A.M.S.E.

Association for the advancement of Modelling
& Simulation techniques in Enterprises

2004 - Vol. 73. N° 1.2

Modelling, Measurement & Control

B

GENERAL PHYSICS, ELECTRONICS,

ELECTRICAL ENGINEERING

ISSN 1259-5985

Received: Nov. 2002; Revised (last): May 8, 2003; Accepted: Sept. 11, 2003

Determination of clay brick wall thickness for comfortable room temperature in Bida town

F. O. Akinbode and O. J. Okegbile

Department of Mechanical Engineering, Federal University of Technology, Minna, Niger State, Nigeria.

Abstract

The thickness of clay brick wall has been analyzed for comfortable room temperature in Bida town of Niger State(Latitude 9°8'). This comfortable room temperature is without the need to use air-conditioner. Conductive heat transfer analyses, with and without heat sources were made for unsteady state conditions to obtain a suitable thickness. To validate the result, a prototype structure of clay was built without windows. Experiment was performed using this prototype by keeping it in the sun throughout the day. The variation of temperature both inside and outside the prototype structure were recorded. The theoretical results were then compared with experimental results and were found to be in agreement. A brick thickness of 224.5mm was found to be suitable for building application.

Keywords

Heat transfer, numerical analysis, modelling.

Introduction

The quest for a safe and comfortable environment dates back to antiquities. Birds build nests and Rabbits dig holes. Early human society created remarkably pleasant accommodation for themselves. Cliff dwellings carved under an overhang to block the summer heat, yet accessible to the warming rays of the winter sun is an example. The little that archaeology has revealed and the information from ethnographic and historical sources point to a rich architectural heritage in Nigeria[1].

The house started as a living space for human shelter. It later developed to provide space not only for residence but also for craft making, storage and relaxation. Traditional habitations differ in style and form according to the socio-economic pursuits and backgrounds, kinds of materials used and skills of the builders[2]. Materials commonly used to build houses in developing countries like Nigeria include timber, mangrove poles, palm fronds, grass, sand and swamp, clay and laterite soils, stones, wattle and daub (for walls)[3].

Despite that Nigeria is rich in various species of timber, timber houses are rare in Nigeria. One reason for this is that our erstwhile colonial rulers deliberately discouraged it to serve their home country's economic interests. They preferred a design in Reinforced concrete and steel materials which they could sell to Nigeria. Most of the reasons given for not using timber for building houses include that they are prone to fire outbreak; not durable because of susceptibility to termite and fungal attack; wear away rather quickly; and are easily broken into by burglars. The problem of fire has been solved by the introduction of certain chemicals, which completely inhibits burning of Wood. Chemicals that protect the timber from termite, beetle, beavers and fungal attack are also available.

Although construction with clay bricks has reached a sophisticated level, it has in recent times been neglected in favour of building methods from the developed countries. The universal availability and relative cheapness of clay are of great advantages today in view of the soaring prices and shortage of other materials. Clay brick remains unaffected by the international market system. Proper firing of clay brick can solve the associated problem of constant repairs after the rain.

Comfort and health are essential for productivity in all environments especially in the modern work environment. Thermal comfort has proved to affect the rate of recovery from sickness and performance such as vigilance, level of arousal, fatigue, attention and boredom. In the tropics, heat is a predominant problem. Tropical regions account for about 50% of the globe's surface[4]. In tropical regions, summer is long (over 100 day a year). In this period, temperature as high as 45°C is recorded and the average daily temperature in the hottest month of the year is not less than 20°C[5]. Thermal judgement of comfort or discomfort depends primarily on climatic variables such as air temperature, relative humidity, air movement and sun radiation. Other subjective factors that affect the sensation of comfort and discomfort include clothing, acclimatization, age and sex, body shape, subcutaneous fat, state of health, food and drink and skin colour.

Effective air conditioning for comfort can only best be achieved by mechanical cooling (air conditioning unit). Cooling is more difficult and costly than heating[6]. The economic depression in many developing countries like Nigeria makes it difficult for an average income earner to buy an air conditioner for thermal comfort. But by improved thermal insulation, the rate of heat flow into the building can greatly be reduced so as to have a comfortable environment without the use of cooling equipment. Good choice of clay and determination of a suitable thickness of brickwall can achieve comfortable temperature inside the building. By this heat conducted is minimized and the heat absorbed by the brick wall is dissipated to the surrounding after sunset when the ambient temperature has fallen.

Heat flows into a building by conduction through walls, convection through openings such as doors and windows and radiation from the sun. The rate at which heat is conducted through the wall of a building depends on temperature difference, thermal properties and thickness of the wall. The amount of Sun's radiation taken by a building can be regulated by choosing building materials of suitable solar radiation absorption factor. The ability of a material to take up solar energy largely depends on its colour. The availability of clay makes it convenient to assume that the cost of building with clay in Nigeria is cheaper than that of concrete (cement and aggregates). The thermal conductivity of clay (about $1.28 Wm^{-1}\,°C^{-1}$) makes it a better insulator than concrete (about $1.37 Wm^{-1}\,°C^{-1}$). Apart from its thermal advantage over concrete, clay vitrifies when fired to give a shining surface. This surface serves dual purpose; it is suitable for decoration and therefore may be left unplastered and unpainted, and it reflects heat radiated from the sun.

Theoretical analysis

The following are the assumptions made for the analyses;

(a) Conduction heat flow is one-dimensional through the wall

(b) Thermal properties of the material wall do not vary with position and temperature within the range considered

(c) Variation of moisture content of masonry is negligible

(d) Convection and radiation effects are negligible

(e) Walls do not have windows

(f) Binding mortar is well mixed such that thermal properties do not vary with positic and temperature.

One-dimensional conduction heat transfer equation with constant therm conductivity is given by equation (1)[7,8].

$$\frac{\partial^2 T}{\partial x^2} + \frac{q_g}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (1)$$

This governing equation can be solved with or without heat source q_g dependi on the case been considered and the applicable boundary and initial conditions.

Case 1: Without heat source

Consider a plane wall initially at uniform temperature T_i. The outs temperature is suddenly raised and maintained at T_o without heat source. The differen equation for unsteady state, one-dimensional conduction heat transfer becomes:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (2)$$

The initial and boundary conditions are:

$T(x,0) = T_i$ (uniform temperature throughout at time zero)

$T(0,t) = T_o$ for $t > 0$

The solution to this case is given by Schneider[9] as

$$\frac{T(x,t) - T_o}{T_i - T_o} = erf\left(\frac{x}{2\sqrt{\alpha t}}\right) \qquad (3)$$

with the Gauss-error function:

$$erf\left(\frac{x}{2\sqrt{\alpha t}}\right) = \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{\alpha t}}} \exp(-\eta^2)\, d\eta \qquad (4)$$

Case 2: With heat source

Consider a plane wall initially at temperature T_i and suddenly exposed constant heat flux of q_g/A. The initial and boundary conditions for the gove equation (1) are

(i) $T(x,0) = T_i$ (uniform temperature at time zero)

(ii) $$\frac{q_g}{A} = \left[-k\frac{\partial T}{\partial x}\right]_{x=0} \qquad for\ t > 0 \tag{5}$$

(the heat flux conducted to the system)

The solution for this case is[7]

$$T - T_i = \frac{2q}{kA}\sqrt{\frac{\alpha t}{\pi}}\exp\left(-\frac{x^2}{4\alpha t}\right) - \frac{qx}{kA}\left(1 - erf\left(\frac{x}{2\sqrt{\alpha t}}\right)\right) \tag{6}$$

Equations (3) and (6) were solved to obtain the thickness of the wall, x. Computer programs were written in Basic code to solve the equations. Equation (6) was solved by Newton-Raphson's method which is given as[10]

$$X_{n+1} = X_n - \frac{F(X_n)}{F'(X_n)} \tag{7}$$

An experiment

In order to validate the theoretical analyses an experiment was performed using a prototype structure shown in Figure 1.

A practical example

Materials

In our example we considered an unplastered rectangular clay brick (kaolinitic type) structure without windows (as shown in Fig. 1). Having dimensions:

Length – 560mm; Width – 557mm; height – 510mm; thickness – 80mm.

Thermometer, Thermistor Thermometer of range –40 to 100°C. Plywood of dimension 600mm by 600mm painted white on one surface and 1 Polythene sheet was considered.

Method

The structure was kept outside in the sun. It was covered with plywood with the face painted white facing the sun. The thermometer was directly exposed to the sun's radiation while the thermocouple was connected to measure the temperature inside the structure. The experiment was conducted for nine days. The readings were recorded simultaneously for the first three days at intervals of fifteen minutes, three days each for time intervals of thirty minutes and one hour respectively. The period of experiment was between 8.00am and 6.00pm. After each day's experiment, the structure was covered with polythene sheet to protect it from rain and forms of precipitation.

Thermal and Environmental parameters

The parameters substituted for the theoretical results are the data for Bida obtained from the Meteorological Department of the Bida Airport and Solar Centre of the Federal Polytechnic, Bida, Niger State. They are:

Initial uniform temperature $T_i = 24.0°C$

Sudden temperature rise $T_o = 37.3$ °C (average temperature of sunshine hours of the hottest day of the year)

Constant heat flux $q_a = 230\ Wm^{-2}$

Other parameters are:

Solar heating time $t = 8 \times 60 \times 60 = 28{,}800s$

Comfort temperature $T_c = 27.0$ °C[5]

Thermal properties of Kaolinitic type of clay used[7,11]:

Thermal diffusivity $\alpha = 5.4 \times 10^{-7}\ m^2\ s^{-1}$

Thermal conductivity $k = 1.28\ Wm^{-1}\ °C^{-1}$

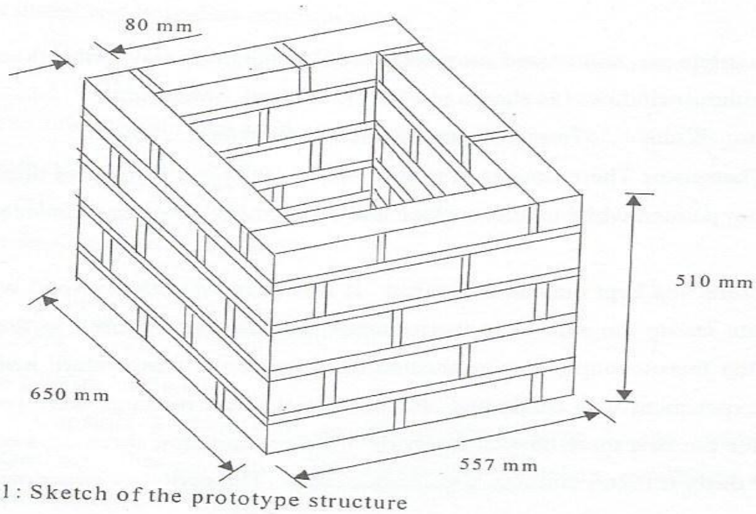

Fig.1: Sketch of the prototype structure

Results and discussion of results

Table 1: Thickness of Brickwall obtained for Bida

Case	Thickness (mm)
1. Sudden temperature change	224.47
2. Exposed to constant heat flux	225.79

Discussion

To validate the theoretical analysis, experiment was performed on a clay brick structure shown in fig. 1. Equations (3) and (6) were solved to determine the theoretical temperature history in the structure for the two cases considered. Figure 2 shows the graph of temperature against time of the day while figure 3 shows the graph of comfort temperature against brick thickness. The sharp increase in temperature for the case of change in temperature in Figure 2 was due to the small thickness of the brickwall relative to the temperature gradient. There was quick thermal response. This sharp increase accounts for its non-parallel behaviour with experimental result before convergence. The early increase is not the same for experimental results because the temperature outside was not suddenly raised as assumed in the computation.

As from the eleventh hour, the increase in temperature for the case of sudden change in temperature increased linearly converging to 33.5 °C. This is very close to the value 34.0°C that the experimental result also converged too. The case of constant heat source gives a linear increase in temperature without convergence. This is due to the second boundary condition that makes the constant heat flux to be conducted into the structure without any losses. From the graph of temperature of comfort versus corresponding thickness of brickwall (Fig. 3 obtained from equations 3 & 6), the thickness that will give the desired comfort temperature of 27.0 °C is 224.47 mm for the case of sudden change in temperature and 225.79 mm for the case of exposure to constant heat flux. As can be seen from the graph, an increase in thickness of brickwall above this value will give a very little temperature difference below the comfort temperature. This little temperature difference is negligible when compared with the corresponding increase in thickness of brickwall. It would be a wastage therefore to increase the thickness of brickwall above the thickness obtained for the case of sudden change in temperature.

Conclusion

Based on the theoretical analysis and experimental results obtained, it can be concluded that case 1, the case of sudden change in temperature is preferred to case 2, the case of exposure to constant heat flux. Also based on the weather parameters of Bida, Niger State, Nigeria, the suitable thickness of clay brickwall is 224.47 mm which can be approximated to 225 mm. This thickness is not too big as it is smaller than the conventional 228 mm cement block. Clay is readily available and therefore more economical than the cement block.

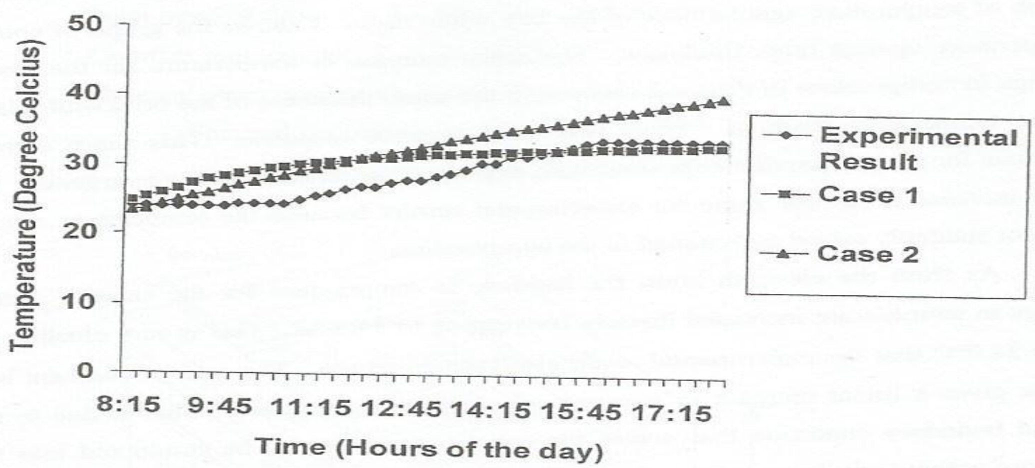

Fig. 2: Temperature Variations with Time

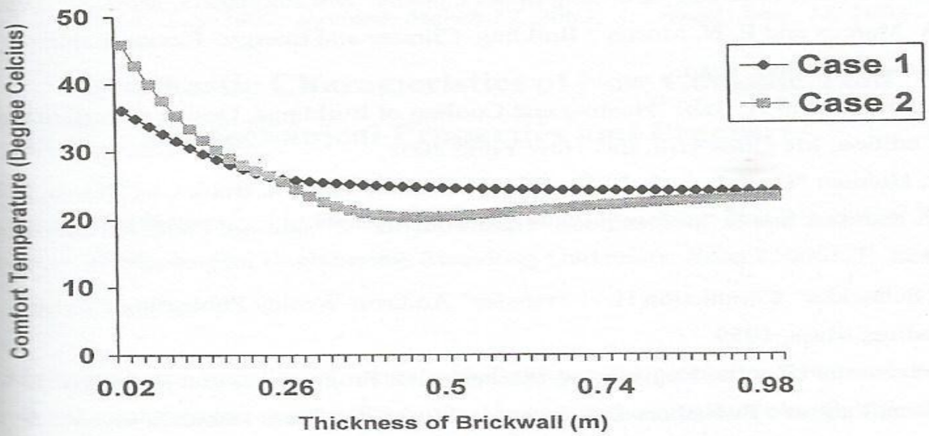

Fig. 3: Variation of Comfort Temperature with Thickness of Brickwall.

Nomenclature

$F(X_m)$ = function of X

$F'(X_m)$ = derivative of function of X

k = thermal conductivity

q_o = constant heat source

t = time

T = temperature

T_i = initial uniform temperature at time 0

T_a = temperature outside (ambient)

T_c = comfort temperature

X_m = m-th variable of X

α = thermal diffusivity

η is a dummy variable

References

1. W. B. Andar "Indigenous Technology" Ibadan University Press, Ibadan, 1992.
2. G. Daniel "The first civilizations" Pengium, Harmondsworth, 1971.
3. R. Spencer and D. Cook "Building Materials in Developing Countries" John Wiley, New York, USA, 1983.

4. T. M. Stoll and Evstrator "Building in hot Climate" Mir Publishers, Moscow, 1987.
5. T. A. Marcus and E. N. Morris " Building, Climate and Energy" Pitman Publishing Limited, London, 1980.
6. J. F. Kreider and A. Rabl "Heating and Cooling of Buildings, Design for efficiency" 2nd edition, Mc Graw-Hill, Inc. New York, 2002.
7. J. P. Holman "Heat Transfer" 9th edition, Mc Graw-Hill Int. Book Co., Tokyo, 2001.
8. B. V. Karlekar and R. M. Desmond "Heat Transfer" 2nd edition, Prentice Hall of India, 1989.
9. P. J. Schneider" Conduction Heat Transfer" Addison-Wesley Publishing Co. Inc. Reading, Mass, 1959.
10. K. A. Stroud "Further Engineering Mathematics, Programmes and Problems" 3rd edition, Palgrave Publishers Ltd (formerly Macmillan Press Limited)New Youk, 1996.
11. N. S. Billington "Thermal properties of Buildings" Cleaver-Hume Press, 1952.
12. M. Goldfinger "Villages in the Sun" Lund Humpries, London, 2001.
13. H. Fathy "Architecture for the poor" Chicago University Press, Chicago, 2000.
14. T. Kuehn, J. Ramsey and J. Threlkeld "Thermal Environmental Engineering" 3rd edition, Prentice-Hall, Englewood Cliffs, N. J., 1998.