

New materials for thermal insulation in rural construction

ABSTRACT

This article presents a study on thermo-physical characterization of local materials used in building. The simulation with EnergyPlus software made it possible to evaluate the energy performance of a building. The studied materials are lateritic blocks no-stabilized and those stabilized with the nere pod, the cement and the lime. Simulation makes it possible to determine the performance of the building and to evaluate the thermal comfort. The asymmetric hot plane method was used to determine the properties of the different types of samples. The values of the thermal conductivities of the different bricks vary from 0.427 to 0.814 $\text{W.m}^{-1}.\text{K}^{-1}$, they are relatively weak. These materials are better for thermal insulation of buildings. This work aims to develop a new composite material, to improve their thermophysical property. Nere pod stabilization economizes 20 to 43% energy depending on the mixing rate compared to simple laterite. The decrement factor and the time lag are better when the wall thickness increases. For the purpose of reducing the building energy consumption, this composite material is intended to be used in walls or false ceilings.

Keywords: Thermal insulation, asymmetric hot plan model, thermophysical properties, economy of energy, nere pod, decrement factor, time lag.

1. INTRODUCTION

The use of a composite material requires first of all knowledge of its thermo-physical ownership, especially if it is about a natural, lasting and environmental material. This study allows of determine the thermophysical characteristics of new types of materials based on laterite and clay mix with nere pod, lime and cement. For this work, we used the method of the hot plan transitional to determine the thermal effusivity, and the method of hot plan in regime permanent to determine thermal conductivity. Studies have already done and published on materials at the root of clay and alfa fibers. The results obtained by Noura Hamour et al [1] show that the addition of alfa fiber treated and untreated in the matrix makes it possible to improve the mechanical properties of the materials. For thermal properties, the stabilization with treated and untreated alfa fibers improves thermal stability. The results

31 obtained by Yassine Elhamdouni et al [2] show that increasing the content of alfa fibers
32 improves the thermal properties, they have obtained samples that are more insulating. A.
33 Oushabi et al [3] showed that composite materials (PU-DPP) have good mechanical and
34 thermal performance compared to insulating materials available on the market. So, the (PU-
35 DPP) is a good isolate because it is inexpensive and safe. Laaroussi et al [4] studied the
36 thermal properties of samples stabilized with alfa fiber. The results obtained show that
37 increasing the levels of alfa fibers improves the thermal properties. This makes the sample
38 more insulation and allows economize the energy. Also , Pierre Meukam [5] determined the
39 mechanical and thermal properties of the briks of earth stabilized with the aim of use in
40 building. They showed the dependence of thermal conductivity and thermal diffusivity of
41 these materials as a function of the water content remains low. these results also show that
42 made-up clay bricks can be used in building construction without presenting a high risk of
43 cracking. O. Bahloul and al [6] evaluated the effect of alfa fibers on the values of the
44 mechanical and thermal resistance of mortar of cement. Imbga and al [7] determined the
45 thermal and mechanical performance of laterite blocks stabilized with nere pod for the
46 thermal insulation of buildings. Thermal conductivity decreases as the Nere pod rate
47 increases. The mechanical strength is reduced depending on the dosage rate which enables to
48 conclude that the Nere pod does not stabilize laterite. The stay time of the Nere pod in the
49 laterite impacts the thermal and mechanical performance. They have found that the thermal
50 conductivity and the compressive strength increase depending on the maturing time of the
51 Nere pod. Imbga and al [8] have determined the thermophysical properties of various
52 formulations with laterite and slaked lime. The value of the thermal conductivity decreases
53 when the lime rate is lower than 4% and increases for rates higher than 4%. The thermal
54 conductivity was $0.623 \text{ W.m}^{-1}.\text{K}^{-1}$ for a rate of 4%; it increases to 21.13% for 16% of lime
55 used. Recent works were carried out by Azakine S and al [9] on earth blocks stabilized with
56 lime. The results of the thermal properties of the various formulations were measured using
57 the hot wire method. They obtained $0.59 \text{ W.m}^{-1}.\text{K}^{-1}$ for a 4% lime rate, $0.62 \text{ W.m}^{-1}.\text{K}^{-1}$ for a
58 rate of 8% and $0.68 \text{ W.m}^{-1}.\text{K}^{-1}$ for a rate of 12% of lime used as stabilizer. Results indicate
59 that thermal conductivity increases when percentages of cement and lime increase.
60 However, it decreases when the rates of the sawdust increase. Moreover, thermal resistance
61 decreases according to the percentages of lime and cement, and increases according to the
62 percentages of the sawdust. Seckou Bodian and al [10] have determined the mechanical et
63 thermal properties of unfired and fired clay soil bricks made from a mixture of clay soil and
64 laterite. The thermal conductivity and thermal effusivity were measured by the asymmetric

Hot plate method. The results show that the variation of thermal conductivity with laterite percentage has the same shape for unfired and fired bricks. Cherki and al [11] carried out an experimental study about the thermal properties of a cork-gypsum composite by using the asymmetrical Hot plate method. They demonstrated that the composite material is three times more insulating and twice lighter than cork-free gypsum. Mustapha Boumhaout and al [12] aimed to study the thermomechanical characterization of composite materials made from mortar and date palm fibers mesh. Their objectif is to evaluate the thermal insulation properties as well as the mechanical performance of this material for insulation of buildings . The volume percentage of date palm fibers mesh in the samples was varied from 0% to 51% . The results show that the values of thermal conductivity decrease as the fibers rate increases. While thermal conductivity of the reference mortar is $0.795 \text{ W.m}^{-1}.K^{-1}$ it drops to $0.243 \text{ W.m}^{-1}.K^{-1}$ for the reinforced fiber mortar 51 % composite material which corresponds to an abatement of about 70%.

2. MATERIALS AND METHODS

2.1. Clay and laterite

We have used clay from the quarter of karpala from the city of Ouagadougou (Burkina Faso). The laterite we used comes from a company located in the Gandigal region in sénégál. The diameter of its lower than or equal 4mn. Atterberg limits and size of laterite studied were studied by Sekou Bodian [13].

$W_p = 16.02\%$, $W_p = 16.02\%$ $W_p = 16.02\%$ and The finess modulus is 2.476 .

2.2. Nere pod

The nere pod are used because they are available and inexpensive..

2.3. Preparation of samples

For this study, we used four (04) types of samples of the same dimensions. These samples are in laterite and laterite stabilized with nere pod, lime and cement. To evaluate the influence of stabilizers (nere pod, lime and cement) on thermo-physical properties, several mixtures were made by varying the levels of these stabilizers. For characterization, we used bricks in the dry state.

2.4. Theoretical approach of determination the thermo-physicals propieties

2.4.1. Method of determination of thermal conductivity

Thermal conductivity is determined by the hot plan method in permanent regime developed by Y. Jannot et al [14]. This method is based on the determination the values of the temperature in the centre of the heating plate inserted between the material to be characterized and the thermal insulation in polyethylene. Fig.1 illustrates the fundamental schema of method. The brick of dimensions $100 \times 100 \times 25 \text{ mm}^3$ is put on a heating plate of section $100 \pm 1 \text{ mm} \times 100 \pm 1 \text{ mm}$ and a thickness $0.22 \pm 1.01 \text{ mm}$ equal to that of the sample. The uncertainty in the heating device area is thus around 2 %. We must add the uncertainty to the sample thickness estimated at 1 % and to the heat flux produced in the heating device estimated at 0.5 %. The sum of these uncertainties leads to an overall uncertainty rate of 3.5 % to which must be added the estimation error due to noise measurement on ΔT and the errors due to phenomena that have not been taken into account in the model. Most of the heat dissipated into the heating device which electric resistance $R_e = 40 \Omega$. The temperature evolution recorded at every each 0.1s. The presence of the thermocouple does not increase the contact resistance between the heating element and the polystyrene. Since polystyrene is an insulating material, this thermal resistance will be marginal . The system is modeled with the unidirectional transfer hypothesis (1D). At the center of the heating element and the sample during the measurement . This hypothesis is checked with (3D) simulation using comsol and residues analysis : the difference between the temperature provided by the theoretical model $T_{\text{mod}}(t)$ and provided by the experience $T_{\text{exp}}(t)$. They put, under the heating element , an insulationg foam of dimension $100 \text{ mm} \times 100 \text{ mm} \times 40 \text{ mm}$. In order for the great party of the heat flux emitted by the hot plate to pass into the sample, the brick is placed between this plate and the thermal insulation. this allows the system to reach thermal equilibrium as quickly as possible.

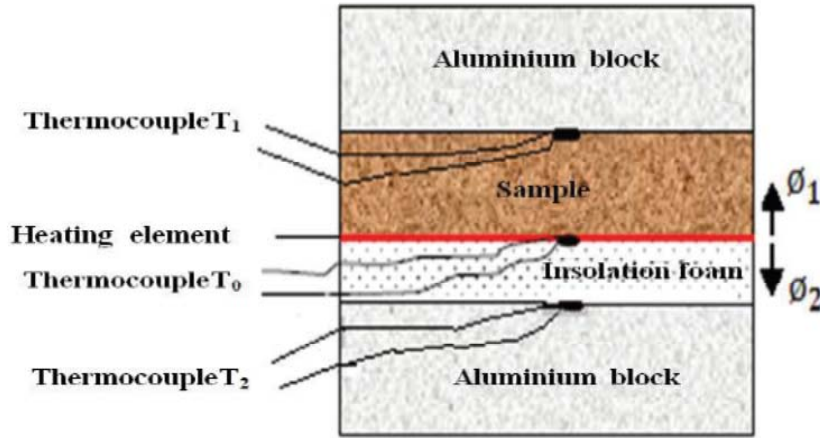


Fig.1. Experimental mounting of the hot plate method

One thermocouple is placed in the center of the lower face of hot plate to determine the temperature values T_0 . The second thermocouple placed on the unheated face of the sample and the third on the unheated face of the thermal insulation are used respectively to determine the temperatures T_1 and T_2 . With this shape, we can write :

$$\Phi = \Phi_1 + \Phi_2 \quad (1);$$

$$\text{with } \Phi_1 = \frac{\lambda_1}{e_1} (T_0 - T_1) \quad (2);$$

$$\text{and } \Phi_2 = \frac{\lambda_2}{e_2} (T_0 - T_2) \quad (3)$$

Φ_1 is the heat flux through the material, Φ_2 is the heat flux through the thermal insulation. Φ is the total flux emitted by the heating element, λ_1 is the thermal conductivity of the sample as we seek to determine, e_1 is the thickness of the sample, λ_2 and e_2 are successively thermal conductivity and thickness of the thermal insulation. The heating plate is an electrical resistance R dissipating heat flux by Joule effect when it is crossed by an electric current I under of voltage (U), so :

$$\Phi = \frac{U^2}{R.S} \quad (4)$$

Combining equation 1 and 2, we have :

$$\lambda_1 = \frac{e_1}{T_0 - T_1} \left[\frac{U^2}{R.S} - \frac{\lambda_2}{e_2} (T_0 - T_2) \right] \quad (5)$$

Equation 5 allows to determine the thermal conductivity when system reaches the steady state regime.

2.4.2. The method of determining thermal effusivity

Thermal effusivity is determined using the hot plane method in transient regime [15]. We use the asymmetric experimental device (represented on the fig. 2). An element of heating plan having the section of $100 \pm 1 \text{ mm} \times 100 \pm 1 \text{ mm}$ is put under the sample. One thermocouple of type K with two sons accomplished with a 0.005 mm diameter is glued together on the lower face of heating element. This arrangement is placed enter two thermal insulation in polystyrene having a thickness of 40 mm fixed between two aluminum plate with a thickness of 40 mm.

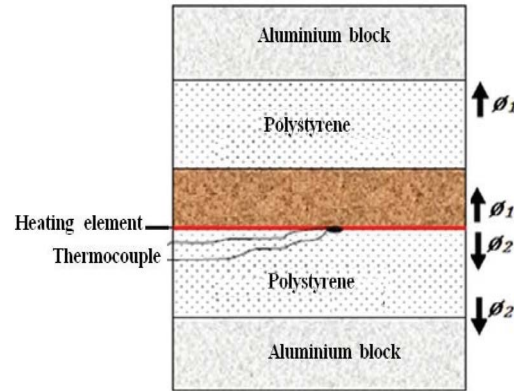


Fig. 2. Schema of the experimental Plate

The heat flux sent by the heating plate and the transitional temperature $T(t)$ are recorded. It is assumed that the thermocouple in contact with the insulation does not increase the thermal contact resistance between plate and polystyrene, this thermal resistance is neglected. The system is modeled using the unidirectional heat transfer assumption (1D) at the center of the sample. Temperatures are assumed constant at the level of the aluminum blades because the value of the heat flux passing through the polystyrene is very low.

Within these hypotheses one can write :

Using the temperature of the side before the sample $T_1(t)$:

$$\begin{bmatrix} \theta_1 \\ \Phi_{01} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ C_s p & 1 \end{bmatrix} \begin{bmatrix} 1 & Rc_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1' \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1 \end{bmatrix} \quad (6)$$

$$C_s = \rho_s c_s e_s \quad (7)$$

$$\begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} = \begin{bmatrix} ch(qe) & \frac{sh(qe)}{\lambda q S} \\ \lambda q S sh(qe) & ch(qe) \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} = \begin{bmatrix} ch(q_i e_i) & \frac{sh(q_i e_i)}{\lambda q_i S} \\ \lambda q_i S sh(q_i e_i) & ch(q_i e_i) \end{bmatrix} \quad (9)$$

$$q = \sqrt{\frac{p}{\alpha}} \quad (10)$$

$$q_i = \sqrt{\frac{p}{\alpha_i}} \quad (11)$$

$$\text{Concerning the (polystyrene) insulator. we have } \begin{bmatrix} \theta_1 \\ \Phi_{02} \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_2 \end{bmatrix} \quad (12)$$

$$\text{With } \Phi_0 = \Phi_{01} + \Phi_{02} = \frac{\varphi_0}{p} \quad (13)$$

where θ , Φ_{01} , Φ_{02} , Φ_0 , Φ_1 et Φ_2 are respectively the symbols of Laplace transforms: the temperature, the heat flux density coming from the heating element (upstream), the thermal flux density coming from the heating element (downstream), the total flux produced in the element heating, the thermal flux density entering the upper aluminum block, the thermal flux density entering the lower aluminum block.

θ the thermal flux density produced in the heating plate, C_s the surface heat capacity of the heating plate and R_c the thermal contact resistance between the plate and the material.

λ_i the polystyrene thermal conductivity, a_i and a are successively the thermal diffusivity of polystyrene and sample. e_i and e are successively the thickness of polystyrene and sample.

Combining equation 4 and 5, the system leads to :

$$\theta(p) = \frac{\Phi_0(p)}{\frac{D}{B} + \frac{D_i}{B_i}} \quad (14)$$

This method makes it possible to determine the value of the thermal effusivity. The thermal conductivity λ of the block and the contact resistance R_c that minimize the Mean Squared.

$$\text{Error of the sum } \psi = \sum_{j=0}^N \left[\Delta T_{\exp(t_j)} - T_{\text{mod}(t_j)} \right]^2 \quad (15) \text{ between the theoretical curve}$$

179 $T_{c\text{mod}(t)} = T_{c\text{mod}}(0, t)$ (16) and the experimental curve $\Delta T_{c\text{exp}} = T_{c\text{exp}}(0, t) - T_{c\text{exp}}(e, t)$ (17)
 180 in the Levenberg-Marquardt-like algorithm program [16].

181 3. RESULTS AND DISCUSSION

182 The results of the thermophysical characterization of the different samples as a function of the
 183 percentage of nere pod, lime and cement are shown in Table 1.

184 **Table 1: Thermophysical properties of laterite plus the different pod of Nere**

material	$\lambda (W / m.K)$	$\frac{\Delta \lambda}{\lambda} \%$	$E (J / m.K.s^{1/2})$	$\frac{\Delta E}{E} (\%)$
LS	0.750	±0.121	1277.561	±0.027
LG4%	0.603	±0.226	1160.735	±0.017
LG8%	0.552	±0.175	1082.955	±0.053
LG12%	0.483	±0.240	1056.508	±0.013
LG14%	0.428	±0.113	1005.946	±0.016
LG16%	0.427	±0.118	975.141	±0.019

185
 186 Table 1 shows that the thermal conductivity of laterite decreases as the nere pod level
 187 increases. It is reduced when Nere's pod is added to the laterite and if Nere's pod is added to
 188 the laterite. It can be seen that the thermal effusivity also decreases as the néré pod rate
 189 increases in the laterite. It is reduced when we add 8% and 23.67 % of nere pod. The
 190 materials LG14%, LG16%, LG12% have lower thermal conductivities than the brick in
 191 straw-clay (3%) formulated by David Y.K. Toguyeni and al which have a good thermal
 192 performance [17].

193 **Table 2. Thermal properties of Karpala clay stabilized with cement and Nere's pod**

Material	$E (J / m^2.K.s^{1/2})$	$\frac{\Delta E}{E} (\%)$	$\lambda (W/mK)$	$\frac{\Delta \lambda}{\lambda} (\%)$	$\rho c (KJ/m^3.K)$	$\frac{\Delta \rho c}{\rho c} (\%)$
Clay	1269.447	±0.183	0.814	±0.173	1985.900	±0.539
Clay96%C4%	1125.987	±0.018	0.572	±0.165	2225.730	±0.201
Clay92%G4%C4%	1069.651	±0.068	0.544	±0.129	2104.479	±0.265
Clay88%G8%C4%	985.146	±1.930	0.443	±0.434	2194.722	±4.294

194
 195 Table 2 indicates that thermal effusivity and thermal conductivity decrease as the clump rate increases
 196 in the clay. Thermal effusivity decreases with the addition of cement and clay seed in the clay and
 197 when cement and clay seed are added to the clay. However, the volume heat capacity increases when
 198 the rate of néré pod increases in the clay.

Material	$\lambda(W/m.K)$	$\frac{\Delta \lambda}{\lambda}(\%)$	$\rho(KJ/m^3.K)$	$\frac{\Delta(\rho c \%)}{\rho c}$
La92%lime4%G4%	0.458	± 0.367	2079.561	± 0.399
La92%lime4%C4%	0.509	± 0.367	1871.197	± 0.399
La96%C4%	0.611	± 0.183	2605.126	± 0.219
LaG4%	0.603	± 0.226	2234.337	± 0.260

The results in Table 3 indicate that the addition of the cement in the laterite-chalk mix increases the thermal conductivity compared to the addition of the pearl pod.

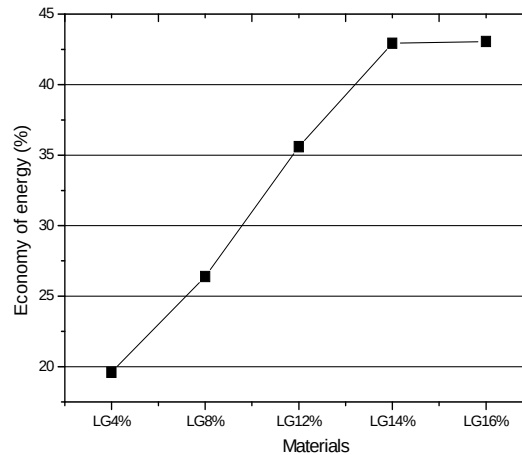
Consider two envelopes of the same habitat that are subjected to the same temperature gradient. We can write the following relation:

$$\frac{\Phi_{Laterite + x\% gn}}{\Phi_{Laterite}} = \frac{\lambda_{Laterite + x\% gn}}{\lambda_{Laterite}} \quad (18)$$

This relationship allows us to estimate energy saving by using composite materials by the relation the following relation

$$Es = 100 \left(1 - \frac{\lambda_{Laterite + x\% gn}}{\lambda_{Laterite}} \right) \quad (19)$$

$\lambda_{Laterite + x\% gn}$: Thermal conductivity of the laterite mix + a percentage of néré pod; Es : economy of energy.



A wall with a more insulating envelope saves more energy because the percentage of energy savings increases when the conductivity is low. The performance of the envelope is determined by the decrement factor f (equation 20) and the time lag φ_d (equation 21).

$$f = \frac{T_{mi}^{max} - T_{mi}^{min}}{T_{me}^{max} - T_{me}^{min}} \quad (20)$$

$$\varphi_d = t_{T_{mi}^{max}} - t_{T_{me}^{max}} \quad (21)$$

f : decrement factor ; T_{mi}^{max} : Maximum temperature of the interior wall (°C); T_{mi}^{min} : Minimum temperature of the interior wall (°C); T_{me}^{max} : Maximum temperature of the outside wall (°C); T_{me}^{min} : Minimum temperature of the outside wall (°C); φ_d : time lag (h); $t_{T_{mi}^{max}}$: Time when the temperature of the interior wall is maximum (h); $t_{T_{me}^{max}}$: Time when the temperature of the outside wall is maximum (h).

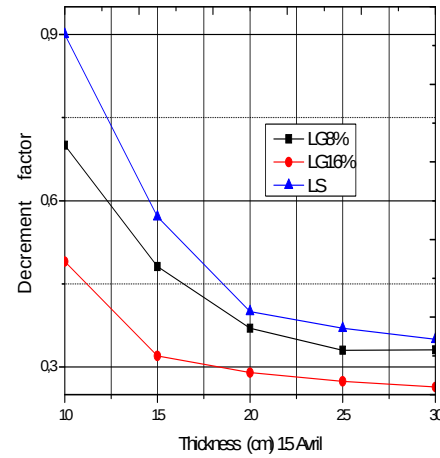
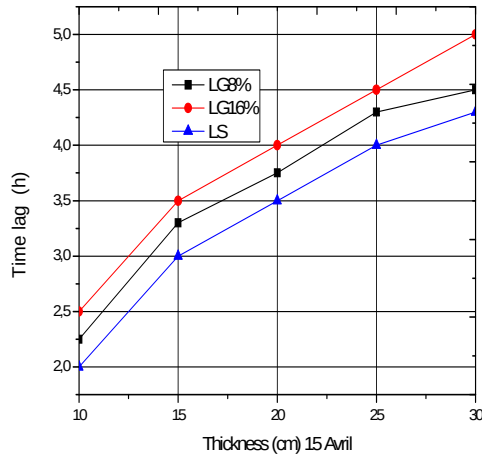
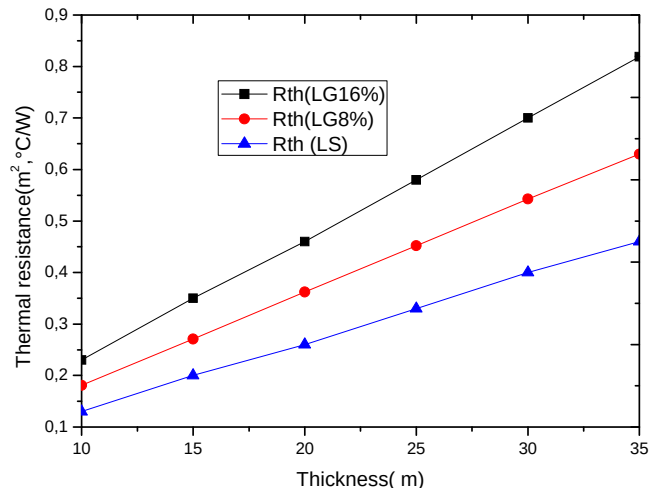


Fig. 5. Time lag according to the thickness

Fig. 4. Decrement factor according to the thickness

The decrement factors are calculated on the south wall (Fig. 5) because they are most exposed to solar radiation. The decrement factor decreases with increasing thermal capacity and wall thickness, and augments with increasing thermal conductivity. The time lag (Fig. 4) increases as the thermal capacity and wall thickness increase and the thermal conductivity decreases. B. Belhadj et al [16] carried out an experimental study also on the influence of cereal fibers on the thermal properties of concrete. The thermal results from this experimental

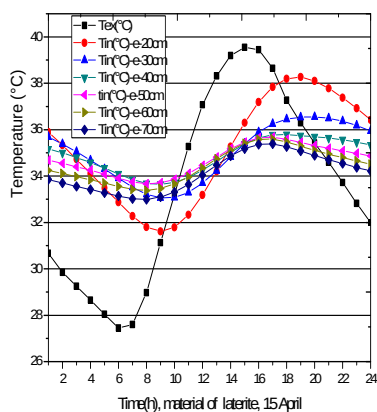
study were used to simulate using the EnergyPlus software to determine the decrement factor and the time lag. Vincent SAMBOU [18] has shown that the thermophysical properties of the wall have important effects on the time lag and decrement factor of the thermal wave.



233

234 **Fig. 6. Thermal resistance of stabilized materials with laterite and néré pod.**

235 The performance of the insulation is also related to the thermal resistivity of the insulation.
 236 For a new building, the thickness of the insulation may vary depending on the type of
 237 material, the nature of the wall and the level of performance. The resistivity increases when
 238 the material is insulating, it also increases with the thickness of the wall. Reducing air
 239 infiltration in low-energy housing is an important lever for achieving energy performance.



240

241

Fig. 7. Air temperature according to the thickness of the wall.

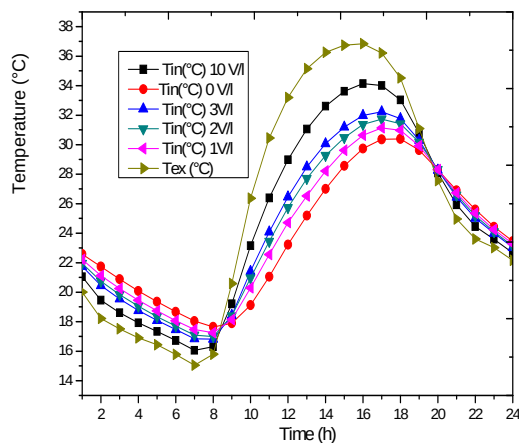


Fig. 8. Indoor air temperature according to the air infiltration rate

The same amount of heat uniformly distributed in the wall will cause in it a temperature that is a function of its thickness and the thermophysical properties of the materials used for construction (Fig. 7), plus a wall receiving a quantity of heat is thick minus its temperature internal rises, it rises all the less as the mass heat C is great. The flux density crossing the two media is proportional to the thermal effusivity. The rate of air infiltration increases the temperature of the air during the day and refreshes it at night (Fig. 8).

4. CONCLUSION

This paper presents the results of the thermophysical properties of local materials stabilized with lime, cement and néré pod by the asymmetric hot plane method. The results indicate that the values of the thermal conductivity decreases when the nere pod rate is high in laterite. The values of the thermal effusivity and those of the thermal conductivity of the mixture (clay plus cement) decrease when the rate of néré pod increases. The thermophysical results obtained were simulated under the EnergyPlus software, the results resulting from this simulation indicate that the thermal phase shift increases as the thermal conductivity decreases and the thickness of the wall increases. The decrement factor decreases when the thermal conductivity decreases and when the thickness of the wall is large. The indoor air temperature of a home is stable when the thermal time lag is high and the decrement factor is low.

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