Measured Temperature values of Lokoja

	Temperature (Min) (^{0}C)	Temperature (Max) (^{0}C)	Temperature (Mean) (^{0}C)
0SEP-DAY 1	22	29	25.5
SEP DAY 2	21	29	25.0
SEP DAY 3	22	30	26.0
SEP DAY 4	21	29	25.0
SEP DAY 5	21	28	24.5
OCT DAY 1	21	31	26.0
OCT DAY 2	22	30	26.0
OCT DAY 3	22	30	26.0
OCT DAY 4	21	29	25.0
OCT DAY 5	21	30	25.5
NOV DAY 1	21	29	25.0
NOV DAY 2	22	30	26.0
NOV DAY 3	22	29	25.5
NOV DAY 4	22	30	26.0
NOV DAY 5	21	31	26.5
DEC DAY 1	21	31	26.5
DEC DAY 2	19	32	25.5
DEC DAY 3	19	32	25.5
DEC DAY 4	19	32	25.5
DEC DAY 5	18	33	25.5

Table III : Table of Computation of Temperature Values

Mean External Temperature, T_{ext} (^{0}C)	**Mean Internal Temperature of SSIM Mould wall, T_{ssim} (^{0}C) (prototype)**	**Mean Internal Temperature of normal Sandcrete wall, T_s (^{0}C)**	**Temperature Value at the interface SSIM mould, T_1(^{0}C), $K_S(T_s-T_1) = K_b(T_1-T_b)$**	**Temperature Difference through the Sandcrete Section, ΔT_s (^{0}C), $T_{ext}-T_1$**	**Temperature Difference through the strawbale section, , $\|\Delta T_b\|$ (^{0}C), $\|T_1-T_{ssim}\|$**
25.5	19.5	22.0	23.38	2.12	3.88
25.0	19.0	21.0	22.89	2.11	3.89
26.0	18.0	22.5	23.20	2.80	5.20
25.0	17.5	21.5	22.37	2.63	4.87
24.5	18.0	21.0	22.23	2.27	4.23
26.0	19.5	23.0	23.72	2.28	4.22
26.0	17.0	21.0	22.85	3.15	5.85
26.0	20.0	24.0	23.90	2.08	3.9
25.0	16.5	22.0	22.05	2.95	5.55
25.5	18.5	23.0	23.03	2.47	4.53
25.0	17.5	22.5	22.40	2.60	4.90
26.0	18.0	23.0	23.20	2.80	5.20
25.5	17.5	22.0	22.68	2.82	5.18
26.0	18.0	21.5	23.20	2.80	5.20
26.5	17.5	21.5	23.36	3.14	5.86
26.5	19.0	22.0	23.89	2.61	4.89
25.5	17.0	21.0	22.51	2.99	5.51
25.5	18.5	21.0	23.03	2.47	4.53
25.5	17.0	21.5	22.51	2.99	5.51

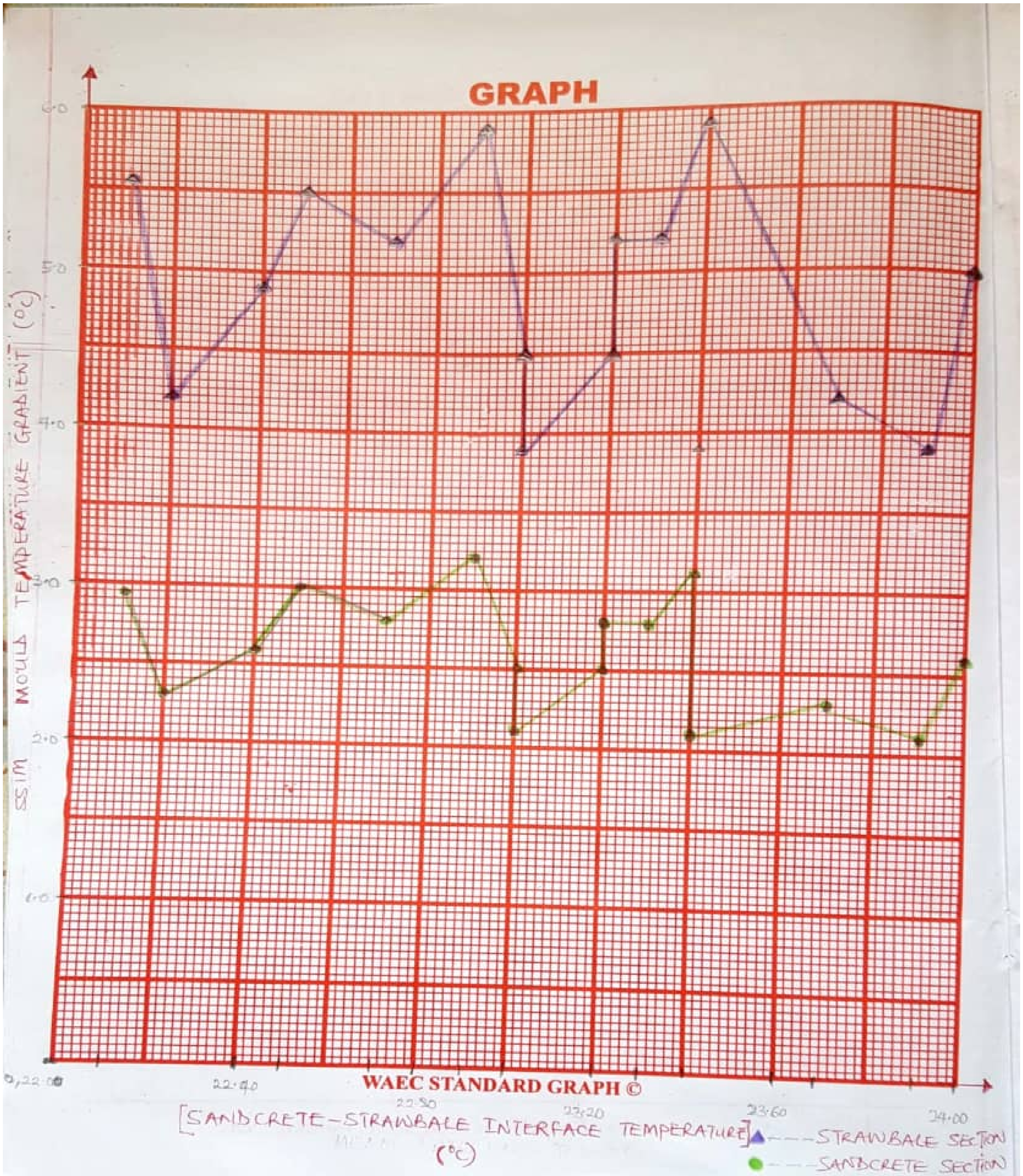

Fig 6. A graph showing the independent temperature gradients of the sandcrete and strawbale in a mould sample.

III. RESULTS OF QUESTIONNAIRE

The numbers of responses collated from distributed questionnaires to 100 inhabitants of Lokoja and its nearby villages are summarized as follow

Table IV : Tabulation of Questionnaire Reports

FACTOR / REMARK	THERMAL INSULATION	STRUCTURAL STRENGTH	COST CONVINIENCE	SOUND INSULATION	AVAILABILITY
EXCELLENT	SSIM=35 Sandcrete=05	SSIM=10 Sandcrete=34	SSIM=25 Sandcrete=18	SSIM=10 Sandcrete=26	SSIM=18 Sandcrete=21
VERY GOOD	SSIM=37 Sandcrete=02	SSIM=15 Sandcrete=20	SSIM=07 Sandcrete=05	SSIM=15 Sandcrete=17	SSIM=11 Sandcrete=21
GOOD	SSIM=10 Sandcrete=2	SSIM=2 Sandcrete=5	SSIM=04 Sandcrete=03	SSIM=07 Sandcrete=13	SSIM=05 Sandcrete=08
INDIFFERENT	SSIM=4 Sandcrete=3	SSIM=1 Sandcrete=8	SSIM=05 Sandcrete=11	SSIM=03 Sandcrete=08	SSIM=13 Sandcrete=none
FAIR	SSIM=none Sandcrete=2	SSIM=1 Sandcrete=3	SSIM=04 Sandcrete=05	SSIM=none Sandcrete=01	SSIM=2 Sandcrete=1
BAD	SSIM=none Sandcrete-none	SSIM=1 Sandcrete-none	SSIM=02 Sandcrete-11	SSIM=none Sandcrete-none	SSIM=none Sandcrete-none
TOTAL	**100**	**100**	**100**	**100**	**100**

3.1 Pearson's chi square analysis of thermal insulation responses

A Chi Square χ^2 is used to investigate whether distributions of categorical variables differ from another.

For a 2x2 contigency table, the Chi Square statistic is calculated as

Chi Square $\chi^2 = (ad\text{-}bc)^2 (a+b+c) / (a+b)(c+d)(a+c)(b+d)$

Degree of freedom = (Number of row -1) x (Number of column-1) = (2-1)(2-1)= 1

Table V: General Notation of Contingency table and Chi Square Distribution Probability Level

Variable 2	Data type 1	Data type 2	Total
Category 1	a	b	a+b
Category 2	c	d	c+d
Total	a+c	b+d	a+b+c+d = N

Df	0.5	0.10	0.05	0.02	0.01	0.001
1	0.455	2.706	3.841	5.412	6.635	10.827
2	1.386	4.605	5.991	7.824	9.210	13.815
3	2.366	6.251	7.815	9.837	11.345	16.268
4	3.357	7.779	9.448	11.668	13.277	18.465
5	4.351	9.236	11.070	13.388	15.086	20.517

For this purpose, the the most favourable responses are considered ('Excellent' and 'very good').

Table VI : Table of Computation Values

	SSIM WALLS	SANDCRETE WALLS	SUM
EX	35	05	40
VG	37	02	39
SUM	72	7	79

Computing the values using the equation above, we have a Chi Square, χ^2 value of 1.328.

From the Chi distribution table, the predetermined level of significance, p-value is 0.05, and the degrees of freedom from the table above are 1.

The Chi Square value of 1.328 falls between 0.455 and 2.706. P is more than probability level of 0.05, i.e, P>0.05. Therefore, we fail to reject the null hypothesis. That means there is no significant difference in the proportion of preference for each of the SSIM walling and sandcrete walling. The interpretation of this is that there is conformity in the high preference for SSIM wall over a sandcrete wall respectively

IV. DISCUSSION OF RESULTS

From the results of the research, it can be proved that straw bale has a lower thermal conductivity, lower thermal transmittance and higher thermal resistivity. When the temperature difference of the interior containing the strawbale and the interface section temperature,T_1-T_b, is compared with the exterior containing the sandcrete and the interface section temperature, T_s-T_1,It can be proven that the former has a higher temperature values. The higher temperature difference value in the straw bale section of the Sandcrete-Strawbale Interface Mould indicates that straw bale has a lower thermal transmittance. This higher temperature gradient, as can be deduced from the graph means that straw bale retains more heat than sandcrete. The addition of strawbale to sandcrete gives the Stawbale-Sandcrete Interface Mould, SSIM, a good temperature control, thereby making the interior wall cooler for living comfort. The outer sandcrete layer gives the wall external aesthetic and solidity from external factors. It can also be proven from the temperature readings during the course of the research that walling materials containing sandcrete-strawbale Interface mould, SSIM has cooler interior temperature compared with conventional sandcrete wall.

In calculating the thermal conductivity of the strawbale, it was expedient to calculate the density of the straw that will give an intrinsic thermal conductivity. The graph of density is plotted against thermal conductivity values for a straw bale. It is found that the higher the density, the higher the thermal conductivity values. The mass of strawbale used for the mould was 111g.The volume of the mould was calculated to get the volume of the straw used. The volume was found by multiplying the area of the mould by the thickness. The density was then calculated for the straw. The density was found to be 73.3 Kg/m^3.This was used to trace the thermal conductivity value of 0.062W/m.K. The thermal conductivity of the sandcrete layer is extracted from established research works on sandcrete blocks and the value is calculated to be 0.115W/m.K.

The mean external temperature value is used for the purpose of this experiment as it represents the conventional external climatic temperature of the area under study.

The questionnaire samples results for other building factors (thermal comfort, cost, availability, structural and sound insulation) also shows that strawbale is a viable building materials and it has a lot of positive improvements to the construction industry.

The Chi Square statistical analysis shows that there is no significant difference in the proportion of preference for each of the SSIM walling and sandcrete walling respectively. The interpretation of this is that there is conformity in the high preference for SSIM wall over a sandcrete wall.

V. CONCLUSION AND RECOMMENDATION

In the light of the findings from the study, the thermal comfort and cost of residential buildings are major factors. From past researches, there have been works on various building material that suit different environmental needs. Some of these materials are preferred to another. In this research, Sandcrete-Strawbale Interface Mould, SSIM, has been proven as a more effective walling system in tropical regions. As can be deduced from the temperature readings, heat flux calculations and questionnaire analyses through the use of Pearson’s Chi Square statistical analysis, SSIM Composite Mould is recommended for builders in the construction industry.

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