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TIME DELAY AND DIMENSIONLESS FACTOR: THE INFLUENCE OF CLAY WALL THICKNESS ON THE TWO DYNAMIC CHARACTERISTICS OF BUILDING

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ABSTRACT

The evaluation of time delay and dimensionless factor provides a measure of the developed indoor thermal conditions and from an energy point of view, the possibility of reducing the energy load demands. For this Investigations were carried out on the time delay and dimensional factors of a clay building. In the computations, the periodic boundary and the convection boundary conditions to the outer surface of the wall were applied to the one dimensional transient heat conduction equation. A set of clay building was used in the analysis. The computations were repeated for the five different clay walls thickness and the influence of the wall thickness on time delay and dimensionless factor were investigated. It was found that thickness of wall has a very pronounced exponential relation with the dimensionless factor and time delay.

Keywords: Time delay, Dimensionless factor, Dynamic Characteristics and Building.

INTRODUCTION

The geometrical and the thermo-physical properties of building materials, as well as the position and the allocation of masonry and insulation have a very profound effect on the thermal inertia parameters[1]. The determination of the variable thermal characteristics of buildings is recently receiving great interest, due to the potential of upgrading and optimizing the thermal performance of the active system building environment. Several studies dealing with these variable thermal characteristics of buildings were conducted recently[2].

The evaluation of time delay and dimensionless factor provides a measure of the developed indoor thermal conditions and, from an energy point of view, the possibility of reducing the energy load demands[3]. An author[4] investigated time delay and dimensionless factor by employing the Crank-Nicolson scheme. In these studies the heat wave that represents the sol–air temperature is assumed to show a sinusoidal variation. Another study[5] has examined experimentally and analytically the thermal response of various wall formations under the effect of solar radiation. In the present work, the influence of clay wall thickness on time delay and dimensional factor were tested.

Variable Thermal Characteristics of Wall

Dimensionless factor and time delay are very crucial thermal inertia parameters for the interpretation and evaluation of the heat storage capabilities of building envelopes. Their determination is valuable primarily in cases where there are wide diurnal temperature variations and where the average ambient temperatures are within the comfort zone. These are typically the cases for regions with hot and dry climate. Furthermore, their study promotes the design and realization of energy-efficient passive solar buildings with minimal reliance on machinery[5].

Time delay t_L (or phase lag or time shift or time lag) is defined as the time required for a heat wave, with period P, to propagate through a wall from the outer to the inner surface.

On the other hand, dimensionless factor D_f (or decreasing ratio or dimensionless amplitude or temperature attenuation) is defined as the decreasing ratio of its temperature amplitude during the transient process of a wave penetrating through a solid element. The desired dimensionless factor and time delay values can lead to the design of a more efficient building shell in which the stored heat during the daytime is released during the night, when outdoor temperatures drop significantly.
Time delay and dimensionless factor as defined by some authors ([6], [5] and [2]) are;

$$t_L = t_{T_{i,\max}} - t_{T_{o,\max}} \quad \text{...} \quad (1)$$

$$D_f = \frac{A_i}{A_o} = \frac{T_{i,\max} - T_{i,\min}}{T_{o,\max} - T_{o,\min}} \quad \text{...} \quad (2)$$

Where $t_{To,max}$ and $t_{Ti,max}$ represent the times when exterior and interior surface temperatures are at their maximums, respectively. In addition, $T_{o,min}$, $T_{i,min}$, $T_{o,max}$, and $T_{i,max}$ are the minimum and maximum developed temperatures on both wall boundaries. See fig. 1 for t_L.

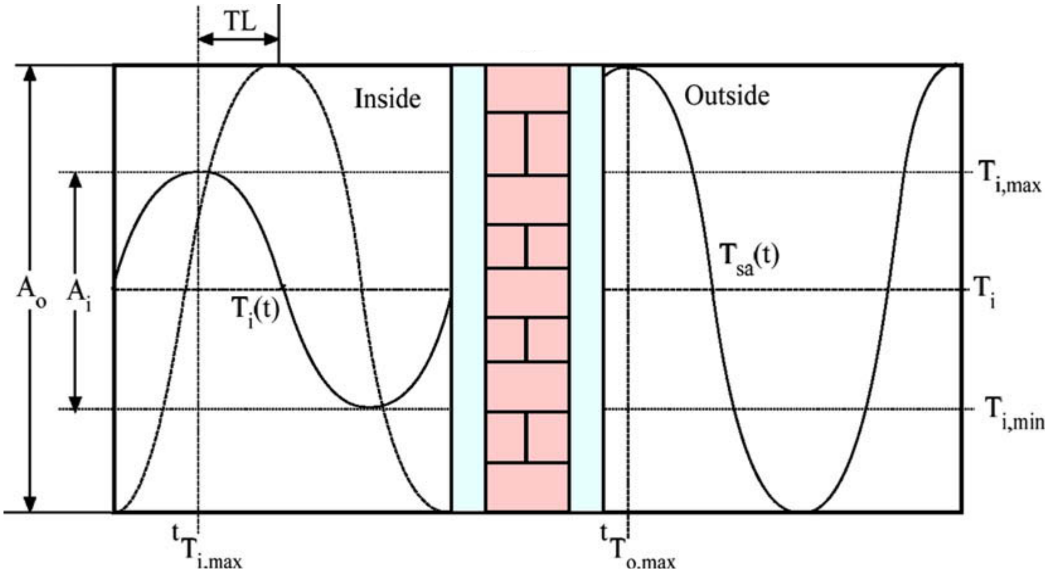

Fig. 1: Representation of time delay and dimensionless factor [7]

Heat Flow Analysis

For this problem, the one dimensional, transient heat conduction equation is as stated by Givoni, (1991) is;

$$k\frac{\partial T}{\partial x^2} = \rho c\frac{\partial T}{\partial t} \quad \text{...} \quad (3)$$

In solving this problem, two boundary conditions and one initial condition are needed. On both sides of wall, convection boundary conditions are present.

At the inner surface, the boundary condition is;

$$k\left(\frac{\partial T}{\partial x}\right)_{x=0} = h_i\left[T_{x=0}(t) - T_i\right] \quad \text{...} \quad (4)$$

On the outer surface of the wall, the boundary condition is;

$$k\left(\frac{\partial T}{\partial x}\right)_{x=L} = h_0\left[T_{sa}(t) - T_{x=L}(t)\right] \quad \text{..} \quad (5)$$

By applying, the initial and boundary conditions given above into the heat conduction equation 3 according to an author [5] it gives;

$$T(x,t) = \sqrt{X_1^2 + X_2^2}\left[\sin(wt + t_L)\right] \quad \text{..} (6)$$

And this is the analytical solution of the problem. It is stated [5] that X_1 and X_2 are function of x and are determined from the following equations:

$$X_1 = \left[T_{a.out}\frac{(h_{in}/S\sqrt{i})\sinh\left[(S\sqrt{i}/k)(L-x)\right] + \cosh\left[(S\sqrt{i}/k)(L-x)\right]}{\left((S\sqrt{i}/h_{out}) + (h_{in}/S\sqrt{i})\right)\sinh\left((S\sqrt{i}/k)L\right) + \left(1 + (h_{in}/h_{out})\right)\cosh\left((S\sqrt{i}/k)L\right)}\right] \text{...........} \ (7)$$

$$X_2 = \left[T_{a.in}\frac{(h_{in}/S\sqrt{i})\sinh\left((S\sqrt{i}/k)x\right) + (h_{in}/h_{out})\cosh\left((S\sqrt{i}/k)x\right)}{\left((S\sqrt{i}/h_{out}) + (h_{in}/S\sqrt{i})\right)\sinh\left((S\sqrt{i}/k)L\right) + \left(1 + (h_{in}/h_{out})\right)\cosh\left((S\sqrt{i}/k)L\right)}\right] \text{............} \ (8)$$

Where according to the author [5], the heat storage capacity

$$S = \sqrt{\rho c k} \quad \text{..} \quad (9)$$

The time lag

$$t_L = \arctan\left(\frac{X_2}{X_1}\right) \quad \text{...} \quad (10)$$

And the decrement factor

$$D_f = \sqrt{X_1^2 + X_2^2} \quad \text{..} \quad (11)$$

COMPUTATIONAL PROCEDURE FOR T_L, AND D_F

In order to find t_L, and D_f values, computer program in, EES, which are based on the mathematical model presented in the previous sections were used. The experimentation was done at the Sokoto energy research centre. Sokoto - Nigeria. The measurements for the month of May 2006 were taken at hourly interval, using hygrometer, thermocouple - thermometer anemometer, pyranometer and data logger. The readings taken were for the following outside and inside parameters;

(a) Relative humidity
(b) Wind speed
(c) Ambient temperature
(d) Global horizontal radiation
(e) Walls and roof temperatures.

Program was written in EES for the determination of the relationship between dimensionless factor D_f and clay wall thickness L in one hand and time delay t_L and clay wall thickness L on the other hand.

The following measured parameters (table 1) for the clay wall were used in the computation.

S/N	Items	Values
1.	Convective heat transfer coefficient (outside room), h_0	23 W/m^2 K
2.	Convective heat transfer coefficient (inside room), h_i	6 W/m^2 K
3.	Thermal conductivity, k	0.62(W/m K)
4.	Absorptivity of clay surface, α	0.6
5.	Emissivity of surface, ε	0.9
6.	Material density, ρ	1620 (kg/m^3)
7.	Specific heat capacity,c 0.826 (kJ/kg K)	0.826(kJ/kg K)

Table 1: Properties of wall and roof materials [9]

Fig. 2: Experimental clay wall building [10]

RESULTS AND DISCUSSION

The results of the computations were plotted as shown in the fig. 3 to fig. 5 below.

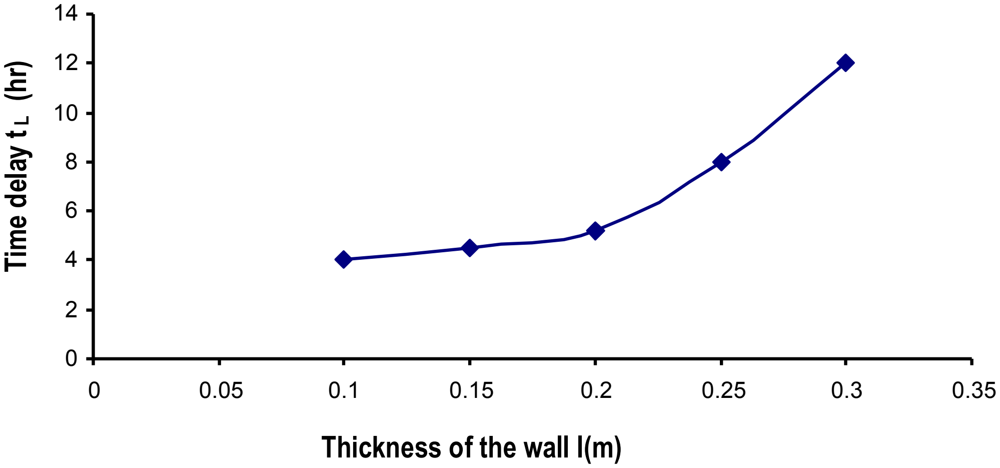

Fig. 3: Time delay t_L (hr) versus Thickness of the wall l(m)

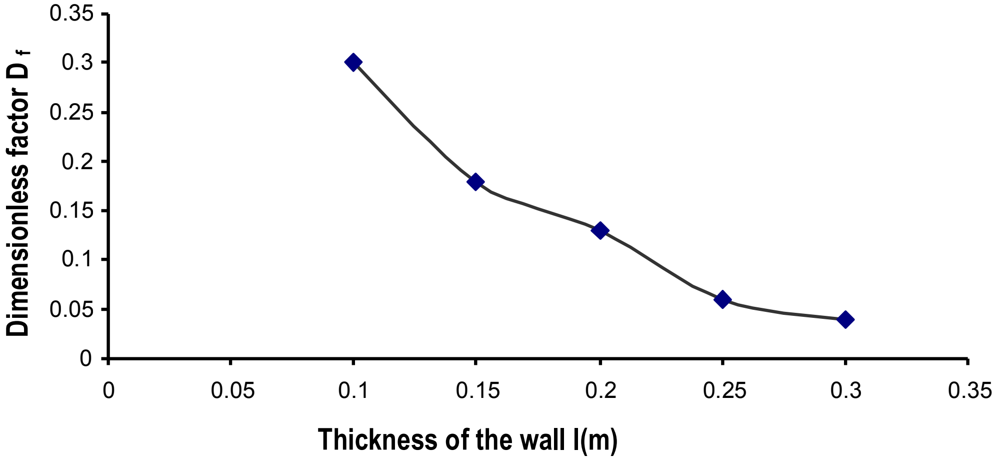

Fig. 4: Dimensionless factor D_f versus Thickness of the wall l(m)

Figure 3 above, shows the variation between the time delay t_L (hr) and the thickness of the wall l (m), it indicate that as the thickness of the clay wall increase the time delay also increases. Figure 4 above, shows the variation of dimensionless factor D_f and the thickness of the clay wall l (m), it indicates that as the thickness of the wall increases the dimensionless factor decreases.

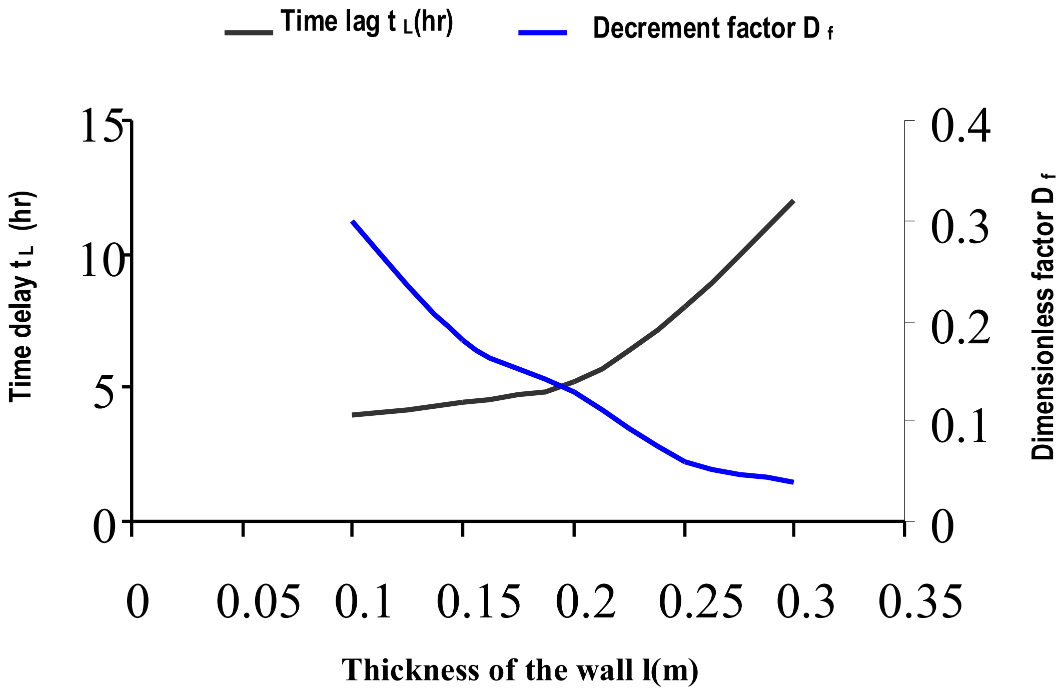

Fig. 5 Time delay t_L (hr) and Dimensionless factor D_f versus Thickness of the wall l(m)

Figure 5 shows how the time delay t_L (hr) and dimensionless factor D_f varies with Thickness of the wall l(m), it indicates that t_L has an exponential relation with thickness of the wall, while D_f has an inverse exponential relation with the thickness of the wall.

CONCLUSIONS

In this work the two dynamic parameters of building were studied. It is found that both the time delay and the dimensionless factor depend on the thickness of the clay wall and they are having a pronounced exponential relationship with the thickness of the wall.

REFERENCES

1. Duffin, R. J., & Knowles G.A. (1984). Passive Wall Design To Minimize Building Temperature Swings. *Solar Energy*, 33, 337–342.

2. Asan, H. & Sancaktar, Y.S. (1998) Effects of Wall's Thermo-Physical Properties on Time Lag and Decrement Factor. *Energy Building*, 28, 159–166.

3. Kossecka, E. (1999). Correlations Between Structure Dependent and Dynamic Thermal Characteristics of Building Walls. *Journal of Thermodynamics Envelope Build Science*, 22, 315–333.

4. Asan, H. (2000). Investigation of Wall's Optimum Insulation Position from Maximum Time Lag and Minimum Decrement Factor Point of View. *Energy Build*, 32, 197–203.

5. Ulgen, K. (2002). Experimental and Theoretical Investigation of Effects of Wall's Thermophysical Properties on Time Lag and Decrement Factor. *Energy Build*, 34, 273–278.

6. Asan, H. (2006). Numerical Computation of Time Lags and Decrement Factors for Different Building Materials. *Build Environment*, 41, 615–620.

7. Önder, K., R. Yumrutas., & O Arpa. (2009). Theoretical and Experimental Investigation of Total Equivalent Temperature Difference Values for Building Walls and Flat Roofs in Turkey. *Applied Energy*, 86, 737–747.

8. Givoni, B. (1991) Characteristics, Design Implications, and Applicability of Passive Solar Heating Systems for Buildings. Solar Energy, 47(6), 425–435.

9. Hamza, B. S (2011). *Predicting the Indoor Conditions of an Adobe Room for the Storage of Onions*. Unpublished Master of Philosophy Dissertation, Usmanu Danfodiyo University, Sokoto - Nigeria.

10. Hamza, B. S. (2002). *Effect of Water Pond on the Thermal Performance of an Adobe Room for the Storage of Onions*. Unpublished Master's thesis, Usmanu Danfodiyo University, Sokoto - Nigeria.

NOMENCLATURE

a	Thermal diffusivity ($m^2 s^{-1}$)
EES	Engineering Equation Solver
k	Thermal conductivity ($Wm^{-1}K^{-1}$)
t	Time (h)
T	Temperature (°C)
x	Thickness (m)
A	Amplitude
C	Specific heat capacity ($Jkg^{-1}.K^{-1}$)
D	Decrement
h	Convective heat transfer coefficient ($Wm^{-2}K^{-1}$)
S	Heat storage capacity ($Ws^{1/2}m^{-2}K^{-1}$)
P	Period (24h)
w	Angular speed (rad s^{-1})
ρ	Mass density (kgm^{-3})

Subscript

a,in	indoor amplitude
a,out	outdoor amplitude
f	factor in indoor
out	outdoor
sa	sol-air temperature
s,i	indoor surface
s,o	outdoor surface

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