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NATURAL VENTILATION: SHIELDING SHELTERS FROM THE SOLAR RADIATION

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ABSTRACT

This work involves the assessment of buildings for their internal microclimatic condition in the southern and northern parts of Nigeria as case study. Meteorological data, used for the analysis, were collected so as to assess possible ways of enhancing internal microclimate by controlling direct solar radiation entering the building. From the results, about 60% of heat gained directly from the sun's rays are assumed to take place through building envelopes (walls) and openings (windows). Minimum opening sizes required was obtained in January with 15% opening size, ensuring proper cooling and reduce heat-gain when shading is used. Without shading however, 70% opening size is necessary. It can be seen that for critical period the available wind ventilation is enough to counteract the heat transmitted through walls. Though, this work has shown that the unplastered earth is the best material for wall for a building structure as it resists heat transmission better than the plastered earth and sandcrete wall, and because a building wall cannot be left unplastered, the plastered earth wall is always considered favourable. Sun shading and the effect of opening have shown simple and effective ways of regulating direct sunshine seeping into our buildings. It could be recommended, as an added advantage, that the use of an opening of low central inlet be considered with high outlet.

KEYWORDS: Solar radiation, ventilation, heat transfer, shield and intensity

1.0 INTRODUCTION

Solar energy is the energy received by the earth from the sun. The earth receives energy amounting to 1×10^{18} kilowatt-hours (Caldas and Norford, 2003). This energy is equivalent to about 1000times the known reserves of oil or more than the 20000 times the present annual consumption of the energy of the world. However despite this abundance, solar energy is the major source responsible for heat built up inside a building during hot season. Man has contributed immensely to the depletion of ozone layer, which naturally shields the earth and her inhabitants from outburst of sunrays. This single action has called for a way of protecting our living buildings from direct sun radiation. The heat from the sunrays is transmitted into the rooms through building material elements (walls, roofs and others) by conduction, convection, and radiation. Conduction is the mechanism of heat transfer by which heat or cold energy is transferred through a solid matter while convection is the transport of energy by mixing in addition to conduction and radiation is the transfer of thermal energy by electromagnetic waves (Mcquiston and Parker, 1977). The heat and cold affect the comfortability of the occupants of a building, and must therefore be reduced by selection of suitable building materials for wall, which is the major building envelope, so as to regulate the internal microclimate whereby minimizing the unnecessary consumption of fuel that could be utilised otherwise.

Today, roughly half of energy consumption is used to run services for ventilation in buildings (Ayres et al, 1998). Crude oil (fuel) that will not be available in future accounts for large quantity of non-renewable fossil used to generate this energy at home. Apart from this the processes of conversion of energy from one form to another also have lasting negative effect on the environment through emission of gases and harmful products. This situation calls for a rapid and fundamental reorientation in our thinking, particularly on the part of the planner and institutions involved in the process of construction and energy use. The form of our future built environment must be based on a responsible approach to nature and use of the inexhaustible energy potential of the sun in building.

This paper covers the assessment of buildings for their microclimatic conditions in the southern and northern parts of Nigeria as a case study. The country was zoned in two because of similarity of each zone's climatic conditions. Meteorological data were therefore collected, from Lagos for the three southern zone, while four northern states (namely, Katsina, Sokoto, Niger and the Federal Capital Territory (FCT)) were chosen for the northern zone, for the analysis. The data were collected so as to assess possible ways of enhancing internal microclimate by controlling direct solar radiation entering the building. Different and common wall materials (earth and sandcrete) were chosen to help evaluate a more reliable building material to be used in regulating and controlling internal environment. In this work however, emphasis was laid on natural control of the environment by utilizing the effect of openings and preventing the transfer of heat, by the sun radiation, through the wall material into the building.

Climatic data collected covered major weather elements that affect the use of natural ventilation including 1) rainfall, 2) solar radiation and sunshine hour, 3) maximum and minimum temperature, 4) cloud covers, 5) relative humidity and 6) wind speed and direction. The active solar system uses mechanical means to collect store and distribute solar energy to heat or indirectly cool a building. Encyclopedia of Science and Technology (1997) classified active system as generally composing of collector, converter, distributor and a control. This system is efficient but requires installation and maintenance of the collector and converter to function well. The passive solar energy system uses the building itself in combination with solar energy as an energy-saving system. This system uses its environment, feature of its site, its materials and structure so that it reduces consumption of fuel in the expedition of energy. It consists of cooling and heating system. This method is adopted herewith by producing natural ventilation in our building.

2.0 HEAT TRANSFER

From the theory proposed by Bansal et al (1993), air flow induced by thermal force is proportional to square root of pressure head and force of the inlet, that is,

$$Q = K A h (\Delta T)^{1/2} \qquad (1)$$

where Q = Volume rate of air flow (m^3/hr), A = free area of the inlet opening m^2, K = Constant developing upon resistance, h = Vertical distance between inlet and outlet, ΔT = Average temperature between indoor and outdoor ($T_1 - T_2$). Heat transfer through conduction in Watt is given by,

$$q = K A (T_1 - T_2) / d \qquad (2)$$

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where K = Thermal conductivity of material, A = Area of the material in contact with heat, d = Material thickness. Heat can also be transmitted without using either a solid or a fluid as a medium. Radiant heat transfer according to Stefan – Boltzman given as,

$$q = \sigma \varepsilon A (T_1^4 - T_2^4) \quad (3)$$

where σ = Stefan–Boltzman and .ε = emissivity of the material.

2.1 Climatic Factor

The basic climatic factors, their significance and how they are taken into consideration in building depend on the region in which the building situates. Basic climatic factors include 1) Temperature, 2) Solar radiation, 3) Rainfall and air humidity, 4) Wind speed and direction, 5) Sunshine. These data collected are considered in the assessment of the natural ventilation with respect to three building materials (plastered sandcrete or control, plastered and unplastered earth) in this work.

3.0 COLLECTION AND ANALYSIS OF DATA

In order to assess the effects of climatic conditions, with respect to the sun energy reaching directly into our building, by transfer through the building envelope or through the openings, data (main source: Meteorological Department Agency of Nigeria, for both the southern and northern zones) were collected for the two zones while the average of five years data are shown in Table 1 and 2.

Table 1: Average meteorological monthly data of 5 years (1998-2002) for Northern zone

Month	Max Outside Temp (°c)	Min outside Temp (°c)	Sunshine Hours(hr)	Mean Cloud Coverage (Eighths)	Rainfall (mm)	Relative Humidity (%)	Wind Speed (m\s)	Solar Radiation Intensity (w/m^2)
JAN	32.2	18.6	7.3	6.7	0.0	25.8	7.5	188.0
FEB	35.5	20.4	8.6	6.8	2.8	23.7	7.1	310
MAR	37.3	23.4	6.5	6.9	26.6	35.5	5.5	392
APRIL	37.1	24.5	7.4	6.8	48.4	50.3	5.6	619
MAY	35.1	23.9	7.4	6.9	113.3	66.1	5.3	640
JUNE	33.5	27.8	7.9	6.9	105.6	69.5	5.6	605
JULY	30.7	22.5	6.4	6.8	196.4	79.5	5.1	640
AUG	29.3	21.8	5.2	6.9	261.3	84.0	4.6	612
SEP	31.4	22.2	6.9	6.9	156.3	72.5	3.7	392
OCT	33.7	21.3	8.4	6.7	62.5	61.2	3.0	310
NOV	34.4	19	8.7	6.6	28.6	36.2	4.9	188
DEC	32.6	17.5	7.9	6.7	0.0	31.0	6.7	68.3

Source: Meteorological Department Agency of Nigeria, FTC, Abuja.

Table 2 : Average meteorological monthly data of 5 years (1998-2002) for Southern zone

Month	Sunshine Hour (hrs)	Temperature (max) ^{0}C	Relative Humidity @9GMT %	Relative Humidity @15GMT %	Cloud Cover-Age (Eighths)	Rainfall (mm)	Wind speed	
							(Knot)	(m/s)
JAN	4.36	31.25	71.8	57.6	6.575	4.5	4.06	5.5
FEB.	5.30	32.14	79.5	67.75	5.075	26.7	4.58	5.1
MAR	5.42	32.12	75.8	67.4	6.825	105.2	4.98	5.5
APRIL	6.02	31.8	78.2	73.4	6.65	141.6	4.66	5.6
MAY	5.93	30.68	79	73	6.7	255.4	3.6	4.3
JUNE	3.86	39.5	83	76.5	6.82	331.26	3.92	5.6
JULY	3	27.9	35.2	79	7.25	212.76	4.9	6.1
AUG	2.95	28.02	84.25	79.6	7.02	55.13	4.78	5.6
SEP	3.2	28.48	84.67	70.50	7.03	285.78	4.2	5.7
OCT	3.87	28.53	81.5	75.25	6.85	119.03	3.72	4.2
NOV	5.75	31.10	79.5	66	7	25.13	3.4	4.1
DEC	5.8	31.53	75.6	60.67	7.05	19.5	3.26	5.7

Source: Meteorological Department Agency of Nigeria, FTC, Abuja.

From Adedeji & Adegun (2001) the results of the internal temperatures of un-plastered and plastered earth wall, as well as sandcrete block walled building were shown in Table 3 for each month, while the internal air temperature proposed by Ogunrinde for wall of various materials are given in the empirical formulas as:

For unplastered earth wall $Y = 1.0591X - 2.4668$ (4)

Plastered earth wall, $Y = 0.7501X + 7.4462$ (5)

And sandcrete wall $Y = 0.500X + 15.997$ (6)

where Y, X = external and internal air temperature respectively.

Table 3: Internal Air Temperature of Building walls (^{o}C)

Month	External Air Temperature	Room (internal) air Temperature		
		Unplastered Earth wall	Plastered Earth wall	Sandcrete block Wall
JAN	32.2	31.9	31.6	30.1
FEB	35.5	35.5	34.1	33.7
MAR	37.3	37.4	35.4	34.6
APRIL	37.1	37.2	35.3	34.5
MAY	35.1	35.0	33.8	33.5
JUNE	33.5	33.3	32.6	32.7
JULY	30.7	30.3	30.8	31.3
AUG	29.3	28.8	29.4	30.6
SEP	31.4	31.1	31.0	31.7
OCT	33.7	33.5	32.7	32.8
NOV	34.4	34.3	33.2	33.2
DEC	32.6	32.4	31.9	32.3

Source: Adedeji and Adegun (2001)

Heat transmission Q in Watt through those materials was examined and calculated based on.

$$Q = U\ A\ \Delta T \qquad (7)$$

Where U = heat transmittance coefficient, $\Delta T = T_2 - T_{,}$ T_1 = internal temperature, T_2 = external temperature. Negative indicates heat gain while positive indicates heat loss.

For un-plastered earth wall, U = 1.431 W/ $m^2\,^{o}C$, while the plastered earth wall has U = .9606 W/ $m^2\,^{o}C$ and a 225mm sandcrete block wall has U = 3.279 W/ $m^2\,^{o}C$.

4.0 ANALITICAL APPROACH

4.1 SOLAR INTENSITY

Temperature of the solar radiation that is the intensity of sun reaching the surface of the wall is derived from equation of heat due to solar radiation and convection to ambient air temperature,

$$I_s = \frac{(T_{es} - T_{ea})h}{\alpha} \qquad (8)$$

while,

$$T_{es} = \frac{I_s \alpha}{h} + T_{ea} \qquad (9)$$

where T_{es} = equivalent temperature of the sun's radiation, T_{ea} = external air temperature around the wall, h = coefficient of heat transfer (13 – 15 W/ $m^2\,^{o}C$ for the external surface of a vertically placed wall), α = absorptivity of material (0.8 – 0.9) for light and red earth respectively. Influence of solar radiation on internal temperature may be cut off through shading. The equivalent temperature of the internal surface of the wall, due to sun's radiation is shown in Table 4 based on the external temperature in Table 3. The value shows a significant value of temperature between April and August.

Table 4: Equivalent temperature of the sun's radiation ^{o}C

Month	Tea	I_s	Tes
JAN	32.2	188	45.2
FEB	35.5	310	57.0
MAR	37.3	392	64.4
APRIL	37.1	619	80.0
MAY	35.1	640	79.4
JUNE	33.5	605	75.4
JULY	30.7	640	75.0
AUG	29.3	619	72.2
SEP	31.4	392	58.5
OCT	33.7	310	55.2
NOV	34.4	188	47.4
DEC	32.6	68.3	37.3

Note: Equivalent temperature is calculated from T_{ea} in Table 3

4. 2 . Wind Power

Wind power per unit area is calculate form $q = \rho v^3 /3$ (Sheatan) in which ρ = density of the air varying from 1.225kg / m^3 at sea level to 75% this value at higher elevation and v is the speed of air. Relationship between the speed of wind and the wind power is shown in Table 5. The results for only the northern zone are shown here.

Table 5 Wind Power (average for the northern zone)

Month	Wind Speed (v) m/s	Wind Power(q) W/m^2
JAN	7.5	251.9
FEB	7.1	213.7
MAR	5.5	99.4
APRIL	5.6	103.4
MAY	5.3	88.9
JUNE	5.6	103.7
JULY	5.1	79.4
AUG	4.6	58.1
SEP	3.7	30.3
OCT	3.0	16.1
NOV	4.9	70.3
DEC	6.7	179.6

4.3. Temperature- Humidity Index

The temperature humidity index of an environment is calculated using the temperature-humidity equation, which is given by (Ogunrinde, 1998):

$$THI = T_d - (0.55 - 0.55 * RH) * (T_d - 58) \qquad (10)$$

where THI = Temperature-Humidity Index (^{o}F), T_d = dry bulb temperature which is given by the mean maximum temperature, RH = Relative Humidity from Tables 1 and 2. Thus with the above Equation (10), the temperature-humidity index (THI) are presented as shown in Table 6, while Table 7 gives the relationship between the temperature and the THI.

Table 6: showing heat transmission through wall, THI and the corresponding wind power.

Month	Heat transmission in Plastered Mud- wall (W/m^2)	Wind Power in (W/m^2)	THI %
JAN.	-0.35	5.93	84
FEB	-0.62	8.54	86
MAR	-0.56	10.91	86
APRIL	-0.48	8.99	85
MAY	-0.21	4.12	84
JUNE	0.07	5.36	83
JULY	0.45	10.40	80
AUG	0.42	9.68	80
SEP	0.32	6.55	81
OCT	0.07	4.53	82
NOV	-0.32	3.48	85
DEC	-0.41	3.08	85

Table 7: Temperature-Humidity Index ^{O}F

Month	Dry bulb temperature		Relative humidity (RH) %	THI %
	T_d °C	T_d °F		
JAN	32.2	90.0	25.8	76.9
FEB	35.5	95.9	23.7	80.0
MAR	37.3	99.1	35.5	84.0
APRIL	37.1	98.8	50.3	84.5
MAY	35.1	95.2	66.1	87.6
JUNE	33.5	92.3	69.5	88.3
JULY	30.7	87.3	79.5	86.5
AUG	29.3	84.7	84.0	84.0
SEP	31.4	88.5	72.5	82.4
OCT	33.7	92.7	61.2	83.9
NOV	34.4	93.7	36.2	81.3
DEC	32.6	90.7	31.0	78.3

5. 0 ANALYSIS AND DISCUSSION OF RESULTS

Sun as the determinant and controller of entire earth energy available and use has major effect on structure and ventilation in many ways. Adequate ventilation, daylight, and energy consumption directly rely on openings because they initiate and determine air temperature, air humidity, airflow, air circulation and solar radiation in our buildings. As shown in Table 3, the external air temperature (T_{ea}) is enough to cause significant discomfort to human being. A slight decrease in sunshine coupled with higher cloud cover and rainfall between June and October force air temperature to drop to values below 30°C. In addition to air temperature, radiation also varies with those factors. This explains why room temperature is higher due to lower cloud cover and higher sunshine hour.

Comfortability does not depends on temperature alone, humidity also play a major role. Low humidity favors heat loss. Normally in hot weather around the equator, relative humidity should be below 50% (Encyclopedia of Science and Technology (1997)). As illustrated in the Table 2, the temperature in June hits 39.5 within only 3 hours sunshine and relative humidity of 83% of 6.82 cloud cover which cannot be compared to the allowable of less than RH of 50%. It is highest in the early morning hours when fog and dew are most likely to form. Humidity depends on temperature radiation, presence of water bodies and evaporation from surfaces.

Evaporation created in human body, an avenue for cooling by drying is affected by air velocity. Generally, air circulation in building relies on wind speed and direction. Wind speed plays a major role in sizing of opening, building location and construction. However, in our environment the wind speed is too low to trigger off any meaningful use. The lowest observed data was recorded in October and January (2 m/s).

5.1 Comfortability

From the analysis of the temperature and humidity through THI, a non-comfortable interpretation showed up where nearly the building occupants may feel uncomfortable. At critical period (October – April), THI was too high that could cause a rapid decreasing work efficiency. In order to build a reliable indoor climate the building material and design, shading and opening in building are considered.

5.2. Building material and design

Heat transfer through building material can give clear illustration of indoor climate. For instance in Fig 1 and 2, the heat transfer through three building walling materials was shown. Heat transfer in an un-plastered earth (for both north and south conditions) wall pluck negative all through proofing adequately prospective in increasing heat gain in the construction. This is often necessary at a certain time to aggravate heat loss instead of the latter. This illustrates importance of plastering the earth wall also as a better material (within the materials in this work) for regulating heat loss and heat gain. Sandcrete has a very high heat transmittance coefficient (U) if compared with earth wall despite an enhancement of air movement through solar chimney as proved by Ogunrinde (1998).

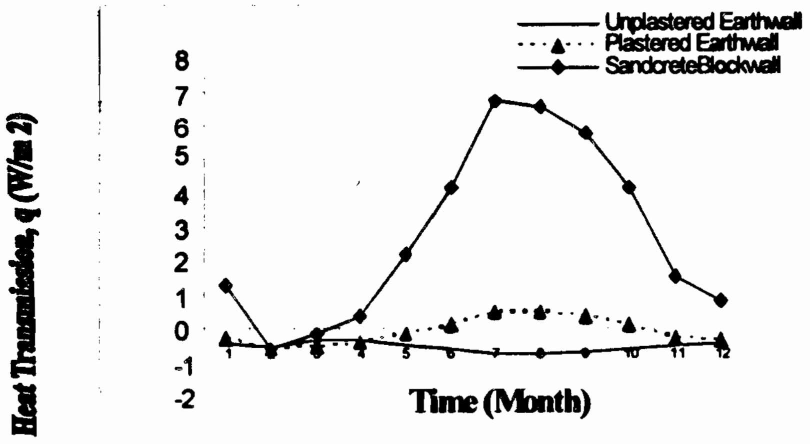

Fig 2 Monthly heat transfer into the rooms through different wall materials for Northern zone

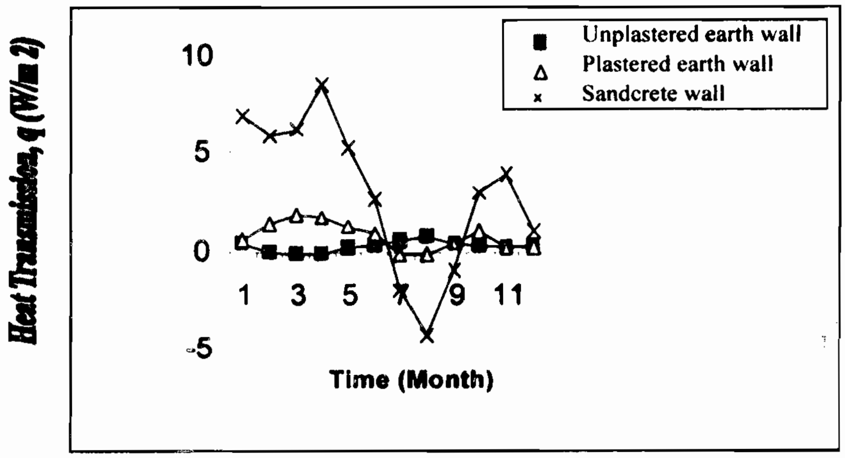

Fig 3: 2 Monthly heat transfer into the rooms through different wall materials for Northern zone

5.3 Sun shading

The variation of indoor temperature with and without shading for a plaster earth wall, being the favourable material in this work, is as shown below in Fig 4. Shading removes increase in temperature due to solar influence leaving only the air temperature, and a significant change in temperature was obtained as the temperature increases .Sun shading may include the use of shading devices, landscaping and other structures. Any method of shading applied should be done so as not to block daylight, damage drainage, footing or foundation or affect structural stability of the building.

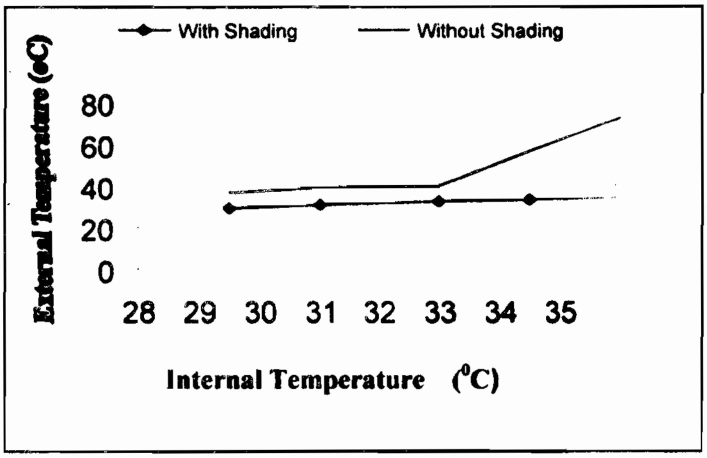

Fig. 4 Design variation of internal and external temperatures

5.4 Effect of opening

Air movement and cross ventilation greatly depends on building opening and air velocity. For minimum opening, about 60% of heat gain is assumed to be taking place in building wall and opening(s). Minimum opening required from the graphs in Fig 5 and 6 were obtained in January with 15% opening size, this will ensure proper cooling and reduce heat gain when shading is used. Without shading however, 70% opening size is necessary. It can be seen that for critical period the available wind ventilation is enough to counteract the heat transmitted through walls.

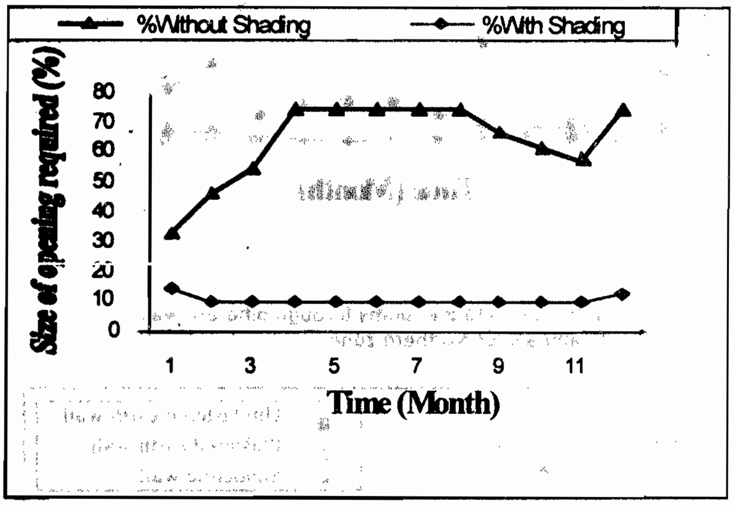

Fig. 5: Shading effects of openings on the plastered earth wall (Southern zone)

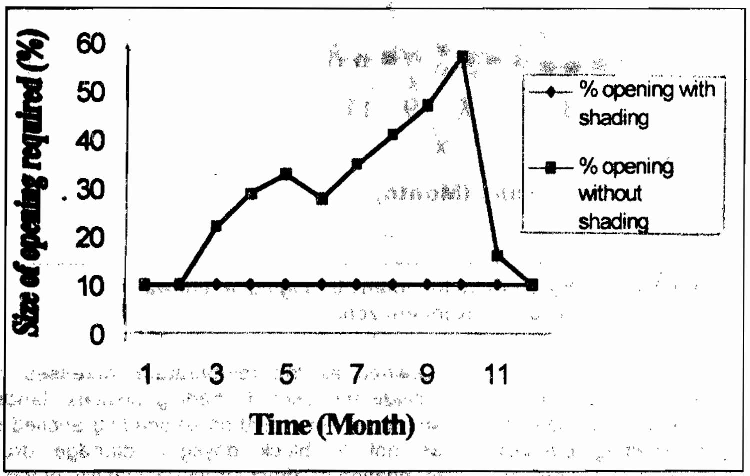

Fig 6: Shading effect on the plastered earth wall (Northern zone)

6.0 CONCLUSION AND RECOMMENDATION

From the results of this study, it is confirmed that solar energy can be used to enhance room ventilation, which is also depending on how the selection is made concerning building material and design of shading and opening size. Recommended values in this work could be used to effect the ventilation in our buildings.

It can thus be concluded that the unplastered earth wall is the best wall for a building structure as it resist heat transmission better than the plastered earth wall and the building block wall. However, because a building wall cannot be left unplastered, the plastered earth wall is always considered favorable. And that rainfall relative humidity and mean cloud coverage affect the temperature of an environment, which in turn determines the level of comfort in a building structure. Therefore ventilation can only be effective in a building structure if other factors are kept below minimum.

Sun shading and the effect of opening have shown simple and effective ways of regulating direct sunshine seeping into our buildings. It could be recommended as an added advantage that the use of an opening of low central inlet should be considered with high outlet. Colour selection in painting could as well slow down the transfer of heat through the plastered earth wall.

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