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Comparative Study of the Thermal Holding Capacity of Some Current Building Materials in BENIN

Dr Vincent Prodjinonto[1], Ing Oscar Godonou[1*], Chakirou Akanho Toukourou[1], Antoine Vianou[2]

1. Polytechnic School of Abomey-Calavi (EPAC), University of Abomey-Calavi, Cotonou, 01 BP 2009, Benin

2. Laboratory of Thermophysical Characterization of Materials and Energy Appropriation (LCTMAE), University of Abomey-Calavi, Cotonou, 01 BP 2009, Benin

Abstract: The importance and the quality of the buildings, represent an index of development of a country. We attend so more and more in our countries and particularly in Benin, an unrestrained research for improvement of the energy performances of the building. Our work enter within this scope. It seeks the improvement of the quality of the envelope of the as well as possible being opposed building through materials, with the variations in external temperature i.e. having a great thermal holding capacity. This holding capacity is characterized by damping, dephasing, heat capacity and coefficient of transmission. During our study, four materials: composite cement and fibres of ronier, composite cement and rice balls, agglomerate and composite cement and ground of bar, were designed under the same conditions and according to same mixture. They were then subjected simultaneously to solar flow during four days. From the data of flow and temperatures collected as well as modeling of a semi-infinite medium, we succeeded in estimating then to compare their holding capacities. The classification of materials by descending order of holding capacity is: composite cement and rice balls, composite cement and fibres of ronier, composite cement and ground of bar and agglomerate.

Key words: Fibre of ronier, rice ball, agglomerate, ground of bar, damping, dephasing, coefficient of transmission, heat capacity.

1. Introduction

The importance and the quality of the infrastructures, in particular of the buildings, represent an index of development of a country. The improvement of the quality of the envelope of the building thus constitutes a major stake of development of a nation. Considerable efforts are made these last years to leave the building its precariousness. On the one hand, the materials manufacturers compete of ingeniousness to increase the mechanical properties of building materials, on the other hand, of notable progress are made within the field of the research for new building materials.

In department of the Mechanical and Energy Engineering of the EPAC, at the Thermophysical Laboratory of Characterization of Materials and Energy Appropriation, several work was carried out in the direction of a better comprehension of the thermal behaviors of building materials. But this work related for the majority to the thermophysical characterization of the materials. Most of the results remain unexploited because misunderstood by most of the users of the building.

It is thus imperative to find materials with low thickness being able to make the envelope of the building to maintain a certain thermal comfort and to adapt to the climatic changes because in the heart of double energy and environmental problems. Our work falls under this logic. It is an effort of improvement of the performances of the envelope of the building by the determination of the damping, the dephasing, the coefficient of transmission and the heat capacity of existing and new materials. We have estimated these thermal properties for four materials including two new manufactured starting from the vegetable rejections. We hope that our results will contribute to change the practices of building constructions in BENIN.

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[*] **Corresponding author:** Ing Oscar Godonou, lecturer, research fields: mechanics and materials.

2. Bibliographic Study

Many researchers were interested in the study of thermal comfort in relation to the envelope of the building like the determination of the damping, the dephasing, the heat capacity, the coefficient of transmission and the inertness of building materials.

Coulibaly, Ouédraogo and et al. [1] led in 2011, a thermal study on a bioclimatic building with double wall, fore-mentioned Newango, in Ouagadougou. This study related to the evaluation of comfort and the power consumption according to the nature of building materials of the walls. With this intention, they optimized a building in double wall on seven floors, which made it possible to obtain a damping of temperature about 6 to 7 ºC on 24 h between external and intern surfaces of the envelope of the building.

Chaffa, Awanto, and et al. [2] studied the improvement of the conditions of interior environment in the septentrional area of Benin precisely in Kandi. This study made it possible to analyze the thermal answers of the envelope of the building, as well as the conditions of interior environment which result from them for traditional material walls various thicknesses the such walls in hollow block (12 cm), those out of solid bricks (18 cm) and those out of puddled earth (25 to 30 cm). After simulations, they obtained results which show that in dry tropical area, the buildings out of puddled earth protected well from the sunning support better conditions of environment of day and night.

Lagesse, Barthelmé and et al. [3] carried out in 2013, an investigation on the impact of the inertness of the heavy walls on the comfort of summer in the buildings. They could show that the inertness of the walls is a very significant factor to improve the comfort in the buildings and thus to reduce the consumption of energy requisite for the cooling of the buildings.

Chaffa, Sanya and et al. [4] studied the influence of the factors relating to the elements of envelope of the building according to the power consumption of the building. Their study revealed that the consumption of the air-conditioned building is all the more reduced as the buildings are well directed, the picture windows are of small size and protected from the direct sunning: Small Ouverture/Mur ratio, Report/ratio Depth of the auvent/Hautor of window (RAH) and Width Report/ratio of Arêtes/Largeur of windows (RLL) large and glazings are not very permeable to the solar radiation (solar Factor Fsweak).This power consumption could be reduced of about 38 to 45% by applying adequate measurements of exploitation of the equipment of air-conditioning to the whole of 110 buildings more énergivores of the Coast-Ivoire. The analysis of the energy effectiveness of the buildings was carried out in two stages: the first stage relates to the influence of the elements of envelope on the power consumption of the buildings while the second examines the influence of measurements of exploitation of the equipment, in particular of air-conditioning, on their power consumption. Our study lies rather within the scope of the first stage.

G. E. Cossali [5] studied in 2006, the dynamic storage capacity of a periodically heated plate. This study allowed obtaining and the application to some cases, of the equations in the fields temporal and frequential making it possible to calculate their storage capacity. These equations show that the harmonic heating is not the most effective manner to store energy in the finished and semi plates infinite. G. E. Cossali [6] extended then his study to the plate heated periodically in the case of the States General of border and general periodic profiles of excitation of any form. A general relation to calculate the storage capacity is obtained in the form closed for the harmonic case. Equations in the fields temporal and frequential make it possible to calculate the storage capacity under the heating (not-harmonic) periodic.

Vincent Prodjinonto [7] developed in 2011, a technique allowing to measure the dynamic storage capacity of a wall of building in situ. The wall of building used for its experimentation is a multi-layer wall of 51.3 cm for thickness. It had outside and inside the Western wall building NAPEVOMO, a sensor made up of a thermocouple of temperature measurement of surface of the type K, and of a Peltier element; the whole connected to a power station of acquisition. By regarding the wall as being a semi-infinite medium, it determined using the results of flows and outside temperatures and interior obtained. It estimated with the dynamic storage capacity of the wall.

3. Materials and Methods

3.1. Manifacture of the Test-Tubes

Work was carried out at the LCTMAE. The manufacture of materials proceeded in the environment of this laboratory at atmospheric pressure and the ambient temperature. In our study, we were interested to four various building materials using in BENIN. They are the composite cement and fibres ronier, the composite cement and rice balls, the agglomerate and finally the composite cement and ground of bar.-The manufacture of these various materials requires water, cement, fibres of ronier (scientific Name Borassus Aethiopum), rice balls, sea-sand and of the ground of bar.

It is significant to note here that all the materials were manifactured under the same conditions, same dimensions and according to same cement and water proportionings; this in order to appreciate effectively the results of the comparative analysis of the thermal holding capacity of these composite materials only on the basis of their composition. This proportion is based on the study of DOKO [8] in 2013 about the composite cement and fibres of ronier and the composite cement and rice balls.

For the clothes industry of the test-tubes, we used a metal mould of dimensions 14.5 × 10 × 7.5 cm^3 which we manufactured. The Table 1 following shows the mass composition for 1 m^3 of material.

3.2. Instrumentation

3.2.1. Materials

For the experimentation we used 05 Peltier elements converted into fluxmeters, 05 thermocouples of temperature measurement of surface of the type K, 04 polystyrene insulators, the power station of Benchlinck acquisition and a computer.

3.2.2. Mode Operation

The procedure followed for our experimentation is as follows: Coat on one of the bases 14.5 × 10 cm^2 each sample a fine coat of black paint; Pierce the base of each insulator (polystyrene) using a needle; Pass in each hole bored, one wire of a thermocouple and one wire of a Peltier element; For each insulator, stick the Peltier element and the thermocouple corresponding to the other bases (not covered with black paint) of the one of 04 materials; Put each material in corresponding insulator; Stick on one of the faces covered with black paint one Peltier element and one a thermocouple; Connect the wire of the 05 thermocouples and the 05 Peltier elements to the plate of connection of the power station of acquisition (Agilent Benchlink Dated Logger 3); Connect the power station of acquisition to the computer; Start the computer and the power station of acquisition and make the necessary adjustments to the level of the power station; Launch the application of piloting of the power station and configure the types of measurement. the type of thermocouple; Configure the type of thermocouple (K), the meantime of getting data

Table 1 Mass composition for 1 m^3 of materials.

Composition / Materials	Mass of cement (kg)	Mass of water (kg)	Mass of aggregate (kg)	Total mass (kg)
Composite cement and fibres of ronier	500.00	175.00	546.34	1,221.34
Composite cement and rice balls	500.00	175.00	438.41	1,113.41
Agglomerate	500.00	175.00	1,752.29	2,427.29
Composite cement and ground of bar	500.00	175.00	1,765.61	2,440.61


(a) (b) (c) (d)

Fig. 1 View of the 4 various samples: (a) composite cement and fibres of ronier, (b) composite cement and rice balls, (c) agglomerate and (d) composite cement and ground of bar.

Fig. 2 Materials and the samples in the course of experimentation.

(10 s); Expose the four (04) various samples to the sun i.e. with the ambient air in a released medium deprived of shades and safe from any disturbance; Launch the catch and the recording of the values by the power station of acquisition during 96 hours (04 days); Safeguard the data collected and shut down the power station of acquisition (Agilent Benchlink Dated Logger 3) and the computer.

3.2.3. Description of the Experimentation

The tests were held from 27 to 30 Nov. 2015, that is to say throughout 96 hours in the environment of the University of Abomey-Calavi. During these 4 days of experimentation. We made sure of the correct operation and the safety of all equipment as well as effective catch and recording of the data by the power station of acquisition. The following sight presents the materials and the samples in the course of experimentation. The driving software of the power station of acquisition, Agilent BenchLink Dated Logger 3, makes it possible to collect the data about temperatures and flux.

3.3.Implementation of the Quadripoles for the Estimate of the Holding Capacity and the Coefficient of Transfer U

The physically possible walls are primarily of three types:

- Purely capacitive walls of which ρc is largely dominating;
- The purely resistive walls of which conductivity λ is very small;
- The hybrid wall which is mid-capacitive, mid-resistive.

The two first cases obey purely to the mathematical considerations and only meet very seldom in reality. This is why we will adopt for our study. a fascinating hybrid wall of account the two preceding cases and whose thermal behaviors can be deduced by simplifications from the general case.

The quadripolar diagram of a semi wall infinite complete arises in the form:

The preceding quadripolar diagram can be translated in the field of Laplace (frequential field) by the relation:

$$\psi(\omega) = j\omega(\rho ce)\times\Theta(\omega) \tag{1}$$

where, $\psi(\omega)$ is transform of Laplace of the density flux. $\Theta(\omega)$ is transform of Laplace of the temperature.

The return to the temporal field (Transform reverses of Laplace) is written:

$$\phi(t) = (\rho ce)\frac{dT}{dt}(t) + \frac{\lambda}{e}T(t) + cst \tag{2}$$

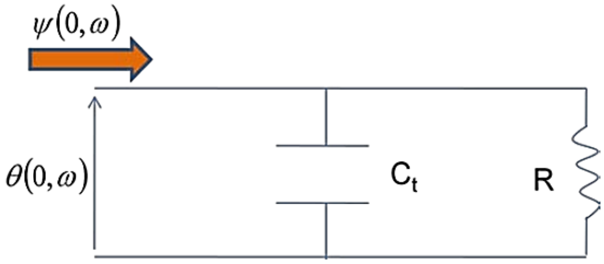

Fig. 3 Quadripolar diagram of the semi medium infinite complete

$$\phi(t) = (\rho ce)\frac{dT}{dt}(t) + \frac{U}{S}T(t) + cst \qquad (3)$$

This model enables us to treat all the thermal scenarios which our samples subjected to the solar thermal requests would present.

If we would not have a response opposite interior for a sample external flow φ_{ext} and the outside temperature T_{ext} are data to be implemented in the model.

If we would have response opposite interior for a material flow to be considered would be $\varphi = \varphi_{ext} - \varphi_{\text{int}}$, and the temperature to be considered would be $T = T_{ext} - T_{\text{int}}$ in the implementation of this model. Thus, for N observations of the couple we obtain the system of equations according to:

$$\begin{bmatrix} \phi(t_1) \\ \phi(t_2) \\ \vdots \\ \vdots \\ \phi(t_N) \end{bmatrix} = \begin{bmatrix} \frac{dT}{dt}(t_1) & T(t_1) & 1 \\ \frac{dT}{dt}(t_2) & T(t_2) & 1 \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ \frac{dT}{dt}(t_N) & T(t_N) & 1 \end{bmatrix} \begin{bmatrix} \rho ce \\ U/S \\ cst \end{bmatrix} \qquad (4)$$

which can also be put in form condensed like

$$\phi = X\beta \qquad (5)$$

where, ϕ is the vector of the observations of density flux of heat indicates, β is the vector of the parameters to be estimated and X is the matrix of sensitivity to the vector parameter β.

This stage when certain conditions are filled up:

- The exact value ϕ_o of ϕ is known with an error of null average and constant standard deviation (there is no correlation between N measurements);
- The matrix of sensitivity X is known without noise of measurement.

Then under these conditions, the theorem of Gauss Markov [9] ensures that the optimal estimator of the vector parameter β i.e. matrix of minimal covariance is given by the estimator of Linear Least Squares (MCL):

$$\hat{\beta} = (X^T X)^{-1} X^T \phi \qquad (6)$$

The optimal parameter $\hat{\beta}$ can thus be calculated starting from the data of temperature and density flux measured. The heat capacity ρc and the coefficient of transfer U of each sample subjected to the study can be thus obtained.

4. Results and Discussion

Having beforehand programmed the power station of acquisition for a recording of the data of temperature and flow interior and external each 10s, we collected on the whole 34560 data. These data underwent a preprocessing in the Excel software then were exported towards the Matlab software for use in the program. Elaborate the Matlab program allows to:

- Plot the curves of temperature and flux variations interior and external for each material during the 96 h of experimentation;
- Determine the coefficient of transfer and the heat capacity ρc of each material while basing itself on the model;
- Determine the interior average temperature of each of 04 studied materials;
- Determine the average quantity of heat having been able to cross all the thickness of each material per day.

4.1. Presentation of Curves

Views 2 and 3 following present the curves of temperature and flux variations interior and external for each material during the 96 h of experimentation.

4.2. Determination of Damping

Let us remember that damping is the difference between the maximum amplitude of outside temperature and the maximum amplitude of interior temperature. The data of damping are consigned in Table 2 following:

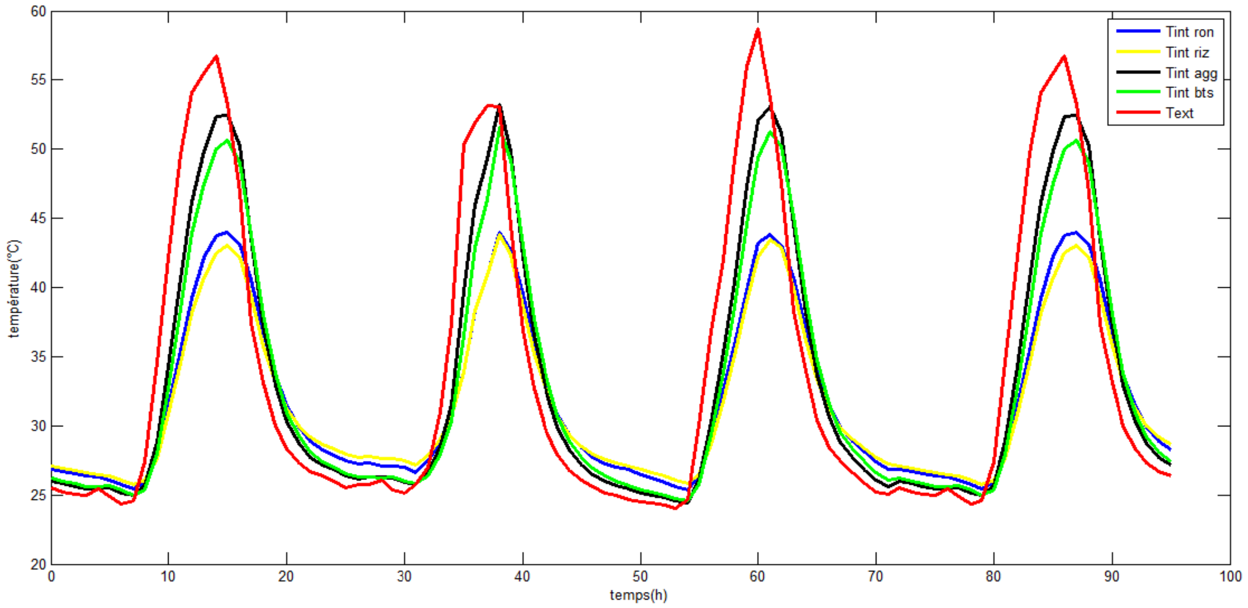

Fig. 4 Variations in temperatures of the four materials during the four days.

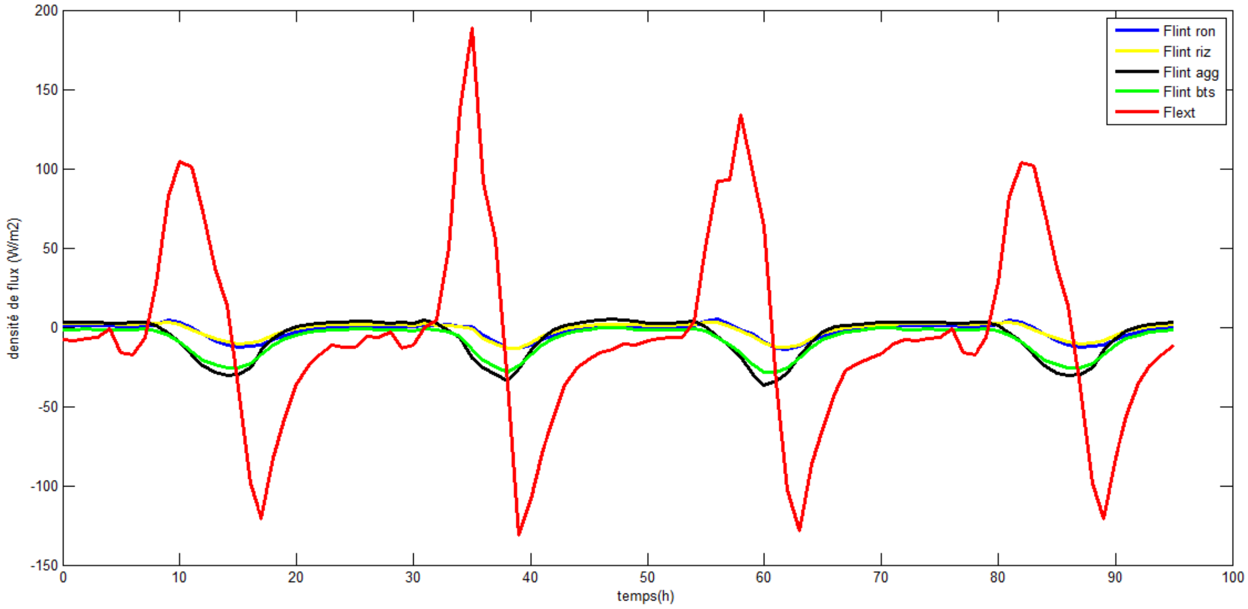

Fig. 5 Variations in thermal flux of the four materials during the four days.

4.3. Estimate of the Heat Capacity and the Coefficient of Transmission

The programming of the model (4) followed by its resolution into (5) makes it possible to consider the vector-parameter optimal $\hat{\beta}$ whose components are, the heat capacity ρc of material, the coefficient of transmission U and a constant which is an intrinsic value related to the thermal past of the material. The importation towards the program of the data of flow and interior and external temperatures makes it possible to estimate this parameter $\hat{\beta}$ for each material. The results obtained are consigned in the Table 3 following.

4.4. Discussion

The data of flow and temperatures interior and external collected are coherent and reflect first, the periodic alternation of the day and the night and after, share the thermal transfers within each of four studied materials. The observation of these data, in particular of the data of flow, makes it possible to notice the ` respiration' of each material, i.e. the movements of flow and backward flow.

Surfaces external of each material being covered with black paint for the main aim to homogenize the external heat flow we include. So, we understand well why the peak of outside temperature is somewhat high compared to the ambient temperature. However, in reality, for the construction of a building, the materials used are covered with coatings or not. Thus, we will have a lowering of the peak of outside temperature at surface of each material. Basing itself then on the principle "Who can more can less", we expect lower peaks of interior temperatures and thus an improvement of damping.

Interior surfaces of each material being isolated using polystyrene we include. We understand well why the data of interior temperatures are somewhat high. However, in reality, these interior surfaces correspond to the enclosure of the building and the phenomena of natural convection will contribute to the lowering of the values of interior temperatures what would improve comfort in the building.

The data collected relate to a thickness of material equal to 7.5 cm. In constructions with Benin, the thickness generally adopted for materials entering the envelope of the building varies between 10 and 15 cm. Thus, for a thickness of each of four studied materials, taken between 10 and 15 cm, us will be able to hope for lower temperatures and flows interior; therefore , a favorable damping .

From the various results, we draw up the Table 4 following .

According to this Table 4, following interpretations can be done:

The classification of materials studied by descending order of the values of damping and heat capacity gives: composite ciment + fibres of ronier, composite ciment + rice balls, composite ciment + ground of bar and agglomerate. The classification of

Table 2 Data of damping in ºC of each of 04 materials.

Materials / Days	Composite cement and fibres of ronier	Composite cement and rice balls	Agglomerate	Composite cement and ground of bar
J1	14.27	15.29	5.45	7.51
J2	12.00	12.03	2.11	4.11
J3	17.35	17.98	7.40	9.57
J4	14.21	15.22	5.38	7.44
Mean	14.46	15.13	5.09	7.16

Table 3 Data of the heat capacity, coefficient of transmission and constant of each of 04 materials.

Materials / Parameters	Composite cement and fibres of ronier	Composite cement and rice balls	Agglomerate	Composite cement and ground of bar
Heat capacity ρc	2,834,266.67	2,871,733.33	2,137,333.33	2,385,333.33
Coefficient of transmission U	0.10	0.09	0.21	0.17
Constant	-20.43	-18.91	-17.99	-22.24

Table 4 Summary table of the thermophysical characteristics.

Material / Parameters	Composite cement and fibres of ronier	Composite cement and rice balls	Agglomerate	Composite cement and ground of bar
Thickness e (m)	0.075	0.075	0.075	0.075
Surface S (m²)	0.0145	0.0145	0.0145	0.0145
Damping (ºC)	14.46	15.13	5.09	7.16
Dephasing (min)	66.00	60.75	55.75	57.50
Heat capacity ρc ($J \cdot m^{-3} \cdot K^{-1}$)	2,834,266.67	2,871,733.33	2,137,333.33	2,385,333.33
Coefficient of transmissionU ($W \cdot K^{-1}$)	0.104	0.0918	0.218	0.171

materials studied by ascending order of the values of coefficient of transmission get the same result as in the preceding case. Thus the best material which can fight effectively against the external thermal variations is the composite ciment + balles of rice. It is followed by the composite ciment + fibres of ronier. This result agrees with that of Doko [8] in 2013, which stipulates that the composite ciment + rice balls rice has better thermal performances than the composite ciment + fibres of ronier.

The values of damping and heat capacity of the composite cement + ground of bar are higher than those of the agglomerate. This result is in agreement with the values of coefficient of transmission. Thus, construction with the ground of bar offers better interior conditions to that with the agglomerate.

The values of damping and heat capacity of the composites ciment + rice balls and ciment + fibres of ronier are higher than those of the composite ciment + ground of bar and the agglomerate. Thus the composite of cement and fibre plants and cement get a better thermal holding capacity to materials containing ground. So the incorporation of vegetable fibres in the manufacture of materials used for the construction of the envelope of the building makes it possible to improve thermal comfort within the building.

5. Conclusions and Prospects

In front of the unrestrained increase in the request for energy in the world and the climatic reheating , the men are more and more confronted with a double challenge: to satisfy its requirements in energy while limiting the impact for its consumption on our environment.

This work is a contribution to the improvement of the efficacy energy of the building through an envelope which makes it possible to fight against the variations in external temperature. The knowledge of the thermal holding capacity i.e. of damping, dephasing, heat capacity and coefficient of transmission of building materials constitute a very significant link in the control of energy for the reduction of the energy losses in the building. It acted during our study, to compare the thermal holding capacity of four various materials used in the construction of the buildings with the Benin. Of this study we retain that the best material which can fight effectively against the thermal variations external and having thus the largest holding capacity is the composite ciment + rice balls. It is followed by the composite ciment + fibres of ronier. Then follow the composite ciment + groung of bar which is better with the agglomerate. This last material which is nowadays the most used in the construction of the buildings in Bénin, has a very low holding capacity. It is then important to revisit our practices of construction in the irection of the use of adequate materials, for example, using the composite ciment + rice balls allowing to improve thermal comfort and/or to reduce the energy consumption related to air-conditioning.

This work could be used as guide for conscious construction and minimization of the energy consumption related to the building in Benin and even in all the under-area. It will have to follow upon a thorough study taking of account the weather conditions such as the pressure, the moisture, the speed of the wind and sunning. This study will lead to a mathematical modeling followed by a simulation. the whole leading to the development of a software which would be a very significant tool for the design of the buildings in a given zone of our country and even of the under-area. Also, other investigations following this work could consist to:

- Study the evolution of the thermal holding capacity of materials having best holding capacities (here the composites ciment + rice balls and ciment + fibres of ronier) according to the thickness;
- Study the thermal holding capacity of various formulations of a composite ciment+ rice balls and a composite cement+fibres of ronier as well as double-layered or multi-layer materials;
- Study the thermal holding capacity of other

building materials local to Benin like the composites ciment+ fibres of coconut and ciment + hulls of nut of cabbage tree;

- Study the influence of the variation of cement and water's proportionings on the holding capacity of materials;
- Seek possible additions being able to increase the thermal holding capacity of studied building materials.

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