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Improvement of the Energy Saving of a House With Biosourced Materials Walls (Rice Husk-Cement) by a Judicious Choice of Its Thickness

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ABSTRACT
This document has two essential parts: a first part which summarizes a comparative study of thermal retention capacity of some local materials of common construction. At the end of this study, a classification is made, followed by a case study of economic energy gain.
The second part, offers a thorough analysis of the best material according to the previous classification in terms of the effect of its thickness on its thermal and economic performance. In this context, five samples of rice husk composite materials are manufactured at thicknesses of 7.5; 10; 12; 15 and 20 cm. They are kept in the laboratory (LEMA) for 1 month. They are then wrapped in glass wool, instrumented and exposed for five days to solar thermal solicitations. Flow and temperature data are collected and processed. Curves of phase shift and damping variations as a function of the thicknesses are plotted.The analysis of the data processing and the interpretation of the curves shows that the increase in thickness improves the damping and the phase shift of this material and consequently a saving of energy necessary for the comfort of a building. We note a maximum to this evolution, which shows that beyond a certain value of the thickness these parameters do not evolve anymore.

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Introduction

The search for aesthetics and the fight against precariousness have moved the contemporary world away from what is essential. The current discourse is the return to ecological or green habitats since the problems engendered by the modern design of the building threaten the very survival of humanity. In coastal regions of sub-Saharan Africa, for example, erosion and sea-to-continent migration due to wild exploitation of marine sand pits is a matter of great concern.
Meanwhile, industrial waste of rice husks clog our production units or end up being rejected in nature, because we do not know what to do with it. It is quite natural that research is directed, in the LEMA laboratory, towards the development of new building materials based on rice husks, with the aim of providing an alternative to the use of marine sand source of serious environmental problems. These new materials must nevertheless meet the requirements: be available, less expensive, have good mechanical and thermal properties and not too thick. The cement-rice husk composite material is derived solely from rice husk waste, water and cement. Not a handful of sea sand is used.
The present work follows the work of Doko [1] in 2013 which showed that cement-rice husk composite materials have interesting mechanical properties. In particular, that they can be used for the realization of light concretes. Subsequently, in 2016, PRODJINONTO et al. classified these materials and those commonly used in construction in sub-Saharan Africa in terms of damping, phase shift of heat capacity and cooling time. It is clear from this classification that the cement-rice husk composite is better for the others in all respects for a thickness of 7.5 cm and therefore offers a certain economic interest. This is why we are studying the effect of thickness on damping and phase shift to see if we can do more energy saving than the 7.5 cm thick material.
The process and the details that led to the results announced in the summary are described in the rest of the document.

Summary of the comparative study of thermal retention capacity of some local current construction materials

In this part, the study is done on four samples of different materials:

- cement-fiber composite of rônier;
- Composite cement-rice husk;
- Agglomerated cement-sand marine;
- Composite cement-bar earth.

The formulation of the composites comprises the fixing of the dosage D in cement; the choice of the mixing water ratio on cement dosage E / C and the determination of the mass of plant aggregates or not to use to make 1 m^3 of materials.

In reference to the results of DOKO [1], we take:

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$$\frac{E}{C} = \frac{masse\ eau}{masse\ ciment} = 0.35 \quad (1)$$

For the determination of the mass of aggregates, we start from the equation:

$$V_{abs\_mel} = V_{abs\_cim} + V_{eau} + V_{abs\_granu} \quad (2)$$

V_{abs_mel} : absolute volume of the fresh mixture; V_{abs_cim} : absolute volume of the cement; V_{eau} : absolute volume of mixing water; V_{abs_granu} : absolute volume of aggregates.

Taking an absolute volume of the fresh mixture equal to $1\ m^3$; where you get :

$$1 = \frac{D}{\rho_{cim}} + \frac{\frac{E}{C} \times D}{\rho_{eau}} + \frac{m_{granu}}{\rho_{granu}} \quad (3)$$

From $\rho_{cem} = 3150\ kg/m^3$, $\rho_{water} = 1000\ kg/m^3$ and $D = 500\ m^3/kg$the following Table 1 is obtained.

On the basis of its data, samples of $14.5 \times 10 \times 7.5\ cm^3$ are manufactured. The samples, after conditioning and instrumentation, as will be described in the second part are exposed to solar thermal stresses. It is very important, for a better understanding of the whole work, to know that the data that is manipulated in the following, come from a procedure and an instrumentation which will be explained in the second part. Indeed, we recalled at the beginning that it is the deepening of the results of a previous work that justifies the present and therefore the methods are the same.

Table 1: Composition of samples

Composition / Material	Mass of cement (kg)	Mass of Water (kg)	Mass of aggregates (kg)	Mass of Total (kg)
Cement-fiber composite of rônier	500	175	546,34	1221,34
Composite cement-rice balls	500	175	438,41	1113,41
Agglomerate	500	175	1752,29	2427,29
Composite cement and bar ground	500	175	1765,61	2440,61

In general, the complete model is adopted or the samples behave as a medium that is both capacitive and resistive [3]. From a quadrupole diagram, the Laplace transformation of the flux passing through the wall of a sample is written:

$$\psi(0\,,\omega) = j\omega(\rho ce) \times \Theta(0\,,\omega) \quad (4)$$

With: $\Theta(0\,,\omega)$the Laplace transform of the temperature. The return to the time domain is written:

$$\phi(t) = (\rho ce)\frac{dT}{dt}(t) + \frac{\lambda}{e}T(t) + cst \quad (5)$$

Or

$$\phi(t) = (\rho ce)\frac{dT}{dt}(t) + \frac{U}{S}T(t) + cst \quad (6)$$

Thus, with the acquisition of N couples (ϕ, T) of flow and temperature thanks to the Peltier element and thermocouple sensors, we obtain the following system of equations:

$$\begin{bmatrix} \phi(t_1) \\ \phi(t_2) \\ \vdots \\ \phi(t_N) \end{bmatrix} = \begin{bmatrix} \frac{dT}{dt}(t_1) & T(t_1) & 1 \\ \frac{dT}{dt}(t_2) & T(t_2) & 1 \\ \vdots & \vdots & \vdots \\ \frac{dT}{dt}(t_N) & T(t_N) & 1 \end{bmatrix} \begin{bmatrix} \rho ce \\ U/S \\ cst \end{bmatrix} \quad (7)$$

which can also be condensed next

$$\phi = X\beta \quad (8)$$

where $\boldsymbol{\phi}$ denotes the vector of heat flux density observations, $\boldsymbol{\beta}$ the vector of parameters to be estimated and $\boldsymbol{X}$ the vector sensitivity matrix $\boldsymbol{\beta}$. Under Gauss Markov conditions a least squares linear estimator is obtained by:

$$\hat{\beta} = [X^T X]^{-1} X^T \phi \quad (9)$$

The estimation of the parameter $\widehat{\boldsymbol{\beta}}$ makes it possible to directly obtain the thermal capacity (ρc), the transmission coefficient (U). The other values of the table are obtained by calculation in particular, the cooling time.

$$T_{ref} = \frac{\rho ce^2}{\lambda \cdot 3600} \quad (10)$$

The larger (T_{ref}), the longer the wall will take to cool, and the external temperature fluctuations will be felt later in the interior.

Table 2: Thermophysical properties of the four materials

Composition / Settings	Cement-fiber composite of rônier	Composite cement-rice balls	Agglomerate	Composite cement and bar ground
Thickness (cm)	0,075	0,075	0,075	0,075
Area S (m2)	0,0145	0,0145	0,0145	0,0145
Amortization(°C)	14,461	16,415	5,087	7,161
Phase shift (mn)	66	106	55,75	57,5
Capacité thermique $\rho c\ (J.m^{-3}.K^{-1})$	2834266,67	2871733,33	2137333,33	2385333,33
Coefficient of transmission $U(W.K^{-1})$	0,104	0,0918	0,218	0,171
Thermal resistance R $(K.W^{-1})$	9,608	10,891	4,58	5,856
Conductivity $k(W.m^{-1}.K^{-1})$	0,538	0,475	1,129	0,883
Effusivity $e(J.s^{-1/2}.m^{-2}.K^{-1})$	1235,227	1167,822	1553,66	1451,537
diffusivity $a(m^2.s^{-1})$ (m2.s-1)	1,898 E-07	1,654 E-07	5,282 E-07	3,702 E-07
Cooling time T_{ref} (h)	8.231	9.446	2.958	4.221

The results are shown in Table 2. From the results in Table 2, we make a classification with respect to damping, phase shift to heat capacity and cooling time, which places the composite cement-rice balls in the lead, followed by the cement-fiber composite of palmyra. The cement-to-earth bar composite and chipboard come in last place.

We recall that the damping A is the difference between the maximum temperature (T_{Max}) at the upper face of the sample exposed to the thermal radiation and the maximum temperature (T_{Max}) at the lower face insulated by the glass wool. As for the phase shift D_{ph}, it expresses the time difference between the time t_{max} set to reach (T_{max}) and the time t_{Max} set to reach (T_Max). We have: $A = T_{Max} - T_{max}$ et $D_{ph} = t_{max} - t_{Max}$. Considering the triangle whose vertices have coordinates $(t_{Max}; T_{max})$; $(t_{Max}; T_{Max})$ and $(t_{max}; T_{max})$ (see figure 1), we define average values, which are the coordinates of the center of gravity of the triangle:

$$t_{int_{moy}} = \frac{1}{3}(2\, t_{Max} + t_{max}) \quad (11)$$

$$T_{int_{moy}} = \frac{1}{3}(2\, T_{max} + T_{Max}) \quad (12)$$

These average values can also be expressed as:

$$t_{int_{moy}} = \frac{1}{3}(3\, t_{Max} + D_{ph}) \quad (13)$$

$$T_{int_{moy}} = \frac{1}{3}(3\, T_{Max} - A) \quad (14)$$

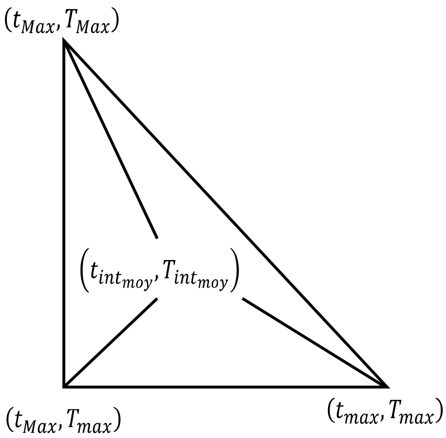

Figure 1: Thermal average point from the external and internal maxima

These two expressions, comparable to the delay factor [4], show that, for an external maximum temperature T_{Max} obtained in a given time t_{Max}, the increase of the phase shift D_{ph}, extends the duration of attaining the mean internal time $t_{int_{moy}}$ and an increase in damping A, lowers the average internal temperature. These properties are very favorable to a good indoor atmosphere in summer and its good regulation in any season.
Formulas (13) and (14) show the influence of damping and phase shift on the formation of the interior temperature of a dwelling. In other words, if we start from two distinct materials, and thus from different damping and phase shift, under chaotic conditions, the one with the highest phase shift and damping will offer the best indoor climate conditions.

Economic analysis by a case study

We propose to take the example of a ground floor, used as a VIP restaurant whose summary plan is presented in Figure 2 below :

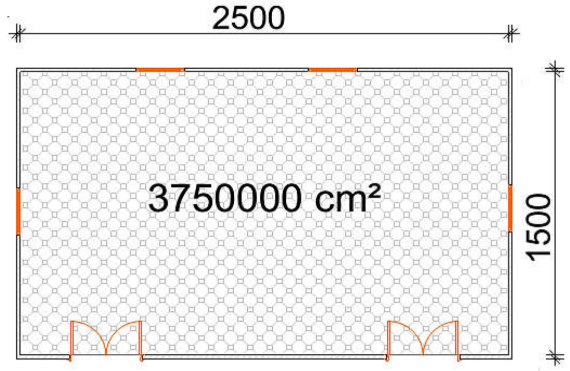

Figure 2: Plan of the studied building

The total area exposed to solar radiation is estimated at: $S_{tot} = (15 \times 25) + 2 \times (15 + 25) \times 3 = 615\, m^2$. The living area is $S = 375\, m^2$ and the height is $H = 3\, m$.
We will study the following four cases:

1st case: The building is built with cement-fiber composite materials of rônier;
2nd case: The building is built with composite materials cement-rice balls;
3rd case: The building is built with agglomerates;
4th case: The building is built with cement-earth bar composites.

From the flow and temperature data recorded, we establish the following table defining for each of the four studied materials, the average internal temperatures and the amount of heat that crossed the entire thickness of the material per day and per square meter. These values are obtained through a Matlab program developed for this purpose.

Table 3: Data on average indoor temperatures and heat quantity through the thickness of each material

Case	1st	2nd	3rd	4th
Mean temperature indoor T_{int_moy} (°C)	31.91	31.74	33.34	33
Amount of heat that has passed through the whole thickness of the material Q_{sup} $(J/day/m^2)$	36910	24940	194400	78950

In the tropics, a good atmosphere is obtained for temperatures around 22°C and the occupants use an air conditioning system to maintain it. On this basis, we calculate the additional heat load related to the building envelope:

$$Q_{tot} = 2 * S * H * \rho_{air} * c_{\rho_{air}} * \left(T_{int_{moy}} - 22\right) + Q_{sup} * S_{tot} \quad (15)$$

$S = 375\, m^2$: living space; $S_{tot} = 615\, m^2$ total area exposed to solar flux; $H = 3\, m$: height of the building; $\rho_{air} = 1.29\, kg.m^{-3}$: density of the air; $c_{\rho_{air}} = 1004\, J.kg^{-1}.K^{-1}$:

Table 4: Economic balance of the four materials

case	1st case	2nd case	3rd case	4th
Mean temperature indoorT_{int_moy} (^{o}C)	31.91	31.74	33.34	33
Amount of heat that has passed through the whole thickness of the materialQ_{sup} (J/day/m^2)	36910	24940	194400	78950
The additional heat load $Q_{tot}(kJ/day)$	51578.480	43721.531	152602.007	80609.460
Additional energy consumption$E_{tot}(kJ/day)$	20631.392	17488.613	61040.803	32243.784
additional energy consumption per day $(kW\ \ )$	5.731	4.858	16.956	8.957
additional energy consumption per month $(kW\ \ )$	171.928	145.738	508.673	268.699
increase in the electricity bill in one month (€)	29.14 €	24.70 €	86.20 €	45.54 €
Profit for one month (€)	57.07 €	61.51 €	0	40.67 €
Profit for one year (€)	684.8 €	738.06€	0	488.01 €
Profit for one year per unit of living space (€/m^2)	1.83 €	1.97 €	0	1.3 €

specific heat of the air; Q_{sup} : amount of heat that has passed through the entire thickness of the material in $(J/day/m^2)$ and Q_{tot} : the additional heat load (J/day). The coefficient 2 corresponds to the frequency of air exchange in the building per day.
Taking the coefficient of performance of the $COP = 2.5$air conditioning system, we evaluate the additional energy consumption related to the additional heat load Q_{tot}.

$$E_{tot} = \frac{Q_{tot}}{COP} \quad (16)$$

We summarize all the calculation results in Table 4 below. It can be seen that the expected benefit compared to a construction with agglomerate (common construction material) in this typical case is:

1.97 $€/m^2/yr$for the construction with cement-rice husk composites;
1.83 $€/m^2/yr$ for the construction with cement-fiber rônier composites;
1.3 $€/m^2/yr$for the construction with Composite cement and bar ground.

Experimental

In this part, the operating modes (sample preparation, instrumentation, data acquisition) are also those that prevailed for the results of the four previous samples.
As can be seen with the expressions (13) and (14), an increase in phase shift and damping, improves the indoor environment. We therefore want to see, by studying the specific case of the cement-rice husk composite, whether the increase in thickness increases these two parameters, and in what proportion and limit.

Figure 3: Sample of the rice husk material – cement

Preparation of samples

We begin by reproducing identically this composite with thicknesses 7.5; 10; 12; 15 and 20 cm [2], [1].

Materials

For the experiment, six (06) flow meter calibrated Peltier elements, six (06) K-type surface temperature thermocouples, a glass wool roller, an Agilent 34970A data logger, and a computer are used.

Procedure

The procedure implemented here has already been successfully tested by PRODJINONTO (2011, 2016) [5, 2]. A Peltier element and a thermocouple are attached to the base of each sample at its center. The samples are then all wrapped in 7 cm thick glass wool, except the top surface of $14.5 \times 10\ cm^2$. It is arranged on this upper face of the sample of 7.5 cm thick, a Peltier element and a thermocouple which were used to collect the solar flux and the outside temperature received by each of the samples. It should be noted that this face of this sample is finely painted in matt black in order to standardize the solar flux on all this surface. The Peltier wires and thermocouples are then connected to the datalogger, which in turn is connected to the computer for real-time recording of the data (see Figures 4 and 5). The start of the recording operations can begin with the start of the computer and the datalogger, the adjustments relating to the types of elements connected to the control panel as well as the measurement ranges. The chosen measurement step is (10 s). The samples are exposed to solar thermal variations.The measurement campaign lasted five (5) days. It is important to note that before the protocol described above, the samples are conditioned in a metrology laboratory or have the same temperature and pressure conditions for a week. In a word, the samples are kept under the same conditions.

Description of the experiment

The acquisition step is 10 s. In total, approximately 50,000 temperature and flow data are recorded. These are the temperatures and flux of the bases of the samples covered by the glass wool and those of the upper face of the 7.5 cm thick sample painted in matt black which gives the thermal state of the environment.

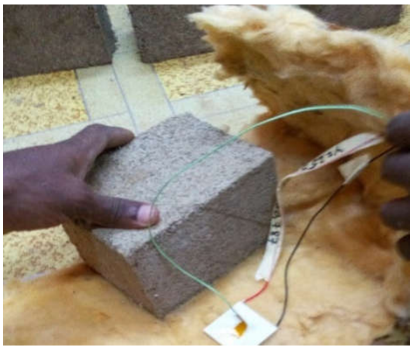

Figure 4: Peltier Element and Thermocouple Sensors Under a Sample

Figur 5: Samples embedded in glass wool with thermocouple and Peltier element underneath

Method of data processing

New alternative materials, to be effective, must be bioclimatic, ecological, green and less energy intensive. They must therefore respond to cross-cutting imperatives. During the last decades, many research efforts are directed towards the achievement of these imperatives as well by practical work as by simulations. Some authors like COSSALI [6], [7], COULIBALY et al. [8], LAGESSE et al. [9], Magyari and Keller [10], have done remarkable work that we draw on in this paper.

Once the flow and temperature data were recorded, an elaborate Matlab program allowed, at first, to cut lots of 8640 data representing each measurement day. They are then organized by an average of 6 to obtain data in minutes. Finally, by an average of 60, the hourly information relating to each measurement day is obtained.

What is hoped for is an increasing evolution of the damping and the phase shift according to the thickness of the sample, until reaching a maximum value. This is a gain in comfort and energy savings.

Table 5: Summary of the depreciation and phase shift estimates of the different thicknesses of the cement-rice ball sample

Thickness e (cm)	7.5	10	12	15	20
Amortization (°C)	16.42	20.46	20.81	21.10	21.66
Phase shift (h)	1.76	2.51	2.86	3.06	3.08

Results and Discussion

Curve of variation of the damping according to the thicknesses

The calculated depreciation values for each of the five samples and for each day are grouped together. An average of its values is calculated for each sample so for different thicknesses (see Table 5). The following curve shows the variations of the damping means as a function of the thicknesses.

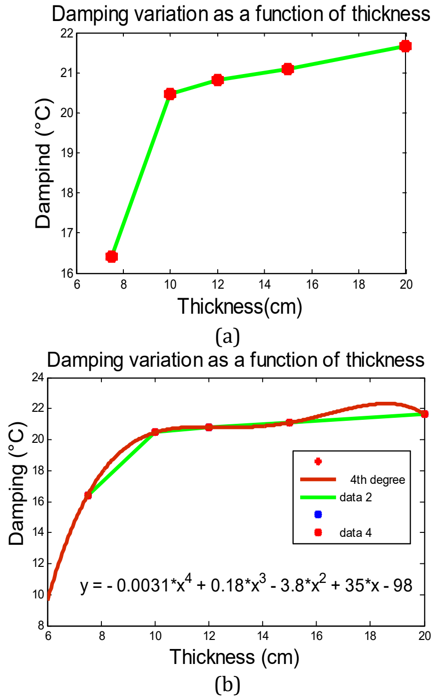

Figure 6: (a) Variation of damping according to thickness, (b) Damping modeling as a function of thickness

Curve of variation of the phase shift according to the thicknesses

The calculated phase shift values for each of the five samples and for each day are grouped together. An average of its values is calculated for each sample so for different thicknesses (see Table 5). The following curve shows the variations of the means of the phase shift as a function of the thicknesses.

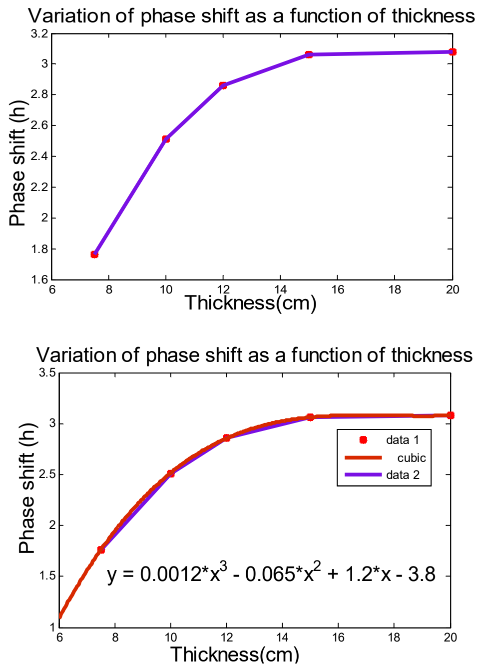

Figure 7: (a) Variation of the phase shift according to thickness, (b) Phase shift modeling as a function of thickness

Table 6: Energy saving relative to the different thicknesses of the material

Benefit compared to the thickness of 7.5 cm				
Thickness	Amortization	Benefit	Phase shift	Benefit
10	20.46	2.45	2.51	2.81
12	20.81	2.50	2.86	2.91
15	21.10	2.53	3.06	3.11
20	21.66	2.60	3.08	3.13

These increasing values of savings in energy savings relative to the thickness of 7.5 cm show that the greater thicknesses and thus the greater depreciation and phase shifts provide a certain advantage. Therefore, the choice of a reasonable thickness of this material is necessary. It must indeed play on saving energy and loss of living space. Too great a thickness certainly offers an economic saving of energy, but drastically reduces the living space.
The reasonable choice taking into account these two points of view would be 15 cm of wall thickness.

Conclusions

In approaching this subject, we are trying to solve economic, ecological and environmental problems. Ecological problem because, rice husks waste is produced by thousands of tons each year around the world, but are very little or not valued. Environmental problems because, the exploitation of sand quarries have reached worrying proportions. The ravages of furious waves all over the West African coast require the call for international help.
These problems find a solution beginning with this use that we propose of this waste. The material uses only rice husk waste and cement. In addition, with a low thickness of 15 cm, we obtain a phase shift of about 3 h 4 and damping at least equal to 22°C, with energy saving compared to any other form of current material of construction. There is also a gain in living space since these results are obtained for other composite walls with thicknesses beyond 22 cm. It is a material that gives better guaranteed mechanical properties.
There remains, however, a study of the aging of this material. We could also see if it cannot come in combination with other materials to improve its phase shift. Perhaps coatings of certain qualities could bring this solution or the incorporation of coconut or cotton vibes.

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