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Which kind of construction material as model to mitigate warming in the city of Lomé in Togo in a context of climate change?

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Abstract

Rapid urbanization in Africa within the last decade promotes the rise of massive buildings made by concrete-cement with high coefficient of thermal conductivity, ranging between 1 and 1, 75W/m/h. Just like the other cities, Lomé is built-up with this material that accumulates more heat, which rejection is done at night. To reduce warming in Lomé, it is proposed the use of blocks of compressed clay (BTC), a local, ecological material that accumulates less heat, which's thermal conductivity is 0.81W/m/h. In order to improve the quality of this material, what will be the effect of the incorporation of sawdust of Khaya senegalensis on its thermal conductivity, or on its thermal resistance? Through the method of determination of the density by the principles of "Poussée d'Archimede" and through the conventional method of manufacture of the BTC, it has been proven that the species k. senegalensis incorporated at 10% in the BTC promotes a significant reduction of the coefficient of thermal conductivity (0.32 W/m/h). Therefore, it makes it more resistant to warming accumulation.

Keywords: Construction material, Khaya senegalensis, compressed clay, thermal resistance.

Introduction

The development of cities led to a transformation of the natural landscape. The Natural leaves way to constructions often by materials, which are harmful to the environment[1]. It appears in the daily life of the people in urban areas, a change in the way of consuming natural resources, the behavior and the nature of the construction materials. This affects the environment that knows pollution through the expansion and the proliferation of greenhouse gases involved in the temperature rise in the urban area[2]. It is one of the fundamental causes of formation of the urban heat island[3]. Levinson R. et al[4] emphasize that the urban heat island (UHI) has direct and indirect consequences on the energy consumption, which's main fraction is from the buildings. One can therefore understand that there is a correlation between the built-up density, and the heat in urban areas[5-7]. Taking into account this point of view, the choice of the material of construction is a very important parameter for inside and outside comfort[8]. It should be noted that most of buildings in urban areas are concrete-cement. This material with thermal conductivity coefficient between 1.00 and 1.75 W/m/h spread quickly around the world to the fact that the trading system made it very available and cheap[9].

However, now, more and more critics are made against it due to the environmental impacts generated by the production of cement. Globally, 5% of the emissions of the total carbon monoxide (CO) are produced by the cement industry[10]. It no longer meets the need of energy saving, use a large amount of non-renewable raw materials and generates more waste to the construction and deconstruction. Yet urban constructions are a trap for the accumulation of the heat, which is rejected at the sunset. They are subject to a thermal inertia stronger and slower depending on the whether we meet downtown or in the outskirts.

Indeed the low albedo areas are generally higher in the city than in the countryside[11]. This phenomenon is growing in warm environment. That is why when building, the nature of materials related to their ownership of reflectivity must be considered[12,13]. The suitability of the materials used in urban outdoor spaces, contributes to reduce the ambient temperature and to fight against the effect of heat island[14]. It puts forward the responsibility of cities and the key role that can play urban design in order to achieve sustainable development[15].

In Lomé, the majority of buildings are made-up with concrete (cement cinderblock). However, it is also noted to a lesser extent the use of other materials for construction. Specifically, in addition to wood, granite blocks and the rocks, Togo has experienced through the center of construction and housing (CCL), a new local economic construction material proposed to the population. It's the Red clay of Togolese soil, used in the manufacture of blocks in compressed soil (BTC). These blocks have high thermal resistance[16] that allows them to resist the passage of heat flow. This is because their coefficient of heat conductivity is 0.81W/mph, which is low to 1W/m/h for the brick-cement[17]. This material also has the advantage of producing less waste to construction and deconstruction.

However, with the warming that is in the city of Lomé and knowing the benefits of local-based material with which the BTC are made, it is desirable to improve it and use it for construction needs in the optics to mitigate global warming and avoid the formations of the urban heat island. To improve the quality of this material, what would be the effect of the incorporation of sawdust from wood such as *Khaya senegalensis* on its coefficient of thermal conductivity, and on its thermal resistance? The species is well known for its various qualities including its easy and fast development in germinating, its medicinal actions, its use in carpentry and its weather resistance. People for the purpose of self-care often exploit it. Valorization of the rests of this species will help to sequester large amounts of carbon, which escape and participate in the increase of greenhouse gases. It is in this context that the present study is conducted and it is intended to seek opportunities to improve the quality of the BTC by incorporating into the mixture of stabilized red soil with 10% of cement, varied amounts of content of sawdust of *K. senegalensis* until obtain a tenor of better thermal conductivity.

Methodology

Location of the study area: Lomé, the capital of Togo is the study area, located in the maritime region in the south of Togo, whose boundaries are confused with that of the prefecture of golf today (Figure-1). It extends over an area of 280 km^2 [18] and positioned between 6°8" and 6°11" north latitude and between 1°11" and 1°18 longitude east. Lomé is the economic center of the country, which justifies its very high density compared with other cities.

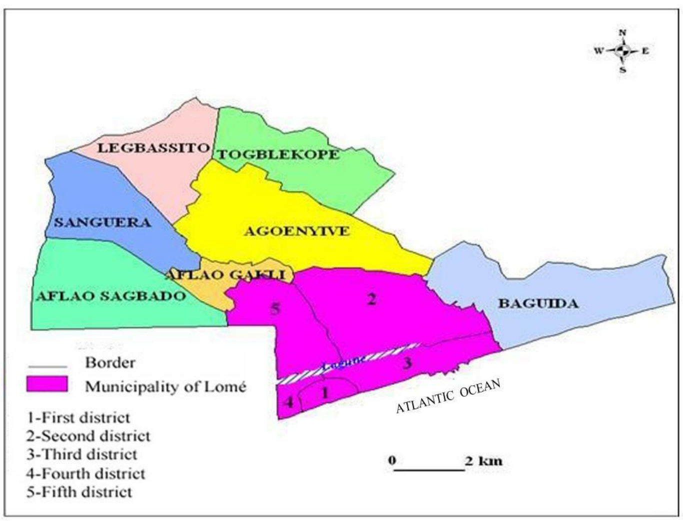

Figure-1: Location of the study area.

In Lomé is located the CCL laboratory at Cacaveli where experience was carried out. This center created by Decree No. 67/258 of 29/12/1967 has as mission, to improve habitat in Togo by the research on available local materials. One of the prowesses of this center is the production of compressed clay brick (BTC).

Data collection: Data collection is relative to the basic elements that go into the preparation of materials for the realization of the experience. The idea is to improve the mix of stabilized red soil with cement at 10% (BTC) with varied tenors of *K. sensgalensis* sawdust, and proceed by testing every time calculations of density, of the coefficient of thermal conductivity, the thermal resistance and the resistance to compression of the resulting product. To do this, the first step is the preparation of the powder of sawdust of *K. Senegalensis*. Indeed, some felled trunks of trees of *K. Senegelensis* have been dried then ground into powder named as the sawdust of *K. senegalensis*. The second step is the making of BTC proportioned to the previously prepared sawdust of *K. senegalensis* (Figure-2 and 3). This was achieved following the steps in the conventional technique of manufacture of the BTC i.e. extraction, preparation, dosage, kneading, compression and drying and storage[19]. Indeed, CCL provided us a quantity of Red soil from Apetsito, a locality at the West of Lomé, on the road of Mission Tove. This red soil, to which it was incorporated 10% of stabilizer which is cement has been kneaded.

Figure-2: Extraction and preparation of materials.

Figure-3: dosage and mixing dry red soil to cement and wood sawdust *K. seneglensis.*

The obtained mixture was divided into six (6) lots. Each lot has been weighed and measured at different tenors of sawdust *K. senegalensis* respectively to 0%, 2%, 4%, 6%, 8%, 10%. These lots are numbered from 1 to 6 (Figure-4). We got from each lot ten (10) compressed bricks for experiments (Table-1).

Table-1: Composition of the experimental materials for the BTC.

Matériaux	Teneur (%)					
	N°1	N°2	N°3	N°4	N°5	N°6
Clay	90	88	86	84	82	80
Ciment	10	10	10	10	10	10
Sawdust of *K. senegalensis*	0	2	4	6	8	10

The third step is to determine, at the level of each type of brick dosed at different percentages of sawdust, the density of the material, the coefficient of thermal conductivity, heat resistance and pressure resistance. To do this, an empirical but very effective procedure was used for the determination of the coefficient of thermal conductivity.

At this level, we used a sample of each brick (BTC) made by an embedded content of sawdust. Each piece taken from each type of brick, shaped manually into a nearly round shape was weighed using the 0.1g precision balance (“m” is the mass). Each weighed sample has been introduced in a drying oven and heated to 50°C for 2 hours of time. The piece then plunged in (Candle) melted for a few minutes is coated by hand with the aim of making the piece impermeable to water. The mass (m') is the mass of the paraffin sample. This has allowed to calculate the mass of the paraffin obtained by the relationship mp = m' - m. Then, knowing the mass density of the paraffin φp = 0.85 g/cm^3, the volume of the paraffin has been calculated by the relationship.

$$Vp(cm^3) = \frac{mp}{\varphi p}$$

In order to determine the volume of the piece of brick, beakers numbered from 1 to 6 were filled with distilled water up to a height of Level h1 (Figure-5). Each piece divided according to tenors has been immersed in one of the six (6) Beakers corresponding to the evolution of tenors. A height of Level h2 has been noted. The gap between the second reading and the first reading represents the volume of the paraffin piece. Vt(cm^3) = h2 - h1. Knowing the volume of the paraffin and the total volume of the body covered with paraffin, the volume of the piece without paraffin has been obtained by the relationship V = Vt - Vp. From all these elements, the mass density is obtained by the relationship $\varphi = \frac{m}{V}$, then by deduction, the density of the sample by the relationship $d = \frac{\varphi}{\varphi_e}$ with φ_e = mass density of the water is equal to 1 g/cm^3.

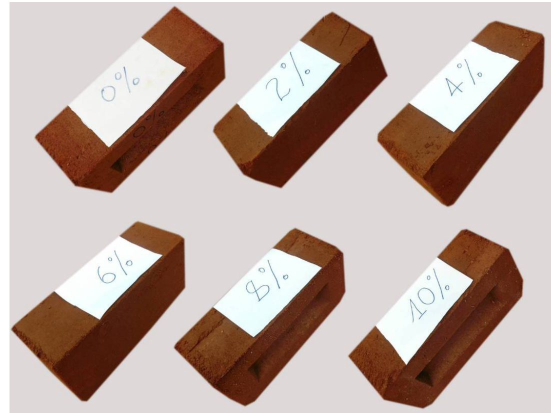

Figure-4: Manufactured BTC stabilized at varied tenor of sawdust and cement.

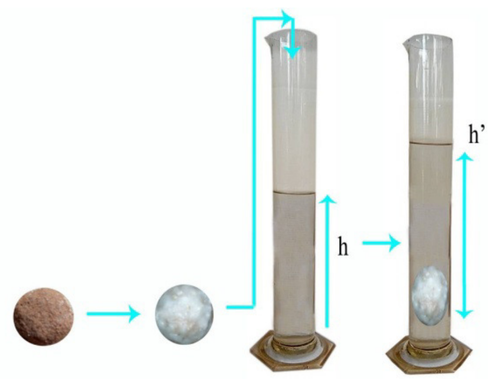

Figure-5: Technique of volume measurement of sample make up in ball drawn according to different tenor of manufactured BTC.

The density being basic to the calculation of the coefficient of thermal conductivity, it has been obtained a coefficient at the level of each type of brick for different tenor. And for the same thickness, the thermal resistance of each type of brick has been calculated. The resistance to compression has been verified after 28 days of age of bricks. The applied force is noted at the crash on the screen at the compression. Note that this experience has been repeated five (5) times with the same tenors for the credibility of results. The numbers used for the result of the work are the average of the five (5) repetitions of the experience according to each tenor.

Data processing: The processing of data is limited to the operations of calculation based on the scientific formulas. As well during the experience the mass density is calculated with the formula $\varphi = \frac{m}{V}$ while the coefficient of thermal conductivity (λ), for bricks up to 200°C, is determined by the relationship related to the density (d) of the substance. $\lambda = 0,9\left[\left(\frac{d}{5}\right) + \frac{d^4}{30}\right]$. It is expressed in the time in kcal/(m.h.°C). By converting the Kcal in JOULE and the time in second the new expression becomes $\lambda = 1{,}0475\left(\frac{d}{5}+\frac{d^4}{30}\right)$ in w/(m.°C). Today the official unit of this coefficient is watt per meter-kelvin (w/(m.K)). The thermal resistance is calculated by the relationship $R = \frac{e}{\lambda}$. It dependent on (e) which is the thickness of the brick in "m", and (λ) the Thermal Conductivity in W/ (m.K). The thermal resistance is expressed in square meters. K/W.

The resistance to compression is given by the relationship Rc = F/S where F is the force of urgent and S the surface of poses of the brick. The Brick is called resistant when the value of the resistance to compression is greater than the normative value, which is 2.4 Mega Pascal (MPa) when it is dry; fixed by decree n°92-13/MISE/CAB of 15/06/1992 (NTG 03010001/1989). Nevertheless, on the international plan the standard of CRATerre[25] establishes the limit of accepted blocks at 4 MPa.

The software R has been used to check the correlation between the density, the coefficient of thermal conductivity, thermal resistance and resistance to compression of this material.

Results and discussion

Physical properties: density: The incorporation of the sawdust of *K. senegalensis* in the stabilized earth occurred following tenors 0%, 2%, 4%, 6%, 8% and 10%. The evolution of the density of the manufactured bricks is intimately related to the density of the sample compared to the water.

Figure-6 shows a regressive variation of the density of the BTC, as the content of incorporated sawdust increases. This reflected the ability of flotation of the sample and its density compared to water. BTC stabilized in cement with a progressive addition of sawdust have a density which varies from 1, 87 to 1.19kg/dm^3. This density is very high (1.91kg/dm^3) at 0% sawdust. The block is therefore more compact when it contains no sawdust and becomes progressively less compact to the gradual incorporation of any tenor of the sawdust.

This property integrated to buildings gives the advantage of having a lighter building compared to those built with cement blocks or compressed earth blocks stabilized with cement and 0% of sawdust. This can be justified by the good quality of reaction of mixing Red soil, cement at 10% and incorporation of a tenor of sawdust. It occurs a perfect synergy of grain composing the sample followed by a reduction of porosity, and a reduction of remarkable weight through a very lightweight density.

Thermal property: This property go through an analysis of the coefficient of thermal conductivity "λ", which represents the basic element, which's changes strongly influence the variation of thermal resistance Rt of a building material. This allows to measure the effect of the incorporation of sawdust of *K. senegalensis* in the BTC on the evolution of thermal resistance R (m^{2}K/W), compared to the heat conductivity λ. (W /(m.°C)).

Figure-7 shows a high conductivity coefficient (0.86) when no percentage of sawdust is embedded in the Red-soil and 10% cement mixture, and a gradual conductivity (λ) of 0.82 to 0.32 and a gradual fall as the incorporation continue. So, the evolution is regressive.

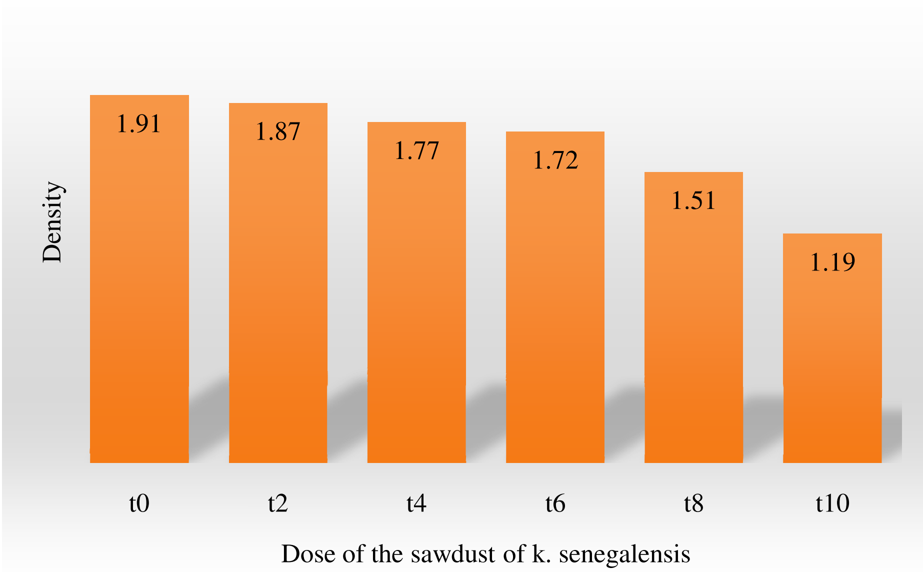

Figure-6: Variation of the density.

However different thermal resistances begin a gradual evolution following the increase in the rate of incorporation of sawdust. Evolution is so antagonistic between the coefficient of thermal conductivity and thermal resistance depending on the content of the incorporated sawdust. The highest values of thermal conductivity correspond to the lower thermal resistance, and vice versa. These values reflect a good ability of insulation of the sawdust combined with the Red soil–cement to 10% mixture.

The gradual fall of the coefficient of thermal conductivity explains the resistance of the material to the accumulation or the passage of heat flow. We can say that the more mix red soil-cement to 10% is dosed to sawdust, the less it conducts heat. However it should be noted that stabilization at 10% of sawdust is the ideal threshold to have an optimal thermal property, beyond which making mass of the mixture is not easy as well as the resistance to compression that approximates the accepted threshold minimum. The Experience has been framed to meet the standard of the national value of 2.4MPa and that international of 4MPa of resistance to compression.

Mechanical properties: resistance to the compression Rc in (MPa): For a content of 0-10%, the results of experimentation show resistance to compression between 9,55MPa and 6.37MPa (Figure-8). According to the evolution, it is observed a decrease in resistance as the stabilized block is metered to the sawdust. However, the value to 10% is beyond the CRATerre standard set at 4MPa and relatively far from the national standard, set at 2.4MPa which are in fact the boundaries of blocks at low of which the material is not accepted. We must emphasize that the incorporation to 10% of sawdust with a compression value of 6.37 is the best percentage of the ideal incorporation for an efficient stabilization of the block.

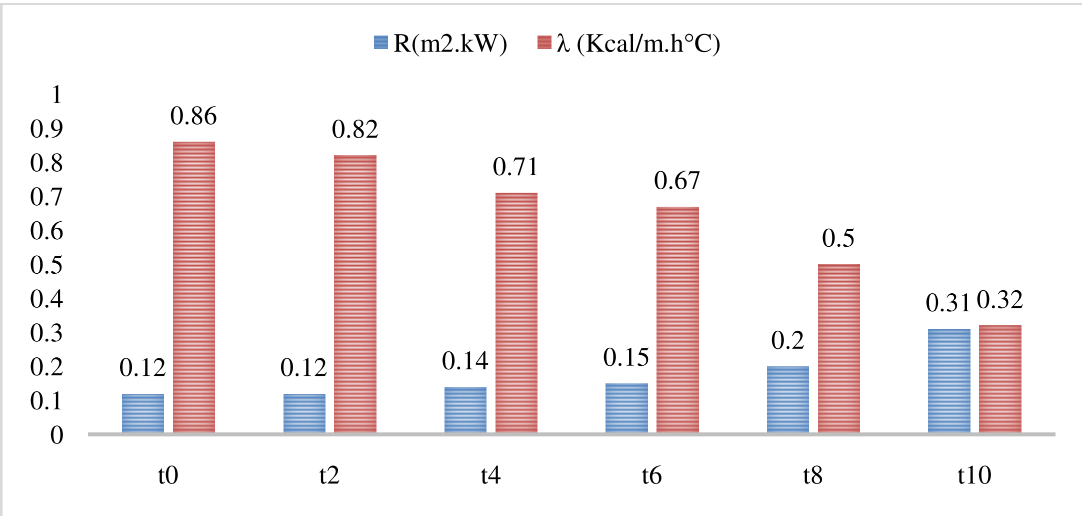

Figure-7: Comparison of thermal conductivity λ and the evolution of the thermal resistance Rt.

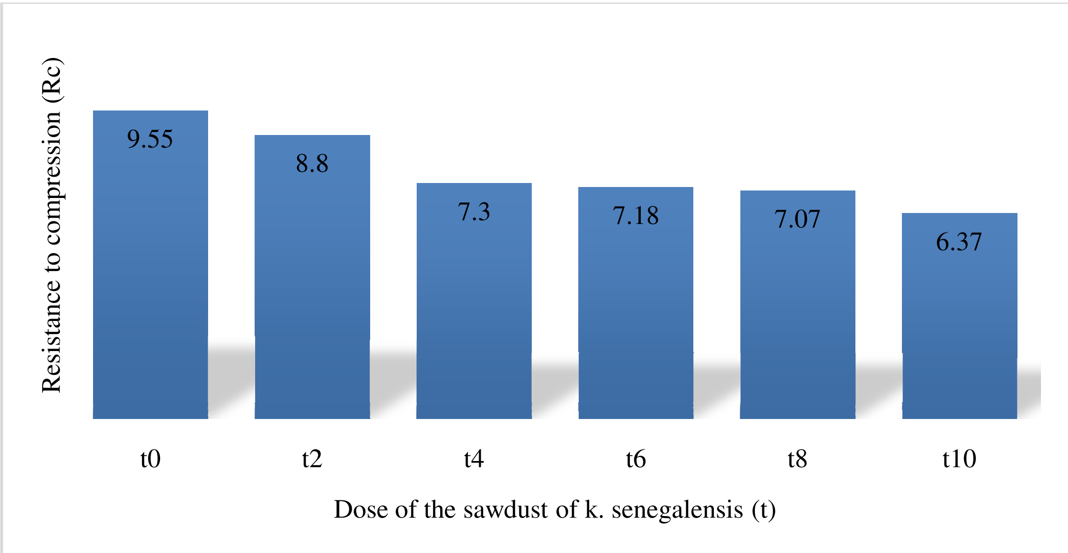

Figure-8: Resistance to compression (Rc).

In a comparative analysis with the previous parameters (λ, Rt), it should be noted that when the compressive strength is low, the thermal resistance is high and so the block resists more to the passage of heat flow. It specifically resists to the accumulation of heat from the Sun's rays during the day and therefore less rejects in the night. It is inferred that the smallest value of compression correspond to a greater value of the thermal resistance. However, the curve relative to the coefficient of thermal conductivity is moving in the same direction as that of the resistance to the compression.

Also the center of construction and housing (CCL) has demonstrated by its calculations through their tools and skills that the constructions made with this new product (N. BTC) dosed to the sawdust of *K. senegalensis* are economic in energetic calorie to 30% and a saving of 20% on the total amount of the cost of construction when comparing with a project of same construction done by cement.

Correlation Test: This test done through the R software enabled to noteglobally a strong correlation between the density, the coefficient of thermal conductivity, heat resistance and pressure resistance. According to Table-2, negative signs in front of the values mean a correlation to the antagonistic effect while positive signs express the opposite i.e. going in the same direction. Therefore, it is easy to see that the density is strongly related to the thermal conductivity and resistance to compression in the same direction, while all are strongly linked to the thermal resistance but in an antagonistic way. This correlation between these parameters vice versa confirms the results of our research experience.

Discussion: The technique led to results that can be use in the manufacture of materials in terms of ecological construction of dwellings in urban areas. These results led to the conclusion that sawdust of the woods of the *K. senegalensis*, incorporated into the mixture Red soil stabilized at 10% to cement lowers significantly the thermal conductivity coefficient (0.86 to 0,32 W/(m°C). Based on this ratio, the thermal resistance becomes high (0.12 at 0.31m2K/W). The same work was done with the similar method where coefficient found is 0.33W/(m.°C) but with the nuance that the incorporation was made with the sawdust collected in a sawmill[20]. This sawdust consists of a mixture of wood from several different plant species. The advantage of the obtained results in this study and those obtained already, is that, it is possible to practice a culture of a species plant like *K. senegalensis* in order to benefit from the environmental benefits like the shade of its trees, pull the medicinal properties of these trees and especially to use its sawdust to get a good insulating material for the construction of the refreshing and ecological buildings. This last advantage allows the carbon sequestration, which solves a problem of rejection of the rests of this tree, which is burned in nature. Further, this also helps to reduce significantly urban greenhouse gases effect [21]also it allows to do energy saving in buildings through new construction techniques[22-23]. That is why constructions that take into account the quality, life cycle, energy gray materials, are classified "green building"[24].

These benefits must lay the groundwork for a new strategy of construction in Togo. The Togolese Government must adapt this technique and adopt it for the construction of any building starting with administrative. With the implementation of the use of these insulation materials to high thermal resistance and low coefficient of thermal conductivity, double with a large-scale tree-planting program, Togo can drastically reduce the global warming in many urban areas including the city of Lomé. It is to oblige Togolese to accompany the eco-construction policy of the Government using insulating material before accessing to the permit for construction. Therefore, it is necessary in a reform to replace the cement with local materials like the results of this study.

A study has shown that the use of cement represents 5% of the global CO_2 emissions for its manufacture[25]. According to Groupe[26] the building presents the most interesting opportunities in terms of mitigation of emissions of greenhouse, with discounts of 25 to 30% of the energy demand and 75% for existing infrastructure[27]. The soil and clay are available in abundance in almost all regions. It covers 33% of the continents[28] and more than a third of the inhabitants of the globe live in habitats in clay[29]. Their transformation into building material (which is recyclable) requires very little, or not at all energy, and does not cause emissions of greenhouse gases. It is completely recyclable and so the environmental impact is almost zero[30-31]. These bricks of compressed soil block participate in sustainable development.

Table 2: correlation between the mass density (MV), the thermal conductivity (λ), the thermal resistance (Rt), resistance to compression (Rc).

	MV	λ	Rt	Rc	TAUX
MV	1.0000000	0.9913729	-0.9894816	0.8228632	-0.9348879
λ	0.9913729	1.0000000	-0.9625429	0.8758218	-0.9688874
Rt	-0.9894816	-0.9625429	1.0000000	-0.7517124	0.8772142
R C	0.8228632	0.8758218	-0.7517124	1.0000000	-0.9429444
TAUX	-0.9348879	-0.9688874	0.8772142	-0.9429444	1.0000000

Conclusion

This study valued the opportunity to mitigate the heat accumulated and rejected by the building through the incorporation into a type of local building material, the industrial product that is the sawdust of *K. senegalensis*. The method based on the use of one of the principles of pousséed' Archimede on a body contributed to the calculation of the density of the coefficient of thermal conductivity, and the deduction of the thermal resistance of the mixture of red soil stabilized with cement to 10% and dosed to the varied contents of this sawdust.

Thus the technique allowed to get a new product with low coefficient of thermal conductivity (0.32W/(m.°C)) λ. That gives to this material a resistance (0.31m2K/W) to heat accumulation in the conservation of its quality demonstrated by its resistance to compression (6.37MPa). This will also solve another environmental problem, which is the sequestration of the carbon escaping in nature when burning the sawdust. The use of this product made clear a saving in energy calories to 30% and a saving of 20% on the total amount of the cost of construction when it pulled a simulation compared with a construction project of the same structure in cement. In terms of Outlook, it would be desirable that studies be conducted on water behavior of this new product of block of compressed soil (N.BTC) under the effect of the rains (cycle of wetting-drying), fire and wind.

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