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Research Article

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Hygrothermal Behavior of Compressed Stabilized Earth Brick In Dynamic Regime

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Abstract In Senegal, the concrete remains the most used material in building construction. The thermal behavior of concrete buildings often makes it necessary to use artificial ventilation or air conditioning to have the minimum thermal comfort at certain hot times of the year. Researchers believe that the use of earth under construction can be a solution to this high energy consumption in the building because of its high thermal inertia. In this work we are interested in the study of the thermal and hygroscopic response of the envelope of an experimental cell built in stabilized earth brick subjected to the real climate conditions of Dakar. Another identical cell is constructed of concrete to make a comparative study. Experimental results show that the relative humidity is better regulated in the earth cell compared to the concrete cell. The earth cell gives a lower damping factor and a higher phase shift. This shows that the earth has a greater transmission inertia than concrete.

Keywords Hygrothermal Behavior, Earth Brick, Dynamic Regime

1. Introduction

In Senegal, concrete remains the main material used in building construction. The thermal behavior of concrete buildings is such that it is often necessary to use artificial ventilation or air conditioning to have the minimum thermal comfort at certain hot times of the year. This makes buildings the basis of high energy consumption. It is therefore necessary to reduce this energy consumption to reduce the impact of buildings on the environment. In addition, the use of alternative low-impact building materials is an alternative. It is in this context that the use of earth under construction is becoming more and more relevant. Because it is available in large quantities, the energy required for its extraction, processing and production is low compared to concrete. The mechanical properties of soil-based materials have been studied by many researchers.

B.S. Waziri et al. [1] worked on compressive strength of cement stabilized compressed laterite bricks for low-cost housing construction in Nigeria. A maximum compressive strength of 2.84 MPa is obtained with samples stabilized with 7.5% cement at 28 days cure. F. Lasisi and A.M. Ogunjide [2] studied the effect of grain size on the mechanical properties of cement stabilized laterite bricks. The results show that the higher the laterite / cement ratio, the lower the compressive strength and the higher the percentage of fines, the greater the compressive strength. O. Izemmouren et al. [3] studied the effect of curing conditions on the mechanical properties of lime stabilized compressed earth blocks at grades of 6, 10 and 14%. The results obtained showed that the steam treatment of blocks stabilized with lime at 80 ° C. for 24 hours at atmospheric pressure leads to considerably greater mechanical strengths than for the cure obtained with humid tissues at room temperature. D. Maskell et al. [4] studied the addition of metakaolin to cement and lime to improve the mechanical performance of extruded and stabilized clay brick. The results show that bricks stabilized with lime and metakaolin have a high compressive strength compared to bricks stabilized with cement and metakaolin. Other studies on mechanical and hygroscopic characterization have been done. A.H. Abdullah et al. [5] made a comparison of compressive strength and water absorption between laterite-based brick and clay-based brick that are compressed and stabilized with cement. The results give the laterite brick a maximum strength of 9 MPa with a water absorption rate of 14.9% at a compacting pressure of 2000 Psi. The water absorption and compressive strength of the compressed earth brick stabilized at different mixing ratios and compaction pressure were studied by A.H. Abdullah et al. [6]. The maximum compressive strength is 14.68 MPa with a mixing ratio of 1: 3: 7 at a compression pressure of 2500 MPa. F. Champiré et al. [7] studied the impact of relative humidity on the mechanical behavior of compressed clay bricks. The results obtained show that the compressive strength decreases with relative humidity.

H.B. Nagarg et al. [8] studied the role of lime with cement on the long-term compressive strength and water absorption of the compressed and stabilized soil block. The maximum compressive strength is achieved with the stabilized soil block with an optimal amount of lime with cement (4% cement + 4% lime). Water absorption decreases continuously with the aging time. A.A. Raheem et al. [9] determined the compressive strength and water absorption of cementitious or lime stabilized lateritic blocks. The maximum compressive strength is obtained with the sample stabilized with 20% cement. Water absorption decreases as the percentage of cement or lime increases. Research on the thermal characterization of these earth-based materials has been carried out. E.A. Adam and P.J. Jones [10] studied the thermophysical properties of lime-stabilized compressed clay bricks and bricks. Compressed cement stabilized using different types of soil. The results showed that for each type of earth the value of the thermal conductivity is higher for bricks stabilized with cement.

S. AzakineSindanne et al [11] made the thermo-physical characterization of compressed clay bricks stabilized with cement and lime. The results indicate an increase in thermal conductivity as the percentage of cement and lime increases. N. Laaroussi et al [12] determined the thermal conductivity of the earthen brick from a Moroccan manufacturing plant. The thermal conductivity value found is 0.346 $Wm^{-1}K^{-1}$. The mechanical and thermal characterization of earth-based materials has been done by other researchers. M. B. Mansour et al. [13] have made an experimental study of the influence of compaction pressure on the apparent density of compressed clay bricks and consequently on their thermal and mechanical performance. The results show that increasing the compaction pressure increases the compressive strength as well as the thermal conductivity, the thermal effusivity and the thermal diffusivity of the compressedclay brick. R. Bahar et al. [14] evaluated the thermal conductivity and compressive strength of compressed and cement stabilized clay bricks. They find a slight decrease in thermal conductivity with increasing cement content and sand content.

Increasing the cement content increases the compressive strength of the bricks. Other work concerning the hygroscopic characterization of earth-based materials has been done. A.C. Houngan et al. [15] studied the sorption isotherm of cement stabilized laterite brick. The results and interpretations of the sorption isotherms have revealed a sorption hysteresis whose loop decreases with increasing temperature. F. McGregor et al. [16] studied the different conditions affecting the calculation and measurement of the buffer moisture value of compressed earth blocks and compressed and stabilized earth blocks. The results show that the addition of soil stabilizers reduces the adsorption properties in all cycles. The determination of the hygrothermal properties of composite materials based on soil has been made by other researchers. P. Maillard and J. E. Aubert [17] studied the effect of anisotropy on the hygrothermal properties of the extruded clay brick. The results confirm that the extrusion process has a major influence on the orientation of the clay layers and has an impact on the hygrothermal properties. H. Cagnon et al [18] studied the hygrothermal properties of five extruded earth bricks produced by five brickworks in France. The results show that the five earth bricks studied have a very low resistance to water vapor.

All of these characterization studies cited above have used materials made in the laboratory. These materials do not reflect reality because they are made under conditions where everything is controlled. Researchers use these results to predict the thermal behavior of an earthen building. This can distort the prediction. In our work we are interested in the study of the thermal and hygroscopic response of the envelope of an experimental cell built in stabilized earth bricks subjected to the real climate conditions of Dakar. Another identical cell is constructed of concrete to make a comparative study. These cells were built at the EcoleSupérieurePolytechnique in Dakar. This comparison is made through a quantitative evaluation of the parameters that make it possible to characterize the inertia of the two materials and to identify the possible thermal advantages of the earth compared to the concrete. These parameters are the time lag and the decrement factor.

2. Definition of the time lag and the decrement factor

The time lag and the decrement factor are defined by the following expressions:

$$\phi = t_{T_{\text{int,max}}} - t_{T_{ext,\max}} \quad (1)$$

$$f = \frac{T_{\text{int,max}} - T_{\text{int,min}}}{T_{ext,\max} - T_{ext,\min}} \quad (2)$$

Where $t_{T_{\text{int,max}}}$, $t_{T_{ext,\max}}$ represent the times when respectively the inside temperature of the cell and the outside temperature are at their maximum. In addition and are the maximum and minimum temperature inside the cell, and are respectively the maximum average and the minimum temperature outside. The average equivalent temperature is calculated as in the following expression:

$$T_{ext} = \frac{\sum S_p T_p}{\sum S_p} \quad (3)$$

Where

S_p is the surface of a given wall, T_p the equivalent temperature of a given wall. This temperature is calculated as in the following expression:

$$T_p = \frac{h_{rc}T_c + h_{re}T_e + h_{cv}T_{ext} + \alpha G_{inc}}{h_{rc} + h_{re} + h_{cv}} \quad (4)$$

Where:

h_{rc} and h_{re} are the radiative transfer coefficients respectively with the sky and the environment

h_{cv} is the convection coefficient

T_c, T_e and T_{ext} are the temperatures respectively of the sky, the environment and the external environment,

α is the solar absorptivity,

G_{inc} is the global radiation incident on a given wall.

This global radiation is the sum of direct and diffuse incident radiation on a given wall. These two radiations are calculated from direct and diffuse radiation on a horizontal plane using these formulas:

$$I_{bp} = (I_{bh} \times \sin(h) \times \cos(\beta)) + (\cos(h) \times \sin(\beta) \times \cos(A - A_p)) \quad (5)$$

With

$$I_{bh} = I_{bn} \times \sin(h) \quad (6)$$

Where

I_{bp} the direct incident radiation on a wall,

I_{bh} the direct radiation on the horizontal plane,

I_{bn} the normal direct radiation,

β the inclination of the wall with respect to the horizontal plane, hthe inclination of the wall with respect to the horizontal plane, h is the height of the sun, which is calculated as follows:

$$h = \sin^{-1}(\cos\delta \times \cos\omega \times \cos\Phi + \sin\delta \times \sin\Phi) \tag{7}$$

Where

δ is the declination,

ω the solar angle,

Φ is the latitude,

A is the solar azimuth,

Ap is the azimuth of the wall.

$$I_{dp} = I_{dh} \times \left(\frac{1 + \cos(\beta)}{2} \right) \tag{8}$$

With

$$I_{dh} = I_{gh} - I_{bh} \tag{9}$$

Where

I_{dp} is the diffuse incident radiation on a wall,

I_{dh} the diffuse radiation on the horizontal plane,

I_{gh} the global radiation on the horizontal plane.

The global radiation on the horizontal plane is measured with a pyranometer and the normal direct radiation is measured by a pyrheliometer with the same time step.

3. Presentation of the experimental device

The two constructed cells are materialized in Figure 1. They have the same internal dimensions that are 1x1x1 m^3, corresponding to a space area of 1 m^2 with a height of 1 m. The concrete cell has a plane roof and the earth cell has a low curvature vaulted roof. The four walls of the concrete cell are built with hollow bricks from a local industrial brick factory, which makes it possible to conform to reality. The floor and roof of the concrete cell are made of reinforced concrete. The roof of the earthen cell and the four walls are built with the bricks of a brickyard. The floor of the earthen cell is made of reinforced concrete. Each cell has a wooden door identical to the other. On the floor of each cell, we put an insulation (2 cm thick glass wool) that is covered with a material impervious to moisture. This eliminates the influence of the exchange of heat and moisture between the floor and the floor on the ambience of the cell.

(a) (b)

Figure 1: Disposition of experimental cells in (a) concrete and (b) earth

4. Instrumentation

Three stand-alone temperature and relative humidity Log Tag recorders were used for monitoring both cells. This sensor "Log Tag" is shown in Figure 2. Inside each cell a sensor is hung on a point fixed on the roof. Another sensor is placed outside away from the sun. The sensors inside the cells measure the temperature and humidity of the environments. The third sensor measures outdoor temperature and humidity. During the instrumentation, the doors of the two cells are closed in order to quantify the response of the materials constituting the envelope vis-à-vis external stresses.

Figure 2: Temperature and relative humidity recorder

5. Presentation of experimental results

The results of the experimental study consist of comparing temperatures and relative humidity inside the cells and calculating the time lag and the decrement factor. We present in Figure 3 the variation of the internal temperatures of the cells and those outside from midnight to midnight

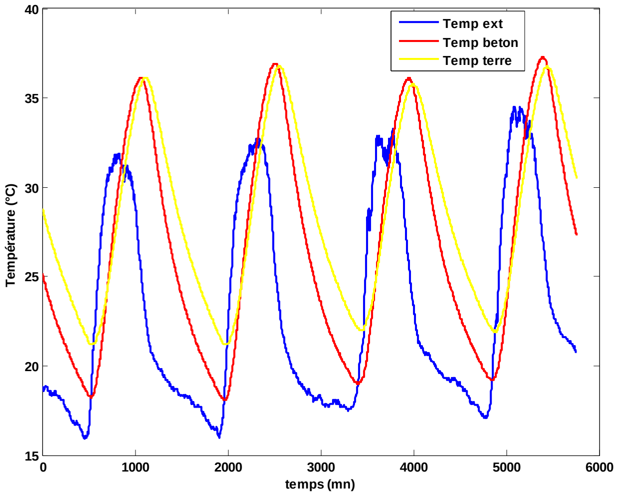

Figure 3: Variation in ambient temperature and outside temperature from midnight to midnight

We find that the average daily temperature obtained at the level of the earth cell environment is higher than that obtained at the level of the concrete cell. The magnitude of the temperature in the earth cell is lower compared to the temperature range in the concrete cell. The time lag of the temperature is more important in the earth cell. The higher average temperature in the earth cell can be explained by the fact that the earth brick has a higher thermal conductivity than that of hollow concrete brick. The amplitude of the low temperature and the high time lag in the earth cell can be explained by the fact that the earth brick has a transmission inertia higher than that of the concrete hollow brick.

Figure 4 shows the variation of the relative humidity inside each cell and the variation of the relative humidity outside..

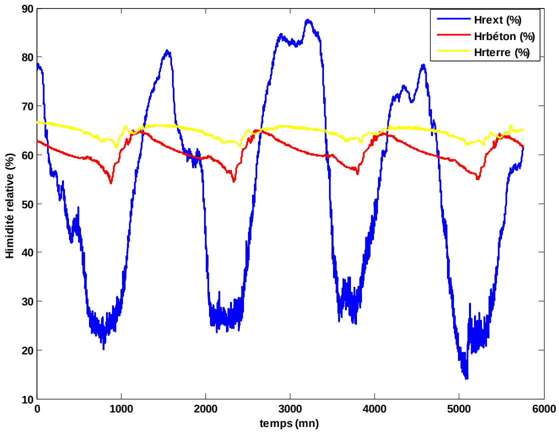

Figure 4: Change in relative humidity at both cells and outside from midnight to midnight

We find that the relative humidity in the earth cell is greater than that in the concrete cell. It is also noted that the relative humidity is better regulated in the earth cell relative to the concrete cell. This shows its good ability to regulate the indoor humidity. The high relative humidity in the earth cell is explained by the fact that the earth is a very sensitive material to moisture.

To calculate the time lag and the decrement factor (equations 1 and 2), we used the average equivalent temperature that is calculated with equation 3. The evolutions of the equivalent temperature on each wall and the average equivalent temperature of midnight at midnight are illustrated in Figures 5 and 6 respectively.

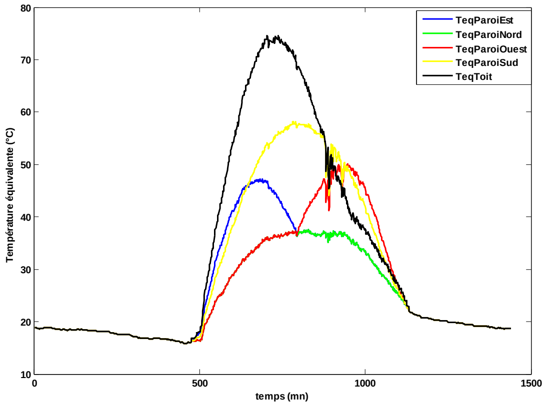

Figure 5: Variation of the equivalent temperature on each wall of the earthen cell from midnight to midnight

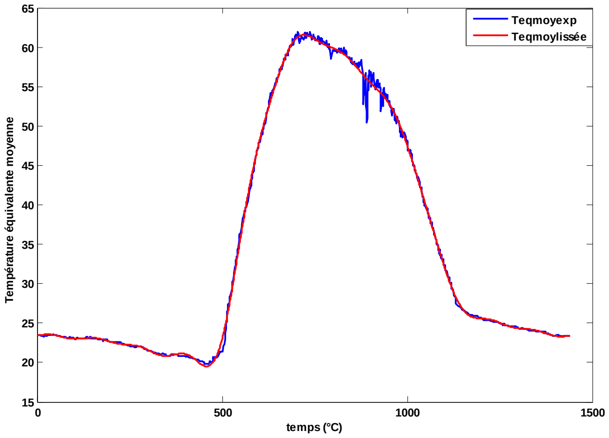

Figure 5: Average equivalent temperature change from midnight to midnight

This calculation is done for each of the cells but the curves presented are those of the earth cell. Fluctuations in average equivalent temperature are due to clouding. The time lag and the decrement factor are calculated with the smoothed curve of the equivalent temperature. On this curve we see that the two curves are almost the same. The results obtained for the phase shift time and the damping factor are summarized in Table 1.

Table 1: Lag values and damping factor for each material

Phase difference		**Damping factor**	
Concrete cell	**Earthen cell**	**Concrete cell**	**Earthencell**
5.47	6.28	0.43	0.31
4.33	5.18	0.45	0.33
4.63	6.03	0.47	0.34
4.80	5.93	0.46	0.34
5.12	6	0.46	0.34
5.13	6.05	0.49	0.35
5.27	5.85	0.43	0.30
5.1	6.07	0.39	0.32

The results in Table 1 show that the earth cell gives a lower decrement factor and a higher time lag compared to the concrete cell. This confirms the analysis made in Figure 3.

6. Conclusion

In this work a comparative study of the thermal and hygroscopic response of an earthen cell and that of a concrete cell was made. This study was carried out using two experimental cells built with these two materials through a campaign to measure temperature and relative humidity. At the end of this measurement campaign the phase shift and the damping factor were determined to quantitatively evaluate the inertia of the two materials in order to determine the thermal advantages of the earth compared to the concrete.

Experimental results show that the average temperature and the average relative humidity at the earth cell level are higher than those obtained at the concrete cell. This can be explained by the fact that the conductivity of the earth brick is higher than that of hollow concrete brick and the earth is a material that is very sensitive to relative humidity. On the other hand, the amplitude of the temperature in the earth cell is lower compared to the amplitude of the temperature in the concrete cell. The relative humidity is better regulated in the earth cell compared to the concrete cell. The earth cell gives a lower damping factor and a higher phase shift. This shows that the earth has a greater transmission inertia than concrete.

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