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Thermophysical and Mechanical Characterization of Local Stabilized Materials Suitable for Buildings in Dry and Hot Climate

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ABSTRACT
In this article, we study the formulation by combining the fibers of hibiscus canabinus and slaked lime and highlight the effect of lime and fibers on the mechanical and thermal behavior of BTC. The results obtained show that fibers and slaked lime considerably modify the mechanical behavior (resistance to compression and bending) and thermal behavior of the material. The physico-mechanical and thermal properties have been studied and we found out that the best compressive strength is obtained with blocks dosed with 10% slaked lime and 1% fibers with a mean value of 4.93Mpa at 70 curing days, while the best thermal properties (thermal conductivity 0.522 W/Km) are obtained with blocks dosed with 10% slaked lime and 2% fibers. The comparison of the thermal behavior of house, study by simulations on TRNSYS, revealed that BTC stabilized with slaked lime and canabinus hibiscus fibers offers better thermal temperature comfort than BLT or breeze block. Indeed, the monthly average indoor air temperatures obtained vary from 29.11°C to 37.31°C in the living room and from 27.09°C to 30.53°C in the bedroom and the average monthly relative humidity varies from 19.65% to 59.21% in the living room and from 24.40% to 49.72% in the bedroom.

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Nomenclature
BTC: Block of compressed earth;
BLT: Cut laterite blocks
Rc: compressive strength of blocks in megapascal (MPa)
F: maximum load applied to blocks in kilonewtons (kN)
S: mean surface area of test faces in square centimeters (cm^2)
L: Distance between the two supports in mm;
B: Base of the cross-section of the block in mm;
H: Height in mm;
λ: Thermal conductivity ($Wm^{-1}K^{-1}$)
C: Thermal capacity or calorific capacity (J / K)
A: Thermal diffusivity (m^2/s):
E: Thermal effusivity ($JK^{-1}m^{-2}s^{-1/2}$)

Introduction

The conduct of this study falls within the purview of the work of identifying and promoting materials with high ecological potential and environment-friendly. Convinced that eco-building materials (or construction materials that meet not only the technical requirements of building materials but also environmental, comfort and health criteria, throughout their life cycle) can play a major role in the development of green economy in Africa [2]. This work has been carried out in the Laboratories of Physics and Chemistry of the Environment (LPCE) and Renewable Thermal Energies Laboratories (LETRE) of the University Ouaga 1 Professor Joseph KI ZERBO in partnership with the Laboratory of Eco Materials of Construction (LEMC) of 2IE.
The objective of this study is to characterize the earth material from the central part of Burkina Faso with natural stabilizers of hibiscus canabinus fibers from the north-central region and slaked lime for use in the housing. This choice is based on the earth material**,** and justified by the fact that this material remains the most used in the construction of habitats in rural and peri-urban Burkina Faso. And the technique of compressed earth block now offers a reliable alternative for an accessible and quality architecture, whose scientific, technical, social and cultural recognition has only been increasing over the last fifty years [3].
The renewed interest that the earth material is currently experiencing is largely justified, since it is a local material by excellence and when it is stabilized with cement, it can serve as insulator, carrier for individual constructions. The first step was to formulate the compressed earth blocks at stabilizer dosages ranging from 5% to 10% for slaked lime and from 1% to 2% for hibiscus canabinus fibers. The mechanical tests were then carried out using electric and hydraulic presses respectively for compression resistance and three-point bending, and thermal tests were carried out by the KD2 Pro apparatus at water corresponding to 55 days of treatment for some and 62 days for others. It should be noted that the BTC water content ranges from 2.21% to 3.29% and that of the BLT from 0.08 to 1.10%. However, all the tests on the BLTs are carried out in the natural state. Finally, the characterization results were exploited by simulating the hygrothermal behavior of a house on TRNSYS.

Experimental

Principle and methods for characterization of samples

The characterization study or the definition of the properties of materials is based on in situ or laboratory

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tests, according to well-defined scientific protocols, the identification tests (water content, density, specific weight, Atterbergs limits), mechanical properties (compressive strength, tensile or flexural strength, shear strength resistance) and thermophysical parameters.

Samples Formulation

To improve the mechanical properties of the soil, it can be stabilized with cement or slaked lime. In this study, nine (9) assay types were performed with and without stabilizers as follows:

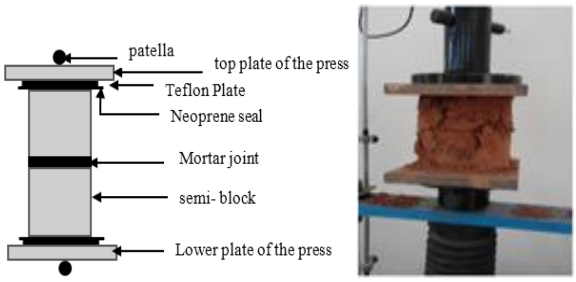
- the control assays are those of 5%, 10% of the slaked lime and the non-stabilized blocks;
- the fiber-stabilized blocks (1% and 2%) and slaked lime and fibers doubly stabilized blocks (5% -1%), (10% -1%) and (10% -2%), respectively;
- these blocks have therefore been subjected to the various tests of characterization of the thermophysical and mechanical properties.

Mechanical properties and characterization methods

The parameters of resistance to compression and tensile strength are most used to appreciate the mechanical properties of the bricks used in the construction. The monoaxial compression and three-point bending tests are governed by the standards NF EN 14617-15 and NF EN 12372 [5]. Resistances of solid bricks such as BTC and BLT require specific procedures and we retain the one prescribed by CRATerre which recommends subjecting to the action of the pressure two superimposed half-blocks of the same sample of BTC.

The procedure of the simple compression test [6] Fig. 1 provides:

- Cut the blocks in half. For this purpose, a bending tensile test may be carried out beforehand;
- Superimpose and glue them with a thin mortar joint (max. 1 cm), moistening them slightly;
- Allow the specimen to dry 2 to 3 days at room temperature;
- Place a greased Neoprene membrane on a Teflon plate and place it on the lower platen of the press. [The procedure for the compression test of the blocks consists of simply superimposing the two half-blocks obtained by specially formulating what has been the case in our study or after the three-point bending used the two pieces obtained. The use of mortar joint is for the purpose of characterizing earthen masonry (BTC or BLT), since the blocks do not retain the same compressive strength before and after being masoned].



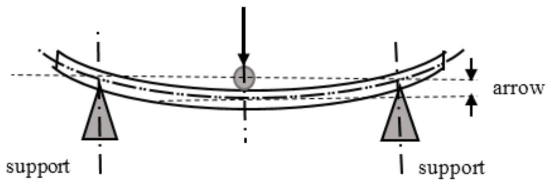
(a) (b)

Figure 1: Diagram of the compression test principle [6].

The compression resistance evaluation is made by the following formula:

$$Rc = 10xF/S \quad (1)$$

For optimal use of brick samples, the strategy was to perform three-point bending strength tests (Fig. 2) and use these bricks for simple compression testing [this was only for BLT].



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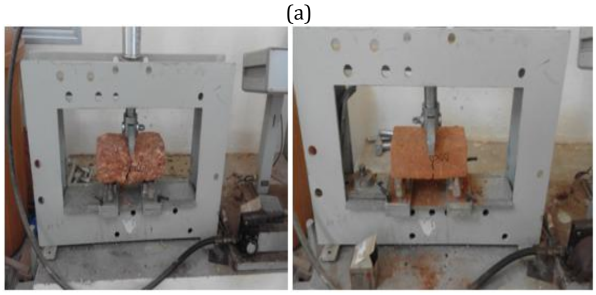


(b)

Figure 2: Three-point bending test device

The test makes it possible to measure the ability of a material to withstand its two supports when force is applied to the medium and the flexural strength (Rf) is obtained by the expression below:

$$Rf = 3Fl / 2bh^2 \quad (2)$$

Thermal properties and characterization methods

The different properties characterizing materials are defined by physical quantities which are all functions of temperature [7]. The study of the thermal properties of materials consists in determining by a recognized method, the parameters, λ, C_p, A *and* E.

Several methods can be used to characterize the thermal properties of a material. These are methods in steady state (hot plate graduated, method of boxes), the methods in transitory mode (flash method, thermal shock probes). All these methods are applicable, knowing that the objective to be achieved when carrying out an experimental study is the accuracy and reliability of the results [8]. It teaches us that the choice of a method will depend on several factors, the most important of which are:

- Reliability of results and duration of measurements;
- The cost of acquiring and maintaining the measuring devices and its robustness;
- The availability of devices.

In view of these factors, we have used the KD2-Pro method, which has advantages in terms of ease of use, speed of measurement and the possibility of operating in situ under any hygrothermal conditions, while respecting the physical state of the environment. [9] It is a heated needle probe developed by the company Decagon (2009) to simultaneously measure thermal conductivity (λ), thermal diffusivity (A) and thermal resistivity (R). [Fig. 3, The device is equipped with several (4) sensors / sensors adapted to different types of materials. Our materials being solid and granulated, the SH-1 sensor is the one adapted].

Figure 3: Thermophysical test [thermal only] of BTC and BLT

Simulation on TRNSYS

Following the characterization tests, a modeling was carried out on TRNSYS 16.1 to simulate the thermal and energy behavior of a house for residential use.

Building Description

The building modelled on TRNSYS 16.1 [10] has a total area of about 41.25 square meters with the main side facing west as shown in Fig. 4. The building envelope is in a mixed structure with the reinforced concrete support structure and the BTC wall. The exterior walls are only coated with cement mortar on the inside, while the internal partitions are coated on both sides. A coating of white paint is applied to the interior coatings. The roof has a sheet metal roof pan and a false ceiling made of 5mm plywood. The exterior doors and windows are in glazed aluminum frames of single glazing thickness of 4 mm with iron frame. The internal doors are made of natural wood.

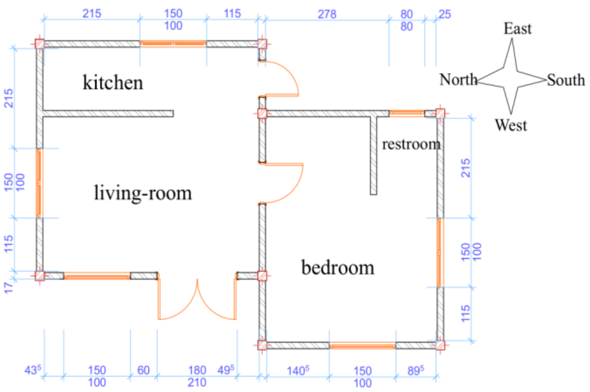


Figure 4: Model level building plan

Simulation data

The thermophysical properties of the materials used in Table 1 are a combination of the characterization results on the stabilized BTC and the literature.

The simulations are carried out over the year with a time step of 1 hour (0 to 8760 h) using the multizone building module (Type 56) given the spatial configuration of the building with three [two] zones. The METEONORM meteorological data from the city of Ouagadougou, proposed in TRNSYS 16.1 are used for the simulation [11].

For the other simulation parameters, we chose a set temperature of 26 ° C and a relative humidity of 50%, with an occupancy scenario of three (03) people in the room and four (04) people in the living room, all week with natural ventilation of 1V/h. In addition, five (05) fluorescent lamps (10W/m²) serve as lighting and other control devices are provided namely a television (175W), a DVD (150W) a refrigerator (70W) with respective coefficients of use of 75%, 40% and 100%.

Table 1: Characteristics of building materials under TRNSYS

Materials	Thickness (cm)	ρ (kg/m³)	λ(kJ/h.m.K)	C (kJ/kg.K)
BTC	14	1924.30	1.8792	1.78870
Mortar	2.5	2200	3.132	0.105
Light concrete	-	2100	3.24	0.850
Single glazing	5.8	-	4.14	-
Sheet aluminum tray	0.12	2700	828	0.897

Results and Discussion

Properties of materials

Physical properties

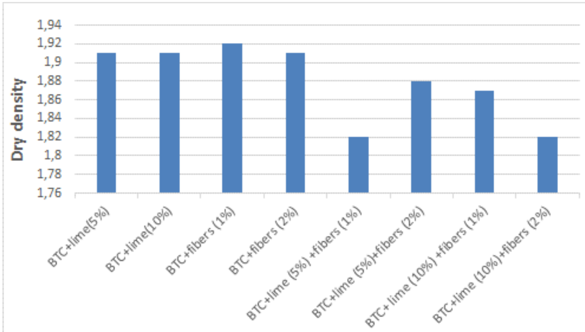


Figure 5: Dry densities of the different compressed earth blocks

From the Fig. 5, the results show that BTC stabilized with slaked lime and canabinus hibiscus fiber have a somewhat low dry density (1.82 to 1.88) compared to those stabilized with slaked lime or fiber (practically Equal to 1.91). This decrease can be explained by a smaller compaction due to the combined effects of the lime and the fibers. The porosity varies between 27.27 and 30.82% for all the BTCs of the different types of dosage. At this age, the average weight is 1937.36 kg / m3. There was also a variation in water content between 2.21 and 3.29%.

Mechanical Properties

(a)Compressive strength

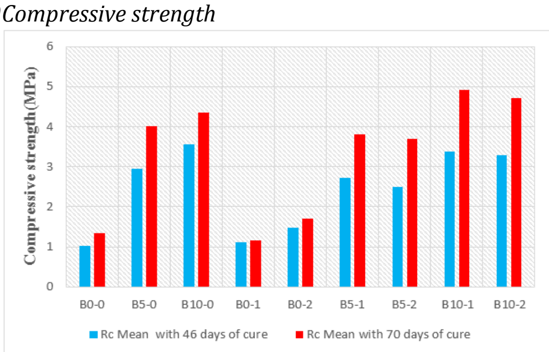


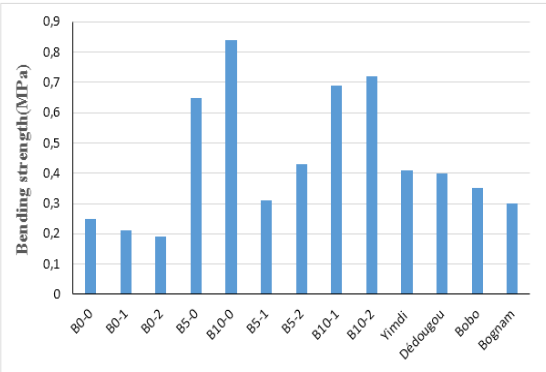
Figure 6: Evolution of the compressive strength of BTCs with curing time in the air of 46 and 70 days

In figure 6, it can be seen that the blocks having undergone a treatment of 70 days have values of the compressive strengths above those of the blocks resulting from the 46-day treatment.

Moreover, the two curves in Fig. 6 indicate that the 10% stabilized blocks of lime with or without fibers exhibit high compressive strengths compared to other types of ground blocks compressed under the same conditions. Also, it appears that the proportion of fibers in the mixture influences the strength of the brick. Indeed, the strength of the stabilized blocks at 1% of fibers is greater than that of the stabilized block at 2% of fibers whatever the lime dosage (the difference varies from 0.09 MPa to 0.23MPa and from 0.12MPa to 0.21MPa respectively for the blocks at 46 days and 70 days of treatment).

In conclusion, the compressive strength depends not only on the curing time but also on the slaked lime and / or hibiscus canabinus fiber. However, in view of these results an optimum dosage of hibiscus canabinus could be limited to 1%. Samples of 10% slaked lime and 1% fiber (B10-1) have the greatest compressive strength (4. 93Mpa). This value is conclusive because in masonry of civil engineering, the norms prescribe an average value of 4Mpa.

(b) Bending strength 3 points



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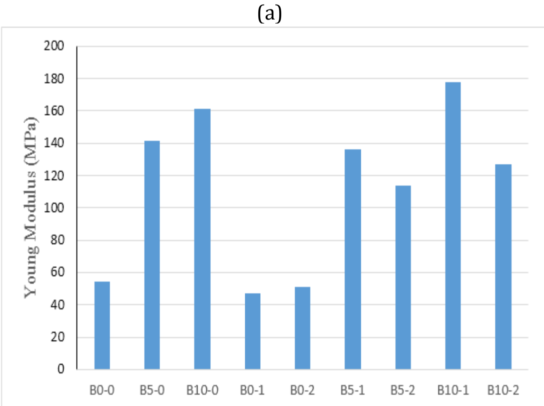


(b)

Figure 7: Evolution of the flexural strength of BTC and BLT (a) and Young's modulus (b)

It can be seen from Fig. 7 that the evolution of the flexural strength is due in large part to the presence of the lime and to a lesser extent the fibers. On all assays, it was found that the fiber did not increase the flexural strength of the BTC for double stabilization (slaked lime and hibiscus canabinus fiber).

Thermal parameters

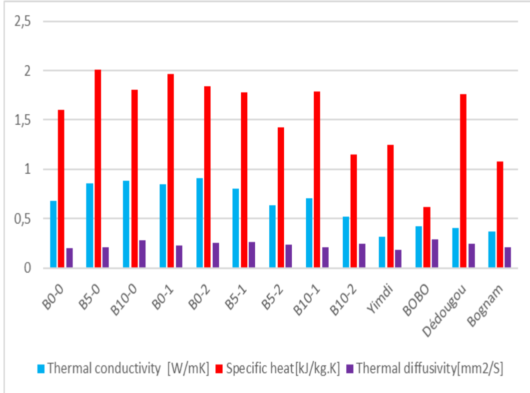


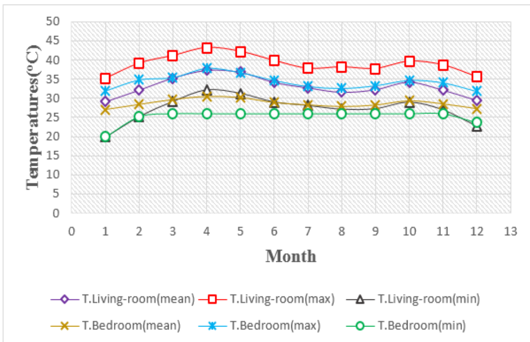
Figure 8: Evolution of thermal parameters of BTC and BLT

It can be seen that the lime and fibers-stabilized compressed earth blocks have, for the set of low thermal properties, only single or lime stabilized blocks. The thermal conductivity values are 0.522W / mK, 0.636W / mK, 0.709W / mK and 0.803W/ mK respectively for B10-2, B5-2, B10-1 and B5-1 as shown in Fig. 8.

In comparison with the BLTs and BTCs studied, the former have low thermal conductivities. More importantly, these quarries have thermal conductivities (<0.5W / mK) more interesting than other quarries such as Dano where λ = 0.510W / mK [8].

Simulations on TRNSYS

The analysis of the simulation results (Fig. 9) is done on the basis of the average of the monthly relative humidity during the year.



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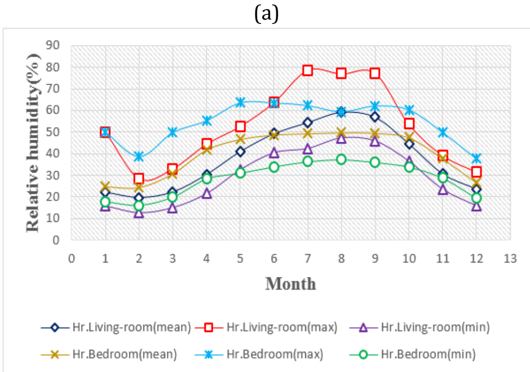


(b)

Figure 9: Change in average monthly temperatures (a) and mean relative humidity (b)

The average monthly temperatures of the indoor air, obtained vary from 29.11 °C to 37.31 °C in the living room and from 27.09 °C to 30.53 °C in the bedroom. The average monthly relative humidity varies from 19.65% to 59.21% in the living room and from 24.40% to 49.72% in the bedroom. These results make these BTCs of so-called environment-friendly materials because it is not necessary to use energy to guarantee thermal comfort. Natural ventilation may be a complementary solution to improve thermal comfort.

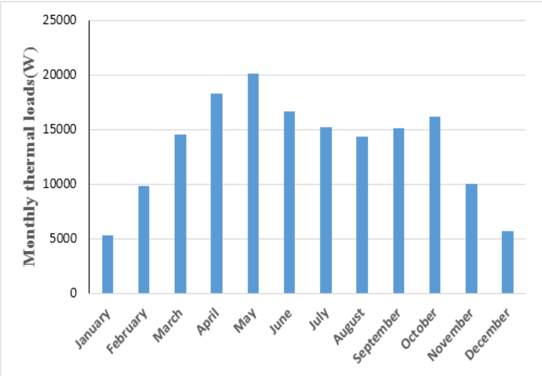
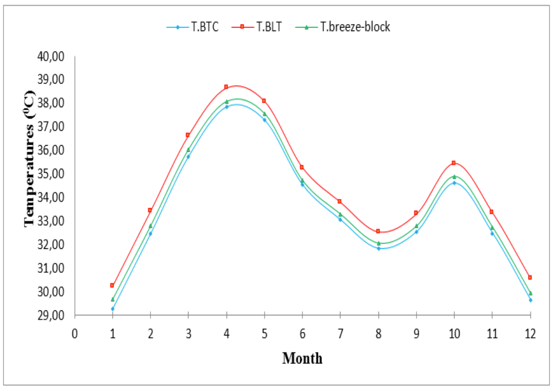


Figure 10: Monthly thermal charges in the bedroom

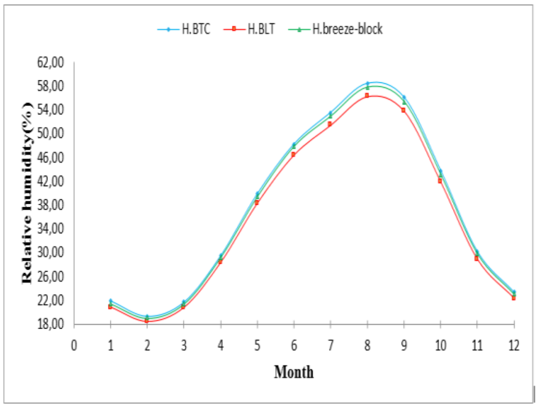
Figure 10 shows that the charges are higher during the months of April and May. This result is expected as the months of April and May, which are the hottest of the year (mean maximum temperature of 37.8 °C and 36.7 °C respectively), are those for which the overall heat gains in the building and consequently the air conditioning loads are the most important [11].

Comparative study of the thermal performances of BTCs with BLTs and breeze blocks

Considering the curves of Fig. 11, the average temperatures vary from 29.25 to 37.84 ° C. for the BTC material against 30.24 to 38.65 ° C. for the BLT and 29.67 to 38.07 ° C. for the breeze block. During the year, the average temperatures of the building in BTC remain lower than those of the building in BLT or in cinder block. However, the observed average relative humidity variation is relating to the average temperatures with higher values for BTC (19.34 to 58.39%) than the BLT (18.38 to 56.21%) or the breeze block (19.04-57.76%). These results show that the formulated BTC material offers better thermal performance compared to BLT and breeze block.



(a)



(b)

Figure 11: Evolution of average monthly temperatures (a) and relative humidity (b) in the living room

Conclusions

The thermal behavior of a F2-type residential building was studied from the characterization data and a simulation with the TRNSYS software. In the process of this study, the determination of the thermophysical and mechanical properties was made by laboratory tests on lime-stabilized compressed earth blocks and hibiscus fibers formulated by us following well-defined dosages.

Stabilization with lime and fibers had an influence on the mechanical strength and on the thermal properties of BTC. Indeed, the best compressive strength is obtained with the blocks of 10% slaked lime and 1% fibers (B10-1) with a mean value of 4.93Mpa (standard deviation = 0.80) at 70 days of treatment in the air, while the best thermal properties are obtained with blocks B10-2: thermal conductivity 0.522 W/Km (standard deviation=0.043).

Subsequently the simulations on TRNSYS allowed to show that the BTC obtained are eco-materials. The evolution of the average internal temperatures is between 27.02 ° C and 30.53 ° C for the bedroom and 29.11 ° C and 37.31 ° C for the living room and that of the relative humidity is between 24.4% and 49.72% in the bedroom against 19.65% and 59.21% in the living room.

With regard to the characterization results, it is noted that the blocks B10-1 and B10-2 have the best mechanical and thermal properties. Then it will be interesting in the perspective of other studies to think of an intermediate fiberdosage in order to further optimize the stabilization of BTC.

At the end of this study, it is reinforced that the use of local building materials can contribute to achieving thermal comfort without using mechanical means of HVAC. The comparative study revealed that BTC stabilized with slaked lime and canabinus hibiscus fibers offers better thermal comfort than BLT or breeze block.

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