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Research Article

Thermal Performance of Clay and Millet Waste Compressed Earth Blocks Stabilized with Cement

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Abstract

As a contribution of the building sector to mitigating the effects of climate change, namely rising sea levels, floods, droughts, cyclones, sandstorms, retreat of arable land and forest fires, in anticipation of the objectives of the Paris Agreement, on the one hand, and energy efficiency on the other hand and the development of sustainable and environmentally friendly building materials, this paper presents the thermal characterization of compressed earth blocks using two clays used by the population of MARADI in Niger for the construction of habitats. The clays are mixed with sand (10%), cement (4%) and varying proportions of millet waste from 0% to 10%. The study shows that the thermal conductivity of composites decreases as the amount of millet waste increases. Conversely, the thermal resistance increases with each addition. Conductivity values varies from 0.268 W. $m^{-1}.K^{-1}$ to 0.644 W. $m^{-1}.K^{-1}$ for MARADAWA clay (BAM) samples and from 0.275 W. $m^{-1}.K^{-1}$ to 0.723 W. $m^{-1}.K^{-1}$ for Jiratawa clay (BAJ) samples. This represents a reduction of 61.96% for Jiratawa clay and 58.39% for MARADAWA clay compared to non-added materials. Composite materials are more effective in terms of thermal insulation.

Keywords

Compressed Earth Bricks, Clay, Millet Waste, Thermal Conductivity, Climate Change

1. Introduction

Anthropogenic global warming is one of humanity's major concerns [1]. In the coming years, climate change will have significant consequences for the security of populations and states. IPCC experts predict that climate change will lead to more extreme weather events, such as droughts, floods, cyclones, sandstorms, retreat of arable land and forest fires, and that these will become increasingly devastating. The expected increase in the frequency and severity of these phenomena is likely to lead to significant population displacements from vulnerable areas to less exposed areas, not to mention the additional economic burden that the affected States will have to face [2]. By 2030, nearly 60% of the world's population is expected to live in urban areas [3]. In the case of Africa, about 56% of the population lives in informal housing. This population is expected to reach 2.4 billion by 2050, and 80% of this population growth will occur in cities. The need to provide housing now and in the future is a major driver of growth for new buildings across the African continent [4].

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The role of the buildings sector and the construction industry is therefore decisive in the fight against climate change as stipulated by the "Paris Agreement" adopted at the summit of the United Nations Framework Convention on Climate Change UNFCCC in 2015 and the achievement of the global Sustainable Development Goals (2030 Agenda) [5-7]. It is in this sector that the potential to reduce greenhouse gas emissions will be greatest. And it would be able to provide significant energy savings [1, 3, 4, 8].

Appropriate use of building materials can contribute to a particular focus on energy efficiency and human thermal comfort [1, 5, 9, 10].

The Maradi region covering an area of 38500 km^2 is located in the south-central part of the country. The housing comes in a diverse range depending on the materials used, the organization of the space and the density of the buildings. There are strong disparities depending on the place of residence. In rural areas, housing is mainly made of straw and clay, often without a precise land tenure status. In urban areas, traditional housing (banco, wood and straw) is associated with evolving housing (imported mixed materials) and residential housing (permanent materials). The region is largely dependent on the outside world for the satisfaction of its energy needs and occupies a poor position in terms of human development [11]. The use of local materials in modern construction can contribute to improving the living conditions of the population.

Raw earth has been widely used for the construction of buildings since the earliest times, as evidenced by traditional housing in many parts of our planet.

It has the advantage of being a material available locally and in abundance, with little or no energy, low greenhouse gas emissions [12-16], unlike industrial materials such as concrete, iron, steel, aluminum, etc.

We are witnessing a return to the use of land in both developing and industrialized countries [15, 17]. The production of earthen materials has nothing to envy to that of other current materials. Among the most elaborate, the technique of compressed earth blocks stands out in particular [15, 18]. It consists of making bricks of stabilized earth thanks to a light addition of lime (or cement) and also of agricultural or industrial by-products. This mixture is compressed using a manual or mechanical press [10, 19]. This technique makes it possible to compensate for the long-recognized inadequacies of raw earth by improving its water resistance and mechanical resistance and thus contributing to the durability of buildings [20, 21].

Thermal comfort is one of the major concerns in building construction. The most common methods are usually electric air control methods such as air conditioners, heaters, and fans. [22] This leads to an increase in energy consumption. However, reducing energy consumption in buildings is a major challenge in order to deal with the scarcity of fossil energy resources and the problem of energy consumption.... To meet this challenge, building insulation is a necessity and represents an efficient and cost-effective way [23]. The thermal performance of the clay material can be improved by incorporating natural additives to achieve a more insulating composite material. The literature reveals several studies that have been conducted on improving thermal comfort in traditional additive-bound raw clay construction [24, 25].

Increasing the amount of fibers, or the length of the fibers, usually reduces thermal conductivity. Thus, the addition of 0 to 3% by weight of barley straw and wheat straw fibers generates a decrease in thermal conductivity of about 34-35% compared to earth bricks without fiber reinforcement [26].

Similar results with barley straw (36% and 60% reduction when barley was added at 1 and 2% by weight respectively) were observed by [27]. The use of a lightweight biocomposite (sunflower pith aggregates) gave the best result among all the materials considered to reduce thermal conductivity, probably due to the large amount of addition (30% by weight), while showing a low compressive strength [28].

In addition, in their work, Saghrouni et al. [29] studied the incorporation of Juncus maritimus fibers in mortar composites at different dosages. They managed to reduce the thermal conductivity by about 65% at 10% fiber addition in the composite, which reached 0.182 W. m^{-1}.K^{-1} while it was equivalent to about 2.8 W. m^{-1}.K^{-1} without any addition. Previously, Belhadj et al. [30] had lightened the concrete by adding barley straw. These authors claimed that manufactured concrete exhibited a reduction in compressive strength with the added fibers and an improvement in flexural strength and other properties such as lightness, deformability, ductility, toughness, and thermal characteristics (1.32 W. m^{-1}.K^{-1}). The study by Drissa B. et al. [31] shows that for a sawdust ratio between 0% and 8%, the value of the thermal conductivity decreases from 0.962 to 0.512 W.m^{-1}.K^{-1}, i.e. a decrease of 46.77%.

Omrani et al. [32] showed that the addition of 20% Juncus acutus fibers made a clay-sand composite decreased the thermal conductivity from 0.902 W/m K for the reference sample (without fibers) to a value of 0.327 W/m K. Laaroussi et al. [33, 34] measured the thermal properties of the clay bricks using different experimental characterization methods as reported by Mohamed L. et al. [35]; Ashour et al. [36] studied the thermal conductivity of unfired earth bricks composed of earth, gypsum, cement, and straw. Two types of fiber, namely wheat straw and barley straw, were used with different mixing ratios. The integration of plant aggregates into unfired clay bricks was explored in a study carried out by Laborel-Préneron et al. [37]. The hygrothermal characteristics of seven formulations composed of soil with different percentages by weight of maize, barley straw and hemp, ranging from 0 to 6%, were evaluated. The performance of earth bricks incorporating two types of straw has been evaluated by Giroudon et al. [38]. The straw additions were made at mass ratios of three percent and six percent. One of the types of straw examined was barley straw, which belongs to the group of cereal straws and has been extensively studied for similar applications. The other type was lavender straw, an unrecovered byproduct that had not previously been studied for its potential in the production of earthen bricks. Tests were carried out on three samples for each mixture to investigate their effect on thermal conductivity.

The objective of this study is the thermal characterization of compressed earth blocks based on clays taken from two quarries (Maradawa and Jiratawa) located in the Maradi region of Niger. These soils are then stabilized with 4% cement to increase compressive strength. Bricks were made from a mixture of clay, sand and cement, incorporating proportions varying from 0% to 10% of millet waste.

2. Materials and Methods

2.1. Presentation of Sampling Sites

This study focuses on two clays taken from Maradi, a region located in the south-central part of Niger between 13° and 15°26' north latitude and 6°16' and 8°36' east longitude about 540 km east of Niamey, the country's capital, on the main National Road 1. The clays come from open quarries: one in Maradawa located on the outskirts of the city of Maradi (latitude: 13°29'10", longitude: 7°5'33", altitude: 331.0 m) and the other of Jiratawa located about ten kilometers to the southwest (latitude: 13°24'20"; longitude: 7°8'7"; altitude: 344.6 m). These are quarries exploited by local residents for their construction needs. Figures 1 and 2 provide an overview of the sites.

13°29'10"N; 7°5'33"E; Elevation: 331.0 m

Figure 1. *MARADAWA site.*

13°24'20"N; 7°8'7"E; Altitude: 344.6 m

Figure 2. *JIRATAWA site.*

Table 1. *Values of the different identification tests on clay materials.*

Clay	Initial water content: w_i (%)	Specific weight: γ_s (kN/m^3)	Bulk density	Liquidity Limit: LL (%)	Plasticity Limit: LP (%)	Plasticity Index: PI (%)	Optimum Proctor Moisture Content (%)	Proctor Maximum Dry Density
Maradawa	6,3	2,54	1,18	55,6	29,2	26,4	16,33	1,64
Jiratawa	1,9	2,60	1,21	36,3	19,5	16,8	9,65	1,91

2.2. Sample Characteristics

The characteristics of the clays are determined and presented in a previous study [21]. Maradawa clay (Plasticity index Ip = 26.4; proportion of clay grains passing through a sieve with a diameter of 2 µm d (≤2 µm) about 27.4%; Soil condition: very plastic according to the Casagrande diagram (Figure 3); clay mineral: Illite; Class: A-7-6 (18) according to the "AASHTO" classification) is a swelling, waterproof soil. Jiratawa clay (Ip = 16.8; proportion of clay grains passing through a sieve with a diameter of 2 µm d (≤2 µm) about 12.8%; Soil condition: low plastic; clay mineral: kaolinite; Class A-6 according to the H-R-B) classification is more permeable to water. The characteristics are grouped in Table 1.

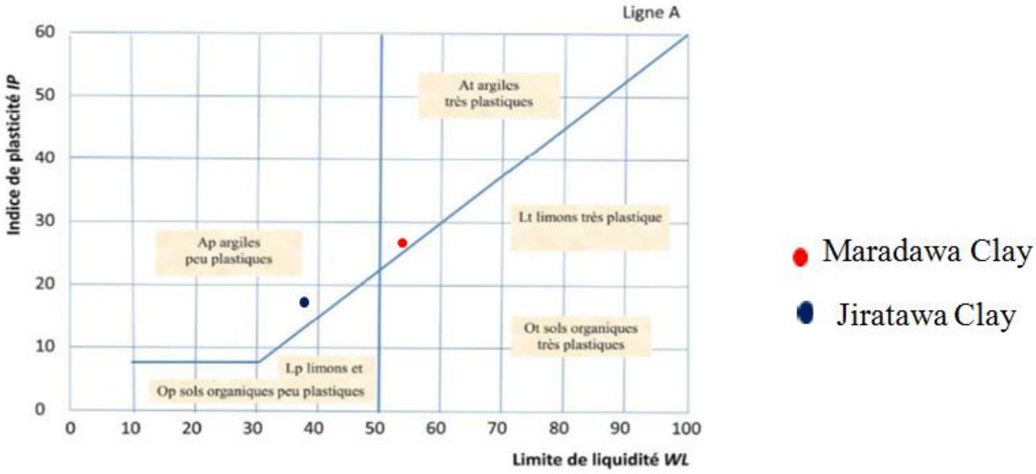

Figure 3. *Casagrande diagram [22].*

The particle size curves of the two clays are shown in Figure 4. The base materials are outside the recommended zones of texture and plasticity. A correction is made by adding sand as a degreaser and stabilized to the cement.

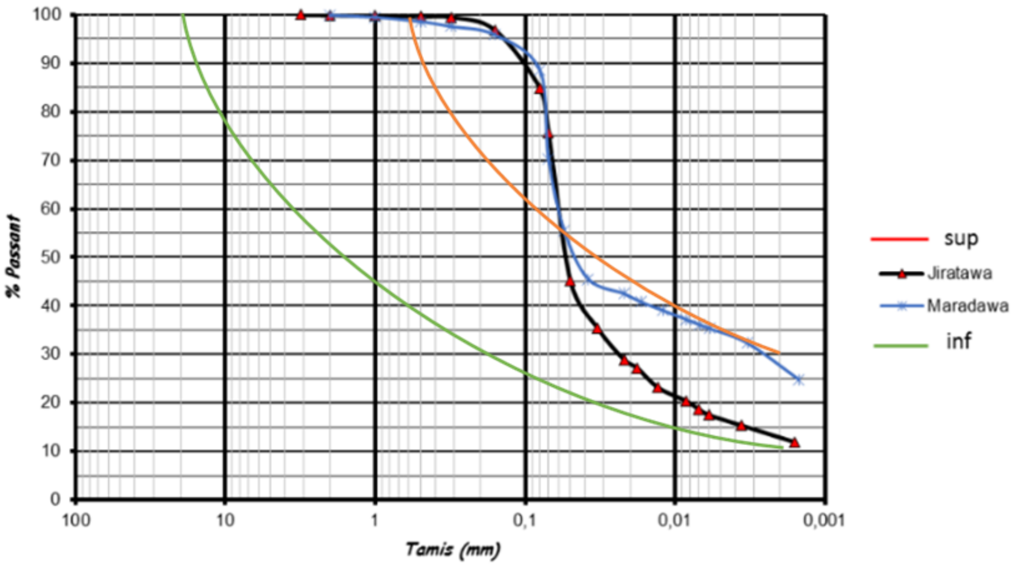

Figure 4. *Clay particle size curves with upper and lower granular spindle limits.*

The sand used (1.5% gravel, 91% coarse sand and 6.8% fine sand) comes from the BATCHIRAWA KORI sand quarry (14°56 N and 8°50 E), in the ZINDER region. [23]

The cement used is that of the MALBAZA Cement Company MCC NIGER: CEM II 42.5 NL-B. AFNOR NF P 15-301/EN 197-1: 2000.

The millet waste is recovered from the surrounding fields on the outskirts of Niamey. Once separated from the millet seeds, the waste is left in the open air. It is a material with a very low bulk density. It is available in large quantities virtually at no cost. Traditionally, it is mixed with earth material in constructions. Figure 5 shows the appearance of millet waste.

Figure 5. *Appearance of millet waste.*

2.3. Experimental Method

2.3.1. Sample Making

The clay materials were first crushed and then sieved. In order to allow for better humidification, we have retained the loops with a 3.16 mm sieve. The clay is mixed with 4% cement, because for cement to perform its role as a stabilizer, a minimum of 3 to 4% by weight of cement is needed in relation to the weight of the earth used, otherwise there is not enough binder [39] and with 10% sand. Indeed, cement and clay are made up of fine particles, sand makes it possible to bring in larger elements. This makes it possible to correct the granularity of the material (see figure 4), while remaining within the proportions of the elements as recommended by [39]. A percentage varying from 0 to 10% of millet waste is added to the mixture before pouring water until the desired consistency for making compressed earth blocks. These blocks measuring 14 cm x 14 cm x 10 cm are presented in Figure 6.

Figure 6. *Photo of compressed earth blocks.*

2.3.2. Thermal Properties

Figure 7. *KD2 Pro Device.*

The measuring device used is the KD2 Pro (Figure 7). This device uses the model for solving the heat transfer equation by the method of propagation of a linear heat source in a transient regime in a semi-infinite medium, an equation published in the IEEI standards [24]. Before the measurements, the samples are dried in an oven at 105 ℃ to remove the water they contain.

The thermal characteristics measured are thermal conductivity and thermal resistance:

1) Thermal conductivity, which represents the ability of a material to transmit heat flow under the effect of a temperature gradient. The lower the thermal conductivity, the more insulating the material.
2) Thermal resistance, which reflects the material's ability to resist heat transmission. It depends on the thickness of the material (e, in metres) and its thermal conductivity (λ): $R = e/\lambda$. The higher the thermal resistance, the more insulating the wall is.

2.3.3. Energy Gain of Composite Material

This composite material of cement-stabilized millet clay waste was made for use in construction. The heat flows through a material with a surface area of 1 m^2 is expressed:

$$\emptyset = \frac{\Delta T}{R_t}$$

With $R_t = \frac{1}{U} = \sum R_i$

Conductive thermal resistance for a homogeneous wall

$$R_t = \frac{e}{\lambda}$$

$$\emptyset = \frac{\Delta T.\lambda}{e}$$

If we compare two exterior walls, one containing the composite material and the other material without millet waste, having the same thickness, the same surface area and subject to the same temperature gradient, we can deduce the ratio of the two heat flows passing through these walls by:

$$\frac{\emptyset_{mat+waste}}{\emptyset_{mat}} = \frac{\lambda_{mat+waste}}{\lambda_{mat}}$$

This allows us to calculate the energy savings when using composite in construction

$$savings_{energy} = 100 \times \left(1 - \frac{\emptyset_{mat+waste}}{\emptyset_{mat}}\right)$$

3. Results and Discussion

The measured values of the conductivity and thermal resistance of bricks as a function of millet waste dosage are given in Table 2 for MARADAWA Clay (BAM) and Table 3 for Jiratawa Clay (BAJ).

Table 2. *Conductivity and thermal resistance as a function of the millet waste assay of the samples (BAM).*

Percentage by Mass	**0 %**	**2 %**	**4 %**	**6 %**	**8 %**	**10 %**
λ (W/m/K)	0,644	0,497	0.421	0,389	0,285	0,268
R ((m^2.K)/W)	155,3	201,4	237,6	215,3	351,3	272,2

Table 3. *Conductivity and thermal resistance as a function of the millet waste assay of the samples (BAJ).*

Percentage by Mass	**0 %**	**2 %**	**4 %**	**6 %**	**8 %**	**10 %**
λ (W/m/K)	0,723	0,488	0,376	0,310	0,302	0,275
R ((m^2.K)/W)	138,4	207,4	265,9	322,6	331,1	363,9

Table 4. *Energy Gain on BAM and BAJ Composites.*

Dosage (%)	**λ (W(/m/K))**		**Gain (%)**	
	BAM	**BAJ**	**BAM**	**BAJ**
0	0,644	0,723	0	0
2	0,497	0,4875	22,83	32,57
4	0,421	0,376	34,63	47,99
6	0,389	0,31	39,60	57,12
8	0,285	0,302	55,75	58,23
10	0,268	0,275	58,39	61,96

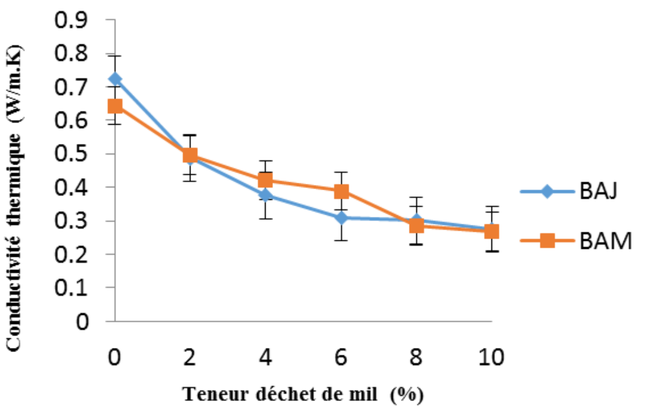

Figure 8. *Thermal conductivity of blocks as a function of millet waste content.*

The curves in Figure 8 show that the thermal conductivity decreases as the waste millet content increases for both materials used. It ranges from 0.268 W/ (m. K) to 0.644 W/ (m. K) for Maradawa clay (BAM) samples and from 0.275 W/(m. K) to 0.723 W/(m. K) for Jiratawa clay (BAJ) samples. This decrease can be explained by the low thermal conductivity of the millet waste and also by the fact that as the amount of millet waste increases, there is an increase in porosity and therefore more and more trapped air favourable to the reduction of conductivity. On the other hand, we note that the Jiratawa clay has a higher thermal conductivity at 0%, but that the incorporation of millet waste resulted in a reduction of 61.96% compared to 58.39% for the Maradawa clay (see Table 4).

We can deduce that the clay composite from Jiratawa with millet waste has a better thermal performance compared to that from Maradawa. Indeed, since Maradawa clay is more compact than Jiratawa clay, the presence of millet waste creates more voids in the blocks made from Jiratawa clay. The more compact internal structure results in greater cohesion between the particles. This promotes a better transfer of heat flow, hence the increase in thermal conductivity [25].

The results obtained for the 10% millet waste clay, the subject of this study, are comparable to those obtained by K. El Azhary et al. [40] whose results, on the clay-straw composite, vary between 0.263 W/(m.K) and 0.504 W/(m.K). Lertsatitthanakorn C et al. [41] obtained a thermal conductivity of 0.33 W/(m.K) for cement-sand blocks and rice husk ash compared to 0.72 W/(m.K) for commercially available clay bricks. In addition, the thermal conductivity of laterite bricks is reduced from 1.4 W/(m.K) to 0.29 W/(m.K) by adding millet waste, with the same percentage [42].

Omrani et al. [32] showed that the addition of 20% *Juncus acutus* fibers decreased the thermal conductivity from 0.902 W/m K for the reference sample (without fibers) to a value of 0.327 W/m K

Drissa B. et al. [31] montrent que pour un rapport de sciure de bois variant entre 0% et 8%, la valeur de la conductivit é thermique diminue de 0,962 à 0,512 $W.m^{-1}.K^{-1}$, soit une diminution de 46,77%.

Figure 9 shows the variations in the thermal resistances of the two composites. Here again, we see the better thermal performance of the Jiratawa clay-based composite compared to the Maradawa clay composite because it has higher values.

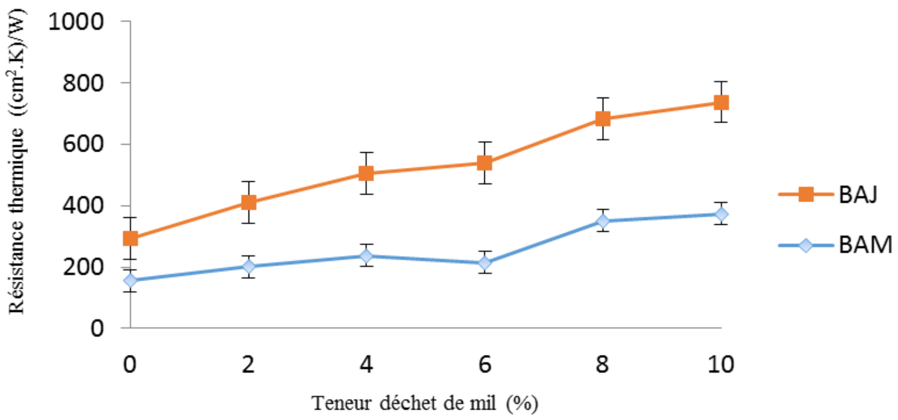

Figure 9. Thermal resistance of blocks as a function of millet waste content.

4. Conclusion

The thermal characterization of clays, the subject of this study, shows a decrease in thermal conductivity and thus an increase in the thermal resistance of the two types of composites made by incorporation of millet waste. Conductivity values decrease by about 62% for Jiratawa clay-based bricks and 58% for Maradawa clay-based bricks compared to non-added bricks. The gain is worth about 48% with an addition of 4% for the Jiratawa clay and 34% for the Maradawa clay. The study shows that the Jiratawa clay has a better thermal performance than the Maradawa clay by the same percentage. The study shows that the Jiratawa clay has a better thermal performance than the Maradawa clay. In short, our composites can be used as an alternative to conventional materials for thermal comfort in homes.

Abbreviations

BAM	Brick Made from Maradawa Clay
BAJ	Brick Made from Jiratawa Clay
UNFCCC	United Nations Framework Convention on Climate Change
AASHTO	American Association of State Highway and Transportation Officials
IPCC	Intergovernmental Panel on Climate Change
H-R-B	Highwway Resarch Board
Ip	Plasticity Index
wi	Initial Water Content
LL	Liquidity Limit
LP	Plasticity Limit
MCC	Malbaza Cement Company
EMC	Portland Cement
AFNOR NF French	Association for Standardization (French Standard)
λ	Thermal Conductivity (W/(m.K)
e	Thickness
R	Thermal Resistance
U	Voltage
Ø	Heat Flow
ΔT	Temperature Variation

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Author Contributions

Garba Salifou: Conceptualization, Data curation, Writing – original draft

Sani Dan Nomao Harouna: Writing – review & editing

Makinta Boukar: Project administration, Resources, Supervision, Validation

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Sahnoune, S., Benhassine, N., Boussalem, A., «Adaptation au changement climatique dans le contexte du développement durable - Adaptation to climate change in the context of sustainable development» Revue de l'économie financière et des affaires, 03(03), pp. 780-797 Octobre. 2019.

[2] Les défis environnementaux en Afrique, quels enjeux pour le continent ? Mathieu Mérino – Forum de Dakar 2021.

[3] Réchauffement climatique: selon le GIEC quel rôle le bâtiment et ses industries peuvent-ils jouer ? Mars 2022.

[4] Rapport sur l'état mondial des bâtiments et de la construction en 2022: Vers un secteur des bâtiments et de la construction à émission zéro, efficace et résilient. Nairobi.

[5] Kathrin, S., Klaus, T., Marcelo, W. A. W. et Clara-Luisa W., «Modes de construction répondant aux défis climatiques,» Bischöfliches Hilfswerk MISEREOR e.V. 2019.

[6] K. A. J. Ouedraogo, J.E. Aubert, C. Tribout et al., Ovalbumin as natural organic binder for stabilizing unfired earth bricks: Understanding vernacular techniques to inspire modern constructions, Journal of Cultural Heritage, https://doi.org/10.1016/j.culher.2021.05.004

[7] Brahim Mazhoud. Elaboration et caractérisation mécanique, hygrique et thermique de composites bio-sourcés. Matériaux. INSA de Rennes, 2017. Français. NNT: 2017ISAR0024. tel-01801946.

[8] GIEC, 2018: Résumé à l'intention des décideurs, Réchauffement planétaire de 1,5 °C, Rapport spécial du GIEC sur les conséquences d'un réchauffement planétaire de 1, 5 °C par rapport aux niveaux préindustriels et les trajectoires associées d'émissions mondiales de gaz à effet de serre, dans le contexte du renforcement de la parade mondiale au changement climatique, du développement durable et de la lutte contre la pauvreté [Publié sous la direction de V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor et T. Waterfield]. Organisation météorologique mondiale, Genève, Suisse, 32 p.

[9] M. Boumhaout, L. Boukhattem, H. Hamdi, B. Benhamou and F. Ait Nouh, "Mesure de la conductivité thermique des matériaux de construction de différentes tailles par la méthode des boites", 3ème Congrès de l'Association Marocaine de Thermique, Agadir (Maroc) 21-22 Avril 2014.

[10] ECOLOGICAL ARCHITECTURE: Guide méthodologique pour l'éco-réhabilitation du patrimoine bâti dans le sud-ouest européen, INTERREG IVB SUDOE, 2010, p. 35.

[11] Programme Conjoint d'Appui au Développement de la Région Maradi (PCM), République du Niger-Système des Nations Unis, 2011–2013.

[12] Collectif Terreux Armoricain, Confédération de la Construction en Terre Crue: Guide de Bonnes Pratiques de la construction en Terre Crue: Bauge, 13 Décembre, 2018.

[13] Sophie B., Basile C., Léo B. Cycle Terre: Fabriquer la ville bas carbone: Guide de conception et de construction, vol. 1, Museo amàco, Mai, 2021.

[14] Confédération de la Construction en Terre Crue: Guide de Bonnes Pratiques de la construction en Terre Crue: Brique de terre crue, 15 Octobre, 2020.

[15] Houben H., Rigassi V., Garnier Ph. CRATerre: Blocs de terre comprimée: équipements de production, 3ème édition, Technologies N°5, Bruxelles, Belgique, 1996.

[16] E. Losini, A. C. Grillet, M. Bellotto, M. Woloszyn, G. Dotelli, "Natural additives and biopolymers for raw earth construction stabilization - a review," Construction and Building Materials, October, 2021, https://doi.org/10.1016/j.conbuildmat.2021.124507

[17] Van Essa L. Kamga. Samen et al., "A Low Thermal Conductivity of Lightweight Laterite‑cement Composites with Cotton Wastes Fibres," Springer Nature, Silicon, 2021, https://doi.org/10.1007/s12633-021-01584-5

[18] GUIDE DES MATÉRIAUX ISOLANTS pour une isolation efficace et durable Programme energivie.

[19] M. Ouakarrouch, K. El Azhary, M. Mansour, N. Laaroussi, M. Garoum, "Thermal study of clay bricks reinforced by sisal-fibers used in construction in south of Morocco," Energy Reports 6 (2020) 81–88; https://doi.org/10.1016/j.egyr.2019.11.045

[20] Soumia Mounir, Abdelhamid Khabbazi, AsmaeKhaldoun, Youssef Maaloufa, Yassine ElHamdouni, Thermal inertia and thermal properties of the composite material clay–wool, Sustainable Cities and Society 19 (2015) 191–199. http://dx.doi.org/10.1016/j.scs.2015.07.018

[21] Salifou GARBA, Aboubacar ALI, Makinta BOUKAR and Saïdou MADOUGOU, "Optimization Study of the Physical Parameters of Clays from Three (3) Quarries in the Region of MARADI, Niger," International Journal of Engineering Trends and Technology (IJETT) – Volume 68 Issue 2- Feb 2020 pp 74-81.

[22] Magnan, Description, identification et classification des sols 21. J.-P., 1997.

[23] Salifou G., Aboubacar A., Makinta B., and Saïdou M., "Influence of Millet Pod on the Compressive Strength of Clay Blocks Compressed and Stabilized by Cement," Technology Reports of Kansai University, Volume 62, Issue 03, April (2020) 333-340.

[24] Y. MILLOGO, M. HAJJAJI, R. OUEDRAOGO, Microstructure and physical properties of lime-clayey adobe bricks. Construction and Building Materials, 22 (2008) 2386–2392.

[25] 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. Ivoir. Sci. Technol., 36 (2020) 42–51.

[26] T. Ashour, A. Korjenic, S. Korjenic, and W. Wu, "Thermal conductivity of unfired earth bricks reinforced by agricultural wastes with cement and gypsum," *Energy Build.*, vol. 104, pp. 139–146, 2015, https://doi.org/10.1016/j.enbuild.2015.07.016

[27] M. Palumbo, F. McGregor, A. Heath, and P. Walker, "The influence of two crop by-products on the hygrothermal properties of earth plasters," *Build. Environ.*, vol. 105, pp. 245–252, 2016, https://doi.org/10.1016/j.buildenv.2016.06.004

[28] Y. Brouard, N. Belayachi, D. Hoxha, N. Ranganathan, and S. Méo, "Mechanical and hygrothermal behavior of clay – Sunflower (Helianthus annuus) and rape straw (Brassica napus) plaster bio-composites for building insulation," *Constr. Build. Mater.*, vol. 161, pp. 196–207, 2018, https://doi.org/10.1016/j.conbuildmat.2017.11.140

[29] Saghrouni Z, Baillis D, Naouar N, Blal N, Jemni A (2019) Thermal properties of new insulating juncus maritimus fibrous mortar composites/experimental results and analytical laws. Appl Sci 9. https://doi.org/10.3390/app9050981

[30] Belhadj B, Bederina M, Makhloufi Z, Dheilly RM, Montrelay N, Queneudec M (2016) Contribution to the development of a sand concrete lightened by the addition of barley straws. Constr Build Mater 113: 513–522. https://doi.org/10.1016/j.conbuildmat.2016.03.067

[31] Drissa B., P. Florent Kieno, Emmanuel O..: Experimental Study of the Thermal and Mechanical Properties of Compressed Earth Blocks Stabilized with Sawdust According to the Rates for the Thermal Insulation of a Building, International Journal of Construction Engineering and Management 2017, 6(3): 103-109. https://doi.org/10.5923/j.ijcem.20170603.05

[32] Omrani, H., Hassini, L., Benazzouk, A., Beji, H., Elcafsi, A.: Elaboration and characterization of clay-sand composite based on Juncus acutus fibers. Constr. Build. Mater.238, 117712 (2020). https://doi.org/10.1016/j.conbu ildma t.2019.117712

[33] Laaroussi N, Cherki A, Garoum M, Khabbazi A, Feiz A, Thermal Properties of a Sample prepared using mixtures of clay bricks, Energy Procedia 2013; 42: 337–346.

[34] Chaussinand A, Scartezzini J L, Vahid N. Straw bale: A waste from agriculture, a new construction material for sustainable buildings, Energy procedia 2015; 87: 297-302.

[35] Lachheb, M.; Youssef, N.; Younsi, Z. A Comprehensive Review of the Improvement of the Thermal and Mechanical Properties of Unfired Clay Bricks by IncorporatingWaste Materials. Buildings 2023, 13, 2314. https://doi.org/10.3390/buildings13092314

[36] Ashour, T.; Korjenic, A.; Korjenic, S.;Wu, W. Thermal Conductivity of Unfired Earth Bricks Reinforced by AgriculturalWastes with Cement and Gypsum. Energy Build. 2015, 104, 139–146.

[37] Laborel-Préneron, A.; Magniont, C.; Aubert, J. E. Hygrothermal Properties of Unfired Earth Bricks: Effect of Barley Straw, Hemp Shiv and Corn Cob Addition. Energy Build. 2018, 178, 265–278.

[38] Giroudon, M.; Laborel-Préneron, A.; Aubert, J. E.; Magniont, C. Comparison of Barley and Lavender Straws as Bioaggregates in Earth Bricks. Constr. Build. Mater. 2019, 202, 254–265.

[39] Emmanuel O., Ousmane C., Abdoulaye O., Adamah M., «Caractérisation mécanique et thermophysique des blocs de terre comprimée stabilisée au papier (cellulose) et/ou au ciment.» Journal of Materials and Engineering Structures 2 (2015) 68–76.

[40] K. El Azhary, Y. Chihab, M. Mansour, N. Laaroussi, M. Garoum "Energy Efficiency and Thermal Properties of the Composite Material Clay-straw," Energy Procedia 141 (2017) 160–164.

[41] Lertsatitthanakorn C, Atthajariyakul S, Soponronnarit S. Techno-economical evaluation of a Rice Husk Ash (RHA) based sand–cement block for reducing solar conduction heat gain to a building. Construction and Building Materials. 2009 Jan; 23(1): 364-9.

[42] Bal H, Jannot Y, Gaye S, Demeurie F. Measurement and modelisation of the thermal conductivity of a wet composite porous medium: Laterite based bricks with millet waste additive. Construction and Building Materials. 2013 Apr; 41: 586-93.

Biography

Garba Salifou was born on 13-12-1976 in Maradi. He did his primary education in Niamey, secondary education in Maradi and university studies at the Faculty of Sciences of the Abdou Moumouni University of Niamey, after obtaining his Baccalaureate series C in 1998. His school and university courses are sanctioned by the diplomas of CFEPD (Certificate of Completion of First Degree) in 1989, BEPC (Brevet d'Études du Premier Cycle) in 1995, the Baccalaureate in 1998, and a Master's degree in Physics in 2003. After a stint at the Institute of Radioisotopes (I. R. I) of the University of Niamey from 2004 to 2008, he enrolled at the University of Ouagadougou from 2009 to 2011 where he obtained his DEA in Applied Physics with a Thermal option. Mr. Garba Salifou is a secondary school teacher of Physical Sciences and is enrolled at the University of Niamey to prepare a doctoral thesis in Physics.

Sani Dan Nomao Harouna was born on 01-01-1991 in Maradi. He attended primary school in Maraka and secondary school in Gabi (Madarounfa) and Maradi. He continued his university studies at the Faculty of Sciences of the Abdou Moumouni University in Niamey, after obtaining his Baccalauréat série D in 2012 at the Lycée dan Baskorée in Maradi. His school and university education includes the CFEPD (Certificat de Fin d'Études de Premier Degré) in 2003, the BEPC (Brevet d'Études du Premier Cycle) in 2009, the Baccalauréat in 2012, and a research Master's degree in 2019. He has registered for a PhD thesis in 2020. He is currently author and co-author of 9 scientific publications.

Makinta Boukar is currently a full professor in the Department of the Faculty of Science and Technology at the Abdou Moumouni University in Niamey. He holds the following degrees: Docteuar d'Etat (Doctorate of State) in 2013; Docteur-Ingénieur (Doctorate-Engineering) in 1992; DEA (Master's equivalent) in 1986; DUES (second year in university) in 1983; Baccalauréat in 1980. He is coordinator of the "Renewable Energies" master's degree in the Physics department, head of the thermal team at the energetics laboratory, head of the central service for monitoring teaching at the Rectorat, member of the scientific council of Abdou Moumouni University and one of Niger's two representatives on the Specialized Technical Commission (CTS) of the African and Malagasy Council for Higher Education (CAMES). He has also been awarded the distinction of “Chevalier dans l'ordre des palmes académiques” of Niger.

Research Field

Garba Salifou: Building materials, Thermal

Sani Dan Nomao Harouna: Solar thermodynamics, thermal storage, Energy, Electronics, Internet of connected objects, Embedded systems

Makinta Boukar: Materials characterization, Cold production, Solar drying, Thermal storage, Thermal comfort