International Journal of Engineering, Science and Mathematics
Vol. 12 Issue 4, April 2023
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell’s Directories of Publishing Opportunities, U.S.A

Development and characterization of thermal insulation panels based on rice husks and kapok fibers stabilized with plaster

Ousmane OUEDRAOGO[*]
Abdoulaye COMPAORE[**]
David NAMOANO[***]
Wendsida Serge IGO[****]
Alfa Oumar DISSA[****]

Abstract

This study is part of the recovery of agricultural residues and plant fibers in the thermal insulation of buildings. Set plaster is commonly used in construction as a thermal insulation for roofs or walls (in the form of panels or coating). The study analyzed the influence of the incorporation of rice husk and kapok wool on the thermal and mechanical properties of the set plaster. It consisted initially in finding the right mass ratios plaster/rice husk, plaster/kapok wool and water/plaster which combine good thermal performance and good mechanical resistance. Then, these ratios were used to develop two biosourced eco-materials in the form of thermal insulation panels made from rice husk and kapok wool using plaster as a binder. These panels were tested in the thermal insulation of the roof and walls of a model classroom. Thermal properties were measured with a thermal property analyzer. The results obtained show that the formulated eco-materials offer good thermomechanical cleanliness and improve the thermal comfort of the building. Their thermal conductivity varies from 0.109 to 0.214 $W.m^{-1}.K^{-1}$ depending on the formulation. The study also showed that with these panels, for an insulation thickness of 2 cm, the interior temperature of the room can be reduced by 5°C ± 2°C on average. The eco-materials thus developed can be used as roof or wall insulation in order to reduce heat flows through the building’s envelope.

Keywords:

Rice husk;
Kapok;
Thermal insulator;
Agricultural residues;
Eco-material.

Author correspondence:

OUEDRAOGOOusmane,
Ecole Doctorale Sciences et Technologies, Laboratoire de Physique et de Chimie de l’Environnement
Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso
Email: ouedous@gmail.com

---

[*] Université Joseph KI-ZERBO (UJKZ), Unité de Formation et de Recherche en Sciences Exactes et Appliquées (UFR-SEA), Laboratoire de Physique et de Chimie de l’Environnement (LPCE), Ouagadougou, Burkina Faso
[**] Département Energie, Centre National de la Recherche Scientifique et Technologique (CNRST), Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), Ouagadougou, Burkina Faso
[***] Université Joseph KI-ZERBO (UJKZ), Unité de Formation et de Recherche en Sciences Exactes et Appliquées (UFR-SEA), Laboratoire des Énergies Thermiques Renouvelables (LETRE), Burkina Faso
[****] Département Energie, Centre National de la Recherche Scientifique et Technologique (CNRST), Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), Ouagadougou, Burkina Faso
[****] Département Energie, Centre National de la Recherche Scientifique et Technologique (CNRST), Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), Ouagadougou, Burkina Faso

1. Introduction

Faced with economic and environmental challenges, energy management in buildings has become a major stake [1], [2], [3], [4]. The insulation of a home is essential to obtain a satisfactory level of thermal comfort and to reduce its energy consumption. According to ADEME, 25-30% of the heat escapes from an uninsulated building via the attic and the roof (this is therefore the priority in terms of insulation), 25% via the walls, 10 % or 15% by glass and windows and 7% or 10% by floors [5], [6]. A thermal insulation project must take into account not only these different elements of the habitat but also the thermal properties of the materials because they govern the heat transfers within the materials and from the habitat [7]. The search for local, ecological and low embodied energy insulating materials is very important for the eco-construction of new buildings or the renovation of existing buildings [8], [9], [10]. The recovery of agricultural residues and plant fibers by formulating biosourced insulating materials in housing remains an appropriate solution [11], [12].

In Burkina Faso, the enormous quantities of rice husksproduced each year are not valued very much. The purpose of this study is to valorize agricultural residues and plant fibers by analyzing the influence of the incorporation of rice husk and kapok fiber on thethermomechanical properties of thermal insulation in plaster reinforced with fiber used in construction. Thestudy set out to formulate, manufacture and characterize two thermal insulating eco-materials in the form ofbiosourced panels made from rice husk (agricultural residues) and kapok (vegetable fiber) using plaster as abinder [4], [13].

2. Research Method

2.1. Basic materials used

Rice husk: it is produced in very large quantities each year in Burkina Faso, it comes from the hullingof rice and comes in the form of a loose vegetable aggregate (photograph (a) of Figure 1). Its totalporosity is around 90% [8], so it has an interesting thermal insulation capacity. The thermalconductivity of a mixture of loose rice husks at 24°C varies in the order of 0.046 to 0.057 W.m^{-1}.K^{-1} for a bulk density of 139 to 168 kg.m^{-3} [8]. E. Chabi [14] found that it changes with density andvaries from 0.062 to 0.079 W.m^{-1}.K^{-1} . Rice husk is used in construction mainly as thermal insulationin bulk or in the form of bricks, rendering or agro-concrete.

Kapok: it is a vegetable fiber obtained from the fruit of a tree of the bombacaceae family verywidespread in sub-Saharan Africa, see photograph (c) of Figure 1. This tree is known under the nameof cheese tree or Ceiba Pentandra [16]. According to A. Wereme [1] kapok fiber offers very goodthermal conductivity, this is 0.043 W.m^{-1}.K^{-1} for a density of 35 kg.m^{-3}. Figure 1 below shows thebasic materials used.

(a) Rice husk (b) Plaster (c) Kapok fibers[16]

Figure 1: Basic materials used

β hemihydrate plaster: the word plaster can designate the plaster powder resulting from theindustrial firing of gypsum and the set plaster obtained by mixing the hemihydrate with water [17].The semihydrated plaster is in the form of a white powder obtained by heating soft and crystallinerocks with a high percentage of gypsum, photograph (b) of Figure 1. The heating of the gypsum leads to the evaporation of the water contained in the rock and therefore its dehydration, then itscalcination. Plaster is thermally insulating and fireproof, two highly sought-after characteristics inhousing [18]. It is also a good sound insulator and has good fire resistance, but it is permeable towater vapour. Plaster is a hydraulic binder, mixed with water it hardens when it sets [15]. It is widelyused in construction as a staff (plaster reinforced with tow), false ceiling, ceiling, false floor, façadecladding (plaster), screed, partition, lining, and in the repair of walls (filling). The thermal conductivity of a plaster coating is around 0.26 W.m^{-1}.K^{-1} while that of cement is 1.15 W.m^{-1}.K^{-1}[17].

2.2.Formulation of biobased composites

❖ Dosage of samples

About 10 sample composites were made to find the best formulation and dosages that combine goodthermal and mechanical properties. The rice ball was weighed and pre-wet for 4 hours then drainedon a sieve to get rid of excess water, this prevents it from absorbing the water necessary for thehydration of the plaster and the drainage of the plaster towards the bottom of the sample [19]. Thekapok was cut into fibers of less than 1 cm in length to have more homogeneous composites.Different samples were made by varying the mass percentage of rice husk from 10 to 50% and thatof kapok from 2 to 7%. Table 1 gives the mass ratios of the base materials in the samples.

Table 1. Dosages: mass ratios of base materials

Composites (formulation)	Mass ratios		
	E/P	**P/B**	**B/K**
Plaster + Water	0,5 ; 0,8 ; 1,0		
Plaster + Rice husk + Water	0,8	2,3 à 9,0	
Plaster + Rice husk + Kapok + Water	1,0	4,0	2,9 à 6,7

P: plaster (Binder); B: rice husk (vegetable aggregate); K: kapok (vegetable fiber); E: water

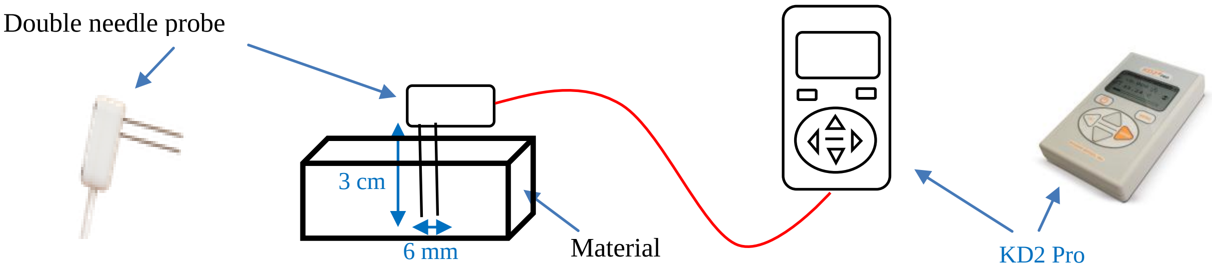
❖ Manufacture of panels

The characterization tests on the sample composites made it possible to retain the appropriate dosagesto make two types of insulating panels with dimensions of 120 x 80 x 2 cm3 each. The first iscomposed of 12% rice husk, 49% plaster and 39% water by wet mass, being the mass ratios: W/P=0.8 and P/B=4.0. The second consists of 12% rice husk, 3% kapok, 47% plaster and 38% water, the massratios being W/P=0.8; P/B=4.0 and B/K=4.0. The control panels are composed of 56% plaster and44% water, i.e., a W/P ratio of 0.8. To manufacture the panels, the plaster is first mixed with waterat a W/P mass ratio of 0.8 from the β hemihydrate powder [20]. Add the rice ball and the kapok,stirring until you have a homogeneous mixture. A first layer of the mixture is projected into the mold which will form the visible and smooth face. A light and airy mattress of tow distributed on the stillfresh composite is then deposited to form a reinforcement and finally, a second layer of the compositeis added to obtain the desired thickness.

2.3. Characterization of thermal and mechanical properties of composites

❖ Measurement of thermal properties

The thermal properties of the composites were determined using a powerful thermal propertyanalyzer, the KD2 Pro. It uses a method called the double needle algorithm [21] and offers anaccuracy of ± 0.01 $W.m^{-1}.K^{-1}$ for thermal conductivity values of 0.02 to 0.2 $W.m^{-1}.K^{-1}$ and ±10%error for those between 0.2 and 2 $W.m^{-1}.K^{-1}$. The method consists of pushing the two needles of thesensor into the material. A heat flux is applied to one of the needles for a defined heating time, andthe temperature is measured on the other (monitoring) needle, 6 mm apart. During the cooling period following the heating, the temperature is again measured. The resulting data is fitted to theappropriate equations using a nonlinear least squares procedure [21].



(a) (b) (c)

Figure 18: Measurement device using the double-needle algorithm (b) with a double-needle probe (a) and a thermal property analyzer (c)

The thermal conductivity of a material quantifies its ability to diffuse heat, it varies according to thetemperature and the nature of the material. When the material is homogeneous and isotropic, the heatflux density passing through the layer is proportional to the temperature gradient and is given by Fourier's law according to Equation (1). In steady state and in the simple case of a one-dimensionalheat flow through a homogeneous material, the thermal conductivity corresponds to the coefficientof proportionality λ between the heat flow and the temperature gradient given by Equation (2).

$$\vec{\varphi} = -\lambda\,.\,\overrightarrow{grad}(T) \quad (1)$$

$$\varphi = -\lambda\,\frac{dT}{dx} \quad (2)$$

φ is the heat flux (in W.m^{-2}); λ thermal conductivity (in W.m^{-1}.K^{-1}); T the temperature (in K); x thedirection of propagation of the heat flux.

The thermal diffusivity characterizes the speed ofpropagation of a thermal wave in the material. It is related to thermal conductivity, specific heat anddensity. When the thermal conductivity is a function of the spatial coordinates and the temperatureof the environment, which itself is a function of time, Equation (3) gives the heat equation [22].

$$\rho.c.\frac{\partial T}{\partial t} = div\left(\lambda.\overrightarrow{grad}(T)\right) \quad (3)$$

For unidirectional heat transfer and when the thermal parameters are independent of temperature, thetransient Fourier equation is written as Equation (4) and the thermal diffusivity is given by Equation(5).

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\rho.c}\frac{\partial^2 T}{\partial x^2} \quad (4)$$

$$D = \frac{\lambda}{\rho.c} \quad (5)$$

D is the thermal diffusivity of the medium (in m².s^{-1});ρ the density of the material (in kg.m^{-3}) and c its specific heat (in J.kg^{-1}.K^{-1}).

❖ Calculation of the thermal phase shift

The thermal phase shift characterizes the ability of a material to delay the flow of heat. It representsthe transfer time of a heat flux through the material. For the wall of a dwelling, it corresponds to thetime interval between the moment when the temperature outside reaches its maximum and themoment when the temperature inside reaches its maximum [23]. The transfer rate v of the heat fluxthrough the material is given by Equation (6). By taking a cycle of temperature variations of 24 hoursand taking into account the thermal diffusivity D, the thermal phase shift is obtained by Equation (7).

$$v = \frac{2\,\pi}{T}\sqrt{\frac{T}{\pi}\,\frac{\lambda}{\rho.c}} \quad (6)$$

$$\tau = \frac{e}{v} = \frac{1{,}38\,e}{\sqrt{D}} \quad (7)$$

With v: speed of heat flow (in m.h^{-1}), T: cycle period of temperature variations (in h), λ: thermal conductivity (in W.m^{-1}.K^{-1}), ρ: density (in kg.m^{-3}) and c: specific heat (in Wh.kg^{-1}.K^{-1}). τ: thermal phase shift (in h), e: thickness of the material (in m), D: thermal diffusivity of the material (in m².h^{-1}).

❖ Three-point bending strength test

Since the panels are intended to be used for roof insulation, the three-point bending method was usedto characterize their resistance to bending. The panels were cut into test specimens of 16 x 4 x 2 cm^{3}which were arranged (its section 16 x 4 cm^2) on two supports spaced apart from each other. A thirdsupport is placed on the upper face of the specimen halfway between the support supports Figure 3.The press exerts a load gradually on the specimen until it breaks [24]. The three-point bendingstrength is given by Equation (9).

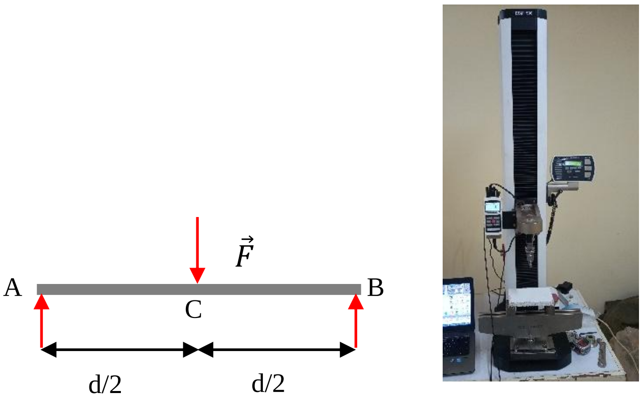


Figure 3: Schematic and device for three-point bending resistance test

$$R_f = \frac{3.F.d}{2\,l.e^2} \qquad (8)$$

With, Rf: the bending strength (MPa), F: the breaking load (N), d: the distance between the supports (mm), l: the width of the specimen (mm), e:the thickness of the specimen (mm).

3. Results and Analysis

3.1.The different formulations

The formulations studied, the dosages and the mass ratios of the base materials that make up the variouscomposites are given in Table 2

Table 2: Formulated composites studied

P + E			**P + E + B**				**P + E + B + K**				
N°	**Composites**	**E/P**	**N°**	**Composites**	**E/P**	**P/B**	**N°**	**Composites**	**E/P**	**P/B**	**B/K**
1	PE0.5	0,5	4	BP3,0	0,8	3,0	8	KB2.9	1,0	4,0	2,9
2	PE0.8	0,8	5	BP4.0	0,8	4,0	9	KB3.5	1,0	4,0	3,5
3	PE1.0	1,0	6	BP5.7	1,0	5,7	10	KB5.5	1,0	4,0	5,5
			7	BP9.0	1,0	9,0	11	KB7.3	1,0	4,0	7,3

P: plaster;E: water;B: rice husk;K: kapok

Dosages No. 5 and No. 9 were used to produce the panels and Dosage No. 2 (standard dosage) was used to make the control panel.Figure 5 and Figure 6 below are the photographs of the samples and formulated insulation panels, respectively.

(a) Photography of samples

(b) Photographs of the panels

Figure 4: Photograph of samples (a) and panels (b)

3.2. Thermophysical characteristics of samples

❖ Composite drying kinetics

After demoulding, the evolution of the mass of the composites was observed during their drying in the openair at room temperature for 14 days (Figure 5). The loss of mass is low during the first three days, then increases significantly until the tenth day before stabilizing, the mass of the composite becomes practically constant fromthe twelfth day. The observation is that the loss of mass is all the more important as the rice husk content is higher, it is even more so with the presence of kapok. After drying, the water content of the composites isaround 8 to 13% depending on the formulation (Figure 6). It is lower in composites containing more kapok wool, this is explained by the fact that kapok wool absorbs water more difficultly than rice husk. Apparentporosity varies from about 50 to 80%, it is higher in composites containing kapok wool. The density of thecomposites decreases with the addition of rice husk and kapok wool, at the same time their porosity increases(Table 3), which improves their thermal conductivity.

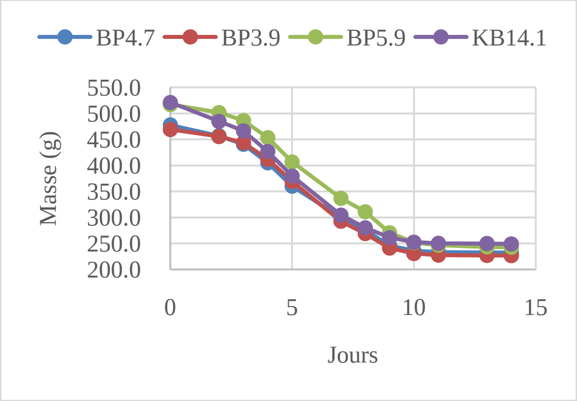


Figure 5: Evolution of the mass of composites over time

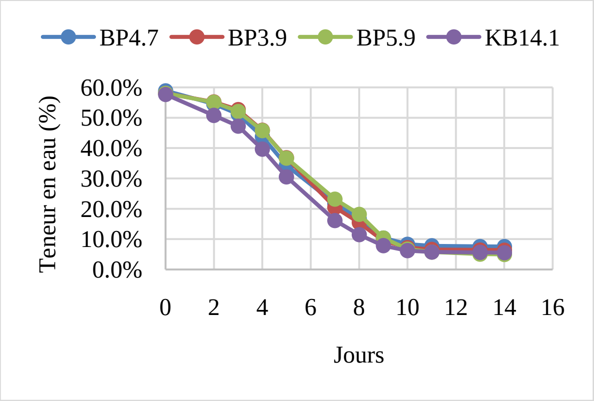


Figure 6: Evolution of the water content of composites over time

❖ Water absorption capacity of composites

The water absorption by the composites was evaluated by immersing them in water and following the evolutionof the mass of each composite as a function of time. The fraction of water absorbed is expressed as a percentage. The absorption of water by the composites is very rapid during the first minutes up to an hour of time and canreach 120% of their masses in water before reaching saturation after three hours of immersion. We found that water absorption is greater when the proportion of kapok increases (samples: KB13.7, KB8.5). This isexplained by the higher porosity of these composites, this porosity was reinforced by the kapok fibers. Figure7 below represents the curves of water absorption by the composites and Figure 8 gives the rate of waterabsorption. The presence of kapok fiber increases the rate of water absorption Text source

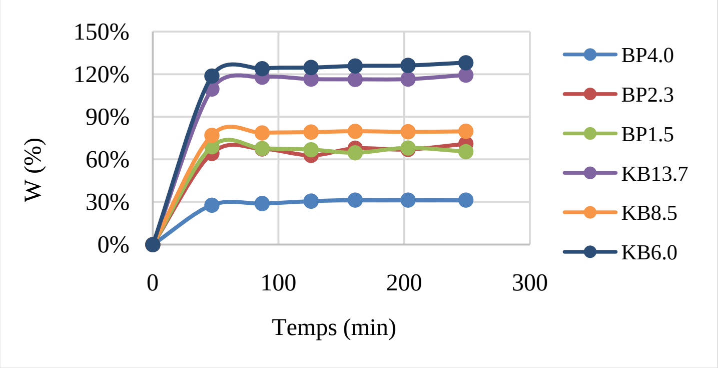


Figure 7: Water absorption kinetics of composites

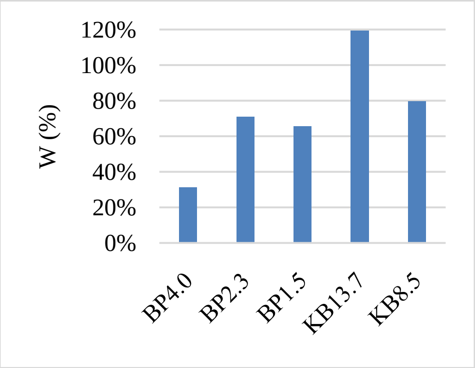


Figure 8: Water absorption rate

❖ Influence of binder content on thermal properties of composites

Adding the rice husk to the plaster decreases the thermal conductivity of the insulation board. It drops from0.135 W.m^{-1}.K^{-1} for a plaster/rice husk mass ratio (P/B) of 2.3 to 0.109 W.m^{-1}.K^{-1} for a (P/B) ratio of 1.0.From a ratio (P/B) of 1.5, the insulating panels obtained are quite light but friable. To avoid this crumbling, thedosage of the plaster was pushed up to a ratio (P/B) of 9.0. In this case, the panels are a little heavier and theirthermal conductivities increase. With a P/B ratio of 1.9 the thermal conductivity is 0.127 W.m^{-1}. K^{-1}, but weretained the ratio of P/B of 4.0 and E/P of 0.8 which is more adequate for the development of the panels. Withkapok wool, the composites are more insulating but also more friable. The best results were obtained with P/Bratios of 1.4 to 2.1 and B/K ratios of 6.0 to 13.0; which gave a thermal conductivity varying from 0.115 to0.146 W.m^{-1}.K^{-1}, the average being 0.126 W.m^{-1}.K^{-1}. These results are in agreement with those of E. Chabi[14] who found that the average value of the thermal conductivity of rice husk concrete varied from 0.070 to0.171 W.m^{-1}.K^{-1} depending on the binder dosage. For the manufacture of the second insulating panel, weretained the proportions P/B of 4.0 B/K of 4.0 and E/P of 1.0; which gave a thermal conductivity of 0.115 W.m^{-1}.K^{-1}. The evolution of the thermal diffusivity is a little irregular, we believe that this is due to the fact thatcertain composites are not strictly homogeneous. Figure 9 below shows the evolution of the thermalconductivity and Figure 10 the thermal diffusivity of this first type of panel as a function of the binder content.

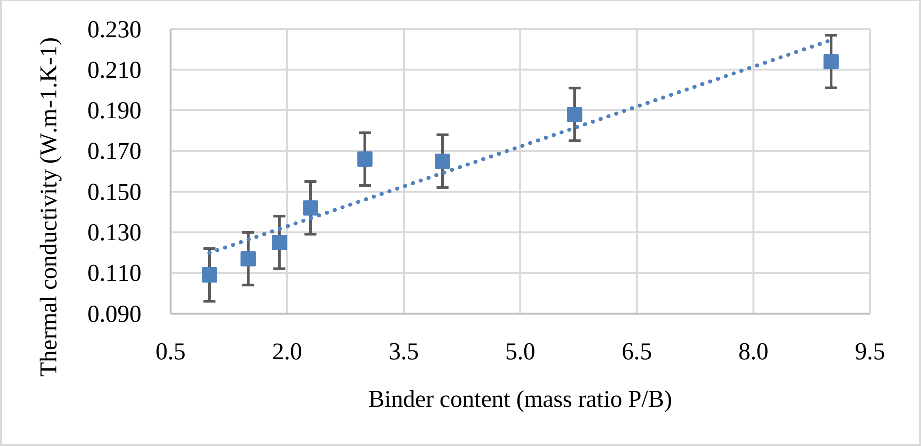


Figure 9: Variation of thermal conductivity as a function of binder content

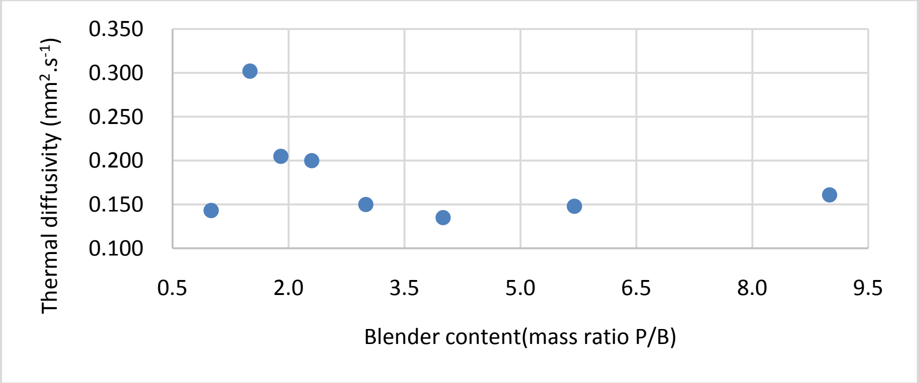


Figure 10: Variation of thermal diffusivity as a function of binder content

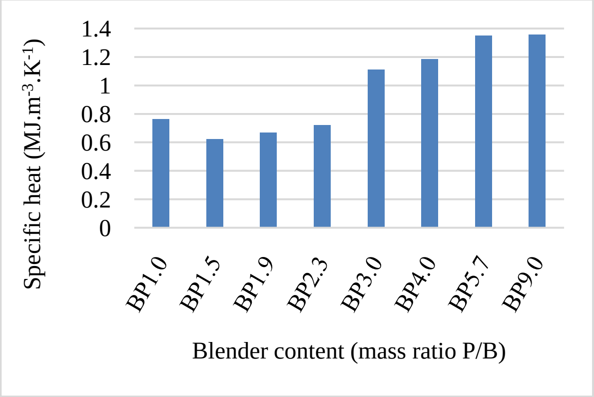


Figure 11: Variation in thermal resistance as a function of binder content

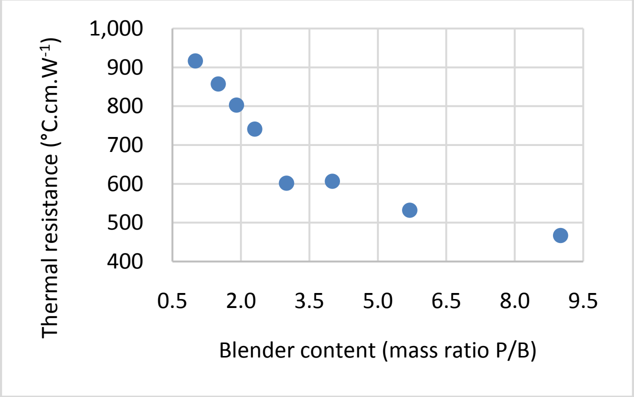


Figure 12: Variation of specific heat as a function of binder content

3.3. Thermophysical and mechanical characteristics of the panels

The results of the panel characterization tests are given in Table 4 below.The flexural strength of the panels increases as the binder content of the samples increases.Thus, for plaster P/B ratios of 1.0 to 4.7, the three-point bending strength increases from 1.62 MPa to 4.0 MPa.

Table 4: Thermophysical and mechanical characteristics

Composites	**Densité ($kg.m^{-3}$)**	**Porosité (%)**	**Conductivité thermique ($W.m^{-1}. K^{-1}$)**	**Capacité thermique ($MJ.m^{-3}.K^{-1}$)**	**Diffusivité thermique ($mm^2.s^{-1}$)**	**Déphasage thermique (h)**	**Résistance en flexion (MPa)**
BP4.0	936	82	0,135 ± 0,010	0,723 ± 0,010	0,200 ± 0,010	4 ±1	3,6 ± 0,4
KB4.0	917	56	0,115 ± 0,010	0,587 ± 0,010	0,201 ± 0,010	5 ±1	3,2 ± 0,1

Bio-based panels can induce a thermal phase shift of 3 to 6 hours for an insulation thickness of 10cm. The test on the pilot building made it possible to see that without insulation, the temperature ofthe air inside the building reaches 40°C whereas with the biosourced panels with an insulationthickness of 2 cm, the temperature of the indoor air in the room is limited to 34°C (Figure 13). Theamplitude of the thermal wave is attenuated by about 5°C ± 2°C on average.

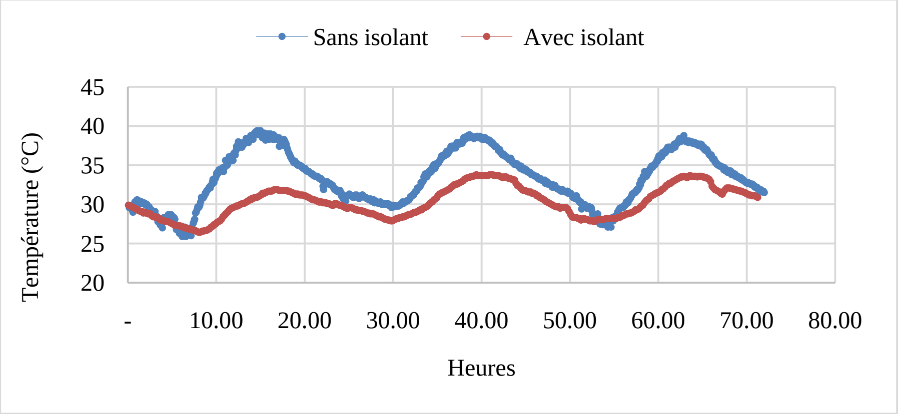


Figure 13: Variation of the air temperature inside the building

4. Conclusion

This study made it possible to develop biosourced insulating panels based on mixtures of rice husksand kapok wool stabilized with plaster. The characterization tests made it possible to evaluate thethermal and mechanical properties of the bio-based panels composed respectively of rice husk +plaster and rice husk + plaster + kapok and gave average thermal conductivities respectively of 0.115± 0.005 $W.m^{-1}.K^{-1}$ and 0.127 ± 0.005 $W.m^{-1}.K^{-1}$. The results obtained show that the panels offergood characteristics for use as thermal insulation for roofs (false ceilings, ceilings) or walls and canimprove the thermal and energy performance of buildings. They have the advantage of being goodinsulators, less expensive and light compared to ordinary set plaster (staff) commonly used inconstruction. They can also be used in the conservation of agri-food products, medicines and vaccinesin southern countries where electrical energy remains inaccessible in rural areas.

References

[1] A. Wereme *et al.*, « Caractérisation des isolants thermiques locaux de type sciure de bois et kapok : mesure de coefficient global d'échange thermique et de la conductivité thermique », *J. Sci.*, vol. 10, n° 4, p. 39‑ 46, 2010.

[2] D. Toguyeni, O. Coulibaly, J. Koulidiati, Y. Dutil, et D. R. Rousse, « Étude de l'influence de matériaux locaux isolants de toiture sur les charges de climatisation d'une maison individuelle en argile-paille », *CIFEM2012 – ART-13-93*, p. 1‑ 4, 2012.

[3] N. Belayachi, D. Hoxha, et I. Redikutseva, « Étude comparative du comportement hygrothermique des matériaux à base de fibres végétales », présenté à Rencontres Universitaires de Génie Civil, Bayonne, France, mai 2015. doi: HAL Id: hal-01167655.

[4] S. O. G. Osseni, B. D. Apovo, C. Ahouannou, E. A. Sanya, et Y. Jannot, « Caractérisation thermique des mortiers de ciment dopés en fibres de coco par la méthode du plan chaud asymétrique à une mesure de température », *Afr. Siences*, vol. 12, n° 6, p. 119‑ 129, 2016.

[5] ADEME, *Rénovation-Isoler sa maison*. 2022. [En ligne]. Disponible sur: www.agirpourlatransition.ademe.fr/particuliers

[6] ADEME, *Rénovation, Isoler sa maison. Pour gagner en confort et dépenser moins*. 2017. [En ligne]. Disponible sur : www.ademe.f

[7] B. S. Umurigirwa-Vasseur, « Élaboration et caractérisation d'un agromatériau chanvre amidon pour le bâtiment », Thèse de Doctorat, Université de Reims Champagne-Ardenne, Reims Champagne-Ardenne, 2014.

[8] M. Chabannes, « Formulation et étude des propriétés mécaniques d'agrobétons légers isolants à base de balles de riz et de chènevotte pour l'écoconstruction », Thèse de Doctorat, Université de Montpellier, Montpellier, 2015. [En ligne]. Disponible sur : https://tel.archives-ouvertes.fr/tel-01316947

[9] N. Dujardin, « Un matériau biosourcé de choix : les fibres naturelles. Caractérisations et applications », in *L'économie verte en question*, Créteil, France, févr. 2014, p. 1‑ 11. Doi : hal-00978360.

[10] E. Chabi, V. Doko, E. Agoua, E. Olodo, E. C. Adjovi, et A. Merlin, « Formulation de béton de balle de riz : étude du comportement au cisaillement et au poinçonnement-flexion », *Afr. Sci.*, vol. 12, n^o 5, p. 114‑ 124, 2016.

[11] C. Magniont, « Contribution à la formulation et à la caractérisation d'un éco-matériau de construction à base d'agroressources », Thèse de Doctorat, Université Toulouse III - Paul Sabatier, Toulouse, 2010.

[12] F. Dejeant, P. Garnier, et T. Joffroy, *Matériaux locaux, matériaux d'avenir : Ressources locales pour des villes et territoires durables en Afrique*, CRAterre Éditions. Villefontaine : CRAterre, 2021.

[13] M. Lahouioui, M. Fois, L. Ibos, et A. Ghorbal, « Étude des performances thermiques de matériaux à matrice cimentaire renforcés par des fibres de bois de palmier traitées ».

[14] E. Chabi, « Étude de la formulation et des propriétés mécaniques et thermiques du béton de balles de riz », Thèse de Doctorat, Université de Lorraine ; Université d'Abomey-Calavi (Bénin), 2017. Consulté le : 30 août 2022. [En ligne]. Disponible sur : https://hal.univ-lorraine.fr/tel-01907795

[15] T. L. Raheliarimanana, « Valorisation des cendres de balle de riz pour la production des liants minéraux », Université d'Antananarivo, Antananarivo, Mémoire de Master, 2018.

[16] L. M. Voumbo, A. Wereme, S. Tamba, S. Gaye, M. Adj, et G. Sissoko, « Caractérisation des propriétés thermophysiques du kapok », *J. Sci.Vol.*, vol. 8, n^o 1, p. 33‑ 43, 2008.

[17] S. Meille, « Étude du comportement mécanique du plâtre pris en relation avec sa microstructure », Thèse de Doctorat, INSA de Lyon, Lyon, 2001. [En ligne]. Disponible sur : https://tel.archives-ouvertes.fr/tel-00477188

[18] Wikipédia, Encyclopédie libre, « Plâtre », *Wikipédia*, 19 juillet 2022. https://fr.wikipedia.org/w/index.php?title=Plâtre&oldid=193343682

[19] A. G. A. Agli, « Étude du comportement thermomécanique du composite balles de riz - sable - ciment », Université D'Abomey-Calavi, Mémoire de Master, avr. 2021.

[20] F. B. Ebanda, « Étude des propriétés mécaniques et thermiques du plâtre renforcé de fibres végétales tropicales », Thèse de Doctorat, Université Blaise Pascal - Clermont-Ferrand II, 2012. [En ligne]. Disponible sur: https://tel.archives-ouvertes.fr/tel-01153478

[21] Decagon Devices, Inc., *KD2 Pro Thermal Properties Analyzer - Operator's Manual*. 2016. [En ligne]. Disponible sur: www.decagon.com

[22] P. Meukam, « Valorisation des briques de terre stabilisées en vue de l'isolation thermique de bâtiments », PhD, Université de Cergy-Pontoise et l'Université de Yaoundé I, Yaoundé, 2004.

[23] A. Compaoré, « Étude des performances thermiques d'un habitat type du Burkina Faso. Application : contribution à la mise en place d'une règlementation thermique », Thèse de Doctorat, Université Joseph Ki-Zerbo, Ouagadougou, 2018.

[24] K. C. Kouadio, S. P. Kaho, S. Ouattara, et E. Emeruwa, « Influence de la teneur en résine de polystyrène expansé sur les propriétés thermomécaniques d'un composite de copeaux de bois stabilisé », *Rev. Ivoire Sci. Technol.*, n^o 36, p. 42‑ 51, déc. 2020.