International Journal of Engineering Research in Africa
ISSN: 1663-4144, Vol. 47, pp 85-101

Submitted: 2019-06-15
Revised: 2019-11-04
Accepted: 2019-11-22
Online: 2020-03-17

The Challenges of Local and Bio-Sourced Materials on Thermal Performance: Review, Classification and Opportunity

Labouda Ba[1,2,3a*], Ikram El Abbassi[1,b], Cheikh Sidi Ethmane Kane[2,c], A-Moumen Darcherif [3, d] and Mamoudou Ndongo[2, e]

[1]Research Laboratory in Energy and Industrial Eco-innovation (LR2E), ECAM EPMI,13 Boulevard de l'Hautil, 95092 Cergy Pontoise Cedex, France

[2]Renewable Energy Applied Research Unit, Université de Nouakchott Al Aasriya, BP 880- Route Nouadhibou-nouakchott, Mauritanie

[3]Quartz Laboratory, Université de Cergy Pontoise, 33 Boulevard de port, 95092 Cergy Pontoise, France

[a*]laboudaa@gmail.com, [b]i.elabbassi@ecam-epmi.com, [c]ottmane6@hotmail.com, [d]m.darcherif@ecam-epmi.com, [e]mndongo6@gmail.com

Keywords: Local materials, Bio-sourced materials, Thermal performance, *Typha Australis*, Building, Energy

Abstract. This paper reviews local and bio-sourced materials for construction through their thermomechanical characteristics, but with an emphasis on their thermal conductivity that allows us to assess the thermal performance (insulation) of these materials. Then, we discuss the energy problems in Mauritania, while highlighting the local and bio-sourced materials existing in this country. These materials could be an alternative to solve these energy problems. Finally, we focus on the thermal performance of Typha Australis, a plant that grows abundantly in fresh water mainly in Senegal and Mauritania, which would have good advantages over the thermal performance of the building.

1. Introduction

More than half of the world's population now lives in cities, with nearly 860 million living in slums and precarious neighbourhoods characterized by, among other things, poor quality electricity supplies [1-2]. The situation in Africa is even more worrying, with the exception of some countries in North and South Africa, less than 30% of the African population has access to electricity, and those lucky enough to have access to it suffer from exorbitant billing [3].

The rate of urbanization is increasing rapidly in developing countries, resulting in an increase in the need for buildings. According to UN-Habitat, the urban population growth rate will reach 65 per cent in 2050 and they have a low energy access rate while facing the production deficit, which is accentuated in the global energy context [4]. Nearly 80% of the population in sub-Saharan Africa has no access to electricity and lives in remote or rural areas [8].

According to a World Bank study published in 2012, nearly half of African countries were in an energy crisis due to limited access to electricity [5]. In addition, Africa is the area most affected by climate change because of its geographical position [6].

These constraints, massive urbanization, depreciating energy resources and climate change, impose new rules of use and energy consumption in all sectors of activity and human life, and more particularly in the building sector. Indeed, the latter alone consumes nearly 40% of the world's energy and is responsible for a third of greenhouse gas emissions [7].

West Africa has a hot and arid climate very different from that of Europe. However, Western architectures are adopted and therefore not appropriate, resulting in uncomfortable buildings and excessive energy consumption. In this document, we will focus on the energy challenges in Mauritania and draw up a general review of the main bio-sourced materials found there, with a particular focus on a local plant (Typha Australis) presumed to have significant physical and thermal properties.

2. Energy Problems in Mauritania

Mauritania is one of those countries facing population growth. Its demand for energy resources, particularly electricity, continues to grow [9]. In 2014, it was one of the countries where 75% of the population did not have access to electricity, as shown Fig. 1.

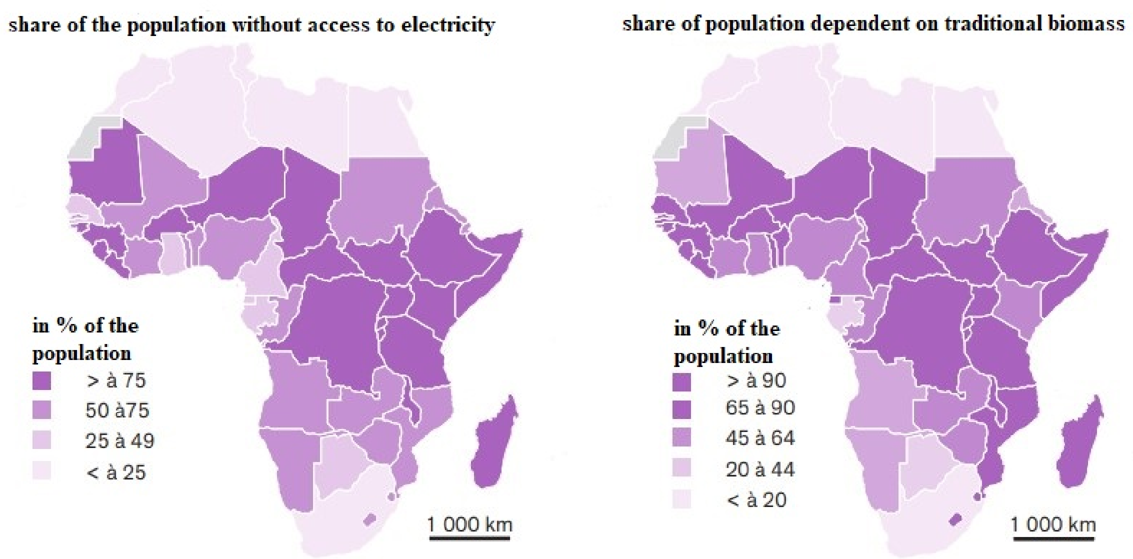

Fig. 1. No-electrification rate in Africa (Source: International Energy Agency, 2014. Africa Energy Outlook; International Energy Agency, 2016. World Energy Outlook).

Electricity production covers only a part of the population (isolated and rural areas), a growth of households connected to the grid has been observed (22% in 2000, 24% in 2004 and 40% in 2010). In the capital Nouakchott, this rate reached 62.5%, or 64.6% in Nouadhibou and more than 89.1% in Zouerate. Installed capacity increased from 130 MW in 1997 to 200 MW in 2009, in addition to self-production in the mining, industrial and commercial sectors [9]. Electricity is a sector that depends heavily on fossil fuels [10], diesel represents 70% of total production in Mauritania in 2007 [11]. A new model has been put in place as part of the country's development strategy to reduce dependence on foreign energy (fossil fuels). Table 1 represents the characteristic data of the energy sector in 2010 for the capital Nouakchott with an installed capacity of 61 MW [12].

Table 1. Energy capacity in Nouakchott

Description of energy sector indicators	*Values*
Primary energy consumption (ktoe/inhabitant)	281
Electricity consumption (kWh/inhabitant)	130
Primary energy consumption growth index (%)	6
Electricity consumption growth index (%)	10
Primary energy production (ktoe)	782
Electricity production (GWh)	470
Installed capacity (MW)	253*
Hydro installed capacity (MW)	97
Installed wind power (MW)	37 (2014)
Installed PV power (MW)	15 (2014)

*excluding industrial and mining sectors

Faced with these problems in Mauritania, the only solution deployed to provide the population with access to electricity is the construction of renewable energy plants (particularly solar photovoltaic and wind power plants), which produce energy that is injected into the electricity grids.

Despite these installations, the population suffers from a lack of access to electricity and recurrent power outages [10]. And renewable energy plants are unpredictable, as they depend on the weather depending on the rate of solar radiation and wind speed. Problems of losses related to the electricity networks during distributions which can reach up to 20%, these problems can be related to meter errors, connections [13].

Therefore, it will be necessary to implement other solutions such as energy management in the home (optimizing energy) given its high energy consumption. Therefore, we will evaluate the local resources (local materials and bio-sources) existing in Mauritania to valorize them energetically.

3. Thermal Performance of Local and Bio-Sourced Materials

It is important to take measures to control energy consumption in the home. The search for new building materials with good thermal insulation is one of the effective solutions to reduce energy needs in a home [14].

Several studies are developing alternatives to optimize energy consumption in the home, the majority of which focus on bio-sourced materials with good thermal performance [15, 16, 17].

We reviewed the most commonly used bio-sourced materials, especially those used as insulation materials to maintain an ambient temperature in the home while optimizing energy consumption. Among these materials we have vegetable fibers, raw or baked clay bricks, etc.

Scientific studies on fibers have been carried out and published in journals to highlight their thermal performance and their potential use as insulation material for the building.

Among these plants, we can mention the alfa fiber used as an insulating material. A study of the thermal characteristics of this fiber was carried out after drying, in order to determine its thermal conductivity by the EI700 heating box method, its mass heat and its thermal diffusivity. The fiber is mixed with plaster with a concentration ranging from 0 to 4%. The results show that alpha fiber reduces the thermal conductivity of the mixture from 0.5 W/mk to 0.22 W/mk.

As an application, the mixture is applied to a habitat located in Meknes (Morocco). Models carried out on TRNSYS software, with zero internal loads and no shading or thermal bridging effects, show that the roof generates more heat, with a mixture at 4%, as well as an improvement in the internal temperature and a reduction in the average heating and cooling demand [15].

Other fibers (sisal fiber, banana fiber, hybrid sisal/banana fiber) were studied by Dujardin [16]. Polymers such as polyester resins and polypropylenes were added to the fibers to strengthen their mechanical properties [16]. The mixture of banana and polypropylene fibers decreases thermal conductivity as the concentration of banana fibers increases, while the mixture of sisal and polyester fibers increases thermal conductivity. Hybrid fibers (banana fiber and sisal fibers) reduce thermal conductivity in the polymer [16].

A comparison was made using clay soil. The comparison is made between the Clay/ Straw mixture and the Clay/Alpha fiber mixture, on the basis of a thermo-physical characterisation by the asymmetric method and a mechanical characterisation, acting on the fiber content (alfa and straw) [17].

The results show that the Clay/Straw mixture reduces thermal conductivity more than the Clay/Alfa mixture, probably because of the shape of the straw stem which also improves the thermal resistance of the straw compared to the alfa fiber. On the other hand, the latter has a better mechanical resistance, provided that its rate does not exceed 2% in the mixture. Alfa fiber increases mechanical strength from 8% to 17%. The Clay/Size mixture allows a better energy saving (4% to 9%) [17].

According to the work of Bederina and al [18], wood chips can influence the thermal conductivity of sand concrete. Two types of sand concrete were analyzed, dune sand concrete (DS-C) and river sand concrete (RS-C) [18]. For the preparation of concrete, the sand is mixed with portland cement, an admixture and a quantity of water for hydration. The study shows that as the wood content increases, the thermal conductivity decreases as well as the mechanical strength (refer with: Table 2). The thermal and mechanical characteristics of river sand concrete are slightly higher than those of sand dune concrete [18].

Table 2. Thermal characterization of river sand and dune concrete

characteristics of the matrix						
B (Kg/m3)	0	20	40	60	80	100
λ (W/mk)						
DS-concrete	1.2	0.98	0.86	0.71	0.65	0.55
RS-concrete	1.3	1.1	0.9	0.8	0.69	0.65
Rc (Mpa)						
DS-concrete	20.0	17.5	13.2	9.4	7.4	5.6
RS-concrete	23.6	21.7	14.3	10.6	9.4	6.2

A review of plant aggregates and fibers in building materials was carried out by Laborel-Préneron and al [19], and the physical, mechanical, hygrothermal and durability performances of the materials were studied. The hygroscopic aspect, on the other hand, has not been studied. Soil is known as a natural moisture regulator and improves thermal comfort, but the addition of aggregates and plant fibers increases its capacity [19]. The fibers studied in this analysis are: cereal straw, wood aggregate, bast fiber, palm tree, residues, leaves and copals of aquatic plants and sheep wool. The study observes a decrease in thermal conductivity with the addition of plant aggregates and fibers, so they are considered good insulators. It also indicates that the addition of plant fibers and aggregates reduces density, reduces cracks and gives better thermal conductivity. The addition of cement or other binders improves mechanical strength [19]. Studies have shown that ground coffee improves the thermal conductivity of plaster, an experiment was carried out to this effect. The latter consists in incorporating percentages of ground coffee into the plaster (0%, 2%, 4%, 6%), the result shows a decrease in the thermal conductivity of the mixture as the ground coffee is added (refer with: Table 3).

A simulation of an 80m² living space in Marrakech was carried out on TRNSYS software and the simulation shows that the composite (plaster + ground coffee) has saved more than 24% of energy thanks to its thermal insulation [20].

Table 3. Thermal conductivity of the material according to the percentage of coffee

Percentage of coffee in plaster (%)	0	2	4	6
Thermal conductivity (W/mk)	0.500	0.410	0.335	0.314

Brouard and al [21], studied the mechanical and thermal behaviour of clay with aggregates such as sunflower and rapeseed straw and gypsum-based bio composites for building insulation. The results show an increase in the density of bio-composites, resulting in an increase in thermal conductivity (235 to 714 kg/m^3, 0.055 to 0.162 W/mk). The addition of sunflower aggregates gives good thermal conductivity but poor compression resistance quality. The mixture of aggregates with clay gives good thermal conductivity, the latter was determined by the transient heating wire method [21].

S.bodian and al [22], also studied the thermomechanical characteristics of fired and uncooked clay bricks by mixing with laterite with percentages ranging from 0 to 50%. The results of this study show that fired clay has better thermal performance (thermal conductivity, thermal effusivity) as well as better mechanical strength than uncooked clay and the addition of 30% laterite is the optimal mixture to improve thermal performance (the addition of laterite has the same effect on both fired and uncooked brick cases) [22].

Several methods can be used to complete the thermal characteristics but according to Sibiath and al [23], the asymmetric hot plane method has a shorter implementation time and allows several parameters to be determined simultaneously. They studied the characterization of cement mortar doped with coconut fiber, with fiber levels ranging from 1 to 4%. Conductivity and effusivity are determined according to the length of the fibers (long, medium, short). The result shows that these two parameters (conductivity and effusivity) decrease by 10% as the percentage of fiber increases, the fiber is a good insulator with a thermal conductivity of 0.05W/mk. The study shows that the thermal density capacity is directly related to the density [23].

A study was carried out on the role of paper and cement in stabilizing compressed earth blocks. It showed that compaction enhances the mechanical characteristics of the material but the material remains sensitive to water. To improve this sensitivity, it is necessary to add hydraulic binders such as cement, which makes it possible to bind sand grains while improving mechanical strength. Three cases were treated: soil with cement at 4%, soil with paper at 0.78% and soil with paper at 0.78% and cement at 4%. The mechanical characteristic (bending) showed that the mixture of soil, paper and cement has a better mechanical resistance, followed by the mixture of soil and cement and then soil and paper. The best thermal performance is observed with the mixing of soil and paper [24].

The addition of natural fibers such as corn marrow and barley fibers to a compressed earth composition artificially manufactured from kaolinite gave good thermal performance. The addition of 1% and 2% of the corn marrow reduced thermal conductivity by 60% and 78% respectively and the addition of 1% and 2%. Barley fibers have also reduced thermal conductivity by 20% and 74% respectively, these two fibers can be used considerably as insulation materials [25].

Sawdust and the addition of Pozzolana to a lateritic brick reduces thermal conductivity while maintaining good mechanical strength of the brick. The addition of cement and pozzolana increases the mechanical strength. The following table shows (refer with: Table 4) the evolution of the thermo-physical properties of three mixtures tested: M1 (92% lateritic soil + 8% cement), M2 (45% lateritic soil, 45% natural pozzolana and 10% cement), M3 (81% lateritic soil, 9% sawdust and 10% cement) [26].

Table 4. Thermomechanical characteristic of the mixtures

Sample	Compacting pressure (MPa)	ρ (kg/m^3)	K (W/m °C)
Mix 1	5.3	1491	0.75
	6.7	1807	0.95
	8.5	1966	1.15
Mix 2	4.1	1329	0.65
	5.8	1576	0.69
	8.9	1643	0.71
Mix 3	6.5	1050	0.50
	7.1	1098	0.51
	9.6	1207	0.65

4. Local and Bio-Sourced Materials in Mauritania

The solutions proposed above can be applied in Mauritania. Construction plays an important role in the development of Mauritania, especially with the increase in urbanization. It has a direct impact on professional integration and the use of local resources.

The construction process depends on the socio-economic category of the population concerned: « modest population/rural area », «affluent population/urban area». The first category practices self-construction, never involves professionals in the sector (architects, engineers, technicians). The construction is generally made of cement block or banco and the roofs are made of sheet metal [27]. The same family can live together in the same room. In urban areas, the building is generally more spacious, higher, of high standing, with one- or two-storey villas [28]. For local resource constructions, we mainly find three clay-based materials: Adobe (sun-dried clay brick), Moulded raw clay block (sometimes stabilized with cement or lime) dried in the shade and compressed, Baked clay block. These materials are proving to be good thermal regulators and energy efficient [28].

We can also find other local materials, such as earth-based coating, which has a minimal cost, hygrothermal behaviour, excellent adhesion to raw earth substrates, and is fully recyclable (when not stabilized) or Pisé which has an average cost, thermal inertia, good strength and durability, and is fully recyclable (when not stabilized).

We can find other more complex local materials such as baked bricks, they have good assets such as their thermal behaviour, strength and the fact that they are fully recyclable, quarry stones that have the same properties as baked bricks, or wild stones [28]. In Mauritania, there are other local material sectors that are binders and they play an essential role in housing:

- Plaster is a derivative of gypsum, it is often used in mortar, interior and exterior plasters, agglomerated masonry units, tile masonry units and ceiling decoration. It has several advantages: very good thermal and acoustic insulation, fully recyclable, very good hygrometric regulator and adapted to hydraulic earth supports [27].
- Lime is obtained after the limestone has been fired and is used as interior and exterior plasters, paints, mortar, concrete. It also has many advantages: Very good hygrometric regulator, antiseptic, coatings perfectly adapted to the ground supports.
- Cement results from the high temperature firing (clinker phase) of more or less clayey limestone and two types of cement are distinguished: natural and artificial portland (artificial mixture of clay and limestone + water).

There is also the plant sector, such as:

- Typha Australis, a wild monocotyledonous plant that has recently been used extensively in many sectors (medicinal, food, industry, construction, energy, etc.). In the construction sector, recent studies conducted on the Typha Australis by researchers at the Cheikh Anta Diop University in Dakar highlight its insulating nature.
- Rice husks are a by-product of rice husking, an operation that transforms harvested rice, or paddy rice, into cargo rice, can be used as a stabilizer for adobes, in earth-based plasters, as fuel for baking bricks or small pottery elements [29].

Cement is the most widely used material in Mauritania. It was imported, but since 1979 there have been companies that manufacture local cement (cement from Mauritania), sand and shells are available on site. These local materials meet housing needs in the face of urbanization. Concerning to construction, habitats (materials and architecture) in Mauritania are influenced by the Western model, which is not adapted to the climate or the population's uses. This leads to a deterioration in the living conditions of the inhabitants, especially in summer [30, 31]. A study carried out on habitats in Mauritania shows the coexistence of three types [32]:

- ❖ These are precarious habitats (tents, huts, huts), and are spread throughout the countryside, representing nearly 36% of households.
- ❖ Sedentary habitats (houses, rooms, cement walls, zinc or cement roofs), these habitats are spread between the countryside and cities and represent about 62% of households.
- ❖ High standing housing (Villa, apartments, buildings), these dwellings are more widespread in the cities (Nouakchott, Nouadhibou) and represent 6.6% of households.

Sustainable habitats that reduce the effects of climate change (greenhouse gas emissions, reduced energy consumption, comfort of use) will have to be put in place [32]. Habitats using eco-materials with a low environmental and energy impact, good thermal performance and ensuring the comfort and health of users.

5. Typha as a Building or Insulating Material

The solution recommended in our work to better insulate habitats in Mauritania is based on the use of Typha Australis (family Typhaceae), a monocotyledonous plant that grows mainly on the edges of calm waters (lakes, marshes, etc.). Typha Australis grows rapidly in an aquatic environment (Senegal River between Rosso Mauritania and Rosso Senegal) and disrupts agriculture and drinking water in the valley. The capacity of Typha resources represents an area of more than 3 million hectares for a capacity of 520,000 tonnes of available dry matter per year. Since the creation of the Diama dam in 1986, which gives the population access to fresh water, a large proliferation of Typha has been observed (more than 300,000 to 500,000 tonnes per year). The proliferation of Typha has serious ecological impacts (health problems, waterborne diseases, reduced access to water) [33]. Several eradication measures such as cutting and storage of the plant have been taken in vain. Indeed, storage is harmful because by rotting Typha releases significant quantities of greenhouse gases (CO_2, CH_4).

This critical situation has prompted authorities and researchers to find ways to exploit this plant to enhance its value while reducing its harms. Typha was first used, in the form of mats and boots, in hotels and restaurants for the decoration of verandas and as a means of providing thermal damping and blocking thermal radiation. Then, it was discussed to use Typha as a building material.
The Typha plant consists of a rigid stem, leaves that represent the internal spongy alveolar structure (aerenchyma) to stiffen and aerate the leaves and a flower made of microfiber and seeds. Aerenchyma has good thermal insulation with a thermal conductivity of 0.032 W/mk [34], lower than that of hemp wool which is 0.06 W/mk and expanded cork 0.049 W/mk [35].

Several organizations such as the tyccao project (Typha Fuel Construction West Africa Senegal and Mauritania) are trying to promote this plant, first of all as a fuel for coal and currently as a building material. But the problem with coal (carbonization) is the ICP (lower calorific value), which is not enough for biomass to be used as a substitute for mineral coal. We will review the studies that have been carried out on Typha in the habitat, including its thermal and mechanical characterization. A study of the valorization of Typha alone was carried out and the latter mixed with concrete (cement, water, sand), the study consists in determining the thermal conductivity and mechanical resistance of these two materials (Typha alone and the mixing of Typha with concrete) [36].

The methodology used is the sampling of the Typha by drying it in the sun for 7 days, chopping, etc. By varying the density, the thermal conductivity is determined. The second sample being the mixture of Typha and concrete according to different percentage of Typha (0.5% to 3%) and thermal, mechanical measurements were carried out. The granulometry of the Typha was evaluated by sieving and shows that the Typha has a higher granulometry than concrete. The results of this study show us that the thermal conductivity of Typha decreases with increasing density (refer with: Fig. 2).

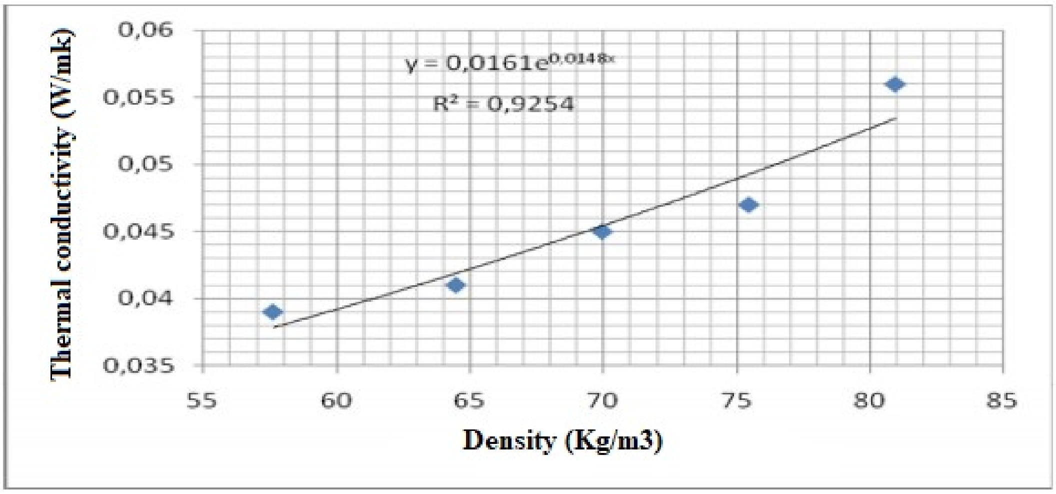

Fig. 2.Thermal conductivity of Typha

The thermal conductivity of Typha alone is 0.045 W/mk which is lower than the threshold conductivity of 0.065 W/mk, so it can be considered a good insulator (a material is considered a good insulator if it is lower than 0.065 W/mk [34]). The mixture of concrete with 3% of Typha has a thermal conductivity equal to 0.126 W/mk for a mechanical strength of 0.89 MPa (refer with: Fig. 3).

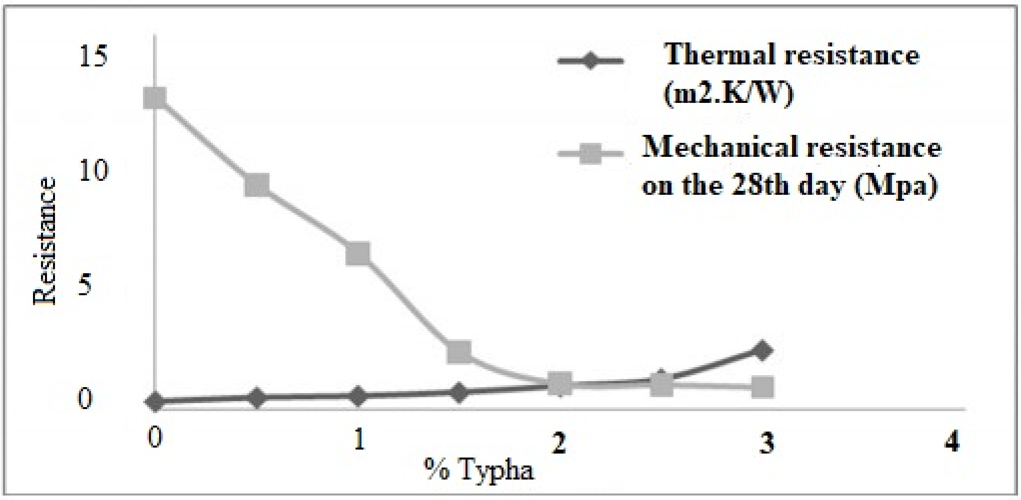

Fig. 3. Mechanical resistance according to the percentage of Typha

Dieye and al [37] also studied the thermo-mechanical characterizations of Typha with clay as a binder. The dried and ground Typha (length 1mm to 42 mm, average length 13 mm) with a volume density of 86.5kg/m^3. He studied the mechanical and thermal press mechanical characterization of the material (mixture) by the hot plate method and the material was heated in the furnace to eliminate its dependence on moisture content[37]. It can be seen that the mechanical strength increases with the increase in binder (clay), compressive strength values range from 0.279 to 0.796 MPa and tensile strength values from 0.340 to 0.969 MPa (refer with: Fig. 4).

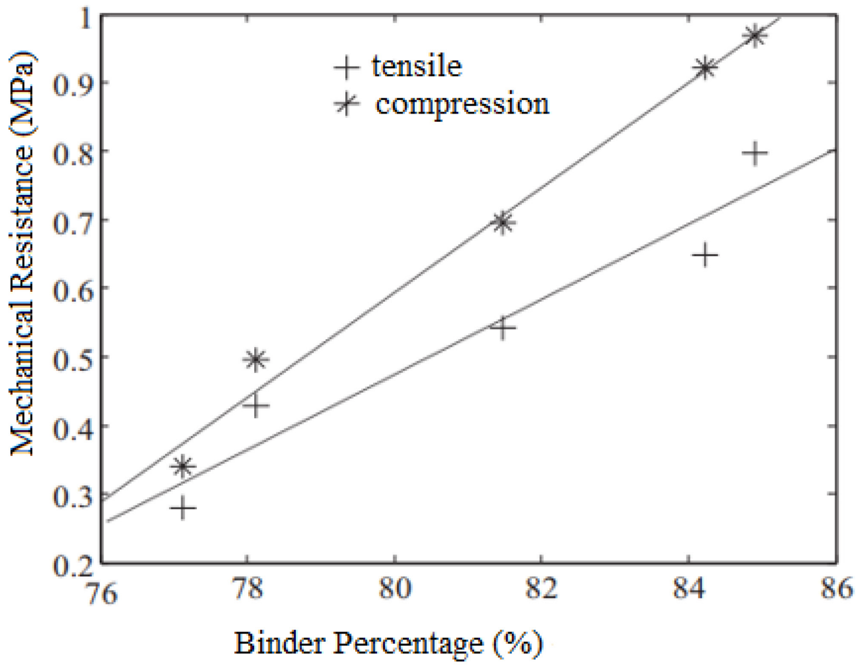

Fig. 4. Mechanical strength according to the percentage of binders

Thermophysical results show that the increase in the percentage of binder increases thermal conductivity and thermal effusivity but decreases the percentage of water (clay reduces the porosity of the fiber) (refer with: Table 5). From the samples of the study the minimum thermal conductivity (0.127 W/mk) is obtained for 77.1% of the binder. The study concludes that the low thermal conductivity value shows the good thermal insulation capacity of the mixture, the following table shows the variation in thermal conductivity and effusivity according to the percentage of water as a function of the percentage of binders.

Table 5. Thermal characteristic according to the percentage of binders

Binder percentage (%)	Mass water content (%)	Thermal conductivity λ (W.m-1.K-1)	Thermal effusivity E (J.m-2.°C-1.s-1/2)
77.1	10.4	0.127	242.0
78.1	9.6	0.136	259.4
81.5	9.4	0.142	268.9
84.2	6.8	0.158	295.6
84.9	6.2	0.163	315.4

An incorporation of Typha with percentages (0 to 3.5% with a step of 0.5%) into a cement mortar was done by Abdelhakh and al [38]. to analyze its influence on thermal and mechanical behaviour. For the mechanical study, it was done by the hydraulic press and the thermal study by the asymmetric hot plate method with an insulating back face, then the application of a method to estimate parameters to calculate the thermal effusivity, the thermal capacity is determined by the following relationship (Refer with: Eq. 1).

$$E = \sqrt{\lambda \rho C}\ . \tag{1}$$

The results of this experiment show that Typha is a very light material with an apparent density of 51.6 kg/m^3 and an absolute density of 144.95 kg/m^3, the density of the mixture is higher in the wet state than in the dry state and decreases with the increase in the proportions of Typha. The following figure (refer with: Fig. 5) shows the evolution of the thermal conductivity compared to the percentage of Typha, we observe a better conductivity with a percentage of 3.5% of Typha [38].

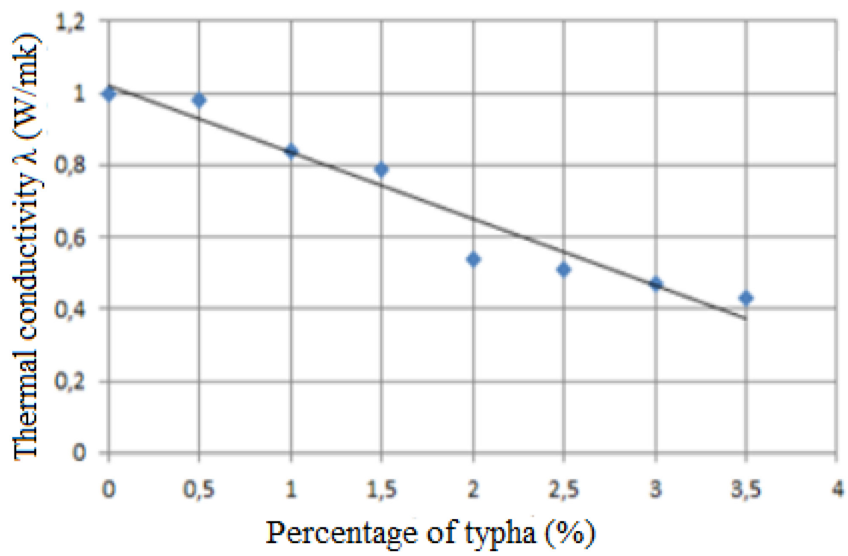

Fig. 5. Thermal conductivity of the mixture

The increase in Typha increases porosity but decreases compressive strength and thermal conductivity (1W/mk (0% of Typha) -0.4 W/mk (3.5% of Typha)), the following figure (refer with: Fig. 6) shows the mechanical strength as a function of the percentage of Typha.

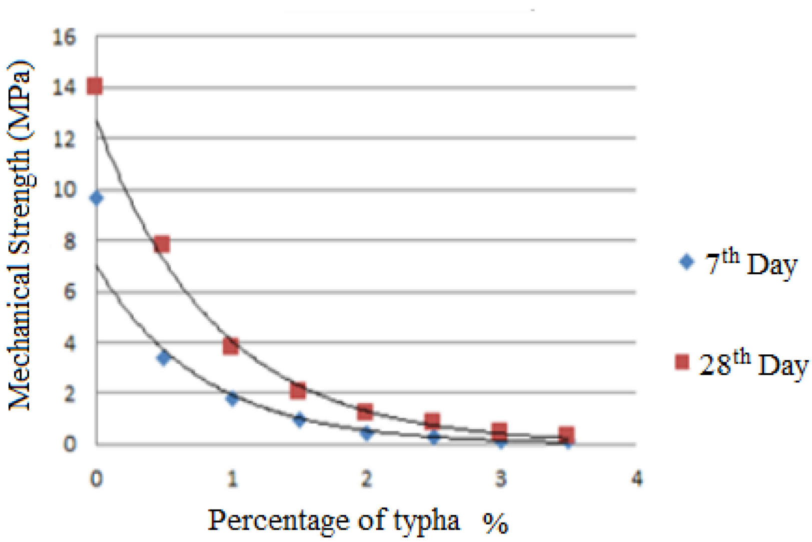

Fig. 6. Mechanical resistance of the mixture

From these results we can conclude that Typha with cement mortar is a good insulator, but its mechanical strength will have to be improved. Massive cross-sections and percentages also decrease thermal conductivity, I. Niang et al [39] studied the influence of Typha morphology and quantity on hygrothermal by focusing on physical characteristics (thermal conductivity, densities and porosity). He used the transverse and longitudinal cutting with 80% Typha and 20% clay (binder) and a longitudinal cutting of 66% Typha and 33% binder called T80/20, L80/20 and L66/33 respectively [39].

The results show that the transverse fraction increases water vapour (the method used to assess moisture) and has increased moisture storage in the material. The thermal conductivity of the compositions in the dry state by the hot wire method of L80/20 is higher than that of T66/33 and which is higher than T88/20 so the latter is the best dosage to have the optimal thermal conductivity. We can see that T80/20=0.115 W/mk is lower than that studied in [36] where the optimal thermal conductivity is equal to 0.4 W/mk.

We can meet other types of Typha that derive from the same family as Typha australis, Sana and al [40] have studied the properties and structures of the foliar fibers of Tunisian Typha. They confirmed the importance of the thermal effect and insulation properties of Typha which can be used in many other sectors (electronic packaging, automotive parts, etc.)[40].

K. Ramanaiah and al [41] also studied the mechanical characteristics and thermal conductivity of natural fiber reinforced polyster composites of Typha Augustifolia, the results of this study showed the increase in tensile strength as the fiber content increases in the polyster matrix. The thermal conductivity of the fiber is 0.137 W/mk and that of the cured matrix 0.432 W/mk, this thermal conductivity has been determined by empirical models (maxweel, russel) and also by the experimental method and the results of these three methods adopted are almost identical. The thermal conductivity of composites decreases with increasing fiber content, the study concluded that Typha is a lightweight material, it has better mechanical and insulating properties, it can be used for various purposes: insulation panel, building, electronic boxes etc [41].

In addition to its use as an insulation panel, Typha could also be used in other areas, G. Wuzella and al. mentioned in their article that binder-free Typha can be used in the industrial and furniture sector, thanks to its bending strength, which increases as the density of the panel increases. They also highlighted the mechanical performance of Typha alone compared to other fibers (Kenaf, flax, hemp, coconut). The results show that these fibers must be mixed with other binders to have the same performance as Typha alone [42].

The study of the structural and mechanical properties of Typha was carried out by J. Liu and al. using the non-linear finite element method. The results highlight the ability of Typha to resist compression and deformation, as well as its possible use in lightweight thin-walled structures [43].

The mixture of clay-based mortar and siliceous sand with fibers (oat straw after being cut and dried in the sun and fiber wool of Typha Latifolia which has been dried in the open air), by making 6 mortars with different fiber volumes with a reference mortar without adding the fiber and the mortars vary according to the percentage of fiber addition. OF10, OF20 represent respectively the addition of 10% and 20% oat straw and TF20, TF40 and TF80 represent respectively the addition of 20%, 40% and 80% of the Typha wool.

These mixtures have been subjected to experiments to determine their characteristics. The results show that the addition of fibers decreases the moisture density but the decrease was smaller with the addition of Typha (which could be due to the small size of its fibers). Oat fiber promotes the reduction of thermal conductivity unlike Typha, which slightly reduces thermal conductivity. These fibers have significant effects on mechanical characterization [44].

Typha has advantages in terms of moisture absorption. Indeed, the addition of 2% of the Typha in clayey sand plasters reduces the intensity of moisture absorption from the air and the same amount absorbed 36.8g of water/m² (wall surface) in 12 hours [45].

6. Assessment of the Thermal Performance of Materials

In this section, we carry out an analysis of the thermal performance of the materials mentioned in this document. The analysis consists in making a comparison between the thermal performance rate of the materials mentioned to identify the most efficient materials. The thermal performance studied here is the thermal conductivity performance, it is the most studied factor in the thermal characterization of material compositions. The thermal performance rate is calculated as follows in percent (Refer with: Eq.2):

$$\tau = \frac{\lambda_i - \lambda_f}{\lambda_i} \quad (2)$$

τ : thermal performance rate of the final mixture (%);
λ_i : thermal conductivity of the building material before the addition of plant fibers (W/mk);
λ_f: Thermal conductivity of the material after adding percentages of vegetable fibers (W/mk);

The result of these thermal performances is shown in Fig.7 as histograms and thermal conductivities before and after the addition of plant fibers are shown in Table 7.Table 6 represents some studies of the most commonly used local and/or biosourced materials, which are used either as insulation or building materials. From the tables, we can deduce that in this bibliographic study, 1/3 of the materials are used for thermal insulation and the remaining 2/3 for building materials (the mixture of insulation materials and building materials). Generally, materials used as building materials have good mechanical performance. In all cases, whether these materials are used as building or insulating materials, a thermal characterization study must be carried out to get an idea of the thermal performance of these materials.

Table 6. The types of materials used in the reviews

References	Materials	Use
LACHHEB, 2017 [15]	Mixture of alfa fiber and plaster	Insulation
DUJARDIN, 2014 [16]	Addition of polymer to hybrid fibers	Insulation of composite materials
Elhamdouni, 2017 [17]	Clay and straw	Building material
	Clay and fiber	Building material
Bederina, 2007 [18]	Sand concrete river or sand dungeon + wood	Building material
Laborel-Préneron, 2016 [19]	Aggregate of plant fibers + soil	Building material
Lachheb, 2019 [20]	Ground coffee + plaster	Insulation
Brouard, 2018 [21]	Clay+ sunflower and rapeseed straw + organic composite based on plaster	Building material
BODIAN, 2018 [22]	Fired and uncooked clay brick with laterite	Building material
Sibiath O. G. OSSENI, 2016 [23]	Cement mortar doped with coconut fiber	Insulation material
Ouedraogo, 2015 [24]	Paper and cement on the stabilization of compressed earth blocks	Building material
Palumbo, 2016 [25]	The ajour of corn marrow and barley fibers on a compressed earth composition	Building material
Meukam, 2004 [26]	Sawdust and the addition of pozzolana in lateritic soil (TL)	Building material
Diatta, 2011 [35]	Typha with concrete (cement, water, sand)	Building material
Dieye, 2017 [37]	Typha and clay	Building material
Abdelhakh, 2016 [38]	Typha and cement mortar	Building material
Lima 2016 [42]	Mortar based on clay soil and siliceous sand + fibers (oat straw and Typha wool)	Building material

The following diagram (refer with: Fig. 7) shows us the thermal performance rate of each study. The materials are either insulation materials or building materials with the addition of insulation materials to improve thermal performance (refer with: Table 7).

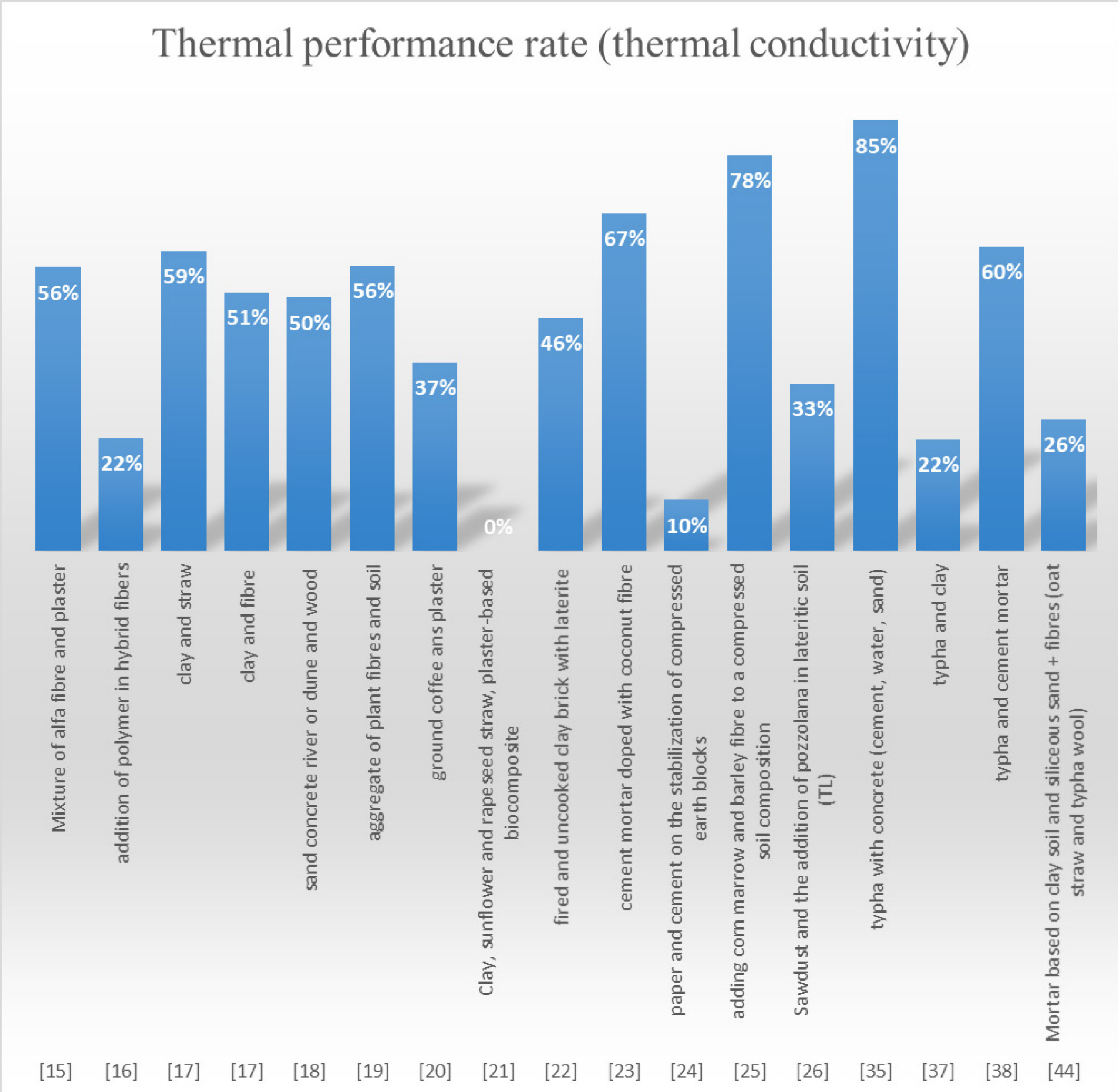

Fig. 7. Thermal performance rate

From the diagram (refer with: Fig. 7) the best thermal performance is obtained with [35], which corresponds to the addition of Typha in concrete with a performance rate of 85% followed by [25] which is the addition of corn marrow and barley fibers on a compressed soil composition with a performance rate of 78% for corn. Coconut fiber also provides good thermal insulation doped with cement mortar, with a thermal performance of 67%. With cement mortar doped with Typha the performance is improved to 60% [38]. Nevertheless, mixing Typha with clay gives a moderately affordable performance with a rate of 22% with the same performance rate as adding polymer to hybrid fibers. The addition of sunflower, rapeseed straw and organic composite based on plaster in clay does not improve thermal performance, on the contrary we have an increase in thermal conductivity.

Table 7. Thermal performance of the materials studied

Reference	Thermal performance (Conductivity)
[15]	λ_i=0.5 W/mk to λ_f=0.22 W/mk (0 to 5 % of the fiber)
[16]	λ_i=0.18 W/mk to λ_f=0.14 W/mk (0 to 50 % of the fiber)
[17]	λ_i=0.98 W/mk to λ_f=0.48 W/mk (0 to 4 % of the fiber)
[18]	λ_i=1.3 W/mk to λ_f=0.65 W/mk (0 to 100 kg/m3 of wood)
[19]	The thermal conductivity varies between 0.08 W/mk to 0.035 W/mk
[20]	λ_i=0.5 W/mk to λ_f=0.314 W/mk (0 to 6 % of coffee)
[21]	λ_i=0.055 W/mk to λ_f=0.162 W/mk (235 to 714 kg/m3 of biocomposite)
[22]	λ_i=0.64 W/mk (earth unfired) to λ_f=0.34 W/mk (earth fired) with 30% of laterite
[23]	λ_i=0.2 W/mk (cement motar) to λ_f=0.4 W/mk (4 % of coconut fiber)
[24]	λ_i=0.55 W/mk (earth), λ_{T+P}=0.49 W/mk (earth + paper), λ_{T+C}=0.67 W/mk (earth + cement) and λ_{T+P+C}=0.58 W/mk (earth + paper+cement)
[25]	λ_i=1.4 W/mk (compressed earth), λ_{f1}=0.3 W/mk (2% of corn), λ_{f2}=0.36 W/mk (2% of barley)
[26]	λ_i=0.75 W/mk (TL + cement), λ_{f2}=0.65 W/mk (TL + cement+ natural pouzolane), λ_{f3}=0.5 W/mk (TL + cement+sawdust)
(35]	λ_i=0.85 W/mk (concrete), λ_f=0.126 W/mk (with 3% of Typha) the average conductivity of typha alone is 0.045w/mk
[37]	λ_i=0.163 W/mk (84.9% of clay), λ_f=0.127 W/mk (77.1% of clay)
[38]	λ_i=1 W/mk (Cement motar), λ_f=0.4 W/mk (with 3.5% of Typha)
[44]	λ_i=1.35 W/mk (motar), λ_{f1}=0.99 W/mk (20% oat straw), λ_{f2}= 1,28 W/mk (80% Typha wool)

7. Conclusions and Perspectives

In this document we have discussed the energy issue in Africa in general, and in Mauritania in particular. We reviewed some of the insulation and construction materials used in homes. Vegetable fibers are good insulators thanks to their thermal performance. The study then focused on Typha, an invasive plant in the Senegal River valley that is found to have good thermal insulation. Some studies have shown that Typha in concrete or cement mortar provides an excellent thermal performance of up to 85% for concrete and 60% for cement mortar. On the other hand, only one in eight articles deals with the energy aspect of bio-source materials in the home. Given the accessibility and abundance of Typha, it would be interesting to enhance its value by undertaking more detailed studies aimed, for example, at:

- Study its thermomechanical characteristics in its pure state and condition it for use as an insulating panel. These studies can be carried out using numerical modelling software (e.g. ANSYS),
- Compare Typha with the most efficient materials (corn fiber (78%), barley fiber (74%)) to evaluate the rate of reduction in energy costs in the home.
- Improve the mechanical performance of the Typha, by mixing it with local building materials while preserving its thermal performance.

References

[1] UN-Habitat, world Habitat day 2014 –voice from shms background paper,2014.

[2] S.Mandelli, J.Barbieri, L.Mattarolo, E.Colombo, Sustainable energy in Africa: A comprehensive data and policies review, Renewable and Sustainable Energy. 37 (2014) 656-686 .

[3] R.Cantoni, M. Musso, L'énergie en afrique : les faits et les chiffres, Afrique contemporaine. 261-262 (2017) 9-23.

[4] HABITAT, ONU, L'ETAT DES VILLES AFRICAINES Réinventer la transition urbaine,2014.

[5] Fact Sheet. The World Bank and Energy in Africa,2012. Information on https://goo.gl/JCuczP

[6] GIEC, Changements climatiques 2007, Groupe de travail II: conséquences, adaptation et vulnérabilité, 2017. Information on https://goo.gl/SoT5KW

[7] M.Kaboré, Enjeux de la simulation pour l'étude des performances énergétiques des bâtiments en Afrique sub-saharienne, 2015.

[8] IEA, world energy oultook <<energy access database >>, 2016.

[9] M. E.Khouna, Renewable Energy in West Africa. Country Chapter Mauritania. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Department Water, Energy and Transport, 2009.

[10] N.K.Dia, A.A.Bayod-Rújula, M. N'Dongo,M.Diallo, C.S.E Kane, B.Bilal, Energy context in Mauritania. Energy Sources, Part B: Economics, Planning, and Policy. 12:2 (2017) 182–190.

[11] Renewable Energy and Energy Efficiency Partnership. Energy Statistics of Mauritania, 2008. Information on http://ww.reeep.org

[12] Perspectives et potentiel du Secteur de l'Electricité. Table ronde pour la Mauritanie, Bruxelles, 2010. Information on http://www.renow.itccanarias.org/fr/

[13] International energy agency <<africa energy outlook>>, 2014.

[14] Z. Zhou, C. Wang , X. Sun , F. Gao , W. Feng , G. Zillante, Heating energy saving potential from building envelope design and operation optimization in residential buildings: A case study in northern China, Journal of Cleaner Production. 174 (2018) 13-423.

[15] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, O. Oussouaddi, An Experimental Investigation on the Thermophysical Properties of a Composite Basis of Natural Fibers of Alfa, International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS. 17 (2017) 27-32.

[16] N.Dujardin, Un materiau biosource de choix : les fibers naturelles. caractérisations et applications, 25èmes Journées Scientifques de l'Environnement - L'économie verte en question (2014).

[17] Y Elhamdouni, A Khabbazi, C Benayad, S Mounir, A Dadi, Thermophysical and mechanical characterization of clay bricks reinforced by alfa or straw fibers, IOP Conference Series: Materials Science and Engineering. 186 (2017) .

[18] M. Bederina, L. Marmoret , K. Mezreb , M.M. Khenfer , A. Bali , M. Queneudec, Effect of the addition of wood shavings on thermal conductivity of sand concretes: Experimental study and modelling, Construction and Building Materials.21 (2007) 662–668.

[19] A. Laborel-Préneron, J.E. Aubert, C. Magniont, C. Tribout, A. Bertron, Plant aggregates and fibers in earth construction materials: A review, Construction and Building Materials. 111 (2016) 719–734.

[20] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, O. Oussouaddi, Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study, Journal of Cleaner Production 209 (2019) 1411-1419.

[21] Y.Brouard, N.Belayachi, D.Hoxha, N.Ranganathan, S.Méo, Mechanical and hygrothermal behavior of clay – Sunflower (Helianthus annuus) and rape straw (Brassica napus) plaster bio-composites for building insulation, Construction and Building Materials.161 (2018)196–207.

[22] S.Bodian, M.Faye, N.A.Sene, V.Sambou, O.Limam, A.Thiam, Thermo-mechanical behavior of unfired bricks and fired bricks made from a mixture of clay soil and laterite, Journal of Building Engineering. 18 (2018) 172-179.

[23] S.O.G. Osseni, B.D. Apovo, C.Ahouannou, E.A. Sanya et Y.Jannot, Caractérisation thermique des mortiers de ciment dopés en fibers de coco par la méthode du plan chaud asymétrique à une mesure de température, Afrique science. 12 (2016) 119-129.

[24] E.Ouedraogo, O.Coulibaly, A.Ouedraogo , A.Messan, Mechanical and Thermophysical Properties of Cement and/or Paper (Cellulose) Stabilized Compressed Clay Bricks, Journal of materials and engineering structures. 2 (2015) 68–76.

[25] M. Palumbo, F. McGregor, A. Heath , P. Walker, The influence of two crop by-products on the hygrothermal properties of earth plasters, Building and Environment. 105 (2016) 245-252.

[26] P. Meukam, Y. Jannot , A. Noumowe , T.C. Kofane, Y. J. Thermo physical characteristics of economical building materials, Construction and Building Materials. 18 (2004) 437–443.

[27] C. Hyon-Naudin. Etudes des filières matériaux de construction en terre et les équipements solaires. Genève : Organisation internationale du Travail, 2017 Information on https://www.ilo.org/

[28] M.Hardy. Le secteur du bâtiment Mauritanien enjeux, orientations et potentiel de réforme Architectures et matériaux durables formations adaptées et emplois décents. Genève : Organisation internationale du Travail, 2017. Information on https://www.ilo.org/

[29] Les villes et le changement climatique : orientations générales. Programme des Nations Unies pour le développement des établissements humains, 2011. Information on https://issuu.com/unhabitat/docs/les_villes_et_le_changement_climatique

[30] Bâtiments. Contribution au projet négociation climat pour toute l'Afrique réussie (NECTAR) 2009. Information on https://www.ifdd.francophonie.org/ressources/ressources-pub-desc.php?id=325

[31] Profi l de la pauvreté en Mauritanie, 2014. Information on http://www.ons.mr

[32] OMVS (Organisation pour la mise en valeur du fleuve sénégal), Rapport de synthèse du forum régional africain sur la contribution des projets FEM à la gestion des bassins transfrontaliers : cas du bassin du fleuve Sénégal, Projet de gestion des ressources en eau et de l'environnement du bassin du fleuve Sénégal, Dakar, 2006.

[33] D. Sow, S. Gaye, M. Adj et D. Azilinon, Valorization of Agricultural Wastes by their Integration in Construction Materials:Application to Rice Straw. Proceeding of AMSE International Conference MS'09, Trivandrum, (2009) 314 -347.

[34] L.R.Misse. projet PNEEB / TYPHA « Transfert de technologie : Projet de production de matériaux d'isolation thermique à base de Typha.» Grenoble 2014.

[35] M.T.Diatta, S.Gaye, A.Thiam, D.Azilinon, Détermination des propriétés thermo-physique et mécanique du Typha Australis. Cong. SFT, Perpignan 2011.

[36] S. Gaye, G. Menguy, Transmission de chaleur: cours et problèmes. Édition CUT, Liban 2008.

[37] Y.Dieye, V.Sambou, M.Faye, A.Thiama, M.Adj,D.Azilinon, Thermo-mechanical characterization of a building material based on Typha. Journal of Building Engineering, 9 (2017) 142–146.

[38] A.O.Abdelhakh, A..Saleh, M.Soultan, D.Sow, G.Menguy, S.Gaye, Improving Energy Efficiency of Buildings by using a Light Concrete based on the Typha australis. 3rd International Conference on Renewable Energies for Developing Countries (REDEC) 2016.

[39] I.Niang, C.Maalouf, T.Moussa,C.Bliard, E.Samin, C.Thomachot-Schneider, M.Lachi, H.Pron, T.H.Mai and S.Gaye, Hygrothermal performance of various Typha–clay composite. journals of building physics, (2018) 1-20.

[40] R. Sana, J. Mounir, M. Slah, Study of Structure and Properties of Tunisian Typha Leaf Fibers. International Journal of Engineering Research & Technology (IJERT), 2014.

[41] K. Ramanaiah, A. V. Ratna Prasad, K. Hema Chandra Reddy, Mechanical Properties and Thermal Conductivity of Typha angustifolia Natural Fiber–Reinforced Polyester Composites. International Journal of Polymer Analysis and Characterization, 16 (2011) 496–503.

[42] G.Wuzella, A.R.Mahendran , T.Bätge , S.Jury , A.Kandelbauer, Novel, binder-free fiber reinforced composites based on a renewable resource from the reed-like plant Typha sp. Industrial Crops and Products, 33 (2011) 683–689.

[43] J.Liu, Z.Zhang, Z.Yu, Y.Lianga, X.Lia, L.Rena, Experimental study and numerical simulation on the structural and mechanical properties of Typha leaves through multimodal microscopy approaches. Micron, 104 (2018) 37-44.

[44] J.Lima, P.Faria,. Eco-Efficient Earthen Plasters: The Influence of the Addition of Natural Fibers. Natural Fibers: Advances in Science and Technology Towards Industrial Applications,12 (2016) 315-327.

[45] M.Maddison, T. Mauring, K.Kirsima, U. Mander, The humidity buffer capacity of clay–sand plaster filled with phytomass from treatment wetlands. Building and Environment, 44 (2009) 1864–1868.