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Developing New Insulation Building Materials Based on Clay and Ecological Additives

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Abstract: ***The thermal performance of exterior walls is considered as a key factor to improving energy efficiency in buildings, especially in areas with cold climates in winter and warm climates in summer. As part of this study, and whose building materials are known for their low thermal properties. The X-ray diffraction was performed on the clay material and the different fibers in order to determine their crystallinity. An experimental characterization of thermophysical properties of a new biocomposites material for the sustainable buildings construction in southern Morocco is presented. These materials can be used as mortar for ceilings and exterior walls. To this end, several samples were prepared from clay extracted from the Errachidia region (south-east Morocco) and three mass fractions of alfa, fig and reed fibers (20%, 40% and 60%). The thermal characterization method adopted is that of the highly insulated thermal house. The results revealed that the incorporation of alfa, fig and reed fibers into the clay matrix allowed a remarkable reduction in apparent density and thermal conductivity. This result shows the interest of using this biocomposite material in construction buildings to ensure thermal comfort and reduce greenhouse gas emissions.***

Keywords: ***Thermal performance, energy efficiency, biocomposites material, characterization, apparent density, thermal conductivity, greenhouse gas emissions.***

I. INTRODUCTION

The objective announced by the Moroccan government is to achieve a primary energy saving of about 12% to 15% by 2020, through the implementation of an energy efficiency strategy in the various economic sectors [1]. Among these sectors, building is the second largest consumer of energy, with a rate of 25% of the total energy consumption. In terms of energy efficiency in buildings, Morocco is lagging considerably behind.

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Indeed, the most significant example is the thermal losses in building that result in heat losses through exposed walls such as roofs, exposed facade elements and thermal bridges. In order to solve these problems, a thermophysical characterization of the commonly used building materials is necessary in order to choose the most energy-efficient building wisely. In this context, several studies have been carried out on the main construction materials [2-4]. These materials have low thermal insulation properties, which has sparked the interest of several researchers to develop new biocomposite materials by incorporating natural additives dedicated to thermal insulation in housing [5-9]. Date palm fibres have a remarkable effect on the thermal properties of cement mortar [10]. The obtained results of this study show a reduction in thermal conductivity of about 70%. Belhadj et al. [11] have shown that the inclusion of barley straw fibers in the concrete matrix can improve thermal conductivity by 5.71%. The work of Rahim et al. [12] have been devoted to the alloy of mortar with a mass fraction of about 16% of three vegetable fibers, namely straw, hemp, and flax, the thermal conductivity is linear and increasing with the water content which has a remarkable effect at high temperature. Lachheb et al. [13] showed that adding 6% in the mass fraction of the used coffee grounds to the plaster might reduce its thermal conductivity from 0.5 to 0,314W/m.K (38%).

Clay is a sustainable, ecological and very thermally inert building material. It is used for the construction of traditional houses and ksars in southern Morocco, where the climate is cold in winter and hot in summer. The thermal performance of clay can be improved by incorporating natural additives to obtain a more insulating composite material. In this context, Ouakarrouch et al. [14] effected an experimental and numerical characterization to assess the thermal comfort of "Ksar Lamaadid" located in Erfoud region. This ksar is built with a new biocomposite material based on clay and sisal fibers. It demonstrated that the inclusion of 4% of sisal fibers can reduce the thermal conductivity of the material by about 11.2%, which can ensure thermal comfort by reducing greenhouse gas emissions by about 62442 kg of CO_2/year. Aboubou et al. [15] improved the thermal performance of clay extracted in the Bamako region by incorporating different mass fractions of rice husks, they found that the addition of 14% of this additive reduced thermal conductivity from 0.54 to 0.25 W/m.K. The effect of plant fiber addition on the thermophysical proprieties of clay mixtures was investigated by Liuzzi et al. [16]. Similarly, Calatan et al. [17] remarked that the use of hemp fibers has a positive impact on thermal and mechanical proprieties. Mahamat et al.

[18] noted that the thermal proprieties of the soil from N'Djamena in Chad without and with straws increase with water content. The incorporation of olive grains, palm fibres and straw into the clay matrix produces materials that are twice as insulating, and lighter than raw clay. The theoretical energy gain is more than 50% [19]. El Azhary et al. [20] improved the thermophysical proprieties of the unfired clay extracted from the Ouarzazate city by adding straw. Martín et al. [21] studied an assessment of the thermal behaviour in traditional and wooden construction in Spain. The research work of Mokhtari et al. [22] and El Azhary et al. [23] were devoted to studying the strong link between architectural design and thermal comfort in arid areas without the use of air conditioning.

The Draa-Tafilalet region has a huge area containing alfa fibers, fig branches and reed fibers. These natural resources are an important source of energy if properly exploited. Energy recovery can be carried out in an anaerobic bioreactor to produce biogas and compost [24]. However, these fibers can be used to improve the thermal and mechanical performance of building construction materials.

The present study consists of designing and studying new building construction materials based on clay and the above-mentioned additives, in order to use them as mortar for ceilings and external walls. The X-ray diffraction was performed on the clay material and the different fibers in order to determine their crystallinity. An experimental characterization of the thermal conductivity of the biocomposites materials was carried out using the highly insulated thermal house method. The results will be presented and discussed.

II. MATERIALS AND EXPERIMENTAL METHOD

A. Used materials

Unfired clay:

The clay used in this investigation was extracted from the South-East of Morocco (Errachidia city). After sampling, it was ground, then dried and sieved (Sieve of 40µm).

Ecological additives:

Fig: The fig is a fruit tree of the Moraceae family. It can grow from 2 to 6 m depending on the variety, and is resistant to heat and cold weather. It develops easily by cuttings that root simply. The plantations are spaced 3 to 6 meters apart on the row and 5 to 7 meters between the lines. The density is 250 to 400 plants per hectare. The fig tree is an undemanding and very tolerant tree that can manage on its own and can produce for a very long time. To produce fruit bearing branches, it is necessary to cut off the oldest branches that have just grown, and this gives an important source of raw material unfortunately is not very well exploited and rarely used in heating.

Reed: The reed is a plant of the grass family, scientifically known as arundo donax, it grows near watercourses. Its growth process is very rapid, which often creates harms to agriculture, for this reason it is frequently cut, making the raw material widely available. Reeds can grow up to 6 m high and 2 to 3 cm in diameter, and their leaves are 30 to 60 cm long and 2 to 6 cm wide.

Alfa: (Stipa tenacissima) is a perennial grass, native to the arid regions of the western Mediterranean basin, it grows in tufts about one meter in high, forming vast "aquifers" in arid and semi-arid regions. It organizes ecosystems practically without trees and on immense stretches of arid eastern Morocco over an area estimated at 3,000,000 ha.

The alfa plant is considered as an important bar in the fight against desertification, and the advance of the desert. The cultivation of this plant is environmentally friendly because it does not require pesticides and insecticides; it requires little water for its growth. In addition, soils under tufts of alfa have a higher content of organic matter, nitrogen, phosphorus and CO_2 flux than soils in open environments [25,26].

B. Samples preparation

The biocomposite materials under study are obtained by mixing clay with three types of natural fibers, namely alfa, reed, and fig tree (Fig. 1). The fibers are washed with a detergent solution to remove all kinds of impurities, then dried in the open air and ground into small fibers using a mill (type).

Three mass fractions (20%, 40%, and 60%) of these fibers are retained. A pure sample (100% clay) with the same dimensions is prepared to follow the evolution of thermophysical properties. The water is carefully added to the mixture, maintaining agitation to homogenize it. The samples are made in moulds measuring 250x250x30 mm^3.

After drying in the open air for 2 days, the samples were dried in the oven at 50°C in order to eliminate the moisture.

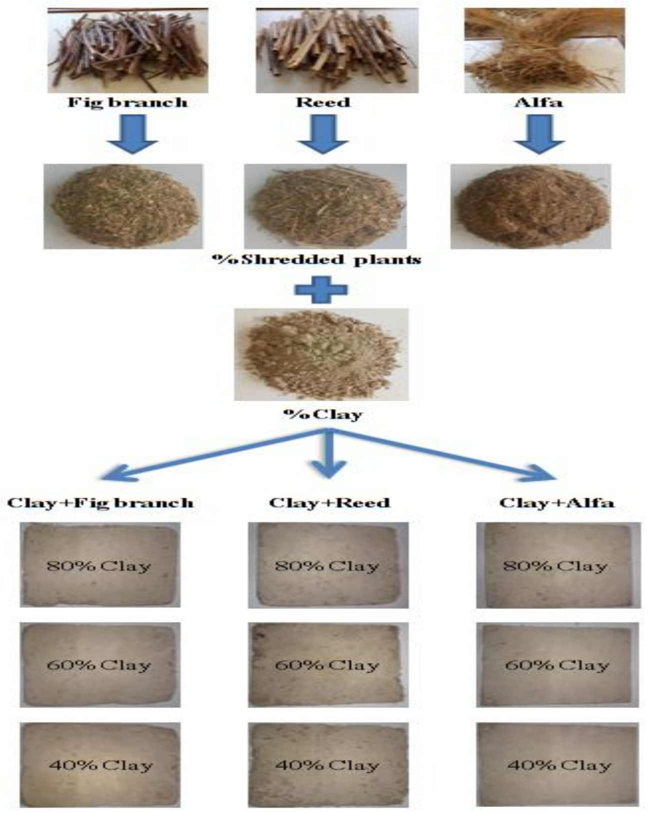

Fig. 1. Differents steps of samples praparation

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C. X-ray diffraction method

X-ray diffraction analyses are carried out at the CNRST-Morocco (National Centre for Scientific and Technical Research). The device used is of the Panalytical X'Pert PRO type. This device is equipped with a copper anticathode tube of wavelength λ=1.54 Å. The excitation conditions are: U = 45 kV, I = 40 mA and the 2θ angle goes from 3 to 90° with a step of 0.067° and a step speed of 121s/step. The diffractometer is controlled by a microcomputer and the results are processed using HighScore Plus© software.

The natural fibers crystallinity was assessed knowing the crystallinity index, which is calculated using Segal's empirical method [26] from equation (1), which uses the maximum intensities of lines 002 (I_{002}) at an angle 2θ between 21° and 23° and the minimum intensity I_{am}, at 2θ between 18° and 20°.

$$I_{cr}(\%) = \frac{I_{002} - I_{am}}{I_{002}} \times 100 \quad (1)$$

I_{002}: denote the maximum diffraction intensity of the grating peak (002) at 2θ angle among 21° and 23°, which represents crystalline and amorphous materials.

I_{am}: denote the diffraction intensity of the amorphous material, which is measured at an 2θ angle between 18° and 20° where the intensity is at least.

D. Highly insulated thermal house

Experimental tests are performed using the highly insulated thermal house with replaceable walls (Fig 1). This method has been used previously in several research works [28,29]. The box has 4 side walls with a square opening of 210x210 mm^2. An incandescent bulb is used as a heat source, and is connected to a thermal regulator inside the box to set the desired temperature. In the steady-state regime, the heat source can maintain an internal temperature of about 70°C.

The characterized sample of dimensions 250x250x30 mm^3 is placed on the inside face of one of the walls side of the thermal house, and a wooden panel of the same dimensions is placed on the outside face. Thermocouples are attached inside and outside to record temperature variations, T_1 inside the sample, T_2 at the interface and T_3 at the outside of wood. Then, the other walls are built using polystyrene panels to avoid heat loss. The measuring box is maintained under laboratory conditions with ambient temperature of 25°C. When the steady state is verified, the values of the three temperatures T_1, T_2, and T_3 are requested.

Fig. 2. Highly insulated thermal house method

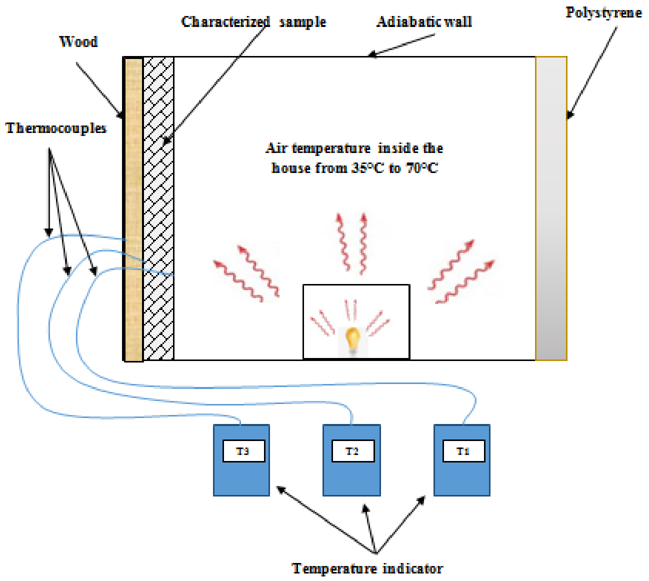

Fig. 3.Schema of Highly insulated thermal house method

- The heat flow through wood:

$$\phi_w = \lambda_w \times S_w \times \frac{\Delta T_w}{e_w} \quad (2)$$

- The heat flow through the sample:

$$\phi_s = \lambda_s \times S_s \times \frac{\Delta T_s}{e_s} \quad (3)$$

λ_s and λ_w denote the thermal conductivity of characterized sample and wood material, respectively.

e_s and e_w denote the thickness of characterized sample and wood material, respectively.

We apply the principle of flow retention:

$$\phi_w = \phi_s \quad (4)$$

As soon as the steady-state regime is established, the thermal conductivity of the characterized sample is calculated using the following equation:

$$\lambda_s = \lambda_w \times \frac{S_w}{S_s} \times \frac{\Delta T_w \times e_s}{\Delta T_s \times e_w} \quad (5)$$

III. RESULTS AND DISCUSSION

A. X-Ray diffraction

Clay:

The clay material was characterized by X-Ray Diffraction analysis to identify its chemical elements.

Spectral analysis indicates that the clay is composed of the following minerals: Calcite Ca (CO_3) Quartz (SiO_2), Nimesite ((Ni_2 Al) (Al Si) (Al Si) O_5 $(OH)_4$), Muscovite (H_2 K Al_3 Si_3 O_{12}) and Zeolite X ($Na_{17.52}$ Al_{24} Si_{24} O_{96} $H_{6.48}$).

The spectrum mainly reveals the presence of two intense elements, the largest corresponds to Calcite has an intensity of 1706 cts corresponding to 2θ = 29° followed by Quartz and Muscovite which has an intensity of about 750 cts at 2θ = 26° and 27°, respectively, and the other elements correspond to a mixture: Quartz, Calcite, Muscovite, Nimesite, Zeolite X; varying between [400, 150] cts, which implies that our clay is heterogeneous.

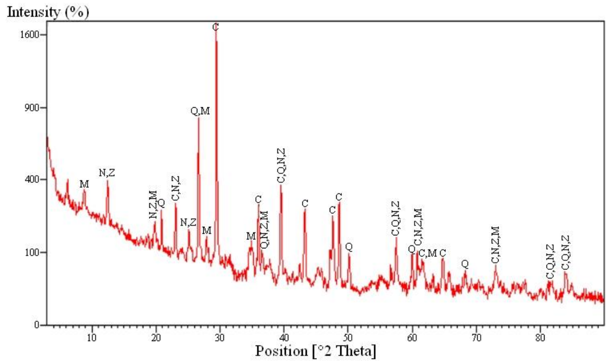

Fig. 4. X-ray diffractograms of clay material

C=Calcite, Q=Quartz, N=Nimesite, M=Muscovite, Z=Zeolite.

Additives:

The three diagrams both have roughly similar peaks but with different intensities that are particularly well defined for vegetable fibers.

The first peak is wide and multiple, at Bragg angles 15° and 16°. The second one is narrow at 22°. These two peaks are characteristic of cellulose I and their presence shows that the fibers are semi-crystalline.

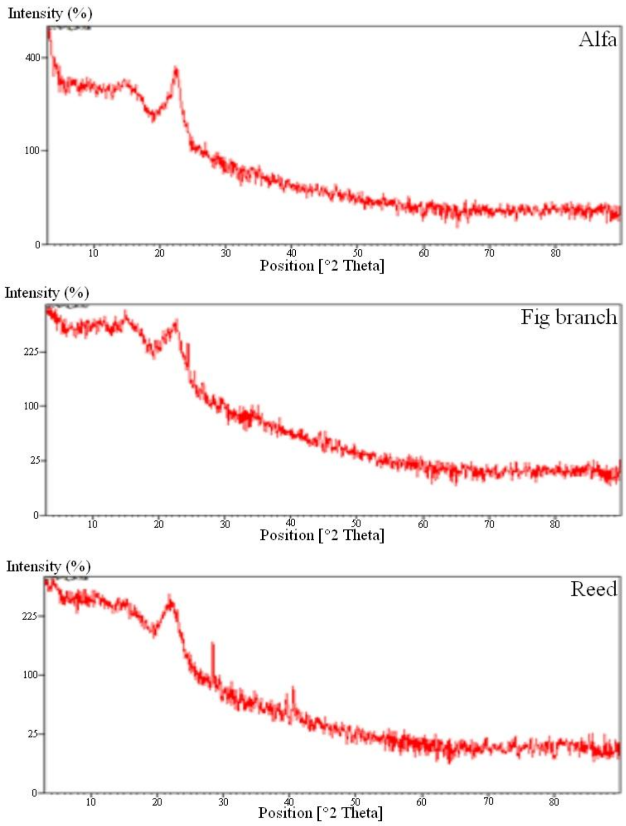

Fig. 5. X-ray diffractograms of various plants

The crystallinity index of different fibers was calculated using equation (1). From Table 1 it can be seen that the alfa fiber has a high percentage of crystallinity index. To some extent, the crystallinity of cellulose gives a picture of the physical and chemical characteristics of the fiber. Rigidity, mechanical strength, relative density and dimensional stability increase with the crystallinity of cellulose. Therefore, the determination of the crystallinity of cellulose allows us to understand the decomposition of the fiber from the structure [30].

Table- I: The crystallinity index of different plants

	I_{002}	I_{am}	I_{cr} (%)
Alfa	370	200	46
Fig branch	320	190	41
Reed	275	164	40

B. Apparent density

The determination of apparent density requires the knowledge of their dry masses and dimensions. In this work, the mass of the five samples was weighed using an electric balance and their dimensions were measured using a high-precision caliper. The apparent density is therefore calculated using the equation (6).

$$\rho_{app} = \frac{m_{app}}{V_{app}} \quad (6)$$

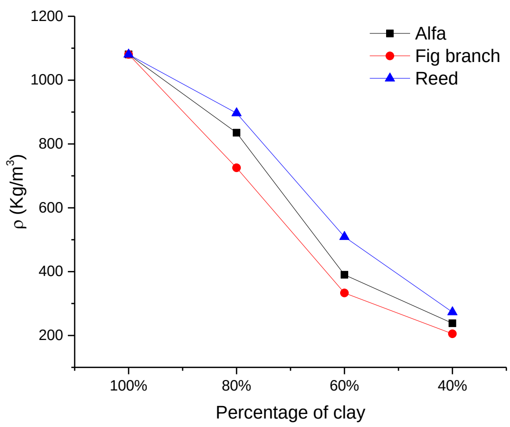

Fig. 6. Apparent density as function as differents mass fraction of clay

The lowest apparent density is found in the mixture of 40% clay with 60% fig branch, followed by the mixture of 40% clay with 60% alfa fiber and finally the mixture of 40% clay with 60% reed, with the respective values 205,1Kg/m^3, 238,3 Kg/m^3 and 273,2Kg/m^3. Indeed, this variation is due to the nature of the fibers studied; fig branches are lighter compared to alfa and reed fibers. In addition, it can be influenced by the porosity created in the material.

C. Thermal conductivity

The thermal conductivity of the various samples studied was measured using the highly insulated thermal house method.

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Each sample was tested three times in order to meet the experimental requirements. The maximum error for the tests is 5,35%, which shows the reliability of the method used. Figure 7 presents the values of measured thermal conductivity of different insulating materials based on alpha, reed, and fig tree branch with different mass fractions of clay. It is noted that the thermal conductivity was reduced as a function of decrease in the percentage of clay. This decrease is caused by the creation of air-filled pores in the material through the incorporation of different fibers, thus, by the fibers low thermal conductivity. By comparing the thermal conductivity values of the different insulators with the same percentage of clay at 40%, it can be seen that the material based on alpha fibers has a better thermal conductivity of about 0,122W/m.K, followed by the material based on fig branches 0,155W/m.K and reed 0,241W.m^{-1}.K^{-1}. The thermal conductivity variation between different clay insulators of the same percentage can be explained by the geometry and size of the pores and the uniformity of the porosity distribution created by the randomly oriented fibers in the mixture.

Several studies have been conducted and published confirming our results. [14,15,18,19,20] have shown that the reinforcement of the earth matrix by a variety of plant fibers improves thermal conductivity and contributes to lightness of composite materials.

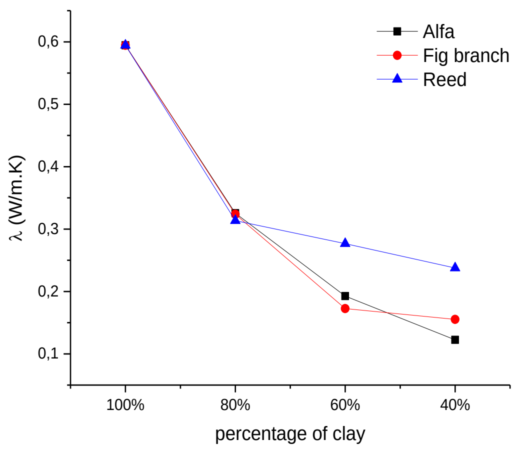

Fig. 7. Thermal conductivity variation as function as differents mass fraction of clay

It can be deduced that there is a strong dependence between thermal conductivity and apparent density since the first decreases considerably with density. The sample becomes less insulating as its density increases. The presence of plants makes the sample lighter and improves its thermal insulation.

This result clearly shows the value of using these new insulating and lightweight materials in the building construction, in order to ensure thermal comfort and minimize energy requirements for heating and cooling, and reduce greenhouse gas emissions.

IV. CONCLUSION

This work aims to design and develop new biocomposites materials based on clay and ecological additives for use as wall and ceiling mortar in the construction of traditional buildings. An analysis using X-Ray diffraction allows to identify the crystalline elements of clay, and to calculate the crystallinity index of different plants in order to have an idea on their adherence with the clay material. An experimental investigation was performed to determine the apparent density and thermal conductivity of new biocomposites materials. The results showed that the incorporation of a 60% mass fraction of alfa, fig branches and reeds fibers can reduce the apparent density by about 78%, 84%, and 74%, and the thermal conductivity by about 79%, 74% and 59%, respectively. These new materials offer several environmental and economic benefits.

REFERENCES

1. Moroccan Agency for Energy Efficiency. Construction and thermal regulation in Morocco.
2. Laaroussi, N., et al. "Measurement of thermal properties of brick materials based on clay mixtures." *Construction and Building Materials* 70 (2014): 351-361.
3. Laaroussi, Najma, et al. "Thermal properties of a sample prepared using mixtures of clay bricks." *Energy Procedia* 42 (2013): 337-346.
4. Ouakarrouch, M., El Azhary, K., Laaroussi, N., Garoum, M., and Feiz, A., “Three-dimensional numerical simulation of conduction, natural convection, and radiation through alveolar building walls,” Case Studies in Construction Materials 11, 2019, e00249.
5. Tilioua, A., et al. "Etude des propriétés thermo-physiques des isolants fibreux textile", Annales du BTP, pages 36-41, february 2012.
6. Agoudjil, B., Benchabane, A., Boudenne, A., Ibos, L., & Fois, M. (2011). Renewable materials to reduce building heat loss: Characterization of date palm wood. *Energy and buildings*, *43*(2-3), 491-497.
7. Tilioua, A., Libessart, L., Lassue, S. "An experimental analysis of thermal properties of a fibrous insulation material based on recycled textile fibers for building applications",soumis au journal Applied Thermal Engineering, (2017).
8. Ali, M. E., Alabdulkarem, A. On thermal characteristics and microstructure of a new insulation material extracted from date palm trees surface fibers, Construction and Building Materials 138 (2017) 276–28.
9. Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4, 1-17.
10. Boumhaout, Mustapha, et al. "Thermomechanical characterization of a bio-composite building material: Mortar reinforced with date palm fibers mesh." *Construction and building materials* 135 (2017): 241-250.
11. Belhadj, B., et al. "Study of the thermal performances of an exterior wall of barley straw sand concrete in an arid environment." *Energy and Buildings* 87 (2015): 166-175.
12. Rahim, M., Douzane, O., Le, A. T., & Langlet, T. (2016). Effect of moisture and temperature on thermal properties of three bio-based materials. *Construction and Building Materials*, *111*, 119-127.
13. Lachheb, A., et al. "Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study." *Journal of cleaner production* 209 (2019): 1411-1419.
14. Ouakarrouch, M., El Azhary, K, Mansour, M, Laaroussi, N., Garoum, M. (2019) “Thermal study of clay bricks reinforced by sisal-fibers used in construction in South of Morocco” Energy Reports.
15. Aboubou I., L. Diabaté, and G. Mengy. 2004. “Détermination de la conductivité thermique de matériaux de construction à bamako (balle de riz).” Journal Des Sciences Pour l’Ingénieur 4: 1–6.
16. Liuzzi, Stefania, Chiara Rubino, and Pietro Stefanizzi. "Use of clay and olive pruning waste for building materials with high hygrothermal performances." *Energy Procedia* 126 (2017): 234-241.
17. Calatan, Gabriela, et al. "Determining the optimum addition of vegetable materials in adobe bricks." *Procedia technology* 22 (2016): 259-265.

18. Mahamat, Ahmat-Charfadine, et al. "Thermo-Physical Properties of Local Materials Used in the Construction of Chad." *American Journal of Civil Engineering* 3.5 (2015): 140-149.
19. Lamrani, M., Mansour, M., Laaroussi, N., Khalfaoui, M. (2019) "Thermal study of clay bricks reinforced by three ecological materials in south of morocco." Energy Procedia, (2019), vol. 156, p. 273-277.
20. El Azhary, K., Chihab, Y., Mansour, M., Laaroussi, N., Garoum, M. (2017) "Energy efficiency and thermal properties of the composite material clay-straw." Energy Procedia, (2017): 141, 160-164.
21. Martin S.,Mazarron, FR, Canas I. Study of thermal environment inside rural houses of Navapalos (Spain): the advantages of reuse buildings of high thermal inertia. Constr Build. Mater 2010; 24: 666–676.
22. Mokhtari, A., K. Brahimi, and R. Benziada. "Architecture et confort thermique dans les zones arides Application au cas de la ville de Béchar." *Revue des énergies renouvelables* 11.2 (2008): 307-315.
23. Azhary, K. E., Ouakarrouch, M., Laaroussi, N., Garoum, M., & Mansour, M. (2020). Impact of Traditional Architecture on the Thermal Performances of Building in South Morocco. In Green Buildings and Renewable Energy (pp. 339-347). Springer, Cham.
24. Ouakarrouch, Mohamed, et al. "Thermal Insulation and Operation by Photovoltaic Solar Energy of a Bioreactor." *6th International Renewable and Sustainable Energy Conference (IRSEC)*. IEEE, 2018.
25. Kaouthar, Jeddi, and Mohamed Chaieb. "The effect of Stipa tenacissima tussocks on some soil surface properties under arid bioclimate in the southern Tunisia." *Acta Botanica Gallica* 156.2 (2009): 173-181.
26. Cortina J, Martín N, Maestre FT, Bautista S. Disturbance of the biological soil crusts and performance of Stipa tenacissima in a semi-arid Mediterranean steppe. Plant Soil 2010;334(1–2):311–22.
27. Segal L., Creely, J.J., Martin, A.E., Conrad, C.M. (1959), “An empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer”. Text. Res. J, Vol. 29, pp.786-794.
28. Silva, F. J. G., Baptista, A., Pinto, G., Campilho, R. D. S. G., & Ribeiro, M. C. S. (2018). Characterization of hybrid pultruded structural products based on preforms. Composites Part B: Engineering, 140, 16-26.
29. Gounni, Ayoub, and Mustapha El Alami. "The optimal allocation of the PCM within a composite wall for surface temperature and heat flux reduction: An experimental Approach." *Applied Thermal Engineering* 127 (2017): 1488-1494.
30. Garkhail SK, Heijenrath RW, Peijs T. Mechanical properties of natural-fibre-mat-reinforced thermoplastics based on flax fibres and polypropylene. Applied Composite Materials. 2000 Nov 1;7(5-6):351-72.

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